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Comparative study of methane oxidation within various biofilter media

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COMPARATIVE STUDY OF METHANE OXIDATION WITHIN VARIOUS BIOFILTER MEDIA

by

Sepideh Nourbakhsh, B.Eng.

Ryerson University, Canada, 2007

A thesis

Presented to Ryerson University

In partial fulfillment of the
requirements for the degree of
Master of Applied Science
in the Program of
Civil Engineering

Toronto, Ontario, Canada, 2009

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ABSTRACT

COMPARATIVE STUDY OF METHANE OXIDATION WITHIN VARIOUS BIOFILTER MEDIA

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Master of Applied Science in Civil Engineering (2009)

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A considerable fraction of the methane gas generated by landfills can be oxidized by the landfill cover. In this study, the use of disposable sawdust material to utilize and reduce methane gas from the landfill gas (LFG) was demonstrated. Three laboratory scale bioreactors were constructed to reflect the performance of sawdust with respect to the compost and sand (control media). Patterns of methane (CH_4) oxidation were evaluated through the degree of methane oxidation in correlation to the bacterial development in all three media. Later, the use of nutrients during the respiration of the bacteria was interpreted through the analysis of chemical oxygen demand (COD), biochemical oxygen demand (BOD), and biomass growth variations. The overall methane oxidation efficiency in the sawdust medium was 60% with a biomass content of 238 g/m^3 , whereas the compost medium had 86% methane oxidation efficiency with 539 g/m^3 biomass content. Furthermore, the COD and BOD removal were 2555 mg/L and 332 mg/L from the compost, and 1984 mg/L and 156 mg/L from the sawdust respectively.

The overall results of this study indicated that the sawdust material can be used as a biofilter media for methane utilization from the landfill. The oxidation capacity of sawdust could be accelerated by adding necessary nutrients to this media before implementation. Moreover, the oxidation rate variance between compost and sawdust may be eliminated over time due to nutrient exhaustion in the compost media, and/or production of usable carbon with decomposition of the sawdust media.

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Furthermore, I would also like to express my gratitude to Dr. Humayun Khandker for his perseverance, continuous help, and friendship during the past year. His assistance, patience and direction in various stages of this project will always be greatly appreciated.

I would also like to extend my gratitude to Prof. Dr. Grace Luk for her relentless support, motivation and advice during my education at Ryerson University. I would also like to thank all other staff and faculty members of the Civil Engineering Department who helped me in the successful completion of my graduate study and for their contribution throughout my study at Ryerson University. My sincere thanks go to Mr. Robin Luong for his continuous collaboration in the laboratory.

All my life I will be deeply indebted to my parents and my sister for their love, care, and dedication.

Sepideh Nourbakhsh

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CHAPTER ONE

1. INTRODUCTION

In recent years, the reduction of greenhouse gas emissions has become an important issue due to its impact on global warming. Since 1750, the atmospheric concentration of carbon dioxide (CO_2) has increased by approximately 31% in addition to an increase of around 151% for the atmospheric concentration of methane (CH_4) (Khalil, 2007; IPCC, 2001). The Oregon Graduate Institute has been monitoring methane concentrations worldwide for several decades, producing an average annual global methane concentration presented in Fig. 1.1 (Khalil, 2007). Methane can increase the greenhouse effect in the atmosphere by about 20 times more than carbon dioxide due to its heat retaining ability (Ramanathan *et al*, 1985; Dickinson and Cicerone 1986). Furthermore, the relatively short decay time of CH_4 , seven to ten years, compared to 10 years for CO_2 ; leads to effective CH_4 mitigation in a shorter period of time.

Fig. 1.1 Annual global methane concentrations in parts per billion (ppb) (Khalil, 2007)

Landfill gas (LFG) emissions are a significant anthropogenic source of CH₄ and LFG treatment is an efficient way for methane reduction along with climate protection. Gas collection systems are commonly installed to collect the LFG in the larger landfills that have sufficient CH₄ production rates. This gas can be utilized as a sustainable energy source to produce electricity or heat. However, the LFG production rate decreases with time and for older and smaller landfills that do not produce enough CH₄, it is not feasible to collect the gas for energy. On the other hand, even if a gas collection system is implemented, the reported gas collection efficiencies for these systems range from 60% to 80% (USEPA, 1999). Therefore, the remaining LFG is just emitted to the atmosphere (Bogner *et al.*, 1993). Other sources of low gas production rates are landfills where mechanically-biologically pre-treated waste has been disposed. In 2002, Canada's net greenhouse gas (GHG) emission from landfills was estimated to be 22Mt (million metric tonnes) carbon dioxide equivalent (eCO₂), and according to Environment Canada only 6.6Mt eCO₂ were captured (Environment Canada, 2005).

For the above-mentioned cases and many others, one alternative of reducing CH₄ emissions is the biological methane oxidation at landfills through the use of the landfill caps as oxidation layers. Biological methane oxidation uses the ability of methanotrophic bacteria; these bacteria can consume methane and oxygen to convert them into carbon dioxide, water, and biomass which are much less harmful for the environment (Whalen *et al.*, 1990; Kightley *et al.*, 1995; Czepiel *et al.*, 1996; Borjesson and Svensson, 1997; Borjesson *et al.*, 1998; Chanton and Liptay, 2000; Borjesson *et al.*, 2004). Bio-covers can also be implemented in the absence of a gas collecting system or as a polishing step in addition to an active system (Barlaz *et al.*, 2004). However, methane oxidation layers are strongly affected by changes in regional climate (Börjesson *et al.*, 2004). Previous studies (Bender and Conrad, 1995; Bogner *et al.*, 1997; Borjesson *et al.*, 2004; Borjesson *et al.*, 1998; Christophersen *et al.*, 2000; Nesbit, 1992; Reyes and Ergas, 2000) have investigated the individual effects of environmental factors on the rate of CH₄ biological oxidation when used as biofilters. The rate of CH₄ oxidation in the landfill cover soil depends on moisture content, temperature, soil characteristics, nutrients, pH, methane load, influx rate, pressure, and oxygen availability.

Methane oxidation rate is defined as mass of oxidized CH₄ divided by mass of CH₄ entering a system. In landfill cover soils, CH₄ oxidation has been reported to vary from 7% to 50% (Gardner and Manley, 1993; Kightley *et al.*, 1995). Czepiel *et al.* (1996) reported 10% CH₄ oxidation in a landfill in a cold climate, suggesting that in warm climates CH₄ oxidation would be much higher. Kjeldsen *et al.* (1997) reported that landfill soil can oxidize up 100% of CH₄ emissions. Under certain circumstances, the landfill cover can even consume atmospheric CH₄ rather than emit CH₄ to the atmosphere (Bogner *et al.*, 1995; Bogner *et al.*, 1997a; Borjesson and Svensson, 1997; Borjesson *et al.*, 1998; Abichou *et al.*, 2006a and b).

Enhanced methane oxidation in engineered systems on landfills seems to be a powerful tool to reduce greenhouse gas emissions from the waste sector, and the increasing importance and high potential of this measure is evident (USEPA, 1996; Whalen *et al.*, 1990). Many new approaches are under development at the moment but must be advanced and improved, particularly for routine application and cost-efficiency monitoring in the field (Abichou *et al.*, 2006a; Barratt, 1993; Boeckx, *et al.*, 1996; Environment Canada, 2005).

From an engineering perspective, to design a suitable biofilter cover, the challenge is to identify the properties that lead to suitable conditions for growth of methanotrophic bacteria, and therefore, high oxidation rates of methane. Such properties are: methanotrophic bacteria existence, porosity, organic matter content, moisture content, pH, and vegetation. As bacteria availability and growth are some of the limiting factors for methane oxidation, a system that enhances bacteria growth and availability in the substrate will enhance methane oxidation (Barlaz *et al.*, 2004).

The presence of nutrients in a media, such as compost, can aid the growth of methanotrophic bacteria. Former studies have proven that various compost materials (Humer and Lechner, 1999; Hilger and Humer, 2003; Barlaz *et al.*, 2004; Abichou *et al.*, 2006a; Stern *et al.*, 2006) are suitable for methane biological oxidation. For instance, compost with high organic content and suitable conditions to hold moisture and methanotrophic bacteria, up to 100% oxidation was reported (Stern *et al.*, 2006; Kightley *et al.*, 1995; Humer and Lechner, 2001).

The objective of this study addresses whether various materials that have low organic content, such as sand and sawdust, can provide a suitable environment for methane oxidation in comparison to compost. Consequently, the views expressed within this paper portray the use of sand and sawdust as biofilter materials that allow for efficient methane emissions mitigation from landfill covers.

In this experimental study, three lab scale biofilters packed with compost, sawdust and sand, under constant temperature and moisture content, were constructed and studied. Laboratory tests were performed to compare the patterns of methane oxidation amongst the compost, sawdust and sand. Additionally, the results of this laboratory study were used to evaluate and examine a relation between biomass growth and methane oxidation rate. Moreover, bacterial population growth trend in various biofilter media were observed.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction to Landfills

A landfill is defined as a site where unwanted waste and trash can be dumped. Solid waste collected from municipalities is commonly discarded into a sanitary landfill, which is generally defined as a Municipal Solid Waste (MSW) sanitary landfill. Moreover, the composition of buried MSW influences the biodegradation processes in the landfill ecosystem, which then affects not only landfill gas (LFG) production and composition, but also leachate quality and quantity. The waste composition varies in each location; by definition, Municipal Solid Waste (MSW) consists of residential, commercial, and non-hazardous industrial wastes but excludes combustion ash, hazardous waste, sludge and industrial process waste. However, many of these other wastes are often deposited in the same landfills that receive MSW (Hilger and Barlaz, 2002). Consequently, researchers favor the use of the term 'refuse' opposed to MSW for solid waste.

In the design of sanitary landfills, the most important parameter is the design of a dependable leachate collection system that will allow for complete groundwater pollution control. In recent years, due to their growing size, landfills typically include gas collection and/or venting systems, in addition to a system that can monitor landfill gas and groundwater conditions (USPEA, 1994).

According to USEPA, all MSW sanitary landfill facilities must include the following components: a strong in-situ foundation, a composite liner system, a leachate collection system, a gas collection or venting system, and a final composite cover system. Fig. 2.1 illustrates a typical landfill. The liner systems must be designed to entirely restrain the solid waste and prevent discharge of leachate and contaminants into groundwater and the surrounding environment (USEPA, 1994). The liner system is placed on the bottom, as well as the sides of a landfill. This composite layer has multiple barriers that are constructed using clay and geosynthetic materials (Qian *et al.*, 2002).

Leachate, by definition, is the liquid that “leaches” from a landfill. It varies depending on the composition of waste in the landfill. Leachate can be formed by existing liquids in the waste, or by water that has infiltrated into the landfill envelope through precipitation and has mixed with the waste (Reinhart and Townsend, 1998). This liquid mix, leachate, will move downward through the waste and reach the top liner system. The leachate must be collected using a leachate collection system to balance the head pressure and protect the surrounding groundwater and environment from contamination.

An efficient way to reduce leachate within a landfill is to minimize water infiltration from the top. This is done by providing a final cover system, shown in Fig. 2.1 as an “engineered cap system.” A final cover system includes several layers such as a hydraulic barrier that is composed of a geomembrane, compacted clay, and/or a geosynthetic liner (USEPA, 1994).

Fig. 2.1 Basic landfill layout (ECO Services International, Copyright 2006)

Over the hydraulic barrier there should be a layer to provide drainage, which could be constructed using granular soil, or geosynthetics. The next step is to build a soil layer that is used as a protection layer for the hydraulic barrier to ensure that the hydraulic barrier is not damaged or punctured. This final layer is usually constructed using 'top soil' to promote plant growth, which greatly improves the erosion control (Qian *et al.*, 2002).

In addition to leachate, landfill gas is also produced through natural decomposition of the organic matter within a landfill. This process generates gas in the landfill envelope that is typically composed of approximately 50% methane and 50% carbon dioxide. A gas collection system, as shown in Fig. 2.1, is designed for the landfill to collect this gas, prevent lateral gas migration, and avoid pressure buildup within the landfill envelope. This collected gas can be vented, flared, or used as an energy source (Perera, *et al.*, 2002).

2.2 Gas Generation

In a municipal solid waste landfill, gas generation is directly linked to the decomposition of organic matter by microorganisms through a naturally occurring process. According to Qian *et al.* (2002), gas production in landfills occurs at five different stages, as shown in Fig. 2.2 and Table 2.1. At the time of waste deposition in a landfill (stage one), oxygen was present in the void space, giving rise to aerobic decomposition during which biodegradable organic materials react quickly with oxygen to form carbon dioxide, water, and other by-products (e.g. bacterial cells). Carbon dioxide is produced in approximate molar equivalents to the oxygen consumed but there is no methane generation.

In stage two, oxygen depletion within the landfill marks the onset of the anaerobic decomposition phase. In this stage, the aerobic phase switches to acid generation by bacteria that decomposes and ferments organic matter in the landfill. In stage three, shown in Table 2.1, there is another phase shift, this time to anaerobic decomposition. There will be production of both methane and carbon dioxide in this stage. These steps are highly inter-dependent and include hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Alexander, 1994).

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Fig. 2.2 Five phases of landfill gas production (UKDOE, 1993)

Table 2.1 Synopsis of landfill gas generation stages (EMCON, 1998)

Stage	Name	Primary Activity Signaling the End of Phase
1	Aerobic	<i>No Oxygen in the landfill gas</i>
2	Aerobic/Acid Generation	<i>Formation of free fatty acids at its peak and methane generation begins</i>
3	Transition to Anaerobic	<i>Methane and carbon dioxide concentrations stabilize and no nitrogen in the landfill gas</i>
4	Anaerobic	<i>Methane and carbon dioxide concentrations begin to reduce and some nitrogen (air) returns to the system</i>
5	Transition to Stabilization	<i>Gas is primary air and all anaerobic decomposition is complete</i>

Gradually, methane and carbon dioxide concentrations will stabilize, as demonstrated in Fig. 2.2, which places the landfill in an anaerobic state for a second time. As the anaerobic process is continued, methane and carbon dioxide production reach their highest levels.

Gas composition in stage four is typically 50% methane and 50% carbon dioxide, with small amounts of trace gases. Stabilization, or stage five, will start as soon as all the carbon containing waste has decomposed. Stage five is the final stage where the majority of the gas within the landfill will be air since all anaerobic decomposition would have ceased (Qian *et al.*, 2002).

Although a landfill ecosystem undergoes an initial short aerobic decomposition phase, the subsequent anaerobic phase is the dominant phase in its age and the more important one from the perspective of gas formation. Investigators have recognized several major steps to describe the anaerobic decomposition phase during which organic materials are converted to methane and carbon dioxide (UKDOE, 1993).

Generally, landfill gas composition is highly dependent on the decomposition stage within the landfill. Under a stabilized methanogenic condition, which is the stage of interest from a beneficial recovery perspective, methane and carbon dioxide are by far the two principal components of landfill gas and form more than 90% of the total gas generated (Kasali, 1986). Nitrogen and oxygen are normally present in small quantities primarily as a result of air entrapment during waste deposition, atmospheric air diffusion through the landfill cover especially in the near surface layers, or air intrusion from negative landfill pressure when landfill gas is extracted. Table 2.2 summarizes the composition of a typical landfill gas. Hydrocarbons and trace compounds are present at a very low percentage in the landfill gas. In addition to their potential adverse health effects and environmental pollution, trace compounds even at low levels could cause toxicity on microbial populations, and hence may inhibit gas formation and stabilization processes within a landfill (Mosey, 1983).

Table 2.2 landfill gas composition (Kasali, 1986)

Component	Concentration Range Percent Dry Volume Basis
Methane	40-70
Carbon Dioxide	30-60
Carbon Monoxide	0-3
Nitrogen	3-5
Oxygen	0-3
Hydrogen	0-5
Hydrogen Sulfide	0-2
Trace Compounds	0-1

2.3 Gas Migration

Landfill gas migrates in the landfill environment through different physical transport methods. These processes include advection and Fickian transport. Fickian transport occurs in two ways: diffusion and dispersion. By definition, mechanical dispersion is the transport of gas due to variable flow paths in a porous media. In the case of a landfill, porous media are soil layers or garbage (Bogner and Matthews, 2003).

There are two types of diffusion: molecular diffusion and turbulent diffusion. Molecular diffusion is the movement of landfill gas from high concentration area to the lower concentration area due to random movement of molecules. During the anaerobic state, large amounts of methane and carbon dioxide are being produced, resulting in a concentration gradient. This concentration gradient occurs because of a higher molecular concentration in the landfill opposed to that of the surrounding environment. Due to this gradient, the gases are going to move from inside the landfill and out to the surrounding environment; this phenomenon is called molecular diffusion. Turbulent diffusion occurs because of random motions caused by turbulent flow (De Visscher and Cleemput, 2003).

Advection is the movement of a gas and/or fluid with a specified direction and magnitude. In a landfill, advective flow is the main transport cause of gas migration. By definition, advective flow occurs when there is a pressure gradient present between inside and outside of a landfill. A pressure gradient is caused when waste decomposition results in gas generation. This gas is trying to expand, causing a pressure build up within the landfill. As a result, the gas will migrate from an area of high pressure within the landfill to an area of lower pressure outside of the landfill (Abichou *et al.* ,2006a).

