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Vancouver, Canada

May 31 – June 3, 2017/ *Mai 31 – Juin 3, 2017*

EVAPOTRANSPIRATION LANDFILL BIOCOVER TO CONTROL ATMOSPHERIC RELEASE OF LANDFILL METHANE

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Abstract: There is considerable interest in quantifying and deploying cost-effective methods to control landfill emissions of methane (CH_4), which is a key greenhouse gas (GHG). Recent studies by the University of Calgary and others indicate one of the most promising options is biological oxidation of CH_4 in a passive system known as a Landfill Biocover (LBC). The LBC utilizes a permeable granular medium placed over a landfill as a final cover, which allows the landfill gas (LFGs) to “breathe out”. The LBC also supports the growth of methanotrophs, which can convert the CH_4 into carbon dioxide (CO_2). Although, successful LBC projects have been developed, there is a risk that the permeable LBC will allow water percolation into the waste matrix, increasing landfill leachate production and potentially contaminating groundwater. A novel approach could be used that integrates components of the Evapotranspiration (ET) cover into the LBC design. The ET-LBC is a novel, hybrid landfill cover design that utilizes a granular medium to promote the growth of methanotrophs and to store water to facilitate evapotranspiration by plants.

A number of issues prevent ET-LBCs adoption in Canada. One major barrier is the inability to accurately assess emissions reductions and carbon credit value associated with ET-LBC projects. Research currently being conducted in Leduc, Alberta is being used as a model to develop protocols to assess these emission reductions. Other ongoing research in this technology includes: determination of the most suitable medium and thickness for maximum CH_4 oxidation; identification and adaptation of a compatible ET configuration for LBC and minimization of water percolation; and assessment and identification of robust and cost-effective method(s) to determine emissions from landfills and the CH_4 oxidation capacity of the ET-LBC system throughout the year. Accurate assessment of emission credits will be possible with the help of increased understanding of the functioning of ET-LBC system.

Key words: Landfill, Biocover, Evapotranspiration

1 Introduction

Landfill covers are constructed to contain waste emissions and prevent infiltration of water to the waste layer. Reducing water infiltration reduces percolation through the waste, decreasing leachate generation from the waste mass and the risk of groundwater contamination. Standard conventional landfill covers have accomplished this goal by using low permeability, resistive materials to prevent water flow into the landfill cover and the waste below. These covers have typically employed some combination of a clay cap layer, geomembrane, gas collection layer, and drainage layer. Conventional covers have been shown to function well, generally limiting percolation to < 1.5 mm/year or 0.2% of precipitation in arid and semi-arid regions. However, due to the high cost and failure rate of conventional cover systems, the use of alternative landfill covers has been increasingly pursued. Most proposed alternative covers are water balance type covers designed as either monolithic, capillary barrier, or anisotropic cover systems, collectively known as Evapotranspirative (ET) covers.

The decomposition of organic solid waste in landfills generates landfill gas (LFG) consisting mainly of methane (CH_4) and carbon dioxide (CO_2). The emission of CH_4 into the atmosphere is a serious concern because its global warming potential (GWP) is approximately 34 times that of CO_2 (Myhre et al., 2013). If volumes are high, LFG can be recovered to produce energy (Haubrichs and Widmann, 2006). However, volumes are too small for the clear majority of landfills and LFG is allowed to escape into the atmosphere. Landfills in Canada are estimated to release 27 million tonnes of CO_2 equivalent (t CO_2eq) of CH_4 per year (Climate Change, 2012) and their emissions constitute approximately 25% of Canadian anthropogenic CH_4

emissions. The estimated annual CH_4 emissions from landfills in Alberta total 4.2 million t CO_{2eq}. Considering these facts, it is imperative that alternative methods are found to control fugitive CH_4 emissions from landfills.

Recent studies by our team and others indicate that one of the most promising options is the biological oxidation of CH_4 in a passive system known as a landfill biocover (LBC) (Huber-Humer et al., 2008). The LBC utilizes a permeable granular medium placed over a landfill as a final cover, which allows the LFG to "breathe out". The LBC also supports the growth of methanotrophs, which are capable of utilizing CH_4 as an energy source, thereby converting the CH_4 into CO_2 without creating toxic byproducts (Bogner et al., 1997). While it is estimated that a traditional cover oxidizes only 10% of the total methane passing through it, LBC systems have been proven to potentially oxidize over 90% of methane emissions from landfills. However, there is a risk that the permeable LBC may encourage water percolation into the waste matrix, resulting in increased landfill leachate production and potentially creating groundwater contamination.

To counter this serious environmental problem, a novel approach may be used that integrates components of the ET cover into the LBC design. The ET cover is compatible with the LBC because it minimizes rainwater percolation by utilizing the water storage capacity of the granular medium and the transpiration capacity of plants, without depending on a low permeable compacted clay or geo-membrane barrier (Lamb et al., 2014). As such, an ET-LBC would allow unhindered LFG migration to promote CH_4 oxidation, but the ET function of the hybrid design would minimize percolation of precipitation into waste.

