UNIVERSITY OF CALGARY

Control of Greenhouse Gas Emissions from Oil Production

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

CALGARY, ALBERTA

MAY, 2005

UNIVERSITY OF CALGARY

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled " Control of Greenhouse Gas Emissions from Oil Production " submitted by Haththotuwa Gamage Chamika Kaumal Haththotuwa in partial fulfilment of the requirements of the degree of Master of Science in Civil Engineering.

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Abstract

The oil industry flares or vents to the atmosphere more than one billion m^3 of methane-rich solution gas each year. Considering the potential global warming impacts, there is a need to identify alternative methods to control solution gas emissions to the atmosphere. This research is focused on assessing the viability of using actively aerated soil biofilters as an alternative technique to control solution gas related methane emissions. In addition, the effect of volatile organic compounds (VOCs) present in solution gas on methane conversion by methanotrophic bacteria was investigated. The research confirmed a high methane oxidation rate of 705 $g/m^2/day$ using actively aerated biofilter columns. This value is 200-300% more than rates reported for passively aerated biofilters. This study also showed that methane oxidation is not affected by the presence of low concentrations of VOCs.

Acknowledgements

First and foremost the author acknowledges the help and able guidance of Dr. J. Patrick A. Hettiaratchi, the research supervisor whose encouragement, constructive criticism and suggestions made this research project a success.

The author acknowledges the contributions made by Mr. A.G.A.N. Nanayyakara, Dr. Alex De Visscher, Dr. Binod Rajbhandari, and Mr. Vincent B. Stein. The many valuable suggestions made by Mr. Changa Mettananda, Mr. Nandana Perera, Mr. Dinesh Pokhrel and Mr. Omar Hurtado are also greatly appreciated.

The author gratefully appreciates the financial support from NSERC and Alberta Energy, and the Department of Civil Engineering of the University of Calgary. The author acknowledges the support given by the laboratory technical staff members: Mr. Harry Pollard, Ms. Heather Mills, and Ms. Dorrie Wiwcharuk.

Finally, the author wishes to thank his dear parents for their understanding and encouragement throughout the period of study.

Dedication

It is my honour to dedicate this thesis to Dr. Sumith Pilapitiya.

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CHAPTER ONE: INTRODUCTION

1.1 Introduction

Carbon dioxide (CO_2) and methane (CH_4) are the two main anthropogenic greenhouse gases that are released to the atmosphere during production and consumption of fossil fuels. Carbon dioxide results primarily from the combustion of fossil fuels for energy. Methane is emitted to the atmosphere during fossil fuel extraction and processing. In crude oil production from petroleum reservoirs, solution gas is emitted to the atmosphere. Solution gas contains primarily methane, with small quantities of other volatile organic compounds (VOCs).

The effect of methane on global warming could be explained by using an indicator called Global Warming Potential (GWP), a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas. Methane has a GWP 23 times and 62 times that of carbon dioxide over the 100-year and 20-year time horizon, respectively (IPCC, 2001; USEPA, 2004).

At present, in Alberta, most of produced solution gas is collected and processed for sale and on-site use. The remainder is flared as a waste product due to uneconomical reasons to conserve. Flaring of solution gas has been identified as a source of gaseous emissions capable of causing adverse effects on human health and the environment. (Strosher, 1996).

To date, only a few researchers have conducted studies on methodologies for mitigation of atmospheric discharge of solution gas. Holford and Hettiaratchi (1998) identified several viable cost effective strategies to abate methane emissions from flaring and venting of solution gas.

1.2 Problem definition

A naturally occurring organism known as methanotrophic bacteria is capable of converting CH_4 to CO_2, thereby reducing GW impacts. However, a technology that utilizes methanotrophic bacteria is not currently available because of lack of sufficient research data. Since methanotrophs are aerobic organisms, actively aerated biofilters containing methanotrophs are expected to oxidize methane at high rates. However, research is lacking to optimize an actively aerated biofilter design. The biofilter performance in terms of methane oxidation, in the presence of non-methane volatile organics under active aerated conditions, is yet to be studied.

1.3 Research goal, objectives and scope

The goal of this research is to evaluate the effect of non-methane volatile organic compounds on methane oxidation in actively aerated biofilters. The scope is limited to application of biofilter columns in controlling solution gas emissions in oil industry.

Objectives of this research are:

1. To evaluate the interaction effects of methane and non-methane volatile organic compounds on performance of biofilter columns under various methane loading rates and methane to non-methane volatile organic compound (VOC) ratios.

2. To evaluate biofilter column behaviour by the following:
   a. developing methane oxidation profiles along the filter depth
   b. evaluating the development and progression of the active methane oxidation zone within a biofilter column.
   c. investigating moisture content and organic carbon variation along the depth over time
3. To estimate the variation of maximum methane oxidation rate (V_{max}) along the depth of column biofilter using batch experiments.