There are a few factors effecting gas direction and migration within a landfill, such as landfill design. Furthermore, landfill gas may migrate vertically or horizontally. Fig. 2.3 shows how gas can migrate horizontally out of the landfill envelope. Horizontal migrations of gases, out of the landfill boundary, are unwanted. Gases that migrate horizontally, outside of the landfill, and into a surrounding community can cause health and public relation problems. To control this problem and to prevent pressure buildup, it is important to supply a venting system for the landfill gases to escape (Abichou and Chanton, 2004).

Fig. 2.3 Lateral gas migration (USEPA, 1994)

2.4 Gas Vents

As discussed earlier, due to decomposition of organic matter, landfills produce large amounts of gases that are predominantly methane and carbon dioxide. If landfill gases are not properly removed or diverted, they can migrate into the surrounding environment. The goal of a landfill gas control plan is to prevent health hazards and air pollution due to unwanted gas. Also, by providing an exit for the gases, pressure build up within the landfill can be avoided (USEPA, 1994).

To help avoid gas leakage problems, landfill gas can be collected by either a passive or an active collection system. A typical collection system, either passive or active, is composed of a series of gas collection wells placed throughout the landfill. The number and spacing of the wells depend on landfill-specific characteristics, such as waste volume, density, depth, and area. As gas is generated in the landfill, the collection wells offer pathways for gas migration. Most collection systems are designed with a safety factor, such as extra gas collection wells, to ensure continued operation and protect against system failure (USEPA, 1996).

2.4.1 Active Vent

According to regulations, designs for new landfills must include active collection systems. Well-designed active collection systems are considered the most effective means of landfill gas collection (USEPA, 1994). It is necessary to design an active vent gas collection system with adequate extraction well spacing and a sufficient amount of vacuum. It is crucial to obtain the maximum vacuum that can be applied; if this vacuum is exceeded, atmospheric gases will be sucked into the landfill. This occurrence is dangerous and could lead to an explosion within the landfill envelope if favorable conditions are available. The spacing and the vacuum are determined by doing on-site field pumping tests. Nonetheless, a common influence radius of 1.5 times the waste thickness can be used (Oweis and Khera, 1998).

Active systems can have vertical wells, trenches, or horizontal collection pipes through the gas collection layer of the cover system. Fig. 2.4 demonstrates a typical vertical active vent. The collection wells are typically constructed of perforated or slotted plastic and are installed vertically throughout the landfill to depths ranging from 50% to 90% of the waste thickness

(Qian *et al.*, 2002). These wells are usually secured in place by being backfilled with high permeability material such as gravel. A geomembrane is placed above the gravel followed by a bentonite seal to prevent gas migration from the well hole. The well is then capped with a well head. Well heads are used for gas sampling, measurement of flow, temperature readings, and may have control valves. These well heads are connected to a header pipe that is attached to a pump or blower, which provides the vacuum for the system. Once the gas has been extracted from the landfill envelope, it can be vented to the atmosphere, flared, collected for an energy source, or treated by a biofiltration method (USEPA, 1994).

Fig.2.4 Example of a vertical active gas extraction well (USEPA, 1994)

2.4.2 Passive Vent

Passive gas collection systems use existing variations in landfill pressure and gas concentrations to vent landfill gases into the atmosphere or a control system. Passive collection systems can be installed during active operation of a landfill or after closure. Accordingly, a passive vent has no mechanical workings, such as a blower or a pump, to pull the landfill gas out. Instead, it relies on advection and Fickian transport to force gases out of the landfill envelope.

A passive vent equipped landfill forces gas migration through advective flow. As described previously, advective flow is caused when there is a pressure difference inside and outside of the landfill causing the gas to move with the pressure gradient. Passive vents are commonly used in older landfills and/or landfills with fairly small gas production. According to Bagchi (1994), passive venting is suitable for “small municipal landfills (40,000 m³)”. Bagchi (1994) also concluded that there is no strict design process existing to determine the number of passive vents needed, but a vent for every 7500 m³ of garbage should be adequate.

Passive wells may be cap venting or trench design. Cap venting wells are “similar to those used for groundwater and consist of perforated pipe surrounded by a permeable media such as gravel” (Reinhart, 1998). Cap vents are inserted into the landfill envelope and may go into the garbage layer, or rest in a gas collection layer just below the hydraulic barrier of the final cover system (Fig. 2.5). In order to further control lateral landfill gas mitigation and optimize gas collection, a geomembrane can be installed on the back side of the trench, as well as just above the horizontal collection pipe (between the compacted soil backfill and the drain layer) as shown in Fig. 2.5. This geotextile will prohibit any horizontal or vertical gas leakage from the landfill or out of the trench; this precaution ensures maximum gas collection efficiency. Gases from passive vents can be flared but are generally emitted into the atmosphere. This venting of gas, mostly carbon dioxide and methane, into the atmosphere contributes to the global problem referred to as the “greenhouse effect” (Reinhart and Townsend, 1998).

Fig. 2.5 Example of a passive gas vent (USEPA, 1994)

2.5 Methane: A Greenhouse Gas

Methane is one of the main contributing gases to the greenhouse effect. Methane concentrations in the atmosphere have been gradually increasing for centuries, but a visible hike has been seen since the beginning of the industrial revolution. According to the IPCC (2001), methane is increasing global warming due to its ability to retain heat at a rate of 21 times more than carbon dioxide within a 100 year time span. According to Hummer and Lechner (1999), methane concentrations within the atmosphere have increased at a rate of about 1% per year since 1978. They also reported that the amount of methane in the atmosphere has increased from 0.8 ppm to 1.7 ppm since the 1800's. Because of its ability to retain infrared radiation, methane, on a molar basis, is 20 to 30 times more powerful than carbon dioxide as a greenhouse gas (Rodhe, 1990; Blake and Rowland, 1988).

Methane has become an important goal for emission reduction because of its relatively short decay time in the atmosphere, approximately 7 to 10 years, and its higher effectiveness as a greenhouse gas (Rodhe, 1990; WMO, 1998; IPCC, 2001). In a report by Stern and Kaufmann (1996) it is shown that around 12% of worldwide methane emissions are caused by the

decomposition of waste within landfills. These are mainly landfills that are designed with passive venting systems that allow for the free movement of methane from within the landfill envelope out to the atmosphere. In recent years, extensive research has been conducted to reduce methane atmospheric emissions from landfills by oxidizing it to carbon dioxide through biofiltration.

2.6 Methane Oxidation

Methane oxidation occurs naturally in areas such as swamps, marshes, and lakes. Recently, this naturally occurring process has been viewed and researched as a possible way to mitigate methane gas emissions from landfills by providing biocovers and/or biofilters. Research for the mitigation of methane emissions through oxidation by the use of biofilter columns has gained momentum in recent years. Some of these studies have been conducted by Kightley *et al.* (1995); De Visscher *et al.* (1999); Hilger *et al.* (2000); Park *et al.* (2002); Scheutz and Kjeldsen (2003); Streese and Stegmann (2003); Wilshusen *et al.* (2004a); Berger *et al.* (2005); Gebert and Grongroft (2005); Haubrichs and Widmann (2006); and Powelson *et al.* (2006). Methane oxidation rates are reported to be in the range of 47% to 95% (Powelson *et al.* 2006).

The mechanism of methane oxidation involves the use of methanotrophic bacteria to transform methane into water, carbon dioxide, and biomass. These methanotrophic bacteria and the amount of methane they oxidize can be affected by a variety of parameters including methane availability, oxygen availability, pressure gradients, temperature, and condition and type of methanotrophic media. The availability of methane from a landfill is of little concern since gas emissions can be assumed to be 50% methane and 50% carbon dioxide with some variability. Where biocovers are used, advective flow can transport landfill gases, including methane, outward through the soil media and out from the landfill envelope. This biocover contains methanotrophic bacteria that can oxidize methane. Some of the other factors affecting oxidation are discussed below.

2.6.1 Water Content

Water content is a critical factor affecting CH₄ oxidation in landfill cover soils. Water content is defined as the mass of water lost from the soil by oven drying at 105°C for 24 hours divided by mass of dry soil. In geotechnical engineering, the water content is measured according to ASTM

D2216 (ASTM, 2000). After investigating the influence of moisture content using a multiple linear regression analysis under different conditions, Boeckx *et al.* (1996) concluded that water content has more influence on CH₄ oxidation than temperature. In another study, Christophersen *et al.* (2000) used statistical methods to analyze the effect of soil water content on CH₄ oxidation and concluded that water content can explain a lot of variation observed in CH₄ oxidation data.

Generally, there are three major means that water can influence oxidation. Firstly, only at specific water content, optimum condition is achieved for CH₄ oxidizing bacteria (methanotrophs). Secondly, water content directly controls oxygen penetration into the soils, which is the limiting factor for CH₄ oxidation. Thirdly, water content affects the air filled porosity of the soil that directly influences gas transport through the soil. As water fills the pores in the soil, it blocks the upward gas flow, leading to CH₄ emission due to the excess pressure built-up in the landfill (Boeckx *et al.*, 1996).

Maximum CH₄ oxidation occurs when the mentioned factors are in balance and the soil attains optimum water content. Below this water content, the oxidation rate will increase as the water content increases. Above this water content, the oxidation rate will decrease as the water content increases (Fig. 2.7). At this optimum water content, there are both rapid gas phase molecular diffusion and a sufficient microbial activity to oxidize the delivered CH₄. The reduced CH₄ oxidizing capacity at higher water contents is caused by a shift of gas-phase molecular diffusion to aqueous-phase molecular diffusion (Boeckx *et al.*, 1996). The low CH₄ oxidation at the low water content in the soil may be caused by less methanotrophic activity. The optimum oxidation water content in the soil will be different for different soil types and depends on temperature and other environmental factors (Czepiel *et al.*, 1996).

The optimal oxidation water content was mostly between 15.6% and 18.8% for soils tested by Boeckx *et al.* (1996) and Christophersen *et al.* (2000). Czepiel *et al.* (1996) measured optimal oxidation water content of 15.7%. Whalen *et al.* (1990) reported a value of 11%. Visvanathan *et al.* (1999) also stated values ranging from 15% to 20%. Christophersen *et al.* (2000) mentioned that the sometimes the soil environment needs more moisture before the growth of methanotrophic bacteria is achieved. It was observed that the longest lag phase takes place in the lowest water content range. Methanotrophic microorganisms can become inactive under ambient

conditions when the water content falls below 13% of the maximum water holding capacity (Bender and Conrad, 1992). Visvanathan *et al.* (1999) reported that at water content lower than 6%, oxidation became zero. As the water content increases to reach saturation, the oxidation rate decreases by around 56% (Nesbit, 1992); this is due to water filled voids in the soil that can inhibit O_2 diffusion (Fig. 2.7).

Fig. 2.6 Response of methane oxidation to soil water content (Czepiel *et al.*, 1996; Visvanathan *et al.*, 1999)

2.6.2 Organic Matter Content

In landfill biocovers, the oxidation rate increases with increasing organic matter content in soils. Organic matter content is defined by the mass loss during ignition at 550°C for 1 hour of oven dried (105°C for 24 hours) soil divided by the mass of oven dried soil. The organic matter content is normally measured using procedures described in ASTM D2974 (ASTM, 2000). It has been reported that using a higher organic matter content cover soil can maximize CH_4 oxidation (Borjesson and Svensson, 1997; Christophersen *et al.*, 2000). Soils collected from old landfills, which have been already exposed to CH_4 emissions for a long time, have higher oxidation rates than fresher soils (Nozhevnikova *et al.*, 1993; Visvanathan *et al.*, 1999). Christophersen *et al.* (2000) reported that there was a direct relationship between optimal water content and organic matter content. Visvanathan *et al.* (1999) stated that higher organic matter content, such as compost, confirmed to be a very efficient CH_4 oxidizer. They reported that compost covers enriched with organic matter were able to entirely oxidize all CH_4 emitted from their landfill mainly because organic matter provides nutrients for methanotrophic bacteria and has high porosity allowing more O_2 penetration (Humer and Lechner, 2001).

2.6.3 Porosity

Another factor influencing methane oxidation is the porosity of soil. This parameter affects oxidation directly because it influences O₂ penetration into the soil. Oxygen is the main reactor of the oxidation process. Higher porosity in soil results in higher O₂ penetration, longer CH₄ retention, and higher contact surface area with methanotrophic bacteria. Borjesson *et al.* (2004) concluded that there is a direct relationship between CH₄ oxidation and particle size distribution. (Humer and Lechner, 1999).

As discussed above, higher porosity means higher oxygen availability. Since methanotrophic bacteria needs oxygen to convert methane into carbon dioxide, water, and biomass, increased oxygen levels results in higher oxidation rates. Czepiel *et al.* (1996) reported that landfill soils could oxidize between 930 nmol/h gram of dry soil and 775 nmol/h gram of dry soil at oxygen ratios of 20.8% to 3%. Below 3% oxygen content, methane oxidation values decreased to zero. In pure cultures, it was observed that optimal oxidation rates could be achieved with oxygen contents varying from 0.45% to 20% (Wilshusen *et al.*, 2004). In order to ensure the availability of oxygen for the oxidizing process, some researchers mix ambient air with the landfill gas emissions before feeding it to the biofilters (Streese and Stegmann 2003; Haubrichs and Widmann 2006).

2.6.4 Soil Temperature

Oxidation values of methane can change with variance in temperatures. This is due to the change of activity in the methanotrophic bacteria according to temperature. Previous research has shown that the most favorable temperature for methanotrophic bacteria to oxidize methane falls between 20°C to 36°C (Visvanathan *et al.*, 1999; Chiemchaisri, *et al.*, 2001). It was reported by Nesbit (1992) that the optimal temperature for oxidation was in the range of 20°C to 30°C. Boeckx and Van Cleemput (1996) reported favorable temperatures between 25°C and 30°C. Christopherson *et al.* (2000), as well as Bender and Conrad (1995), concluded through their research that optimal temperatures were in the range of 25°C to 35°C. In addition to providing optimal temperature, it has been shown that there is a rather significant difference in oxidation rate when combined with water content. Boeckx *et al.* (1996) reported that the optimal incubation temperature for CH₄ oxidation is around 20°C to 30°C and decreases with increasing water content. Dunfield *et al.*

(1993) measured an optimum temperature of approximately 20°C to 25°C. Visvanathan *et al.* (1999) stated that at 20°C oxidation was approximately half of that at 30°C.

2.6.5 Pressure

Pressure variations between the atmosphere and within the landfill can influence the amount of oxidation in a biofilter. As mentioned previously, advection is the major transport process that moves landfill gases within the landfill and out into the atmosphere. If the pressure within the landfill is less than the pressure in the atmosphere, advection movement may be reversed and ambient air can move into the landfill. Gebert and Groengroeft (2006) concluded that due to the atmospheric pressure in a landfill the direction of advective gas flow can change to a reverse direction at least once a day. This change in the direction of gas movement can provide methanotrophic bacteria with the oxygen they need to be able to efficiently oxidize methane as soon as the flow is once again returned to an outward flow. Conversely, Borjesson and Svensson (1997) reported that there is no relationship between CH₄ emission and air pressure, or change in air pressure, over the seasons. This contradiction indicates that when the flow is governed by advection, pressure difference plays a role. However, when the flow is mainly a diffusive flux, it does not depend on pressure difference.

2.6.6 Vegetation

In general, vegetation can be used to enhance CH₄ oxidation. Vegetation influences soil properties such as its pH, water content, and gas transport. De Visscher *et al.* (1999) mentions that plant availability on landfill soil cover may improve CH₄ oxidation by nitrogen uptake. Moreover, plants also provide channels for O₂ penetration into the soil that can inhibit CH₄ oxidation. The root system of vegetation can also stimulate more suitable microbiological environmental for CH₄ oxidation (Maurice *et al.*, 1999).

2.6.7 Physical Inhibitors

In landfill cover soils there is an optimum zone for CH₄ oxidation where optimum conditions for methanotrophs growth occur, such as the existence of O₂:CH₄ ratio, retention time and suitable environmental conditions. In this cover system, gas concentration distribution across the soil

profile depends on diffusion, reaction, and gas flow (De Visscher *et al.*, 1999). Higher CH₄ concentration will increase CH₄ oxidation (De Visscher *et al.*, 2001); however, the high flow rate of CH₄ from the underlying waste reduces O₂ diffusion into the soil, which hinders CH₄ oxidation. Based on a study conducted by Czepiel *et al.* (1996), oxidation rates at different soil depth vary. It was observed that maximum oxidation occurs in the top 5 cm to 10 cm of the soil profile. Visvanathan *et al.* (1999) reported that maximum oxidation occurs at a depth between 15 cm and 40 cm. Other researchers reported different maximum CH₄ oxidation zones at different depths, between 40 cm and 60 cm by Nozhevnikova *et al.* (1993) and Borjesson and Svensson (1997), 15 cm and 60 cm by Barratt (1993), 3 cm and 1 cm by Whalen *et al.* (1990), and 20 cm and 30 cm by Kightley *et al.* (1995).

Another factor is that at the top of the soil profile drier soils inhibit CH₄ oxidation, where below a certain depth, the soil will become anaerobic. Humer and Lechner (2001) found that in their field scale test, the maximum zone of CH₄ oxidation was between 40 cm and 90 cm in sewage sludge compost and municipal solid waste compost. Czepiel *et al.* (1996) and Bender and Conrad (1995) reported that only 30 mL/L of O₂ concentration is required for CH₄ oxidation to occur; above 30 mL/L, the concentration has very little influence on oxidation but will decrease dramatically when the concentration is less than 30 mL/L (Bender and Conrad, 1992).