Since Alberta has a semi-arid climate, the ET-LBC should succeed; however, experiences with these systems in cold climates is extremely limited. The following discussion, therefore, focuses on the current knowledge of methanotrophy and ET-LBC systems to identify knowledge gaps that need to be filled in order to implement this technology in the future.

2 Evapotranspiration (ET) Technology

Typically, ET covers employ a monolithic granular layer to store water and support vegetation (Hauser VL, 2009); however, ET covers can also be constructed to utilize a capillary effect and increase water retention (Abdolahzadeh, 2011, Lacroix Vachon, 2015 and Parent & Cabral, 2005). The granular medium captures and stores precipitation until it is either transpired through vegetation or evaporated from the cover surface. These systems can be aesthetically pleasing because they employ naturalized vegetation, require less maintenance once the plants are established, and may require fewer repairs than a conventional cover (Rock et al., 2012).

There are several different ET cover designs; however, every ET cover should fulfill at least three main criteria: i) The soil should store water to prevent/reduce the downward water movement below cover; ii) the soil should provide the support for excellent root growth of the plants; iii) The plants/vegetation should be well adapted to the soil and the site (preferably native plant species) and meet the requirements of the site. The most common ET cover types are the Monolithic covers, capillary barriers, and anisotropic barriers. A monolithic cover consists of a single layer of vegetated media designed to store precipitation until it is removed by evapotranspiration. A capillary barrier consists of a layer of vegetated fine grained media set on top of a much coarser drainage layer to create a capillary barrier between these layers and increase moisture retention in the finer, top layer. An anisotropic barrier is a capillary barrier system that contains a vegetated soil layer on top of a sand drainage layer, which is set on top of a coarser drainage layer. This creates two consecutive capillary barriers to promote lateral drainage and prevent downward flow.

Each of these types of alternative covers have been shown to be effective at limiting percolation rates to those of a conventional cover, and they are collectively referred to as ET covers. ET covers (or water balance covers or store-and-release covers) are vegetated landfill covers that control water percolation into the waste zone through water balance mechanisms instead of the resistive mechanism employed by conventional landfill caps (Abdolahzadeh et al., 2011; Parent & Cabral, 2005). ET systems are widely acknowledged as an alternative to conventional landfill covers, at least in arid and semi-arid climates (Albright & Benson, 2005), albeit in jurisdictions other than Canada (Albright et al., 2004). The U.S. Environmental Protection Agency's (USEPA) Alternative Cover Assessment Program (ACAP) tested different cover designs in a variety of arid, semi-arid, and humid regions at 11 locations in the US (Albright, et al., 2004). It was found that monolithic ET covers were unable to control percolation in humid climates with high precipitation rates, although others have found ET covers performed better than conventional covers even under humid conditions (Abichou et al., 2006c); however, in arid and semi-arid locations, they achieved comparable or better performance than conventional covers.

A variety of granular media can be effectively used for construction of the ET cover, which allows for ease of construction and cost savings through the use of local soils (Zornberg et al., 2003), provided the chosen medium encourages robust plant growth (Hauser et al., 2001). ET cover thickness is a function of site-specific precipitation and selected granular material (Jacobson et al., 2005). The selection of appropriate vegetation is a critical part of the design. Native vegetation is generally preferable, as it is adapted to local climate (Rock, 2003) and non-native vegetation tends to naturally be supplanted by better-adapted native vegetation over time.

Most of the field research studies reported in literature are from systems located in the US (Hauser et al., 2009, Abichou et al., 2004 and ITRC, 2003). There is very little information available on ET system design and performance in cold climatic conditions. The amount, distribution, and form of precipitation define the effectiveness of an ET cover at a given site (Hauser et al., 2001). For example, during a sudden spring thaw or chinook in Southern Alberta, a large amount of snow melts, but the vegetation is still dormant. The cover may not have sufficient water storage capacity, and percolation may occur (Hauser, 2001; EPA, 2000). These facts point to the necessity of conducting site-specific experiments to generate design data, such as the most appropriate granular material and thickness, and types of plants.

For design and performance evaluation purposes, it is necessary to use two models, i.e. a water balance model and a numerical model (Khire et al 1997). Although several models are available, the unsaturated soil water and heat flow (UNSAT-H) and the HYDRUS-2D/3D are two numerical models that have been used frequently in the design of ET covers (Hauser, 2009).

According to the economic analysis by Hauser et al. (1999, 2001) of the construction of conventional landfill covers and ET covers for similar landfills, estimated construction costs of ET covers were less than half as much as conventional covers. This was because of the fact that ET covers don’t need barrier and drainage layers. Moreover, due to the self-renewing nature of ET covers, the maintenance costs are comparatively small. Repairing conventional covers is more difficult and expensive than ET covers. In the case of ET covers, soil filling and re-seeding vegetation can solve most common issues; however, climate, soil, plant cover, and the site requirements are unique and therefore, demand a site-specific design. Unlike conventional covers, there is a scarcity of the information about design parameters for ET landfill covers. Extensive investigations to increase the methods and innovative strategies to overcome these limitations are critical for the wider acceptance and implementation of this technology.

3 Landfill Biocover (LBC)Technology

Although information on field LBCs is limited, especially in Canada, there exists a large body of fundamental and applied information generated by researchers worldwide. LBCs are constructed with the most suitable granular medium to provide an ideal environment for the growth of methanotrophs. Potential media include organic-rich soil, compost, native soil amended with biosolids, and wood chips (Scheutz et al., 2009). Experiments with soil (Stein and Hettiaratchi, 2001) and compost (Wilshusen et al., 2004) determined that the CH_4 oxidation rate of compost was about three times that of soil; however, the oxidation rate of compost varied due to differences in their moisture holding capacities and nutrient contents. Other media tested include sawdust, lava rock, soil/compost, and sludge/soil (Goya and Hettiaratchi, 2015), but field data are not available for these media. The other main parameters that impact oxidation efficiency are temperature, moisture content, and nutrient availability. The optimal temperature for methanotrophy is about 30°C (Stein and Hettiaratchi, 2001; Whalen et al., 1990), but research has shown that methanotrophic activity continues even at temperatures as low as 4°C (Kettunen et al., 2006). Yet, the current knowledge on the behaviour of methanotrophs in field LBCs under cold climatic conditions is limited. Since the field moisture content changes over time, the design of an LBC entails using a hydrologic model to select a granular media that would maintain optimal moisture content (McCartney and Zornberg, 2006). Even though compost material is the choice of researchers testing top cover layers, there are a number of issues related to the use of this material that should be highlighted. Occurrence of competitive inhibition of methanotrophic activity due to the presence of additional carbon sources for heterotrophic activity in the organic materials makes them potentially problematic and ineffective for landfill gas mitigation. Maturity of the compost is one of the critical design considerations for an effective bio-based system (Scheutz et al. 2009; 2011), as a more mature compost will have less bioavailable carbon sources for heterotrophic competition.

To determine the LBC performance, mathematical models can be used to predict time-dependent changes to the LBC moisture profile (Bohnhoff et al., 2009), but these models should be field-validated under various operating conditions. Since macro- and micro-nutrients, including nitrogen, are needed for methanotroph growth, some researchers have treated media with digested sludge [de Visscher et al., 1999] and nutrient-rich landfill leachate (Watzinger et al., 2005; Chiemchaisri et al., 2010). However, considering the contradictory results obtained and the variability of the nutrient content of these additives, further site-specific research is needed before nutrient addition is adopted in Canada.

Methanotrophs produce exo-polysaccharides (EPS) as a by-product, and the accumulation of EPS causes CH_4 oxidation to decline over time (Hilger et al., 1999; Wilshushen et al., 2004). EPS coats the base biofilm, thereby limiting the diffusion of gases into cells. It also reduces the air-filled porosity of the granular medium, thereby limiting the depth of oxygen (O_2) penetration, which is a critical factor in selecting the type and thickness of granular media (Wilshushen et al., 2004; Rachor et al., 2011). In narrow columns, we can note a narrow zone within which most oxidation occurs (Rachor et al., 2011) and EPS forms. However, the time-dependent changes in the LBC performance due to EPS and the importance of EPS in large surface field LBCs are not well understood.

Researchers have developed reactive-transport models that, when given CH_4 source strength and physical and biological parameters as input, can predict CH_4 oxidation rates (Stein et al., 2001; Hettiarachchi et al., 2007; Perera et al., 2002). Using these models in conjunction with a hydrologic model, the optimal media type for LBCs can be determined; however, relationships between the required biological kinetic parameters and soil properties have not been developed for use in these models in a prescriptive manner. The key to developing an LBC design procedure, therefore, lies in establishing relationships between kinetic parameters and media type, gas concentrations and nutrient status.

4 Combined ET-LBC Technology

The top layers of the ET-LBC, with widely distributed rooted zones and high organic content, can provide ideal conditions for the growth of methanotrophs. Vegetation can indirectly contribute to improved CH_4 oxidation in soils by altering important soil properties, including moisture content (Reichenauer et al., 2011; Ndanga et al., 2015), porosity (Bohn et al., 2011), and inhibition of ammonia toxicity (Hilger et al., 1999; de Visscher and Van Cleemput, 2003; Reichenauer et al., 2011) Additionally, up to 45% of a plant's annual net fixed carbon from the atmosphere can be exuded from the roots as a variety of organic acids, sugars and amino acids (Reichenauer and Germida, 2008). Wang et al. (2008) compared soil samples subjected to CH_4 exposure, with and without vegetation, and determined that the presence of vegetation supports methanotrophy. Similarly, the composition of bacterial species within the rhizosphere can be influenced by the plant exudate, with Type 1 methanotrophs becoming more abundant (Stralis-Pavese et al., 2006). In addition, the aerenchyma of vascular plants are able to transport oxygen from the atmosphere to the rhizosphere surrounding their roots, which can stimulate methanotrophy by creating aerobic conditions within an otherwise anoxic environment (Wu et al., 2009). Conversely, root systems may also compete with methanotrophs for oxygen and nutrients (Wang et al., 2008). Considering the competing processes observed in the presence of plants, further work is required to understand the influence of native Alberta plants on soil methanotrophy and ET potential. Leachate production from landfills presents operational and environmental challenges, since the leachate must be collected and properly treated. Leachate irrigation is one simple and inexpensive treatment option to reduce the volume and improve the quality of landfill leachate on site. Some work has been performed showing that leachate may be used to irrigate an ET-LBC cover without negatively impacting CH_4 oxidation (Chiemchaisri et al., 2010). The maximum rate of leachate irrigation depends on the amount of natural precipitation and type of vegetation on the landfill cover; excess soil moisture may reduce methane oxidation in the landfill cover and high nitrogen levels in the leachate may increase nitrous oxide emissions from the landfill surface, while vegetation may be detrimentally affected by high levels of leachate (Watzinger et al., 2005).