2.7 Biofilter Systems

A biofilter is commonly defined as a layer of porous organic soil, or soil material, containing microorganisms capable of degrading volatile organic contaminants as they pass through the filter. In this case, when a contaminated air stream flows through the filter bed, the contaminants are initially absorbed by the solid phase and then metabolized by the microorganisms (Alexander, 1994). Biofiltration technology has been used in air pollution control (APC) in several European countries and has been successfully implemented for odor control, as well as the treatment of both organic and inorganic air pollutants (Singhal *et al.*, 1997). However, biofiltration is now being used as a new technology in CH₄ removal from landfill gas prior to its release to the atmosphere. If designed properly, this system can significantly reduce atmospheric CH₄ emissions from modern landfills (Park *et al.*, 2002).

Microbial reactions in soils have been occurring naturally for many centuries, but only since the 1950's have such techniques been used to treat waste gases. Extensive biofilter research has been conducted only in the past 35 years thereby limiting the quantity of information. Biofilters are used in wastewater treatment plants, chemical manufacturing facilities, composting, and other industrial air pollution schemes (Nicolie *et al.*, 1999).

Biofilters are mostly categorized by their design (open or closed) and flow sequence (up-flow, down-flow, or horizontal flow). Devinny *et al.*, (1999) discussed the differences between an open and a closed biofilter. In a closed system biofilter, both the biofilter outlet and inlet gas streams are controlled. On the other hand, an open system discharges treated gas directly from the biofilter to the atmosphere.

2.7.1 Biofilter Material

Previous studies (Streese and Stegmann, 2003) focused on the selection of an appropriate biofilter packing material for methane oxidation. Experiments with different packing materials were conducted in these studies at various methane concentrations and temperatures.

Initially, fine grained compost was tested as packing material. This material revealed high degradation rates of more than 50g of CH₄ per (m³·h) in the beginning of the experiments. However, severe material clogging due to the accumulation of exopolymetric substances (EPS) was recorded after a few months. As a consequence, a decline of the degradation rates was observed. EPS are defined as high molecular weight substances that consist mainly of polysaccharides. EPS are believed to be produced by methanotrophic microorganisms in order to avoid formaldehyde accumulation in case of nutrients deficiency (Linton *et al.*, 1986).

Furthermore, coarse biofilter packing materials was also used in another study to prevent material clogging. This material also failed due to insufficient specific surface area for mass transfer and microbial growth, resulting in low degradation rates. After testing different biofilter materials, a mixture of compost, wood fibers, and peat was developed and tested. Because of its structural properties, this material was not subject to clogging and showed stable degradation rates over a period of one year (Streese and Stegmann, 2003).

2.7.1.1 Exopolymeric Substances (EPS) Formation

According to research, CH₄ oxidation in landfill cover soil demonstrates a peak followed by a decrease to a lower steady-state value (Hoeks, 1972; Kightley *et al.*, 1995; Hilger *et al.*, 2000). One possible explanation for this sharp decline is an accumulation of extracellular polymers that either clog soil pores and causes short-circuiting or impede gas diffusion into the cells. Many bacteria, including CH₄ oxidizers, produce exopolymeric substances (EPS).

EPS production may also cause resistance to dehydration, a shield from predators, and a mechanism to keep certain microorganism populations in close proximity (Fletcher *et al.*, 1992). The nature and degree of polymer formations vary widely among both microbial species and environmental conditions, and EPS production has been linked to both nutrient imbalance and O₂ deficiency (Wrangstadh *et al.*, 1986). EPS accumulation can alter the metabolism of bacteria embedded in a biofilm.

Methanotrophs are known to produce EPS both as capsules (Wyss and Moreland, 1968; Whittenbury *et al.*, 1970) and as copious slime. Chida *et al.* (1983) illustrated two polymers produced by a single thermophilic methanotroph. These polymers had molecular weights of 120,000 - 340,000, sugar contents ranging from 37% to 56%, and amino acid contents between 30% and 38%. Southgate and Goodwin (1989) reported both viscous and non-viscous EPS production in pure cultures of *Methylophilus methylotrophus*, and the polysaccharides contained sugars as well as acetate and pyruvate residues. A highly viscous polymer produced by *Methylophilus viscogenes* is harvested and marketed under the name of Poly 54 (Leak, 1992). It has been suggested that for methanotrophs in particular, production of a carbon-rich polymer is used as a metabolic mechanism to prevent formaldehyde accumulation when carbon is in excess (Linton *et al.*, 1986).

Research and experiments conducted by Hilger *et al.* (1999) confirms EPS production in LFG laboratory soil columns and in fresh landfill soil cores. Even though EPS is a normal component of biofilm growth, it was shown that a considerable quantity of highly viscous polymeric substance was produced in response to CH₄ exposure in a biofilter. Although the presence of viscous polymer was established by different measurements, the main cause of short-circuiting

and CH₄ retention times' reduction in the columns was not proven (Hilger *et al.*, 1999; Linton *et al.*, 1986).

In the unfavorable conditions of landfill cover soil, it is possible that EPS formation actually improves CH₄ oxidizer populations by protecting the oxidizer against dehydration or predation. However, CH₄ oxidizer population protection can also be favored as a result of metabolic adaptations to a carbon-rich environment. The source of this simulation is not clear but it is shown that it stops the rate of CH₄ oxidation by restricting O₂ diffusion into cells embedded in the biofilm. A mathematical model was used by Hilger *et al.* (1999) to test the mentioned hypothesis in a laboratory column system. It was observed that trends in CH₄ oxidation can be explained by the development of a viscous EPS layer over a base biofilm layer (Hilger *et al.*, 1999; Linton *et al.*, 1986; Humer and Lechner, 1999).

2.7.2 Microbial Activity in Biofilters

The action of breaking down the compounds, in this case oxidation is performed by the microorganisms in the biofilter. These microorganisms transform and interact with each other in the biofilter media. Biofilters may be self-inoculating, inoculated with activated sludge or compost, or induced with bacteria species (Devine, 1999).

In a study conducted by Ding *et al.*, (2000), microbial ecology and performance of a biofilter were studied. It was observed that changes in the microbial community occurred with changes in the inlet gasses. Furthermore, the research confirmed the ability of the microbial community to respond to changes in the inlet gasses without affecting the treatment of those gasses.

Further research is needed to determine the relationship between microbial community dynamics and biofilter performance, and the rate of microbial community growth in response to changes in inlet gas concentrations. However, this research should not affect biofilter design dramatically since a sufficient amount of media is needed for the microorganisms to effectively remove and oxidize the gas compounds targeted (Devinny *et al.*, 1999).

2.7.3 Biofilter Residence Time

In order to get maximum reduction from a biofilter, the air passing through the filter must contact the filter media for a given amount of time. This amount of time is known as the residence time or empty bed contact time (EBCT). It is defined as the empty bed filter volume divided by the air flow rate (Devinny *et al.*, 1999).

2.7.4 Biofilter Moisture

Biofilter moisture has been reported to be one of the main factors affecting biofilter performance. It has been also reported that most problems in a biofilter are caused by a lack of moisture (Reyes *et al.*, 2000). Dry media can cause channeling and can lead to a decrease in biological activity. Media dehydration is a particular problem in the summer when an increase in temperature causes faster evaporation rates for the water in the media (Devinny *et al.*, 1999).

To overcome dryness of the biofilter media, moisture can be added during mild and warm weather (Nicolai and Janni, 1999). A number of moisture sensors and systems have been recognized to measure biofilter moisture. Classmen *et al.* (2000) used a weight-based method of calculating moisture content on three pilot-scale biofilter units by continuously weighing each biofilter. This method was found to maintain the proper moisture level on each of the three biofilter units within 4%. A problem with this method is that due to uneven distribution of moisture in the filter, the weight system reports the average moisture content in the bed, but some sections may be too dry resulting in air channeling. Reyes *et al.* (2000) demonstrated that a TDR probe could be used to monitor biofilter media moisture content on a real time basis. Their experiment was performed using 60% compost and 40% pearlier.

Another factor affected by moisture content is the pressure drop in the biofilters (Nicolai and Janni, 2001). Pressure drops are usually higher when moisture content is higher. However, this is only noticeable on low compost to wood chip ratios, and is not a major factor on pressure drop through media that consists of high compost to wood chip ratios (Nicole and Janni, 1999).

2.7.5 Degradation of Biofilter Media

The microorganisms in the biofilter that can treat the compounds in the landfill gas can also degrade biofilter media as a result of their activity (Wani *et al.*, 1998). Due to this action, the biofilter can be settled and compacted thus reducing component interchange surface and increasing the resistance to flow. Media dry matter may even increase over time as a result of growth of microorganisms and chemical accumulation (EPS) in the media due to mineralization (Sun *et al.*, 2000). Eventually, the biofilter media must be replaced due to the effect of aging. It is estimated that most biofilter media will remain effective without causing a large pressure drop for 3 to 10 years (Nicole *et al.*, 1999).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Materials

3.1.1 Methane Oxidation Bioreactor Design

The design of a methane oxidation bioreactor was a crucial task for this study since the following conditions should be considered: i) providing optimum air supply for bacterial respiration, ii) proper mixing method for air and methane, iii) constructing an upward flow bioreactor to force carbon-dioxide out from the filter beds, iv) designing a landfill environment representative bioreactor, and v) cost effectiveness. Keeping the factors above in mind, three separate bioreactors were constructed for three different filtering materials. The material used for these bioreactors were locally available and cost-efficient. The schematic diagrams of a bioreactor are shown in Fig. 3.1 [a] and Fig. 3.1 [b], and the comprehensive experimental setup is illustrated in Fig. 3.2. Each biofilter was built using a standard cylindrical PVDF (polyvinylidene fluoride) tank, 90 cm high with a wall thickness of 0.24 cm, and an internal diameter of 54 cm. To obtain maximum mixing, three gas/air diffusers were embedded at the bottom of the tank followed by a 5 cm thick granular stone layer. A fine, non-reactive plastic mesh was used to cover the granular stone layer and to protect the gas/air mixing area from filter material amalgamation. Each biofilter was then filled with filter material to the height of 50 cm to maintain uniform bulk density, and the headspace of the bioreactor tank (35 cm) was used as a collection chamber. The collection chamber (reactor top) was covered using a removable lid with a small sized outlet at the center, providing a vent to the outflow. A flexible sealing material (play-doh) was used along the edges of the removable lid to simplify sampling from the bioreactor. A 20 kg load was placed on top of the lid to develop the required pressure head for easy gas sampling (conversion of pressure head into velocity head). Each bioreactor was fed pure methane gas (one inlet) and air (two inlets) through tubes permanently connected to diffusers (Fig. 3.1 [b]). All three bioreactors were housed in a plastic, confined room erected within the geo-environmental lab. To maintain adequate temperature and humidity, three air heaters and one humidifier were placed in the

confined room. The common outlet of all three bioreactors was connected to a fume hood for proper evacuation and to maintain suitable ambient conditions during the experiment (Fig. 3.2).

Fig. 3.1 [a] Side cross-sectional view of the Biofilter reactor, and [b] Top Cross-sectional view of the Biofilter reactor

Fig. 3.2 Photograph of experimental setup for bio-oxidation of methane in compost, sawdust, and sand media

3.1.2 Biofilter Materials

In this study, compost, sawdust, and sand were selected to build three different biofilter media. The first column was filled using stabilized yard waste compost, sieved with a 6-mm mesh sieve, and collected from Scarborough Transfer Station located in Scarborough (Toronto, Ontario). Additionally, disposable landfill sawdust was transported from Home Depot located in Scarborough. Coarse-grained sand was provided by the Ryerson University Concrete Materials Laboratory. The physical features of the compost, sand, and sawdust samples are shown in Fig. 3.3 [a], Fig. 3.3 [b], and Fig. 3.3 [c] respectively.

Fig. 3.3 Photograph of biofilter materials [a] compost, [b] sand, and [c] sawdust

3.2 Methods

3.2.1 Experimental Procedure

To maintain 2.5% to 3.0% methane inflow concentration, the inflow rate of methane to the bioreactors was adjusted to 5.4 L/h and mixed with 180 L/h of air supplied by both aerators. Pure methane gas obtained from The Linde Canada Limited (min. 98%, Ontario), was regulated and supplied through non-reactive plastic tubes followed by a calibrated flow-meter from Scott Specialty Gases (Ontario, Canada). The filter bed materials were compacted with a standard protocol hammer to obtain the uniform bulk densities. The initial bulk densities, moisture contents, and pH of the materials were determined by standard methods, and the values are listed in Table 3.1.

Table 3.1 Different properties of filter materials

Parameter	Compost	Sawdust	Sand
Bulk Density (kg/m ³)	568	168	1310
Water Content (%)	37.2	4.14	0.44
Ignition loss (%)	45	98	3
pH	7.2	6.8	7.8

Initial moisture content calculation of the three materials used showed that there was not enough moisture available to achieve optimum methane oxidation. Therefore, tap water was added and thoroughly mixed with the material to increase the moisture content. In the event of a decrease in the bioreactor moisture content, a calculated amount of tap water was sprinkled on the top of the bioreactor beds to approximately maintain constant moisture content. In addition, one percent by volume activated sludge collected from Ashbridges Waste Water Treatment Plant (Toronto, Ontario) was mixed with the tap water to inoculate the material, increase bacterial growth and bypass bacterial lag phase. In this study, *methane oxidation, media moisture content, COD, BOD, reactor temperature, gas inflow temperature, biomass content and solution extraction* measurements were performed on a weekly basis.

3.2.2 Moisture Content Monitoring with TDR

A Spectrum Technologies Inc. Time Domain Reflectometer (TDR) was used to monitor the moisture content of the filter beds (Fig. 3.4 [a]). The bioreactor filter bed media consisted of solid, liquid water, vapour water, gaseous methane, carbon-dioxide, and air. Furthermore, the TDR was calibrated at different moisture contents for all three media. The calibrations were done in the lab using the same compost, sawdust and sand that were packed in the biofilter columns at the same bulk densities (Appendix C). TDR probes were inserted from the top and measurements were taken at various locations to obtain representative moisture content. The TDR values were

used to calculate moisture contents from the moisture characteristics curves and characteristics equations (Fig. 3.5, Fig. 3.6 and Fig. 3.7).

**Fig.
3.4**

Photograph of [a] Water content measurement with TDR, [b] Temperature measurement

Fig. 3.5 Moisture characteristics curve for compost filter bed

Fig. 3.6 Moisture characteristics curve for sawdust filter bed

Fig. 3.7 Moisture characteristics curve for sand filter bed

3.2.3 Temperature Monitoring

A portable thermometer (Omega Engineering Inc, Basic type K thermocouple input, HH12A) was used to log soil temperatures. The teflon-coated probe was inserted into the medium at three levels - inlet, center, and surface - to monitor and record temperatures for the biofilter media (Fig. 3.4 [b]). The temperatures were observed at five different locations for each level of the media to ensure uniform temperature distribution.

3.2.4 Methane Gas Concentration Analysis

Methane gas samples were collected from the inlets and outlets of the bioreactors using plastic balloons (Fig. 3.10 [a]), and the respective methane concentrations were analyzed using a Perkin Elmer Auto System XL gas chromatography system available at the Ryerson University Analytical Centre. The gas chromatogram was equipped with a flame ionization detector and Superlco Equity-5 capillary columns. Helium was used as a carrier gas for this analysis; the oven temperature was 40 °C; the injector and detector temperatures were maintained at 200°C. The mass spectrometry data of the gas chromatogram was calibrated using methane standards provided by The Linde Canada Limited (Mississauga, Ontario). The gas chromatograph and gas injection methods are shown in Fig. 3.8 [a] and Fig. 3.8 [b].

A gas-tight syringe was used to collect gas samples from the balloon, and 50 µL of gas was injected into the injection port of the gas chromatogram. All samples were analyzed within 40 minutes of the collection time. TC-Navigate software was used to operate the gas chromatogram and to calculate the methane combustion area represented by the curve at the peak elution time (2.53 minutes for methane). The data obtained from the gas chromatograph were inferred from the methane calibration curve shown in Fig. 3.9.

The results from the gas chromatograph and the calibration curve were used to calculate methane oxidation. The methane oxidation was calculated using equation [1]

$$OXD = \frac{C_{(CH_4)in} - C_{(CH_4)out}}{C_{(CH_4)in}} \quad [1]$$

Where,

OXD = Methane Oxidation

C_{(CH₄) in} = Inlet Methane Concentration

C_{(CH₄) out} = Headspace Methane Concentration

[a]

[b]

Fig. 3.8 Photograph of [a] Gas Chromatograph, [b] GC Syringe opening

Fig. 3.9 Methane calibration curve

3.2.5 Solution Extraction for Substrate Analysis

To perform weekly analyses of COD, BOD, and the biomass, solution extraction from the filter beds was necessary. Therefore, solid pore water examination was chosen for this section. Since the moisture content of the solids used in this experiment were low, direct methods of solution extraction, such as centrifuge or low capacity vacuum pump, failed.

For that reason, solid samples were collected from the bottom of the 30 cm long PVC cylinder placed at the centre of the bioreactors. Approximately 50 g of the solid sample was collected to use in the analysis. The samples were then diluted and mixed with the same amount of distilled water (approximately 50 mL), followed by ten minutes of stirring with a glass rod. These samples were completely covered (to protect from evaporation) and stored for 24 hours as shown in Fig. 3.10 [b]. The supernatants were filtered using a sieve to obtain a representative liquid for further analysis of the stated parameters.