5 Ongoing research/Future work

Research has been conducted in a number of areas related to LBCs, ET covers, and ET-LBCs. There are several barriers to fully implement ET-LBCs as a viable alternative landfill cover. The main barrier is the inability to accurately assess emission reductions and carbon credit value associated with ET-LBC projects. The ability to claim emission credits from LBC projects is a major incentive for industry to implement these projects.

The emission credits largely depend on the ability to accurately measure emissions from a landfill. Both initial (baseline) and project completion emissions have to be measured to accurately measure the emissions reductions achieved by the project. In Alberta, the Specified Gas Emitters Regulation under the Climate Change and Emission Management Act defines a series of protocols for clear implementation of technology and measurement of gas emissions. Currently, LBC technology does not have a developed protocol, hence there is particular interest to develop an acceptable method of quantifying landfill gas emissions to develop an appropriate protocol.

Several technologies are available to estimate the landfill surface emissions. These include theoretical calculations using mathematical models, in-situ techniques, and ex-situ techniques.

Our current research is being conducted in collaboration with industry and the Leduc and District Regional Waste Management Authority in Alberta to demonstrate the different measurement techniques in ET-LBCs and determine the most feasible technique for accurate emissions measurements.

When analyzing a LBC, one of the main problems faced is the large surface area. Many methods have been developed to obtain instantaneous field measurements of landfill methane surface emissions. These include dynamic or static flux chambers, micrometeorological methods, or path integrated optical remote sensing (PI-ORS) techniques. These methods all provide estimates of CH_4 emission levels under the prevailing conditions at the time of measurement. The main method of determining the surface emission rates is using a closed flux chamber method (Perera, 2002; Abichou et al., 2006b; Héroux et al., 2010). The closed flux chamber method is a slow process that can take up to 1 hour to record a single reading, depending on the flux rates; hence, the amount of information that can be obtained under constant environmental conditions is minimal. Several attempts have been made by researchers to address this issue (Héroux et al., 2010; Abichou et al., 2006b; US-EPA, 2005, Huber-Humer et al., 2009).

Some of these available techniques are being tested in Leduc, Alberta, as detailed below. For some of these techniques a limited number of initial results are available.

Optical remote sensing-radial plume mapping (ORS-RPM)

USEPA (2005) proposed the use of equipment called “open-path Fourier transform infrared (OP-FTIR) spectrometer”. The study involved a technique developed through research funded by the USEPA’s National Risk Management Research Laboratory (NRMRL) that uses optical remote sensing-radial plume mapping (ORS-RPM). ORS-RPM uses a horizontal radial plume mapping (HRPM) to map surface concentrations, and a vertical radial plume mapping (VRPM) method to measure total emissions fluxes downwind of the site. Once either the concentration values and flux values are determined the total emission from the landfill could be estimated.

ISM and flux chamber method

Most methods to estimate landfill surface emission follow the approach where the concentration is mapped and corresponding flux values are measured to find a co-relationship between flux and concentration (Héroux et al., 2010). Field measurements of landfill methane emissions show natural variability. The determination of an average emission rate for a given field site requires sampling designs and statistical techniques, which consider spatial and temporal variability. But such an approach necessitates many sampling points using an enclosure method (flux chamber). To mitigate this problem, correlations between methane concentrations on the ground, in general by the instantaneous surface monitoring (ISM) method, and the surface methane emission measured with a flux chamber have to be developed in order to minimize the number of samplings with flux chamber (Fécil et al., 2003). In the ISM method, a portable FID is used to instantaneously measure the concentration of total organic compounds (TOCs measured as methane) at the landfill surface divided into grids.

An initial investigation was conducted at the Leduc and District Regional Waste Management Facility (The Landfill) to compare methane emissions measurements using both a portable FID device (Thermo TVA 100B FID) and closed, static flux readings using a University of Calgary built flux chamber (Plexiglass; cylinder shape; Dimensions: H=0.19 m, D=0.19 m). The concentrations of methane and carbon dioxide in the chamber were measured with either a portable Rki Eagle 2 or a GEM5000 gas analyzer. Comparison data was recorded for three discrete existing “biowindow” features in a closed section of The Landfill: North Biowindow, Central Biowindow, and South Biowindow. Locations identified as emissions “hotspots” generally showed moderate to good spatial agreement between the FID and flux chamber methods, although no direct and consistent relationship between the surface concentration and measured flux rates could be discerned at this stage (representative results shown in Figures 1 and 2).

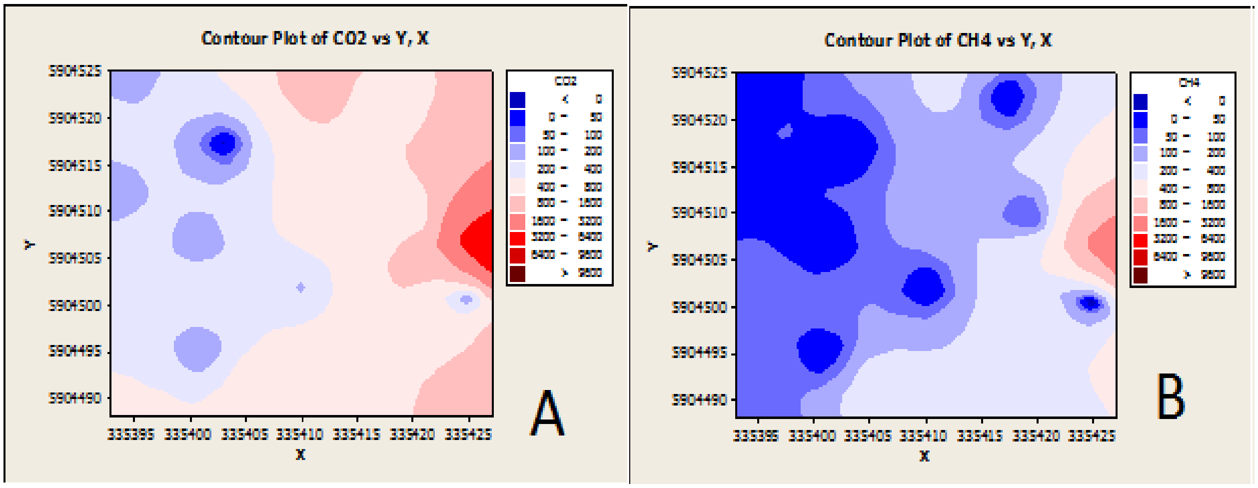

Figure 1: Flux emissions heat maps of the North biowindow (estimated dimensions 35 m by 35 m). Emissions shown as g/m^2/day. Distance shown in metres and represents Northing and Easting of the measured emissions. A) C0$_2$ emissions; B) CH$_4$ emissions.

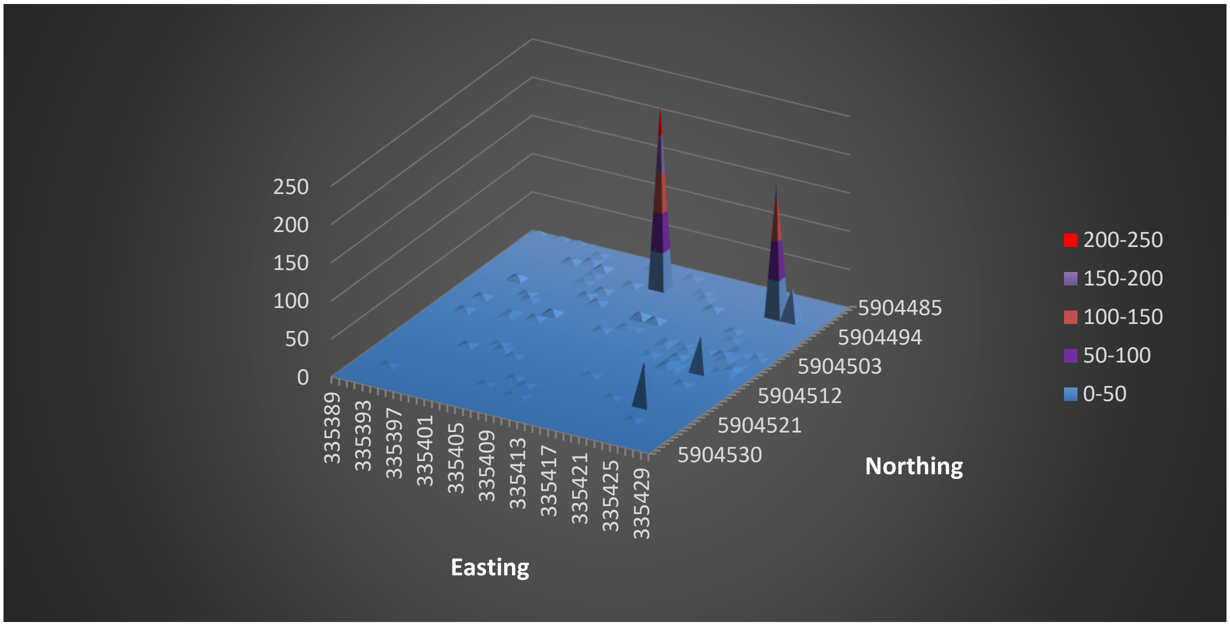

Figure 2: Flux emissions heat map of the North biowindow (estimated dimensions 35 m by 35 m). FID measurements denote total VOCs in ppm. Distance shown in metres and represents Northing and Easting of the measured emissions.