Fig. 3.10 Photograph of [a] Gas collection balloons, [b] Solution extracted from compost, sawdust, and sand media

3.2.6 Biochemical Oxygen Demand Analysis

The analysis of biochemical oxygen demand was carried out to monitor the dissolved oxygen necessary for bio-oxidation. A standard method of determining BOD_5 was adopted to analyse the extracted liquid mentioned and collected in section 3.2.5. Accordingly, the buffer solution for nutrition of the bacteria was prepared by mixing the following compounds: 8.5g KH_2O_4 , 21.75g K_2HPO_4 , 33.4g $Na_2HPO_4 \cdot 7H_2O$, 1.7g NH_4Cl , 22.5g $MgSO_4 \cdot 7H_2O$, 27.5g $CaCl_2$, 0.25 $FeCl_3 \cdot 6H_2O$ per litre of distilled water (USEPA, 1986). The initial pH of the seeded BOD bottles was maintained within the limit range of 6.5 to 7.5. The initial and final dissolved oxygen (DO) were measured with a Thermo Orion3Star DO meter (Fig. 3.11). The bottles were kept for five

days in an incubator at 22°C. Consequently, equation [2] was used to estimate the BOD₅ for each sample:

$$\text{BOD}_5, \text{ mg/L} = \frac{D_1 - D_2}{p} \quad [2]$$

Where:

D_1 = DO of diluted sample immediately after preparation, mg/L

D_2 = DO of diluted sample after 5-day incubation at 22°C, mg/L

P = decimal volumetric fraction of sample used

Fig. 3.11 Photograph of [a] Seeded BOD bottles, [b] DO and pH measurement

3.2.7 Chemical Oxygen Demand Analysis

The COD was measured to monitor the organic matter utilization in the filter materials, therefore verifying bacterial organic matter and/or methane consumptions in the biofilter media. This test was conducted by adding 0.5 mL of extracted solution from the medium to the standard Bioscience Accu-TEST COD vials. The vials were placed in the Heater Block (Bioscience 174-318) at 150°C ($\pm 2^\circ\text{C}$) for 2 hours. The vials were then left for 30 minutes to cool down (Fig. 3.12). Moreover, the absorbance and transmittance data for a 600 nm spectrum were measured by placing sample vials and standard vials in the Thermo Electro spectrometer. The COD values of the samples were calculated using Equation [3], obtained from the standard calibration curve shown in Fig. 3.13.

$$\text{COD (mg/L O}_2\text{)} = 12167 \times (\text{Absorbance})$$

[3]

Where:

COD (mg/L) O₂ = Chemical Oxygen Demand in terms of mg/L of O₂

Absorbance = Absorbance for a 600 nm spectrum

Fig. 3.12 Photograph of COD vials after oxidation

Fig. 3.13 COD calibration curve

3.2.8 Bradford Protein Analysis

The amount of biomass contents at different time periods of the study was monitored through the method of Bradford protein analysis. Initially, a calibration curve shown in Fig. 3.14 was made from the standards using Bradford Dye Method Kit provided by BIO-RAD (Fig. 3.15). The standards were prepared by adding 600 μL of the protein provided in the Bradford Kit to a clean cuvette filled with 3 ml Bradford dye reagent.

To continue the process, 1 mL of the extracted liquid was transferred into a 2 mL centrifuge tube using a pipette. These tubes were centrifuged at 13,050rpm for 15 minutes. The supernatants were then carefully removed and 1 mL of NaOH (1N) was added to the settled particles in the centrifuge tubes. Furthermore, the tubes were boiled for 10 minutes in a hot water bath. After cooling, the tubes were again centrifuged at 13,050rpm for 15 minutes. A 600 μL sample was removed from the centrifuged tubes and added to a clean cuvette filled with 3 mL of Bradford dye reagent. Finally, after leaving the cuvettes for approximately 10 minutes for conditioning, the absorbance of a 595 nm spectrum was measured for each sample using a spectrometer.

Fig. 3.14 Bradford protein calibration curve

Fig. 3.15 [a] Centrifuge Tubes, [b] Bio-Rad Bradford Kit, [c] Standard Cuvettes, [d] Sample Cuvettes

3.2.9 Methanotrophs Plate Count Analysis

To observe the growing patterns of methanotrophs, the plate count procedure used by R.L Mancinelli (1981) was selected for this study. The method was similar to the standard CFU plate count method except the preparation of mineral salts nutrient used in agar. The constituents of the nutrient were 2 ml methanol, 25g Agar, 0.5g K_2HPO_4 , 0.5g KH_2PO_4 , 0.5g NH_4NO_3 , 0.2g $MgSO_4$, 0.01g $CaCl_2$, 0.005g $FeSO_4$, $0.543\mu g$ $FeCl_3 \cdot 5H_2O$, $0.17\mu g$ $CoCl_2 \cdot 6H_2O$, $0.1\mu g$ $ZnCl_2$, $0.011\mu g$ $MnCl_2 \cdot 4H_2O$, and $0.019\mu g$ H_3BO_3 . All these compounds were thoroughly mixed in one litre DDW and boiled to create agar. The cooked agar was then poured in sterile Petri dishes and left for 24 hours to solidify (Fig. 3.16) (Mancinelli, 1981).

To prepare the dilution folds, 1g of solid sample was added to 100 ml sterile saline solution in a flask and left for one hour. By adding 0.5 mL from the flask containing the sample to 4.5 mL of sterile saline solution prepared in a sterile culture tube, a dilution factor of 10^{-1} was created. The tube was shaken to create a vortex and 0.5 mL of this mix was added to the next saline tube to produce the next fold (10^{-2}). This procedure was repeated to form the following concentrations: 10^{-1} , 10^{-2} , 10^{-3} , 10^{-4} , ... , and 10^{-10} .

Subsequently, 100µL solution from each dilution was added to Petri dishes to inoculate the agar. The solution was then spread to form a thin layer all over the agar medium to ensure consistent bacterial growth. These Petri dishes were labelled, inverted, covered with aluminum foil, and left for 12 days at 22°C. After the incubation period, bacterial colonies of each Petri dish with only 30 – 300 colonies were counted. The number of methanotrophic bacteria per millilitre or gram of sample was estimated using equation [4]:

$$\text{Number of Colonies (Methanotrophs)} = [\text{Bacteria (\#)} \div \text{Dilution (mL)}] \times \text{Amount Plated (mL)} \quad [4]$$

Fig. 3.16 Photograph of [a] Material used to prepare agar Petri dishes [b] Culture tube folds

3.2.10 CFU Plate Count Analysis

The CFU culture was also done to observe the other bacterial growth pattern other than methanotrophic bacteria. A cultured medium was made by mixing 15 g of agar with 3 g Tryptone Soy Broth (TSB) in one litre of distilled water. This mixture was autoclaved for 20 minutes at 120°C and left to cool in a 50°C (±2°C) water bath before adding approximately 10 mL of the cooked agar to sterile Petri dishes. The Petri dishes were left for 24 hours at room temperature to harden. Afterwards, the procedures explained in section 3.2.9 were followed to

produce cultured Petri dishes. The Petri dishes were inverted and incubated at 25°C for three days (Fig. 3.17).

Fig. 3.17 Photograph of [a] Material used to prepare agar Petri dishes [b] Culture tube folds

CHAPTER FOUR

4. RESULTS AND DISCUSSION

In order to compare and examine various biofilter media methane oxidation rates, the headspace gases were analyzed and the data was used to calculate methane oxidation efficiencies in compost, sawdust and sand media. In this study, yard waste compost was chosen as the primary medium due to its proven ability to oxidize methane from the LFG. The secondary medium chosen in this study was sawdust. Sawdust, being a by-product of the construction industry, is generally dispensed into landfills and is eventually decomposed. Consequently, if proven to be an efficient methane oxidation media, sawdust can be recycled and used as part of a compound forming the final landfill cover. The last and third medium used as a control was sand. This material was chosen to show oxidation due to methanotrophic activity. If proven to be beneficial to methane oxidation, sand can be used as a final landfill cover since it is widely available.

The observed decrease in CH_4 concentration in the bio-reactors was a clear indication of the methanotrophic activity and methane oxidation in the media. Moreover, trend of bacterial growth, biomass content, chemical oxidation demand (COD), and biochemical oxidation demand (BOD) were estimated to ensure the use of methane as an energy source by the methanotrophic bacteria. The initial experimental conditions for the selected media used throughout this study are illustrated in Table 4.1 followed by the operational data for the biofilters in Table 4.2.

Table 4.1 Initial experimental condition in the Media

Parameter	Compost	Sawdust	Sand
Bulk Density (kg/m ³)	568	168	1310
Moisture Content (% w/w)	37.2	4.14	0.44
COD(mg/L)	4842	3626	122
BOD (mg/L)	457	256	17
Biomass Density(g/ m ³)	876	408	32

Table 4.2 Operational Data for the Experimental Biofilter Design

Parameter	Unit	Experimental Data
Number of Filter Columns	-	3
Total Biofilter Volume	m ³	0.115
Biofilter Packed Bed Depth	m	0.50
Total Biofilter Flow	m ³ /h	185.4×10 ⁻³
Filter Surface Load	m ³ /(m ² h)	23.5×10 ⁻³
Volumetric Filter Load	m ³ /(m ³ h)	4.7×10 ⁻³
Methane Supply Concentration	vol. %	2.70
Methane Load per Filter Vol.	g/(m ³ h)	33.82

4.1 Methane Oxidation Performance

4.1.1 Oxidation Comparison in Biofilter Beds

The three biofilters were operated over a period of ten weeks. In this study, samples were collected each week at the same time to ensure consistency of the results. Moreover, to obtain suitable sampling frequency, a trial set of samples were prepared and the sample were collected and analyzed twice a day for 14 days, since there was not a significant change in the two sample collected each day, a sampling frequency of one week was appointed for this experiment. The quantity of methane eliminated, which depends on the change of methane concentration between the biofilter inlet and outlet, is the key indicator of the effectiveness of the treatment process. In this study, the measured CH_4 concentration from all biofilter outlets confirmed a decrease in concentration from the inlet, suggesting biological CH_4 oxidation occurrence. The percentage of methane oxidation results obtained during this study are presented in Fig. 4.1. As discussed in section 3.2.4, the biological methane oxidation rate is calculated using the data collected from the GC and equation [1] (Appendix A). The overall methane oxidation rate in the compost, sawdust and sand were 86%, 59% and 57% respectively. In all the experimental trials, CH_4 oxidation rate in the compost medium was greater than both the sawdust and sand media.

As presented in Fig. 4.1, the CH_4 oxidation rate in all three media decreased with time. The weekly decline in the oxidation rate for each media was estimated using the trend-line equation. The resulting weekly decline rates of oxidation are 2.7% for compost, 1.16% for sawdust and 0.98% for sand. The linear equation also demonstrates that the performance of the compost media is higher by 27% and 29% over the sawdust and sand media respectively, confirming that the compost offers better landfill cover medium for bacterial growth and CH_4 utilization than the other materials. It is also noticeable that although the initial organic matter content in the sand medium (Table 3.1) was negligible, the CH_4 oxidation rate was over 55% in this media. This result indicates that methanotrophic bacteria activity might be the main mechanism responsible for CH_4 oxidation and that a media with insignificant organic content could still be an appropriate choice to achieve methane oxidation.

Fig. 4.1 Methane oxidation rate in different materials

Fig. 4.2 Methane elimination capacities in different materials

The specific methane elimination capacities of the three materials are calculated using equation [5], equation [6] and presented in Fig. 4.2. The overall elimination capacities in this study were approximately 29.1, 19.9 and 19.3 g/m³/hr for the compost, sawdust and sand filter beds respectively (Appendix A).

$$EC = IL \times X \quad [5]$$

$$IL = \frac{C_{(CH_4)in} \times Q}{V} \quad [6]$$

Where,

EC = Elimination capacity (g/m³/h)

IL = Inlet load (g/m³/h)

X = Oxidation rate

C_(CH₄) = Inlet Methane Concentration (g/m³)

Q = Methane Inlet flow (m³/h)

V = Biofilter Volume (m³)

4.1.2 Effect of Temperature on Methane Oxidation

In this study, methane consumption rates rose with increasing temperature in all three biofilter bed (Appendix C). The average inlet temperatures of the bioreactors were 20.3 °C, while the compost, sawdust and sand average biofilter bed temperatures were 28.6 °C, 26.2 °C and 24.2 °C respectively (Fig. 4.3). Fig. 4.4, Fig. 4.5 and Fig. 4.6 were compiled to show the change of oxidation rate with respect to temperature change within the three biofilters. As previously mentioned, to achieve the objective of comparing various biofilter media and their biomass content, the temperature of the three biofilters were kept within an optimum range (20°C to 36°C). The best fitted line for Fig. 4.4, Fig. 4.5 and Fig. 4.6 also illustrate that the methane oxidation rate increases with increasing temperatures. Increasing temperature affects the bacterial activity in the biofilter media leading to higher methane consumption rate and oxidation

rates. Temperature has a strong effect on different types of methanotrophic bacteria and their population; many researchers reported that only Type I methanotrophic bacteria can grow at low temperatures of 3⁰C and 10⁰C, while two types (Type I and Type II) grow at 20⁰C (Borjesson *et al*, 2004; Gerber *et al.*, 2003; Hanson and Hanson, 1996).

The highest CH₄ oxidation rates for compost and sand were achieved at the same temperature, which was 27 °C, in comparison to 31⁰C for sawdust. Moreover, the least temperature variation was observed in the sand media, which was due to the lack of decomposable materials in this media.

Fig. 4.3 Average biofilter bed temperature with respect to inlet temperature

Fig. 4.4 Methane oxidation rate with respect to biofilter bed temperature in the compost media

Fig. 4.5 Methane oxidation rate with respect to biofilter bed temperature in the sawdust media

Fig. 4.6 Methane oxidation rate with respect to biofilter bed temperature in the sand media

4.1.3 Effect of Moisture on Methane Oxidation

The moisture content of the biofilter media is an important physical parameter in designing a methane oxidation system due to its affect on gas diffusion within the media pores. It has been reported by Whalen *et al.* (1990) that as the soil moisture content increases, CH₄ oxidation rates decreases due to a change from gas phase (CH₄ and O₂) to aqueous molecular diffusion phase, which reduces CH₄ transport to methanotrophic cells. Therefore, optimization is necessary to accommodate the biomass in the medium and to maximize oxidation rates.

To achieve the main objective of comparing media performance and bacterial growth in the biofilter media, an approximately constant but suitable range of volumetric moisture content (VMC) was selected (Appendix C). The range of moisture content and the variations of methane oxidation rates are shown in Fig. 4.7, Fig. 4.8 and Fig. 4.9. The compost media presented optimum performance at a range of 0.37 to 0.385 VMC (Fig. 4.7); beyond this range, oxidation efficiency declined. The sawdust media demonstrated various moisture contents in comparison to the compost media, which is likely due to its porosity and fine texture. The sand media moisture contents were mostly observed to be between 0.040 to 0.045 VMC, this can be linked to lower bacterial activity that can cause lower water production in the media.

Fig. 4.7 Methane oxidation rate in compost media with respect to biofilter moisture content

Fig. 4.8 Methane oxidation rate in sawdust media with respect to biofilter moisture content

Fig. 4.9 Methane oxidation rate in sand media with respect to biofilter moisture content

4.2 Biomass Growth and Methane Oxidation Rate

As discussed previously, biological methane oxidation occurs when methanotrophs utilize methane as an energy source, leading to conversion of methane into carbon dioxide, water, and biomass which are much less harmful for the environment (Whalen *et al.*, 1990; Kightley *et al.*, 1995; Czepiel *et al.*, 1996; Borjesson and Svensson, 1997; Borjesson *et al.*, 1998; Liptay and Chanton, 1998; Borjesson *et al.*, 2004). In this investigation, the aim was to observe the biomass production function in the compost, sawdust and sand medium to demonstrate a relationship between the bacterial availability, growth and the methane oxidation phenomenon.

4.2.1 Biomass Content Variations

As presented in section 3.2.8, the Bradford Dye method was used to measure the amount of protein in the extracted solution of the solid sample collected from the biofilter media. The results were then compiled and the time-dependent variations of bacterial growth in three different media are presented in Fig. 4.10, Fig. 4.11 and Fig. 4.12 (Appendix B).

Fig. 4.10 Biomass content in the compost media

Fig. 4.11 Biomass content in the sawdust media

Fig. 4.12 Biomass content in the sand media

Fig. 4.13 Comparison of biomass content in different biofilter media

Moreover, from Fig. 4.10 it was observed that biomass content in the compost presents a peak every three weeks (peaks at week 3, week 6 and week 9). There is also a visible peak in the sawdust media (Fig. 4.11) in week three and six, therefore it can be concluded that the bacteria took three weeks to reach its highest activity. On the other hand, the biomass content increase in the compost and sawdust media at week three (Fig. 4.10 and Fig. 4.11) can also be due to the high temperature - 35°C and 31°C for compost and sawdust respectively - in both media during week three; therefore, increasing bacterial activity and leading to higher biomass production. In general, the sand media presented a more stable biomass content variation that is due to lower nutrients availability and bacterial activity in this media. Additionally, as illustrated in Fig. 4.13, the biomass content in compost was much higher than sawdust and sand. The compost media had a higher amount of organic matter, showing that the bacterial activity was much higher in this media. Moreover, the sawdust media demonstrated approximately half the compost biomass content during this experiment.

As mentioned previously, the sand media was used as a control biofilter and presented low biomass content. However, distinct variations in the biomass content of all three biofilter beds were noticeable throughout the experimental period that could be due to temperature variations, moisture variation and/or the bacterial production and decay rate. The calculated average biomass contents were 539 g/m³, 238 g/m³ and 32 g/m³ in the compost, sawdust and sand media respectively.