Flux chambers with interpolation

In another similar approach, Abichou et al., (2006a) has attempted to develop surface emission maps without using the ISM method. Here, interpolation methods between different flux values were used. Two commonly used interpolation methods are kriging and inverse distance weighing (IDW). The method used by Abichou et al., (2006a) was the IDW model.

In IDW, the interpolation contours are calculated by weighing neighboring data using the inverse of the separation distance to a power. IDW uses weighted averaging techniques to fill the elevation matrix. The interpolated value of a cell is determined from values of nearby data points considering the distance of the cell from those input points. In kriging, a model of the overall spatial measured variance structure is used to generate the interpolated contours. The measured variance structure is shown as a variogram with half the variance on the y-axis and sample separation distance on the x-axis. Key variables for a variogram are the nugget (unexplained or error variance), sill (total model variance, equal to nugget plus ‘‘scale’’), and range (distance where the variance reaches the sill) (Abichou et al., 2006a; Abichou et al., 2006b). In addition, Abichou et al., (2006b) has found that IDW method and kriging method do not produce largely different results.

Part of our ongoing research includes analyzing the flux data from the ISM-Flux chamber method using the proposed interpolation in this method. However, the flux data to date has not produced the required resolution to be analyzed. Further data collection and analysis is planned to evaluate this method.

Other continuing research

Compost is identified as an ideal media for LBCs, yet, it is not well known how compost would behave in an ET-LBC. Laboratory research is currently being conducted to identify combined properties needed for several different types of material.

Potential cost savings are a key driver for the shift from conventional to ET cover systems. Although ET covers typically have higher design and regulatory costs, they have typically had much lower construction and operations costs. Increased design and regulatory costs stem from the site specific water balance requirements of each ET cover, as opposed to a design hydraulic conductivity for a conventional clay cap. The savings on construction costs are possible both due to the potential to use locally available soil materials for construction, rather than compacted clay, and through the use of simple construction methods, including thicker lifts and decreased requirements for compacting to optimal moisture. ET covers also reduce maintenance costs associated with typical causes of failure to maintain the designed saturated hydraulic conductivity in a conventional clay cap, including desiccation, free-thaw cycles, settlement, or improper compaction during construction (Salt et al., 2011). These cost savings averaged roughly $23,500 per acre for alternative covers built as part of the Alternative Cover Assessment Program run by the USEPA (Albright and Benson, 2005)

Since the main cost savings of an ET cover arise from using locally available soils, the availability and cost of materials was the main consideration in selecting potential materials for this ongoing project. Soils available at The Landfill and possible compost amendments available near the site were tested for their ability to sustain methanotrophic populations, with the goal of identifying the most inexpensive materials that could fulfill the minimum functional requirements of this ET cover. As initial laboratory screening must allow for simple and low cost screening of materials, the primary tests conducted for screening were total organic content (measured as LOI) and pH (Figures 3 and 4). Materials with acceptable measures on these initial tests were screened for C-H-N ratio (Figure 5) and directly tested for their maximum methane oxidation potentials. The topsoil available at The Landfill and a residual compost waste product from a nearby waste management facility were identified as materials with no direct costs, and both of these materials were capable of supporting robust methanotrophic populations at a level capable of oxidizing the expected emissions of 100 – 150 g/m^{2}day^{-1}. Determination of the hydraulic characteristics of these selected materials and a mix of the two components is ongoing.

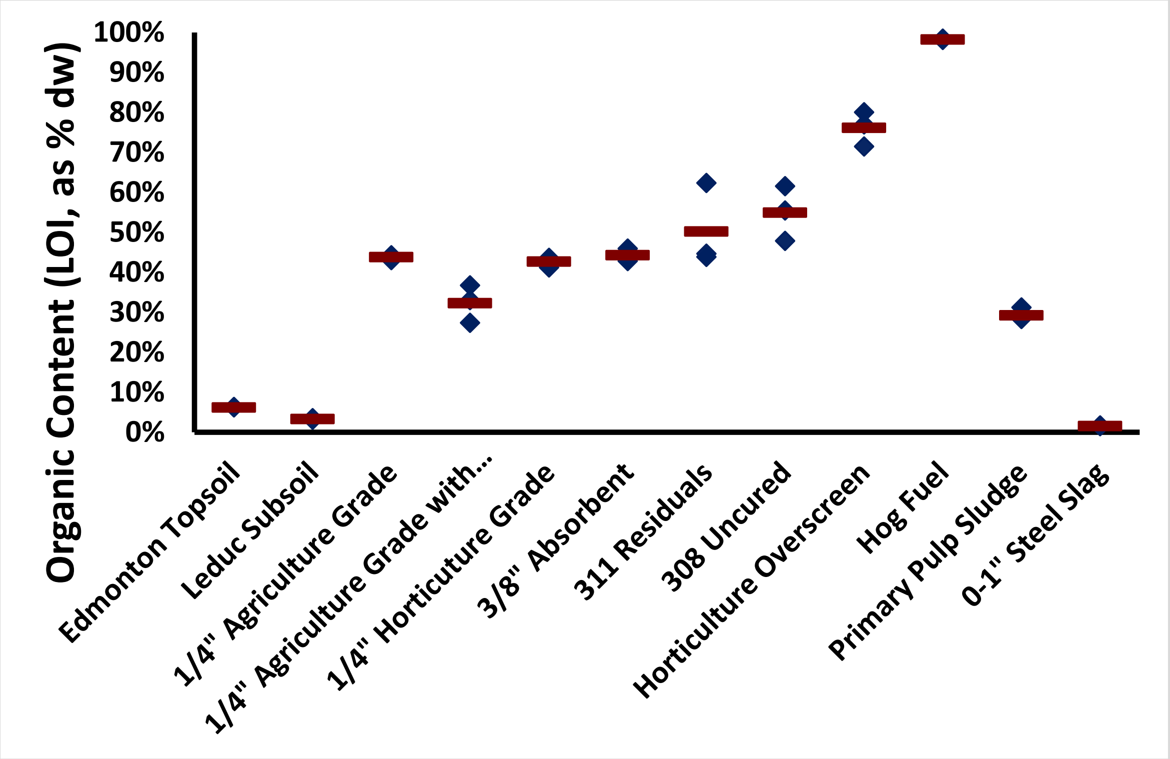

Figure 3: Organic content of materials considered for construction of Leduc ET-LBC. Organic content shown as loss on ignition at 440°C in muffle furnace for 8 hours. Individual replicates shown as point, with means as short line. N=3.

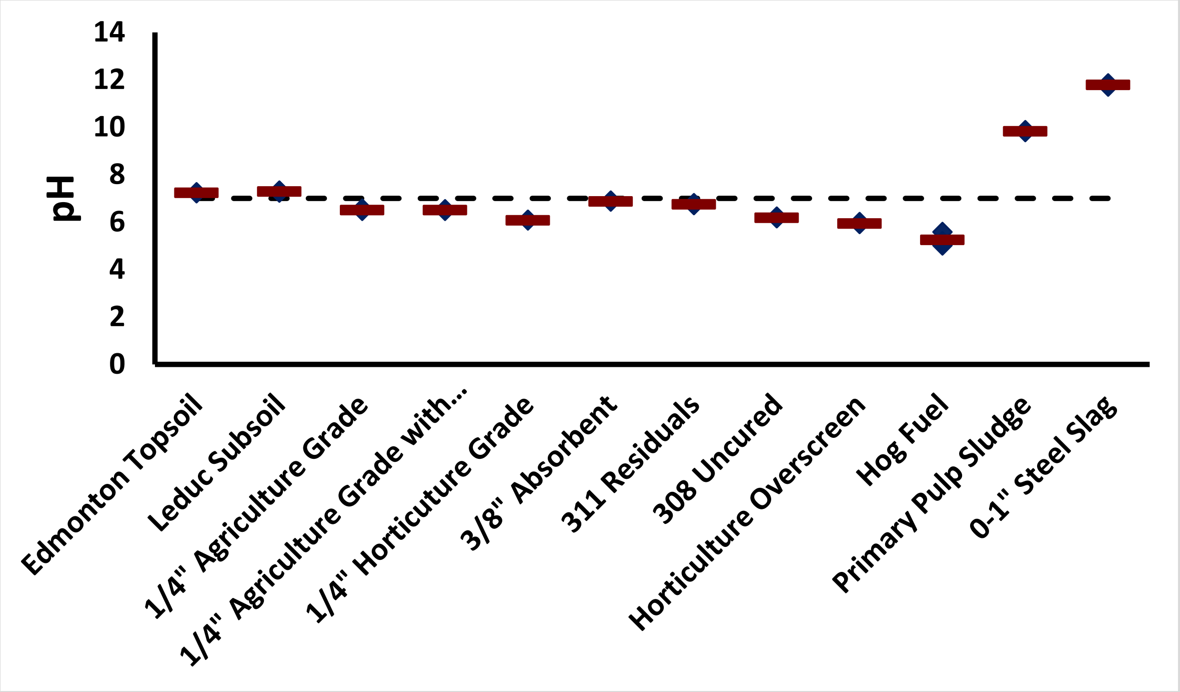

Figure 4: pH of materials considered for construction of Leduc ET-LBC. Individual replicates shown as point, means as short line, and neutral pH (ideal) shown as dotted line. N=3.