The consumption rate of methane in all three biofilter with respect to their biomass content is shown in Fig. 4.14, Fig. 4.15 and Fig. 4.16. It is evident that methane consumption rates were directly proportional to the bacterial density (biomass content) in all three media used in this study, although the decline rate function was different for each media.

In the beginning of the experiment, consumption rates were higher in all three biofilters and with time these rates gradually declined. The descending rate was much higher in compost and sawdust media, and it was almost negligible in the sand medium. The results imply that the higher rate of methane oxidation could be possible by maintaining higher density of methanotrophs. Greater bacterial intensity could be achieved by maintaining favourable conditions in the media such as supplying nutrients, and increasing methane and oxygen influx.

Fig. 4.14 Methane oxidation rate with respect to biomass content in the compost media

Fig. 4.15 Methane oxidation rate with respect to biomass content in the sawdust media

Fig. 4.16 Methane oxidation rate with respect to biomass content in the sand media

4.2.2 Effect of Chemical Oxygen Demand

Microorganism responsible for methane oxidation can also use the organic matter present in the biofilter media as an energy source. The chemical oxygen demand (COD) was evaluated in this study to observe the use of organic matter by the bacteria in addition to their methane consumption. This parameter was measured using the liquid extracted from the biofilter media (section 3.2.7) and the results are presented in Fig. 4.17, Fig. 4.18 and Fig. 4.19 (Appendix E).

The best fitted lines of the mentioned figures demonstrate that organic matter attributed to the survival of the bacteria in the compost and sawdust media; however, due to the unavailability of organic matter in the sand media, bacteria survived by utilizing methane gas. The overall COD uptake during this experimenting was 2555 mg/L for compost, 1984 mg/L for sawdust and 49 mg/L for sand media.

Fig. 4.17 Effect of COD on the compost media

Fig. 4.18 Effect of COD on the sawdust media

Fig. 4.19 Effect of COD on the sand media

4.2.3 Effect of Biochemical Oxygen Demand

The bacterial population that converts CH_4 into CO_2 and H_2O in the biofilter media needs oxygen for survival. These microorganisms use the available O_2 in the media voids and/or the dissolved O_2 in the media pore solution to complete their reaction. The monitoring of the biochemical oxygen demand (BOD) conducted in this study assisted in predicting the status of dissolved oxygen in the extracted pore water solution (section 3.2.6) and indicated bacterial biological activity through their use of oxygen.

The overall BOD uptake (9 weeks) in the compost and sawdust and were 332 mg/L, 156 mg/L and respectively (Appendix D). The trends of BOD level in the biofilters are shown in Fig. 4.20, Fig. 4.21 and Fig. 4.22. The BOD measurements of the compost and sand biofilter media present the use of the dissolved oxygen in the pore solution. However, the results obtained for the sand media showed an increase of BOD that could be caused due to its fine texture. According to Boeckx *et al.* (1997) the soil texture determines the tortuosity of the soil and influences the distribution of the macro and micro-pores. Finer textured soil has higher tortuosity and causes slower gas diffusion in the soil. The authors stated that fine textured soil takes longer to transport methane and oxygen to the methanotrophs. Additionally, throughout this experiment, a

continuous supply of air was ensured to feed the necessary oxygen required for bacterial respiration in the biofilter media.

Fig.4.20 Effect of BOD on the compost media

Fig. 4.21 Effect of BOD on the sawdust media

Fig. 4.22 Effect of BOD on the sand media

4.2.4 Bacterial Growth Pattern

In general, the counts of bacterial growth was done to coincided with oxidation rate measurements, however some plate counts were not truly representative of the in-situ active bacterial biomass, but the collected data ensured presence of methanotrophic bacteria in all three biofilter media throughout this study.

The trend of total bacterial growth population on an agar plate for the compost, sawdust and sand media are shown in Fig. 4.23, Fig. 4.24 and Fig. 4.25 (Appendix F). The existence of methanotrophs in all three media was confirmed by performing specific bacterial plate counts on a methanol enriched agar, and the results are presented in Fig. 4.26 for compost, Fig. 4.27 for sawdust, and Fig. 4.28 for sand media.

Fig. 4.29 presents the comparison of the bacterial population densities in the three media. It is evident that compost and sawdust media had higher bacterial population throughout the study. However, sand presented a sharp increase in the bacterial density at the end, which in fact is in accordance with the results obtained by the BOD test. Overall, the high bacterial population

density presented in the compost and sawdust media are due to the availability of nutrient constitutes in these two media, consequently offering enhanced environmental conditions for bacterial growth.

Fig. 4.23 Photograph of CFU bacterial population in the compost media

Fig. 4.24 Photograph of CFU bacterial population in the sawdust media

Fig. 4.25 Photograph of CFU bacterial population in the sand media

Fig. 4.26 Photograph of methanotrophic bacterial population in the compost media

Fig. 4.27 Photograph of methanotrophic bacterial population in the sawdust media

Fig. 4.28 Photograph of methanotrophic bacterial population in the sand media

Fig. 4.29 Comparison of bacterial population in different biofilter media

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Biological processes can be used to efficiently convert methane to carbon dioxide and to treat other compounds in landfill gases. Previous research has shown up to 100% of landfill gas methane can be oxidized by microbiological activity in the landfill cover. The effectiveness of such systems is known to be dependent upon several factors including the characteristics of biofiltration media through which the landfill gas passes (i.e. porosity, pH, moisture content, temperature, and nutrients availability). Since the landfill cover medium affects methane oxidation processes significantly, the objective of this study was to research and compare the use of three different media as biofilters to reduce landfill methane emissions to the atmosphere.

The results obtained in this study confirm that stabilized yard waste compost provides for a very good landfill cover medium in comparison to sawdust and sand. The overall oxidation rate in compost was 89%, followed by sawdust at 59% and sand at 57%. Since methanotrophic bacteria can be sensitive to varying temperatures and moisture contents, these parameters were also recorded during sampling events. It was observed that temperature is one of the main environmental parameters influencing biological methane oxidation in the landfill cover system.

Additionally, biomass variations in different media were observed. Due to its high oxidation rate and nutrients availability (in addition to methane feed), compost media demonstrated the highest biomass production in comparison to sawdust or sand. The biomass quantity illustrated methane oxidation process in all three media and it was recognized that bacterial density is directly linked to methane oxidation rates. As the oxidation rate decreased throughout the experiment in the compost and sawdust media, so did their biomass contents. This concludes that oxidation efficiency can be achieved through maintenance of higher bacterial population.

Moreover, sawdust and sand were presented as alternative media for the methane biofiltration process. These two media are generally widely available and cost effective to implement. Based on this study, these two media have more than 50% methane oxidation rate, which can be ideal for old landfills that do not produce as much methane, or as a polishing step for a landfill with a gas collection system.

Furthermore, the oxidation rate of the sawdust media could be increased by incorporating necessary nutrients before media implementation. Also, the difference between the oxidation rate of compost and sawdust media might be eliminated after an extended period of time due to nutrient exhaustion in the compost and the generation of edible carbon after gradual decomposition in the sawdust. Additionally, the sand medium could be a suitable media due to its larger pore volume that can reduce the clogging effect and increase oxygen diffusion in the media when compared to compost and sawdust.

5.2 Recommendations

This investigation was conducted under laboratory conditions with low concentrations of methane and the experiment was performed over a relatively short period of time. It is suggested to carry out the experiment in a landfill site for a longer period of time with greater methane concentrations to ensure the effectiveness of the sawdust and sand media. Furthermore, a comparative economic analysis of the materials should be done to quantify the exact benefits. Further research should be conducted to identify the clogging effects of sawdust and sand media in relation to their hydraulic conductivities.

Many different approaches are currently being applied to oxidize methane from landfills. These methods have their strengths and limitations with respect to methane oxidation evaluation, and most of the procedures must be modified and adapted for each site-specific application to achieve reliable results.

Since methane is an important greenhouse gas, the potential trading of methane credit can open doors for further research. Currently, many industries are focused on programs to reduce their greenhouse gas emissions. It is beneficial for these companies to achieve their goal of reducing greenhouse gas emissions through receiving credit for voluntary early action, or obtaining credit based on company's present action to meet future regulatory requirements. Currently some landfill owners and landfill gas project developers are trading landfill gas reductions obtained through gas collection systems and/or biofiltration in the emerging markets for greenhouse gas emissions reductions.

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APPENDIX A

METHANE GAS CALCULATIONS

The following data was used to calculate the methane oxidation rate (%) and methane elimination capacity ($\text{g/m}^3/\text{hr}$) for each biofilter. For demonstration purposes, calculation of the first line in Table.A.1 is illustrated below;

X = Average GC area Reading ($\mu\text{.V}$) = Average of two sample injection data from the GC

$$Y = \text{Methane Outlet Concentration (\%)} = \frac{X}{3191} = \left(\frac{66.5}{3191}\right) = 0.021$$

$$OXD = \text{Methane Oxidation Rate (\%)} = \left(\frac{C_{in} - C_{out}}{C_{out}}\right) \times 100 = 99.22$$

$$IL = \text{Inlet Load (g/m}^3/\text{hr)} = 33.828$$

$$EC = \text{Methane Elimination Capacity (g/m}^3/\text{hr)} = IL \times OXD = 33.828 \times \left(\frac{99.22}{100}\right) = 33.56$$

Table.A.1 Methane gas oxidation rate data for compost

Date	Week	Average GC Area Reading ($\mu\text{.V}$)	Methane Outlet Concentration (%)	Methane Inlet Concentration (%)	Methane Oxidation Rate (%)	Methane Elimination Capacity ($\text{g/m}^3/\text{hr}$)
2008/12/20	0	66.5	0.021	2.699	99.22	33.56
2008/12/27	1	1064	0.336	2.698	87.28	29.59
2009/01/02	2	645.5	0.204	2.699	92.41	31.26
2009/01/09	3	85.5	0.027	2.699	99.00	33.49
2009/01/16	4	1359	0.430	2.698	84.01	28.42
2009/01/23	5	788	0.249	2.699	90.74	30.69
2009/01/29	6	1486	0.470	2.698	82.51	27.91
2009/02/06	7	1477	0.467	2.699	82.61	27.91
2009/02/11	8	1733	0.548	2.699	79.61	26.93
2009/02/19	9	1768	0.559	2.699	79.20	26.70
2009/02/26	10	2426	0.830	2.699	69.13	23.39
Average					85.98	29.07

Table.A.2 Methane gas oxidation rate data for sawdust

Date	Week	Average GC Area Reading (μ .V)	Methane Outlet Concentration (%)	Methane Inlet Concentration (%)	Methane Oxidation Rate (%)	Methane Elimination Capacity ($\text{g/m}^3/\text{hr}$)
2008/12/20	0	3132	0.991	2.699	63.15	21.36
2008/12/27	1	3688	1.167	2.698	56.61	19.15
2009/01/02	2	2420	0.766	2.699	71.52	24.20
2009/01/09	3	4240	1.342	2.699	50.12	16.95
2009/01/16	4	3713	1.175	2.698	56.31	19.05
2009/01/23	5	3744	1.185	2.699	55.96	18.93
2009/01/29	6	2643	0.836	2.698	68.91	23.31
2009/02/06	7	2767	0.876	2.699	67.45	22.82
2009/02/11	8	3147	0.996	2.699	62.97	21.30
2009/02/19	9	4030	1.275	2.699	52.58	17.79
2009/02/26	10	4879	1.544	2.699	42.60	14.41
Average					58.93	19.94

Table.A.3 Methane gas oxidation rate data for sand

Date	Week	Average GC Area Reading (μ .V)	Methane Outlet Concentration (%)	Methane Inlet Concentration (%)	Methane Oxidation Rate (%)	Methane Elimination Capacity ($\text{g/m}^3/\text{hr}$)
2008/12/20	0	3605	1.141	2.699	57.60	19.48
2008/12/27	1	3744	1.185	2.698	55.96	18.93
2009/01/02	2	3020	0.957	2.699	64.44	21.80
2009/01/09	3	3744	1.185	2.699	55.96	18.93
2009/01/16	4	3594	1.137	2.698	57.72	19.53
2009/01/23	5	3164	1.001	2.699	62.78	21.24
2009/01/29	6	3541	1.120	2.698	58.35	19.74
2009/02/06	7	3509	1.110	2.699	58.73	19.87
2009/02/11	8	3201	1.013	2.699	62.34	21.09
2009/02/19	9	4149	1.313	2.699	51.19	17.32
2009/02/26	10	4758	1.506	2.699	44.03	14.89
Average					57.19	19.35

APPENDIX B

BRADFORD DYE TEST ANALYSIS

The following data was obtained from the Bradford Dye test using a spectrometer (wavelength of 595nm). These results were further used to calculate the protein content and biomass content (g/m^3) in each biofilter medium. For demonstration purposes, calculation of the first line in Table.B.1 is illustrated below;

$$AV_{595} = \text{Average Absorption reading} = \frac{(A1_{595} + A2_{595})}{2} = \frac{(1.15 + 1.18)}{2} = 1.165$$

From Bradford calibration curve (Fig. 3.14):

$$\text{Biomass Content (g/L)} = 0.0283 \times \text{Exp}(2.9464 \times AV_{595}) = 0.0283 \times \text{Exp}(2.9464 \times 1.165) = 0.876$$

Therefore,

$$BMC = \text{Biomass Content (g/m}^3\text{)} = 0.876 \times 1000 = 876$$

Table.B.1 Bradford biomass data for compost

Date	Week	Reading 1 (A1 ₅₉₅)	Reading 2 (A2 ₅₉₅)	Average Absorption Reading (AV ₅₉₅)	Biomass Content (g/m ³)
2008/12/20	0	1.15	1.18	1.165	876
2008/12/27	1	0.923	0.902	0.912	416
2009/01/02	2	1.159	1.174	1.166	880
2009/01/09	3	1.210	1.157	1.178	912
2009/01/16	4	0.893	0.892	0.893	393
2009/01/23	5	0.950	0.960	0.955	472
2009/01/29	6	0.970	0.960	0.965	486
2009/02/06	7	0.739	0.608	0.673	206
2009/02/11	8	0.557	0.622	0.589	161
2009/02/19	9	1.094	0.967	1.0305	589
2009/02/26	10	0.977	0.754	0.865	362
Average					539

Table.B.2 Bradford biomass data for sawdust

Date	Week	Reading 1 (A ₁₅₉₅)	Reading 2 (A ₂₅₉₅)	Average Absorption Reading (A _{V595})	Biomass Content (g/m ³)
2008/12/20	0	0.904	0.907	0.905	408
2008/12/27	1	0.567	0.568	0.567	151
2009/01/02	2	0.601	0.631	0.616	174
2009/01/09	3	1.053	1.146	1.049	623
2009/01/16	4	0.662	0.662	0.662	199
2009/01/23	5	0.662	0.715	0.669	203
2009/01/29	6	0.682	0.689	0.685	213
2009/02/06	7	0.556	0.557	0.566	150
2009/02/11	8	0.490	0.588	0.539	139
2009/02/19	9	0.447	0.546	0.496	122
2009/02/26	10	0.010	0.517	0.263	62
Average					238

Table.B.3 Bradford biomass data for sand

Date	Week	Reading 1 (A ₁₅₉₅)	Reading 2 (A ₂₅₉₅)	Average Absorption Reading (A _{V595})	Biomass Content (g/m ³)
2008/12/20	0	0.045	0.047	0.046	32
2008/12/27	1	0.020	0.026	0.023	30
2009/01/02	2	0.056	0.050	0.053	33
2009/01/09	3	0.507	0.610	0.555	147
2009/01/16	4	0.000	0.000	0.000	28
2009/01/23	5	0.061	0.050	0.055	33
2009/01/29	6	0.016	0.026	0.021	30
2009/02/06	7	0.100	0.194	0.0436	44
2009/02/11	8	0.000	0.000	0.000	28
2009/02/19	9	0.000	0.050	0.025	30
2009/02/26	10	0.000	0.000	0.000	28
Average					32

APPENDIX C MOISTURE CALIBRATIONS

I) Moisture Characteristics Curve Calibrations for Compost

Initial TDR reading of air dry sample: 21.2

Volume of Container: 4L

Dry Bulk Density: 0.324 g/m³

Initial tank TDR reading: 50%

Initial Tank WMC: 75.3%

Initial Tank VMC: 42.8%

Volume of Tank: 0.1145m³

Mass of Compost in Tank: 65 kg

Bulk Density in Tank: 0.568 g/m³

Table.C.1 TDR calibration data for compost

Dish No.	TDR Reading	Mass of Dry Sample(gr)	Mass of water(gr)	Water added(ml)	Total Mass of sample in container(gr)	OVEN DRY METHOD	
						WMC%	VMC%
S1	46.3	17.26	12.84	150	2715	74.39	42.25
S2	73.7	13.56	11.44	225	2865	84.36	47.91
S3	79.3	20.26	17.84	75	2891	88.05	50.01
S4	86.5	17.77	21.53	150	2937	121.15	68.81

II) Moisture Characteristics Curve Calibrations for Sawdust

Initial TDR reading of air dry sample: 0%

Volume of Container: 4L

Dry Bulk Density: 0.7 g/m^3

Initial tank TDR reading: 16%

Initial Tank WMC: 153%

Initial Tank VMC: 28.1%

Volume of Tank: 0.1145 m^3

Mass of Saw Dust in Tank: 21 kg

Bulk Density in Tank: 0.183 g/m^3

Table.C.2 TDR calibration data for sawdust

Dish No.	TDR Reading	Mass of dry sample(gr)	Mass of water(gr)	Water added(ml)	Total mass of sample in container(gr)	OVEN DRY METHOD	
						WMC%	VMC%
S1	8.3	8.33	9.57	1000	1394	114.9	21.0
S2	13.9	7.96	11.84	250	1599	148.7	27.2
S3	19.3	7.46	14.14	250	1806	189.5	34.7
S4	29.3	6.87	15.33	250	2022	223.1	40.8
S5	27.8	6.54	17.36	250	2225	265.4	48.6

III) Moisture Characteristics Curve Calibrations for Sand

Initial TDR reading of air dry sample: 0%

Volume of Container: 4L

Dry Bulk Density: 1.78 g/m^3

Initial tank TDR reading: 0.4%

Initial Tank WMC: 5.07%

Initial Tank VMC: 6.64%

Volume of Tank: 0.1145 m^3

Mass of Saw Dust in Tank: 150 kg

Bulk Density in Tank: 1.31 g/m^3

Table.C.3 TDR calibration data for sand

Dish No.	TDR Reading	Mass of dry sample(gr)	Mass of water (gr)	Water added(ml)	Total Mass of sample in Container (gr)	OVEN DRY METHOD	
						WMC%	VMC%
S1	3.2	58.67	1.03	125	6361	1.8	2.3
S2	4.2	68.47	2.43	125	6594	3.5	4.6
S3	6.2	52.02	2.77	125	6743	5.3	7.0
S4	8.7	54.59	3.81	125	6590	7.0	9.1
S5	14.1	60.39	6.41	250	7076	10.6	13.9

IV) Moisture Content and Temperature Calculations

Table.C.4 Moisture content and temperature data for compost

Date	Week	Average TDR Reading (%)	Volumetric Moisture Content (%)	Inlet Temperature (°C)	Outlet Temperature (°C)
2008/12/20	0	71.4	0.372	20.7	27
2008/12/27	1	78.4	0.392	21.1	35
2009/01/02	2	76.0	0.385	21.8	36
2009/01/09	3	69.8	0.368	19	27
2009/01/16	4	70.6	0.370	17.7	26
2009/01/23	5	73.0	0.376	21.2	30
2009/01/29	6	71.0	0.371	18.7	26
2009/02/06	7	70.0	0.370	21.6	24
2009/02/11	8	68.3	0.365	21	24
2009/02/19	9	67.3	0.364	19.9	24
2009/02/26	10	82.3	0.361	20.7	21
Average			0.372	20.3	28.6

Table.C.5 Moisture content and temperature data for sawdust

Date	Week	Average TDR Reading (%)	Volumetric Moisture Content (%)	Inlet Temperature (°C)	Outlet Temperature (°C)
2008/12/20	0	71.4	0.414	20.7	28
2008/12/27	1	78.4	0.419	21.1	30
2009/01/02	2	76.0	0.454	21.8	31
2009/01/09	3	69.8	0.475	19.0	25
2009/01/16	4	70.6	0.461	17.7	24
2009/01/23	5	73.0	0.404	21.2	28
2009/01/29	6	71.0	0.392	18.7	24
2009/02/06	7	70.0	0.496	21.6	24
2009/02/11	8	68.3	0.471	21.0	22
2009/02/19	9	67.3	0.432	19.9	22
2009/02/26	10	82.3	0.390	20.7	22
Average			0.437	20.3	26.2

Table.C.6 Moisture content and temperature data for sand

Date	Week	Average TDR Reading (%)	Volumetric Moisture Content (%)	Inlet Temperature (°C)	Outlet Temperature (°C)
2008/12/20	0	71.4	0.044	20.7	25
2008/12/27	1	78.4	0.041	21.1	29
2009/01/02	2	76.0	0.039	21.8	27
2009/01/09	3	69.8	0.043	19.0	25
2009/01/16	4	70.6	0.036	17.7	22
2009/01/23	5	73.0	0.032	21.2	24
2009/01/29	6	71.0	0.043	18.7	22
2009/02/06	7	70.0	0.049	21.6	23
2009/02/11	8	68.3	0.041	21.0	21
2009/02/19	9	67.3	0.043	19.9	20
2009/02/26	10	82.3	0.039	20.7	21
Average			0.041	20.3	24.2

APPENDIX D

BOD MEASUREMENTS

Using the solution extracted from the biofilter, two BOD bottles with different dilution factors were prepared for each medium in addition to a “blank” bottle (control bottle) weekly. The resulting data was used to calculate the five day biochemical oxygen demand (BOD₅) for the three media (Table D.2). Table D.1 was compiled as a summary of all data proceed and used in this study. Moreover, the following wquation was uased to calculate the overall BOD uptake in compost and sand media;

Overall BOD uptake (mg/L) for compost = Initial BOD – Final BOD = 457 – 125 = 332

Overall BOD uptake (mg/L) for sawdust = Initial BOD – Final BOD = 426 – 62 = 156

$$\text{BOD}_5, \text{ mg/L} = \frac{D_1 - D_2}{p}$$

D₁ = Initial DO of diluted sample immediately after preparation, mg/L

D₂ = Final DO of diluted sample after 5-day incubation at 22°C, mg/L

P = decimal volumetric fraction of sample used

Table.D.1 Summary of BOD₅ data

Date	Week	BOD ₅ (mg/L)		
		Compost	Sawdust	Sand
2008/12/20	0	457	426	22
2008/12/27	1	470	256	17
2009/01/02	2	102	352	16
2009/01/09	3	430	277	13
2009/01/16	4	448	286	37
2009/01/23	5	458	362	11
2009/01/29	6	198	371	31
2009/02/06	7	187	410	47
2009/02/11	8	177	266	35
2009/02/19	9	125	270	33

Table.D.2 Detailed BOD₅ data for the three biofilter media

	Sample	NO.	ml	pH		D.O.Initial(mg/L)				D.O.Final(mg/L)						BOD5 (mg/L)
				pH(i)	pH(f)	1	2	3	AVG	Temp(i)	1	2	3	AVG	Temp(f)	
5-Dec	DDW	98		7.05	6.95	9.09	9.16	9.19	9.147	21	8.12	8.2	8.18	8.167	22.3	
5-Dec	Sand	83	10	7.06	6.98	9.03	9.12	9.15	9.1	20.6	7.85	7.85	7.53	7.743	22.6	40.7
		79	20	7.04	6.91	9.06	9.09	9.1	9.083	20.7	7.7	7.66	7.57	7.643	22.6	21.6
5-Dec	Compost	77	5	7.19	6.95	9	8.95	8.97	8.973	20.7	6.41	6.38	6.42	6.403	22.6	154.2
		76	2.5	7.2	6.95	9.17	9.12	9.1	9.13	20.6	7.2	7.07	7.08	7.117	22.6	241.6
5-Dec	Sawdust	74	5	7.15	6.48	8.95	8.98	8.94	8.957	20.7	1.74	1.89	1.94	1.857	22.6	426
5-Dec	Blank	76		7.17	7	8.78	8.76	8.77	8.77	21.2	8.76	8.48	8.28	8.507	22.3	
5-Dec	Compost	83	2.5	7.14	6.6	8.75	8.74	8.76	8.75	21.1	5.24	5.23	5.28	5.25	23.3	420
		98	5	7.17	6.56	8.7	8.69	8.64	8.677	21.1	1.07	1.03	1.1	1.067	23.5	456.6
5-Dec	Sand	74	15	6.56	6.97	8.83	8.79	8.78	8.8	20.9	7.94	7.95	7.91	7.933	23.4	17.333
		77	2	7.09	6.93	8.89	8.81	8.86	8.853	20.7	8.06	8.12	8.07	8.083	23.2	115.5
5-Dec	Sawdust	79	2.5	7.14	6.65	8.78	8.77	8.82	8.79	20.8	6.85	6.81	6.84	6.833	23.5	234.8
		13	5	7.2	6.78	8.75	8.7	8.73	8.727	20.4	4.1	4.66	4.64	4.467	23.4	255.6
		17	10	7.28	6.89	8.63	8.64	8.57	8.613	20.4	1.04	0.93	0.92	0.963	23.2	229.5
5-Dec	Compost	77	5	7.05		8.65	8.69	8.72	8.687	21.8	0.97	0.82	0.79	0.86	22.7	469.6
		79	2.5	7.03	6.1	8.7	8.75	8.72	8.723	20.6	3.64	3.57	3.56	3.59	22.9	616
5-Dec	Sand	74	15	7.1		8.73	8.81	8.8	8.78	21.7	7.97	7.97	7.96	7.967	22.9	16.27
		76	2	7.01	6.47	8.84	8.82	8.84	8.833	21.7	8.18	8.25	8.21	8.213	22.4	93
5-Dec	Sawdust	13	2.5	7.2	6.32	8.73	8.74	8.83	8.767	21	6.28	6.2	6.26	6.247	22.4	302.4
		17	5	7.21	6.22	8.84	8.82	8.84	8.833	21.2	3	2.99	2.91	2.967	22.5	352
5-Dec	Compost	13	2.5	7.34	6.51	9.87	9.92	10.3	10.02	19.1	9.2	9.28	9.35	9.277	21	89.2
		17	5	7.33	6.71	8.91	9.02	9.22	9.05	19	7.34	7.28	7.45	7.357	20.9	101.6
5-Dec	Sand	77	2	7.44	7.16	10.13	10.23	10.3	10.2	18.7	9.95	9.72	9.49	9.72	20.8	72.5
		79	15	7.7	7.45	10.02	10.14	10.4	10.18	19	9.41	9.51	9.65	9.523	20.6	13.1
5-Dec	Sawdust	74	2.5	7.4	6.87	10.34	10.1	9.76	10.07	18.8	8.02	8.25	8.18	8.15	20.8	230
		76	5	7.52	6.84	9.68	9.67	9.88	9.743	19.1	5.17	5.08	5.13	5.127	20.6	277
2-Jan	Compost	13	2.5	6.52	4.22	11.57	11.63	11.4	11.52	17.7	8	7.92	7.57	7.83	22.9	443.2
		17	5	6.41	5.18	11.36	11.14	11.3	11.26	17.7	4.47	3.87	3.91	4.083	22.9	430.4
2-Jan	Sand	77	2.5	6.31	5.1	10.96	10.56	10.8	10.79	17.4	10.7	10.55	10.2	10.49	23	36
		79	15	6.41	5.7	11.57	11.82	11.7	11.69	17.5	9.83	9.87	9.83	9.843	22.9	37
2-Jan	Sawdust	74	2.5	6.79	5.27	10.69	10.92	10.9	10.84	17.4	8.67	8.42	8.27	8.453	22.9	286.4
		76	5	6.44	5.25	10.66	10.58	10.6	10.62	17.5	9.83	9.87	9.83	9.843	22.9	46.4
2-Jan	Compost	13	2.5	6.61	5.6	10.5	10.85	11.2	10.84	21	5.73	5.34	5.52	5.53	21.5	636.8
		17	5	6.63	6.29	10.6	10.15	10.6	10.45	21.2	2.97	2.99	3.02	2.993	21.5	447.6
2-Jan	Sand	77	10	7.3	7.7	11.82	11.05	10.6	11.15	21.4	11	10.92	10.5	10.79	21.5	10.8
2-Jan	Sawdust	74	2.5	7.01	6.54	11.78	11.78	10.8	11.45	20.8	7.68	7.53	7.5	7.57	21.4	466
		76	5	7.14	6.63	12.01	11.89	12.3	12.05	20.7	6.17	5.92	5.99	6.027	21.4	361.6
2-Jan	Blank	79		6.05	5.86	10.35	10.58	11.5	10.82	20.7	10.3	10.71	10.7	10.57	21.4	

15-Jan	Compost	13	5	6.84	6.09	12.64	12.4	12.6	12.55	18.7	4.92	4.9	4.92	4.913	22	458
15-Jan	Sand	77	15	7	6.66	13.37	13.26	13.4	13.35	18.4	7.95	7.95	8.1	8	21	107.07
15-Jan	Sawdust	74	5	6.96	6.33	13.42	13.44	13.5	13.46	18.7	7.05	7.25	7.53	7.277	21.8	371.2
		76	2.5	6.96	6.46	13.29	13.25	13.3	13.27	18.6	7.11	7.27	7.64	7.34	22	712
15-Jan	Blank	79		6.9	5.96	13.63	13.58	13.6	13.61	18.4	9.35	9.67	9.51	9.51	22	
23-Jan	Compost	13	2.5	6.69	6.24	8.02	8.05	8.06	8.043	21.6	6.31	6.43	6.83	6.523	22.5	182.4
		17	5	6.74	6.23	7.48	7.62	7.56	7.553	21.6	4.36	4.13	4.26	4.25	22.5	198.2
23-Jan	Sand	77	10	6.85	6.04	7.69	7.52	7.47	7.56	21.3	8.01	8.88	8.89	8.593	22.9	-31
		79	5	6.9	6.29	8.25	8.47	8.44	8.387	21.4	7.4	7.53	7.71	7.547	22.8	50.4
23-Jan	Sawdust	74	5	6.81	6.25	7.86	7.91	8.03	7.933	21.4	7.17	7.74	7.43	7.447	22.7	29.2
		76	2.5	6.88	6.19	8.66	8.84	8.29	8.597	21.6	4.25	4.27	4.07	4.197	22.7	528
23-Jan	Blank	98		6.84	5.8	8.04	8.19	8.05	8.093	21.3	7.57	8.4	8.29	8.087	22.8	
30-Jan	Compost	13	2.5	6.77	6.6	9.71	9.74	9.7	9.717	21.4	7.88	7.8	8.04	7.907	24.9	217.2
		17	5	6.89	6.58	9.3	9.01	9.03	9.113	21	6.05	6.01	5.92	5.993	24.9	187.2
30-Jan	Sand	77	5	6.83	6.7	9.5	9.54	9.4	9.48	21.6	8.28	8.12	7.99	8.13	25	81
		79	10	6.85	6.8	9.34	9.37	9.2	9.303	21.6	7.44	7.87	7.87	7.727	25	47.3
30-Jan	Sawdust	74	2.5	6.89	6.58	9.07	9.09	9.05	9.07	21.4	7.88	7.8	8.04	7.907	24.9	139.6
		76	5	6.91	6.42	9.13	9.16	9.18	9.157	21.4	2.54	2.2	2.21	2.317	25	410.4
30-Jan	Blank	98		6.84	6.8	8.68	8.67	8.67	8.673	21.1	8.52	8.73	8.71	8.653	24	
6-Feb	Compost	13	2.5	6.46	6.57	9.5	9.4	9.23	9.377	20	7.43	7.21	7.52	7.387	24.4	238.8
		17	5	6.65	6.41	9.37	9.23	9.11	9.237	19.9	6.41	6.42	6.01	6.28	23.9	177.4
6-Feb	Sand	77	5	6.76	6.67	9.35	9.47	9.4	9.407	19.8	8.58	8.43	8.34	8.45	23.4	57.4
		79	10	6.89	6.53	8.54	8.47	8.54	8.517	20	7.55	7.26	7.23	7.347	22.9	35.1
6-Feb	Sawdust	74	2.5	6.68	6.49	9.32	9.2	9.3	9.273	19.8	7.73	7.62	7.52	7.623	23.8	198
		76	5	6.82	6.48	9.25	9.12	9.13	9.167	19.7	4.94	4.67	4.61	4.74	24.3	265.6
6-Feb	Blank	98		6.79	6.67	9.15	9.26	9.15	9.187	20.2	9.13	8.86	8.75	8.913	23.5	
13-Feb	Compost	13	2.5	6.88	6.7	8.51	8.43	8.26	8.4	19.9	6.94	6.85	6.61	6.8	25.7	192
		17	5	6.8	6.74	7.51	7.15	7.08	7.247	20.7	5.13	5.13	5.24	5.167	25.9	124.8
13-Feb	Sand	77	5	6.73	6.6	8.13	8.17	8.17	8.157	20.5	7.6	7.59	7.61	7.6	25.6	33.4
		79	10	6.72	6.51	7.94	7.91	7.93	7.927	20.6	7.18	7.49	7.3	7.323	25.7	18.1
13-Feb	Sawdust	74	2.5	6.71	6.74	7.61	7.61	7.59	7.603	20.7	6.02	5.67	6.12	5.937	25.8	200
		76	5	6.71	6.76	7.59	7.61	7.62	7.607	20.7	3.32	2.99	3.01	3.107	25.8	270
13-Feb	Blank	98		6.64	6.74	7.53	7.84	7.85	7.74	20.6	7.7	7.6	7.5	7.6	25.4	
20-Feb	Compost	13	2.5	6.9	6.76	8.56	8.49	8.41	8.487	21.4	5.27	5.29	5.21	5.257	25.6	387.6
		17	5	6.91	6.68	7.51	8.31	8.17	7.997	21.3	3.23	3.06	3.12	3.137	25.6	291.6
20-Feb	Sand	77	5	6.86	6.66	7.55	7.54	7.49	7.527	21.6	7.37	7.5	7.54	7.47	25.5	3.4
		79	10	6.88	6.61	8.55	8.47	8.46	8.493	21.7	6.71	6.71	7.11	6.843	25.7	49.5
20-Feb	Sawdust	74	2.5	6.86	6.65	7.57	7.94	7.87	7.793	21.4	7.19	7.21	7.43	7.277	25.5	62
		76	5	6.84	6.63	7.87	7.87	8.2	7.98	21.3	7.15	7.14	7.13	7.14	25.4	50.4
20-Feb	Blank	98		6.7	6.62	8.01	8	8.2	8.07	21.7	7.81	6.84	7.49	7.38	25.4	