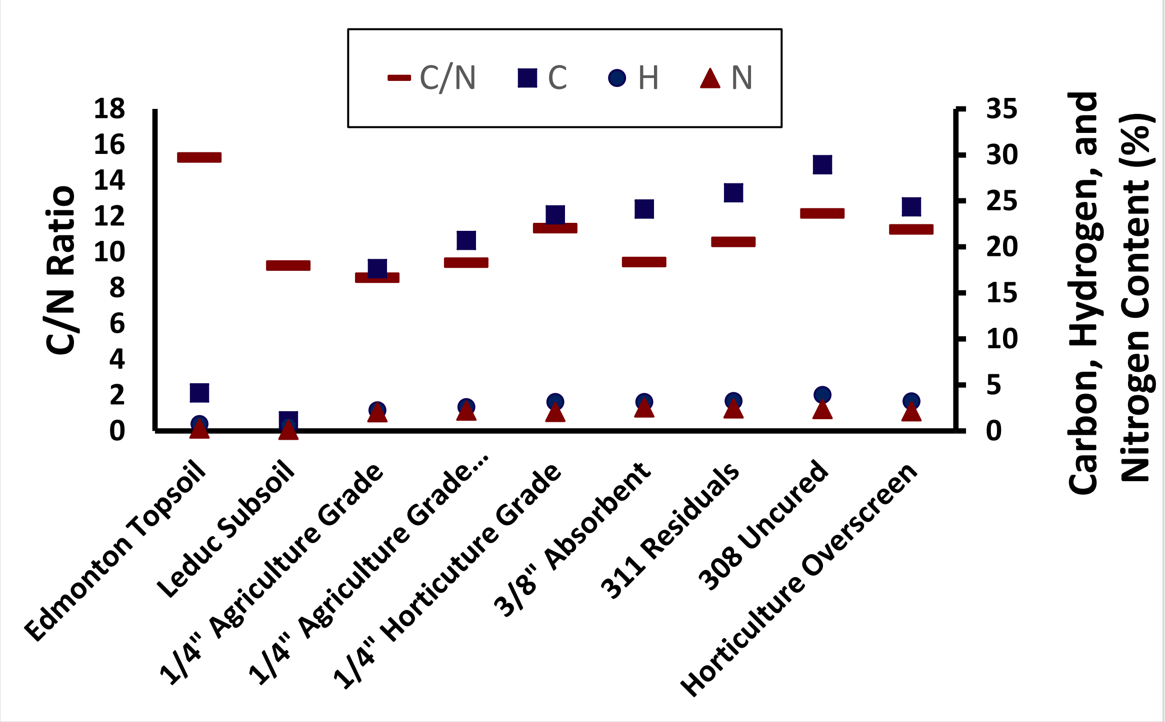

Figure 5: Elemental analysis of materials considered for construction of Leduc ET-LBC. N=1.

ET-LBC vegetation is another interesting area of research that is currently conducted. Considering the competing processes observed in the presence of plants, further work is required to understand the influence of native Alberta plants on soil methanotrophy and ET potential.

There is an ongoing scale-up study in Okotoks, Alberta to demonstrate the effects of vegetation on the water storage and ET capabilities, as well as CH_4 oxidation, of cover media. This project involves 8 test cells specifically designed to demonstrate ET-LBC systems at field scale. The intent of the test cells construction is to simulate the landfill biocover at a controllable scale by growing vegetation over the soil layer and supplying controlled CH_4 flow through distribution piping within an underlying coarse gravel layer (distribution layer). Each test cell is comprised of a wooden frame, liner, gas distribution layer, sump for collection and measurement of any water infiltration, and soil based media; each group of fours test cells is built around a 1 m by 1 m Lexan inspection port to allow for viewing of the complete profile. The liners, which are gas and water tight, prevent loss of gas or water, other than through the surface of the test cells. Each test cell has a soil surface of 3.3 m^2 and soil depth of 0.915 m. The construction of test cells involves placing the layer of fine-grained soil over 0.279 m thick layer of washed gravel layer. The coarse gravel layer acts as a gas distribution layer, which creates homogenous load of the supplied natural gas. In order to preserve the functionality of the gas distribution layer over time, a geotextile cover was placed between the soil and gravel layers. The geotextile cover holds the soil particles out of the gravel, yet allows gas and liquid to pass through it. Each of the test cells will be seeded with selected grass species or shrubs. The soil layer stores water until it is either transpired through vegetation or evaporated from the soil surface.

The system will allow for monitoring of soil gasses to create gas profiles and determine oxidation zones. Moreover, frequency-domain reflectometers will provide data on water infiltration through the test cells following natural and simulated precipitation events. Soil samples at different monitoring depths and times will used to characterize the microbial community using qPCR. The data from the laboratory experiments and field study will be used to accurately model soil water storage, evapotranspiration, for hydrological modeling to design an effective ET-LBC cover for site specific conditions, and to choose an appropriate mixed media to provide target media characteristics.

6 Conclusions/Remarks

Interest has grown recently in the area of methane reduction and elimination. Conversion of CH_4 to CO_2 emitted from landfilled surface is an ideal solution to reduce the GHG effect. ET-LBC technology is an emerging technology that can be used for GHG emission reduction while maintaining the conventional requirements of landfill covers.

ET-LBC technology has a main barrier that needs to overcome, which is development of accurate and acceptable emission measurement methods to incorporate these methods into developing regulatory protocols for industry to be able to measure carbon offsets. Our current demonstration project in Alberta attempts to identify acceptable methods for landfill emission measurement. The technologies used are ORS-RPM, ISM and flux chamber method, and Flux chambers with interpolation. Preliminary results show that, while each method has its advantages and disadvantages, these methods could be used to develop standard emission measurement protocols for carbon offset monitoring.

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