APPENDIX E

COD MEASUREMENTS

Using the solution extracted from the biofilter materials, COD vials were prepared for each biofilter in addition to a “blank” (control vial) weekly. The resulting data was used to calculate the chemical oxygen demand (COD) in each biofilter media (Table E.1, Table E.2 and Table E.3). . For demonstration purposes, calculation of the first line in Table.E.1 is illustrated below;

From calibration curve obtained from standards and shown in Fig. 3.13,

$$\text{COD (mg/L) O}_2 = 12167 \times (\text{Absorbance})$$

Where:

COD (mg/L) O₂ = Chemical Oxygen Demand in terms of mg/L of O₂

A₆₀₀= Absorbance for a 600 nm spectrum

$$\text{COD (mg/L) O}_2 = 12167 \times 0.398 = 4842$$

Moreover, the following equation was used to calculate the overall COD uptake in the compost, sawdust and sand media;

$$\text{Overall COD uptake (mg/L) for compost} = \text{Initial COD} - \text{Final COD} = 4842 - 2287 = 2555$$

$$\text{Overall COD uptake (mg/L) for sawdust} = \text{Initial COD} - \text{Final COD} = 3626 - 1642 = 1984$$

$$\text{Overall COD uptake (mg/L) for sand} = \text{Initial COD} - \text{Final COD} = 122 - 73 = 49$$

Table.E.1 COD measurements for compost

Date	Week	Transmission (T ₆₀₀)	Absorption (A ₆₀₀)	COD (mg/L)
2008/12/20	0	39.8	0.398	4842
2008/12/27	1	53.2	0.275	3346
2009/01/02	2	57.2	0.242	2944
2009/01/09	3	57.0	0.244	2969
2009/01/16	4	51.4	0.289	3516
2009/01/23	5	50.0	0.300	3650
2009/01/29	6	49.8	0.304	3699
2009/02/06	7	60.1	0.218	2654
2009/02/11	8	64.2	0.193	2348
2009/02/19	9	47.0	0.323	3930
2009/02/26	10	72.6	0.188	2287

Table.E.2 COD measurements for sawdust

Date	Week	Transmission (T ₆₀₀)	Absorption (A ₆₀₀)	COD (mg/L)
2008/12/20	0	50.4	0.298	3626
2008/12/27	1	56.9	0.244	2969
2009/01/02	2	68.7	0.163	1983
2009/01/09	3	54.0	0.267	3249
2009/01/16	4	62.4	0.204	2482
2009/01/23	5	59.2	0.228	2774
2009/01/29	6	60.0	0.222	2701
2009/02/06	7	57.0	0.242	2944
2009/02/11	8	54.6	0.233	2835
2009/02/19	9	60.4	0.219	2664
2009/02/26	10	73.4	0.135	1642

Table.E.3 COD measurements for sand

Date	Week	Transmission (T ₆₀₀)	Absorption (A ₆₀₀)	COD (mg/L)
2008/12/20	0	97.8	0.010	122
2008/12/27	1	98.6	0.006	73
2009/01/02	2	99.5	0.002	24
2009/01/09	3	94.0	0.027	329
2009/01/16	4	96.0	0.028	286
2009/01/23	5	95.0	0.020	243
2009/01/29	6	97.0	0.013	158
2009/02/06	7	96.5	0.015	183
2009/02/11	8	99.6	0.002	24
2009/02/19	9	99.6	0.002	24
2009/02/26	10	98.6	0.025	73

APPENDIX F

BACTERIAL POPULATION DATA

Using the solution extracted from the biofilter materials, bacterial growth plates were prepared for each biofilter weekly. The resulting data, shown in Table.F.1, was used to monitor and evaluate bacterial growth patterns for different materials.

Table.F.1 Bacterial Population for various biofilter media

Date	Week	Bacterial Population (10^4)		
		Compost	Sawdust	Sand
2008/12/20	0	75	70	35
2008/12/27	1	100	86	0.75
2009/01/02	2	86	220	9
2009/01/09	3	94	160	5
2009/01/16	4	41	115	73
2009/01/23	5	130	123	0.12
2009/01/29	6	185	170	150
2009/02/06	7	187	167	145
2009/02/11	8	170	25	5
2009/02/19	9	168	72	84

APPENDIX G

GAS CHROMATOGRAPH DATA

Software Version	: 6.1.2.0.1:D19	Date	: 1/15/09 9:40:19 AM
Operator	: manager	Sample Name	: Comp-1
Sample Number	: 482	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 482
Data Acquisition Time	: 1/15/09 11:15:23 AM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth482-20090115-111530.raw
Result File : \\Poweredge\E drive\TC\dennis\meth482-20090115-094018.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth482-20090115-094018.rst
Proc Method : \\poweredge\E drive\TC\dennis\methane5
Calib Method : \\poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

No peaks available to report
Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Area: 1522.44

Height: 917.73

Software Version	: 6.1.2.0.1:D19	Date	: 1/15/09 9:46:57 AM
Operator	: manager	Sample Name	: Comp-2
Sample Number	: 483	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 1/15/09 11:22:05 AM	Cycle	: 483

Raw Data File : \\Poweredge\E drive\TC\dennis\meth483-20090115-112223.raw
Result File : \\Poweredge\E drive\TC\dennis\meth483-20090115-094657.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth483-20090115-094657.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

No peaks available to report
Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Area: 1451

Height: 876

Software Version	: 6.1.2.0.1:D19	Date	: 1/23/09 3:14:55 PM
Operator	: manager	Sample Name	: Comp-2
Sample Number	: 483	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 483
Data Acquisition Time	: 1/23/09 4:50:28 PM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth483-20090123-165045.raw
Result File : \\Poweredge\E drive\TC\dennis\meth483-20090123-151455.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth483-20090123-151455.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

No peaks available to report
Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Area: 1364

Software Version	: 6.1.2.0.1:D19	Date	: 1/29/09 10:01:11 AM
Operator	: manager	Sample Name	: Comp-2
Sample Number	: 483	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 483
Data Acquisition Time	: 1/29/09 11:36:45 AM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth483-20090129-113704.raw
Result File : \\Poweredge\E drive\TC\dennis\meth483-20090129-100111.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth483-20090129-100111.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

No peaks available to report
Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Area: 1657.1

Height: 1024.5

Software Version : 6.1.2.0.1:D19
Operator : manager
Sample Number : 489
AutoSampler : BUILT-IN
Instrument Name : GC
Instrument Serial # : 610N9072715
Delay Time : 0.00 min
Sampling Rate : 12.5000 pts/s
Volume Injected : 1.000000 ul
Sample Amount : 1.0000
Data Acquisition Time : 2/6/09 5:40:56 PM

Date : 2/6/09 4:04:15 PM
Sample Name : Comp-2
Study :
Rack/Vial : 0/0
Channel : A
A/D mV Range : 1000
End Time : 4.00 min
Area Reject : 0.000000
Dilution Factor : 1.00
Cycle : 489

Raw Data File : \\Poweredge\E drive\TC\dennis\meth489-20090206-174112.raw
Result File : \\Poweredge\E drive\TC\dennis\meth489-20090206-160415.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth489-20090206-160415.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [$\mu\text{V}\cdot\text{s}$]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.529	3550.30	2225.25	100.00	100.00	BB	1.5955
		3550.30	2225.25	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/6/09 3:57:30 PM
Operator	: manager	Sample Name	: Comp-1
Sample Number	: 488	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 488
Data Acquisition Time	: 2/6/09 5:34:12 PM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth488-20090206-173427.raw
 Result File : \\Poweredge\E drive\TC\dennis\meth488-20090206-155730.rst
 Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
 drive\TC\dennis\meth488-20090206-155730.rst
 Proc Method : \\Poweredge\E drive\TC\dennis\methane5
 Calib Method : \\Poweredge\E drive\TC\dennis\methane5
 Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [$\mu\text{V}\cdot\text{s}$]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.523	3513.57	2217.32	100.00	100.00	BB	1.5846
		3513.57	2217.32	100.00	100.00		

Missing Component Report
 Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/11/09 1:05:39 PM
Operator	: manager	Sample Name	: Comp-1
Sample Number	: 482	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 2/11/09 2:42:11 PM	Cycle	: 482

Raw Data File : \\Poweredge\E drive\TC\dennis\meth482-20090211-144219.raw
Result File : \\Poweredge\E drive\TC\dennis\meth482-20090211-130539.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth482-20090211-130539.rst
Proc Method : \\poweredge\E drive\TC\dennis\methane5
Calib Method : \\poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

No peaks available to report
Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Area: 2747.

Height = 1699.9

Software Version	: 6.1.2.0.1:D19	Date	: 2/11/09 1:13:49 PM
Operator	: manager	Sample Name	: Comp-2
Sample Number	: 483	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 483
Data Acquisition Time	: 2/11/09 2:50:20 PM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth483-20090211-145039.raw
Result File : \\Poweredge\E drive\TC\dennis\meth483-20090211-131349.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth483-20090211-131349.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

No peaks available to report
Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Area: 2502

Software Version	: 6.1.2.0.1:D19	Date	: 2/19/09 9:30:00 AM
Operator	: manager	Sample Name	: Sand-1 <i>Compost #1</i>
Sample Number	: 484	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: None	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 484
Data Acquisition Time	: 2/19/09 11:07:56 AM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth484-20090219-110810.raw
Result File : \\Poweredge\E drive\TC\dennis\meth484-20090219-093000.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth484-20090219-093000.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

No peaks available to report
Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Area: 83.8

Software Version	: 6.1.2.0.1:D19	Date	: 2/19/09 10:01:27 AM
Operator	: manager	Sample Name	: Comp-2
Sample Number	: 489	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: None	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 2/19/09 11:39:19 AM	Cycle	: 489

Raw Data File : \\Poweredge\E drive\TC\dennis\meth489-20090219-113938.raw
Result File : \\Poweredge\E drive\TC\dennis\meth489-20090219-100127.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth489-20090219-100127.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

No peaks available to report
Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Area : 87.52

Area : 84.94

Software Version	: 6.1.2.0.1:D19	Date	: 2/19/09 10:12:10 AM
Operator	: manager	Sample Name	: Sand-1 Comp #3
Sample Number	: 482	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: None	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 2/19/09 11:50:06 AM	Cycle	: 490

Raw Data File : \\Poweredge\E drive\TC\dennis\meth490-20090219-115021.raw
Result File : \\Poweredge\E drive\TC\dennis\meth490-20090219-101210.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth490-20090219-101210.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

No peaks available to report
Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Area: 84.94

Software Version	: 6.1.2.0.1:D19	Date	: 2/26/09 10:13:16 AM
Operator	: manager	Sample Name	: Comp-2
Sample Number	: 483	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: None	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 2/26/09 11:50:55 AM	Cycle	: 483

Raw Data File : \\Poweredge\E drive\TC\dennis\meth483-20090226-115113.raw
Result File : \\Poweredge\E drive\TC\dennis\meth483-20090226-101315.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth483-20090226-101315.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

No peaks available to report
Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Area: 1295

Height: 826

Software Version	: 6.1.2.0.1:D19	Date	: 2/26/09 10:06:22 AM
Operator	: manager	Sample Name	: Comp-1
Sample Number	: 482	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: None	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 482
Data Acquisition Time	: 2/26/09 11:44:05 AM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth482-20090226-114410.raw
Result File : \\Poweredge\E drive\TC\dennis\meth482-20090226-100622.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth482-20090226-100622.rst
Proc Method : \\poweredge\E drive\TC\dennis\methane5
Calib Method : \\poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

No peaks available to report
Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Area: 1434.52

Height: 920

Software Version : 6.1.2.0.1:D19
Operator : manager
Sample Number : 486
AutoSampler : BUILT-IN
Instrument Name : GC
Instrument Serial # : 610N9072715
Delay Time : 0.00 min
Sampling Rate : 12.5000 pts/s
Volume Injected : 1.000000 ul
Sample Amount : 1.0000
Data Acquisition Time : 1/15/09 11:42:53 AM

Date : 1/15/09 10:07:49 AM
Sample Name : Sawdust-1
Study :
Rack/Vial : 0/0
Channel : A
A/D mV Range : 1000
End Time : 4.00 min
Area Reject : 0.000000
Dilution Factor : 1.00
Cycle : 486

Raw Data File : \\Poweredge\E drive\TC\dennis\meth486-20090115-114307.raw
Result File : \\Poweredge\E drive\TC\dennis\meth486-20090115-100748.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth486-20090115-100748.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

No peaks available to report
Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Area: 2322

Height: 1435

Software Version	: 6.1.2.0.1:D19	Date	: 1/15/09 10:16:03 AM
Operator	: manager	Sample Name	: Sawdust-2
Sample Number	: 487	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 487
Data Acquisition Time	: 1/15/09 11:51:13 AM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth487-20090115-115129.raw
Result File : \\Poweredge\E drive\TC\dennis\meth487-20090115-101603.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth487-20090115-101603.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.527	2964.52	1847.86	100.00	100.00	BB	1.6043
		2964.52	1847.86	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version : 6.1.2.0.1:D19
Operator : manager
Sample Number : 485
AutoSampler : BUILT-IN
Instrument Name : GC
Instrument Serial # : 610N9072715
Delay Time : 0.00 min
Sampling Rate : 12.5000 pts/s
Volume Injected : 1.000000 ul
Sample Amount : 1.0000
Data Acquisition Time : 1/9/09 7:22:42 PM

Date : 1/9/09 5:48:33 PM
Sample Name : ~~Sand-2~~ Saw Dust - 2
Study :
Rack/Vial : 0/0
Channel : A
A/D mV Range : 1000
End Time : 4.00 min
Area Reject : 0.000000
Dilution Factor : 1.00
Cycle : 485

Raw Data File : \\Poweredge\E drive\TC\dennis\meth485-20090109-192259.raw

Result File : \\Poweredge\E drive\TC\dennis\meth485-20090109-174833.rst

Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E drive\TC\dennis\meth485-20090109-174833.rst

Proc Method : \\Poweredge\E drive\TC\dennis\methane5

Calib Method : \\Poweredge\E drive\TC\dennis\methane5

Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [$\mu\text{V}\cdot\text{s}$]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.525	4412.02	2758.54	100.00	100.00	BB	1.5994
		4412.02	2758.54	100.00	100.00		

Missing Component Report

Component Expected Retention (Calibration File)

All components were found

Software Version : 6.1.2.0.1:D19
 Operator : manager
 Sample Number : 484
 AutoSampler : BUILT-IN
 Instrument Name : GC
 Instrument Serial # : 610N9072715
 Delay Time : 0.00 min
 Sampling Rate : 12.5000 pts/s
 Volume Injected : 1.000000 ul
 Sample Amount : 1.0000
 Data Acquisition Time : 1/9/09 7:16:37 PM

Date : 1/9/09 5:42:30 PM
 Sample Name : Sand-1 Saw Dust - 1
 Study :
 Rack/Vial : 0/0
 Channel : A
 A/D mV Range : 1000
 End Time : 4.00 min
 Area Reject : 0.000000
 Dilution Factor : 1.00
 Cycle : 484

Raw Data File : \\Poweredge\E drive\TC\dennis\meth484-20090109-191656.raw
 Result File : \\Poweredge\E drive\TC\dennis\meth484-20090109-174230.rst
 Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
 drive\TC\dennis\meth484-20090109-174230.rst
 Proc Method : \\Poweredge\E drive\TC\dennis\methane5
 Calib Method : \\Poweredge\E drive\TC\dennis\methane5
 Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [$\mu\text{V}\cdot\text{s}$]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.529	4515.52	2808.88	100.00	100.00	BB	1.6076
		4515.52	2808.88	100.00	100.00		

Missing Component Report
 Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 1/23/09 3:35:35 PM
Operator	: manager	Sample Name	: Sawdust-1
Sample Number	: 486	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 1/23/09 5:11:13 PM	Cycle	: 486

Raw Data File : \\Poweredge\E drive\TC\dennis\meth486-20090123-171127.raw
Result File : \\Poweredge\E drive\TC\dennis\meth486-20090123-153535.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth486-20090123-153535.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.531	3403.36	2085.12	100.00	100.00	BB	1.6322
		3403.36	2085.12	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 1/23/09 3:41:45 PM
Operator	: manager	Sample Name	: Sawdust-2
Sample Number	: 487	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 1/23/09 5:17:17 PM	Cycle	: 487

Raw Data File : \\Poweredge\E drive\TC\dennis\meth487-20090123-171738.raw
Result File : \\Poweredge\E drive\TC\dennis\meth487-20090123-154145.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth487-20090123-154145.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [$\mu\text{V}\cdot\text{s}$]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.527	3254.39	1992.30	100.00	100.00	BB	1.6335
		3254.39	1992.30	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 1/29/09 10:24:27 AM
Operator	: manager	Sample Name	: Sawdust-1
Sample Number	: 486	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 1/29/09 12:00:04 PM	Cycle	: 486

Raw Data File : \\Poweredge\E drive\TC\dennis\meth486-20090129-120019.raw
Result File : \\Poweredge\E drive\TC\dennis\meth486-20090129-102427.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth486-20090129-102427.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.530	3096.35	1906.13	100.00	100.00	BB	1.6244
		3096.35	1906.13	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 1/29/09 10:32:24 AM
Operator	: manager	Sample Name	: Sawdust-2
Sample Number	: 487	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 487
Data Acquisition Time	: 1/29/09 12:08:00 PM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth487-20090129-120817.raw
Result File : \\Poweredge\E drive\TC\dennis\meth487-20090129-103224.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth487-20090129-103224.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [$\mu\text{V}\cdot\text{s}$]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.528	3199.17	1946.74	100.00	100.00	BB	1.6433
		3199.17	1946.74	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/6/09 3:45:25 PM
Operator	: manager	Sample Name	: Sawdust-1
Sample Number	: 486	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 486
Data Acquisition Time	: 2/6/09 5:22:04 PM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth486-20090206-172221.raw
Result File : \\Poweredge\E drive\TC\dennis\meth486-20090206-154525.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth486-20090206-154525.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.528	4693.69	2991.56	100.00	100.00	BB	1.5690
		4693.69	2991.56	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/6/09 3:51:28 PM
Operator	: manager	Sample Name	: Sawdust-2
Sample Number	: 487	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 487
Data Acquisition Time	: 2/6/09 5:28:06 PM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth487-20090206-172824.raw
Result File : \\Poweredge\E drive\TC\dennis\meth487-20090206-155128.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth487-20090206-155128.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

No peaks available to report
Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/11/09 1:34:41 PM
Operator	: manager	Sample Name	: Sawdust-1
Sample Number	: 486	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 2/11/09 3:11:12 PM	Cycle	: 486

Raw Data File : \\Poweredge\E drive\TC\dennis\meth486-20090211-151129.raw
 Result File : \\Poweredge\E drive\TC\dennis\meth486-20090211-133441.rst
 Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
 drive\TC\dennis\meth486-20090211-133441.rst
 Proc Method : \\Poweredge\E drive\TC\dennis\methane5
 Calib Method : \\Poweredge\E drive\TC\dennis\methane5
 Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.532	4932.84	3116.47	100.00	100.00	BB	1.5828
		4932.84	3116.47	100.00	100.00		

Missing Component Report
 Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/11/09 1:40:59 PM
Operator	: manager	Sample Name	: Sawdust-2
Sample Number	: 487	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 2/11/09 3:17:32 PM	Cycle	: 487

Raw Data File : \\Poweredge\E drive\TC\dennis\meth487-20090211-151747.raw
Result File : \\Poweredge\E drive\TC\dennis\meth487-20090211-134059.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth487-20090211-134059.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [$\mu\text{V}\cdot\text{s}$]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.530	4826.00	3036.34	100.00	100.00	BB	1.5894
		4826.00	3036.34	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/19/09 9:49:15 AM
Operator	: manager	Sample Name	: Sawdust- 0 #1
Sample Number	: 487	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: None	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 487
Data Acquisition Time	: 2/19/09 11:27:09 AM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth487-20090219-112725.raw
 Result File : \\Poweredge\E drive\TC\dennis\meth487-20090219-094915.rst
 Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
 drive\TC\dennis\meth487-20090219-094915.rst
 Proc Method : \\Poweredge\E drive\TC\dennis\methane5
 Calib Method : \\Poweredge\E drive\TC\dennis\methane5
 Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.529	4243.99	2635.80	100.00	100.00	BB	1.6101
		4243.99	2635.80	100.00	100.00		

Missing Component Report
 Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/19/09 9:55:17 AM
Operator	: manager	Sample Name	: Comp-1 Sawdust #2
Sample Number	: 488	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: None	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 2/19/09 11:33:13 AM	Cycle	: 488

Raw Data File : \\Poweredge\E drive\TC\dennis\meth488-20090219-113328.raw

Result File : \\Poweredge\E drive\TC\dennis\meth488-20090219-095517.rst

Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E drive\TC\dennis\meth488-20090219-095517.rst

Proc Method : \\Poweredge\E drive\TC\dennis\methane5

Calib Method : \\Poweredge\E drive\TC\dennis\methane5

Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [$\mu\text{V}\cdot\text{s}$]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.530	4237.42	2634.83	100.00	100.00	BB	1.6082
		4237.42	2634.83	100.00	100.00		

Missing Component Report

Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/26/09 10:32:58 AM
Operator	: manager	Sample Name	: Sawdust-1
Sample Number	: 486	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: None	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 2/26/09 12:10:42 PM	Cycle	: 486

Raw Data File : \\Poweredge\E drive\TC\dennis\meth486-20090226-121056.raw

Result File : \\Poweredge\E drive\TC\dennis\meth486-20090226-103258.rst

Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E drive\TC\dennis\meth486-20090226-103258.rst

Proc Method : \\Poweredge\E drive\TC\dennis\methane5

Calib Method : \\Poweredge\E drive\TC\dennis\methane5

Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.530	3667.86	2334.22	100.00	100.00	BB	1.5713
		3667.86	2334.22	100.00	100.00		

Missing Component Report

Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/26/09 10:39:11 AM
Operator	: manager	Sample Name	: Sawdust-2
Sample Number	: 487	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: None	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 487
Data Acquisition Time	: 2/26/09 12:16:50 PM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth487-20090226-121706.raw
Result File : \\Poweredge\E drive\TC\dennis\meth487-20090226-103911.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth487-20090226-103911.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [$\mu\text{V}\cdot\text{s}$]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.529	3760.25	2389.36	100.00	100.00	BB	1.5737
		3760.25	2389.36	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version : 6.1.2.0.1:D19
 Operator : manager
 Sample Number : 486
 AutoSampler : BUILT-IN
 Instrument Name : GC
 Instrument Serial # : 610N9072715
 Delay Time : 0.00 min
 Sampling Rate : 12.5000 pts/s
 Volume Injected : 1.000000 ul
 Sample Amount : 1.0000
 Data Acquisition Time : 1/9/09 7:29:42 PM

Date : 1/9/09 5:55:34 PM
 Sample Name : ~~Sawdust-1~~ Sand - 1
 Study :
 Rack/Vial : 0/0
 Channel : A
 A/D mV Range : 1000
 End Time : 4.00 min
 Area Reject : 0.000000
 Dilution Factor : 1.00
 Cycle : 486

Raw Data File : \\Poweredge\E drive\TC\dennis\meth486-20090109-192959.raw
 Result File : \\Poweredge\E drive\TC\dennis\meth486-20090109-175533.rst
 Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
 drive\TC\dennis\meth486-20090109-175533.rst
 Proc Method : \\Poweredge\E drive\TC\dennis\methane5
 Calib Method : \\Poweredge\E drive\TC\dennis\methane5
 Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [$\mu\text{V}\cdot\text{s}$]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.529	4055.00	2535.50	100.00	100.00	BB	1.5993
		4055.00	2535.50	100.00	100.00		

Missing Component Report

Component Expected Retention (Calibration File)

All components were found

Software Version : 6.1.2.0.1:D19
 Operator : manager
 Sample Number : 487
 AutoSampler : BUILT-IN
 Instrument Name : GC
 Instrument Serial # : 610N9072715
 Delay Time : 0.00 min
 Sampling Rate : 12.5000 pts/s
 Volume Injected : 1.000000 ul
 Sample Amount : 1.0000
 Data Acquisition Time : 1/9/09 7:36:05 PM

Date : 1/9/09 6:01:58 PM
 Sample Name : ~~Sawdust-2~~ Sand -2
 Study :
 Rack/Vial : 0/0
 Channel : A
 A/D mV Range : 1000
 End Time : 4.00 min
 Area Reject : 0.000000
 Dilution Factor : 1.00
 Cycle : 487

Raw Data File : \\Poweredge\E drive\TC\dennis\meth487-20090109-193617.raw
 Result File : \\Poweredge\E drive\TC\dennis\meth487-20090109-180158.rst
 Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
 drive\TC\dennis\meth487-20090109-180158.rst
 Proc Method : \\Poweredge\E drive\TC\dennis\methane5
 Calib Method : \\Poweredge\E drive\TC\dennis\methane5
 Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [$\mu\text{V}\cdot\text{s}$]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	1.929	3878.58	2394.15	49.66	49.66	BB	1.6200
2	2.529	3931.80	2451.43	50.34	50.34	BB	1.6039
		7810.38	4845.58	100.00	100.00		

Missing Component Report
 Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 1/15/09 9:55:13 AM
Operator	: manager	Sample Name	: Sand-1
Sample Number	: 484	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1:00
Sample Amount	: 1.0000	Cycle	: 484
Data Acquisition Time	: 1/15/09 11:30:22 AM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth484-20090115-113035.raw
 Result File : \\Poweredge\E drive\TC\dennis\meth484-20090115-095513.rst
 Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
 drive\TC\dennis\meth484-20090115-095513.rst
 Proc Method : \\Poweredge\E drive\TC\dennis\methane5
 Calib Method : \\Poweredge\E drive\TC\dennis\methane5
 Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.527	3745.52	2293.74	100.00	100.00	BB	1.6329
		3745.52	2293.74	100.00	100.00		

Missing Component Report

Component	Expected Retention (Calibration File)
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All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 1/15/09 10:01:38 AM
Operator	: manager	Sample Name	: Sand-2
Sample Number	: 485	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 1/15/09 11:36:49 AM	Cycle	: 485

Raw Data File : \\Poweredge\E drive\TC\dennis\meth485-20090115-113704.raw
Result File : \\Poweredge\E drive\TC\dennis\meth485-20090115-100138.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth485-20090115-100138.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.528	3327.78	2077.16	100.00	100.00	BB	1.6021
		3327.78	2077.16	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 1/23/09 3:22:38 PM
Operator	: manager	Sample Name	: Sand-1
Sample Number	: 484	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 484
Data Acquisition Time	: 1/23/09 4:58:14 PM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth484-20090123-165831.raw

Result File : \\Poweredge\E drive\TC\dennis\meth484-20090123-152238.rst

Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E drive\TC\dennis\meth484-20090123-152238.rst

Proc Method : \\Poweredge\E drive\TC\dennis\methane5

Calib Method : \\Poweredge\E drive\TC\dennis\methane5

Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.530	3523.86	2203.38	100.00	100.00	BB	1.5993
		3523.86	2203.38	100.00	100.00		

Missing Component Report

Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 1/23/09 3:28:41 PM
Operator	: manager	Sample Name	: Sand-2
Sample Number	: 485	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 1/23/09 5:04:19 PM	Cycle	: 485

Raw Data File : \\Poweredge\E drive\TC\dennis\meth485-20090123-170433.raw
Result File : \\Poweredge\E drive\TC\dennis\meth485-20090123-152841.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth485-20090123-152841.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [$\mu\text{V}\cdot\text{s}$]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.533	3480.60	2136.45	100.00	100.00	BB	1.6291
		3480.60	2136.45	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 1/29/09 10:07:41 AM
Operator	: manager	Sample Name	: Sand-1
Sample Number	: 484	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 1/29/09 11:43:15 AM	Cycle	: 484

Raw Data File : \\Poweredge\E drive\TC\dennis\meth484-20090129-114335.raw

Result File : \\Poweredge\E drive\TC\dennis\meth484-20090129-100741.rst

Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E drive\TC\dennis\meth484-20090129-100741.rst

Proc Method : \\Poweredge\E drive\TC\dennis\methane5

Calib Method : \\Poweredge\E drive\TC\dennis\methane5

Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.530	3201.96	1983.84	100.00	100.00	BB	1.6140
		3201.96	1983.84	100.00	100.00		

Missing Component Report

Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 1/29/09 10:16:15 AM
Operator	: manager	Sample Name	: Sand-2
Sample Number	: 485	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 1/29/09 11:51:49 AM	Cycle	: 485

Raw Data File : \\Poweredge\E drive\TC\dennis\meth485-20090129-115207.raw
Result File : \\Poweredge\E drive\TC\dennis\meth485-20090129-101615.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth485-20090129-101615.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.532	5086.75	3198.26	100.00	100.00	BB	1.5905
		5086.75	3198.26	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/6/09 3:32:43 PM
Operator	: manager	Sample Name	: Sand-1
Sample Number	: 484	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 2/6/09 5:09:21 PM	Cycle	: 484

Raw Data File : \\Poweredge\E drive\TC\dennis\meth484-20090206-170939.raw
Result File : \\Poweredge\E drive\TC\dennis\meth484-20090206-153243.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth484-20090206-153243.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.530	4455.76	2820.93	100.00	100.00	BB	1.5795
		4455.76	2820.93	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/6/09 3:39:22 PM
Operator	: manager	Sample Name	: Sand-2
Sample Number	: 485	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 2/6/09 5:16:00 PM	Cycle	: 485

Raw Data File : \\Poweredge\E drive\TC\dennis\meth485-20090206-171618.raw
Result File : \\Poweredge\E drive\TC\dennis\meth485-20090206-153922.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth485-20090206-153922.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.528	4588.13	2885.73	100.00	100.00	BB	1.5899
		4588.13	2885.73	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/11/09 1:20:27 PM
Operator	: manager	Sample Name	: Sand-1
Sample Number	: 484	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s		
Volume Injected	: 1.000000 ul	Area Reject	: 0.000000
Sample Amount	: 1.0000	Dilution Factor	: 1.00
Data Acquisition Time	: 2/11/09 2:56:56 PM	Cycle	: 484

Raw Data File : \\Poweredge\E drive\TC\dennis\meth484-20090211-145715.raw
Result File : \\Poweredge\E drive\TC\dennis\meth484-20090211-132026.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth484-20090211-132026.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.530	4239.49	2662.33	100.00	100.00	BB	1.5924
		4239.49	2662.33	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/11/09 1:28:03 PM
Operator	: manager	Sample Name	: Sand-2
Sample Number	: 485	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: 610N9072715	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 485
Data Acquisition Time	: 2/11/09 3:04:32 PM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth485-20090211-150450.raw
 Result File : \\Poweredge\E drive\TC\dennis\meth485-20090211-132803.rst
 Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
 drive\TC\dennis\meth485-20090211-132803.rst
 Proc Method : \\Poweredge\E drive\TC\dennis\methane5
 Calib Method : \\Poweredge\E drive\TC\dennis\methane5
 Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.531	4059.34	2546.99	100.00	100.00	BB	1.5938
		4059.34	2546.99	100.00	100.00		

Missing Component Report
 Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/19/09 9:36:11 AM
Operator	: manager	Sample Name	: Sand-4
Sample Number	: 485	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: None	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 485
Data Acquisition Time	: 2/19/09 11:14:03 AM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth485-20090219-111420.raw
Result File : \\Poweredge\E drive\TC\dennis\meth485-20090219-093611.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth485-20090219-093611.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [$\mu\text{V}\cdot\text{s}$]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.529	3750.34	2343.16	100.00	100.00	BB	1.6005
		3750.34	2343.16	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/19/09 9:42:14 AM
Operator	: manager	Sample Name	: Sawdust-1 Sand#2
Sample Number	: 486	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: None	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 486
Data Acquisition Time	: 2/19/09 11:20:08 AM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth486-20090219-112024.raw
 Result File : \\Poweredge\E drive\TC\dennis\meth486-20090219-094214.rst
 Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
 drive\TC\dennis\meth486-20090219-094214.rst
 Proc Method : \\Poweredge\E drive\TC\dennis\methane5
 Calib Method : \\Poweredge\E drive\TC\dennis\methane5
 Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.531	3737.17	2327.78	100.00	100.00	BB	1.6055
		3737.17	2327.78	100.00	100.00		

Missing Component Report
 Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/26/09 10:19:55 AM
Operator	: manager	Sample Name	: Sand-1
Sample Number	: 484	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: None	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 484
Data Acquisition Time	: 2/26/09 11:57:38 AM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth484-20090226-115752.raw

Result File : \\Poweredge\E drive\TC\dennis\meth484-20090226-101955.rst

Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E drive\TC\dennis\meth484-20090226-101955.rst

Proc Method : \\Poweredge\E drive\TC\dennis\methane5

Calib Method : \\Poweredge\E drive\TC\dennis\methane5

Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [μV·s]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.526	3574.76	2247.93	100.00	100.00	BB	1.5902
		3574.76	2247.93	100.00	100.00		

Missing Component Report

Component Expected Retention (Calibration File)

All components were found

Software Version	: 6.1.2.0.1:D19	Date	: 2/26/09 10:26:55 AM
Operator	: manager	Sample Name	: Sand-2
Sample Number	: 485	Study	:
AutoSampler	: BUILT-IN	Rack/Vial	: 0/0
Instrument Name	: GC	Channel	: A
Instrument Serial #	: None	A/D mV Range	: 1000
Delay Time	: 0.00 min	End Time	: 4.00 min
Sampling Rate	: 12.5000 pts/s	Area Reject	: 0.000000
Volume Injected	: 1.000000 ul	Dilution Factor	: 1.00
Sample Amount	: 1.0000	Cycle	: 485
Data Acquisition Time	: 2/26/09 12:04:37 PM		

Raw Data File : \\Poweredge\E drive\TC\dennis\meth485-20090226-120453.raw
Result File : \\Poweredge\E drive\TC\dennis\meth485-20090226-102655.rst
Inst Method : \\poweredge\E drive\TC\dennis\methane5 from \\Poweredge\E
drive\TC\dennis\meth485-20090226-102655.rst
Proc Method : \\Poweredge\E drive\TC\dennis\methane5
Calib Method : \\Poweredge\E drive\TC\dennis\methane5
Sequence File : \\poweredge\E drive\TC\dennis\methane5.seq

DEFAULT REPORT

Peak #	Time [min]	Area [$\mu\text{V}\cdot\text{s}$]	Height [μV]	Area [%]	Norm. Area [%]	BL	Area/Height [s]
1	2.528	3614.64	2274.96	100.00	100.00	BB	1.5889
		3614.64	2274.96	100.00	100.00		

Missing Component Report
Component Expected Retention (Calibration File)

All components were found