1.4 Thesis Organization

The thesis report consists of five chapters, a reference section, and several appendices. Chapter one (Introduction) explains the problem definition and research objectives. Chapter two (Literature Review) provides information gathered from literature surveys on solution gas and biofiltration technology. Chapter three (Materials and Methods) describes the analytical and experimental methods and materials used. Chapter four presents the experimental data and interpretation of data and results. Chapter five (Conclusion and Recommendations) provides the conclusions derived from the results. The references cited on the thesis are listed under Reference section and the supportive data, calculations, graphs and tables for chapter three and chapter four are provided in Appendices A-E.

CHAPTER TWO: LITERATURE REVIEW

2.1 The greenhouse effect and methane

In the past, the concern that human activities may be affecting global climate has largely centered on carbon dioxide because of its importance as a greenhouse gas and also because of the rapid rate at which its atmospheric concentration has been increasing. However, it is clear that other greenhouse gases have also significantly affected climate over the past few centuries. Rising methane concentrations are a major contributor to the observed increase in the greenhouse effect since pre-industrial times-second only to carbon dioxide-having a global warming potential of 23 times that of carbon dioxide on a 100-year time horizon. The combined effect of methane and other greenhouse gases has been approximately double the overall increase in the greenhouse radiative forcing in climate relative to that of carbon dioxide alone.

Like other greenhouse gases, methane absorbs infrared radiation (also known as long wave or terrestrial radiation) emitted by the relatively warm planetary surface and emits radiation to space at the colder atmospheric temperatures, leading to a net trapping of infrared radiation in the atmosphere. The balance between the absorbed solar radiation and the emitted infrared radiation determines the net radiative forcing on climate.

The importance of methane's contribution towards the global warming potential was demonstrated by Donner and Ramanathan (1980). They pointed out that the presence of methane at current levels causes the globally averaged surface temperature to be about 1.3 ^{0}K higher than it would be without methane.

Increasing concentrations of methane are thought to be a significant fraction of the increase of radiative forcing from greenhouse gases over the last two centuries. IPCC (1996) calculated that the increase in methane since mid-1700s has produced a radiative forcing increase of 0.47 Wm^{-2} (Watts per meter square), which is about 19 % of total change in radiative forcing due to carbon dioxide and the other greenhouse gases over the time period. Rodhe (1990), Hansel et al. (1989), and MacKay and Khalil (1991) (as cited by Whebbles and Hayhoe, 1999) reported similar results.

In addition to direct radiative forcing effect on climate of methane, it could also influence climate indirectly through chemical interactions affecting other radiatively important gases. Methane is an important influence on concentration of hydroxyl ions, the primary tropospheric oxidizing agent, which in turn determines the rate at which methane is removed from the atmosphere. Methane oxidation is also a significant source of tropospheric and stratospheric ozone, stratospheric water vapour, and its eventual final product, carbon dioxide (Whebbles and Hayhoe, 1999).

Overall, methane's role in global warming is both direct and indirect. Methane is a strong absorber in the infrared portion of the electromagnetic spectrum. It has a strong absorption of about 7.7 micrometers, a wavelength at which no other atmospheric gases are strongly absorbing. For this reason, methane is becoming a proportionately large contributor to the total greenhouse effect. Therefore, the relative greenhouse warming from methane must take into account its residence time in the atmosphere and its subsequent production of other greenhouse gases such as carbon dioxide.

2.2 Solution gas production in Alberta

During production and processing of crude oil, gas dissolved in oil comes to the surface and is released as solution gas. Typically, solution gas is flared, vented, or conserved at crude oil production sites. Even though conservation of solution gas to generate energy is a better strategy, studies have shown that this technique could not be adopted in every situation due to economical reasons (Holford and Hettiaratchi, 1998). In such situations, flaring and/or venting could play a major role. Worldwide, the oil industry flares and vents to the atmosphere more than one hundred billion m^3 of methane-rich solution gas each year (The World Bank, 2004). Specifically, in the province of Alberta, solution gas production in 2003 amounted to about 30 billion m^3 - of which, about 1.4 billion m^3 was flared and vented (i.e. 5% of Alberta total solution gas production). The remainder was conserved (Alberta Energy Utility Board, 2004a, 2004b). The breakdown of total volumes of gas flared and vented in various sectors of the upstream oil and gas industry in Alberta is presented in Figure 2.1. Specific amounts of flaring and venting in each sector are presented in Figure 2.2. Of these sectors, crude oil bitumen batteries and associated wells account for 37 % of flaring and venting, which are also recognized as the most significant source of venting solution gas to the atmosphere. Flaring is of concern because of potential health issues attributed to by-products of flaring and environmental effects associated with such practices (Strosher, 1996).

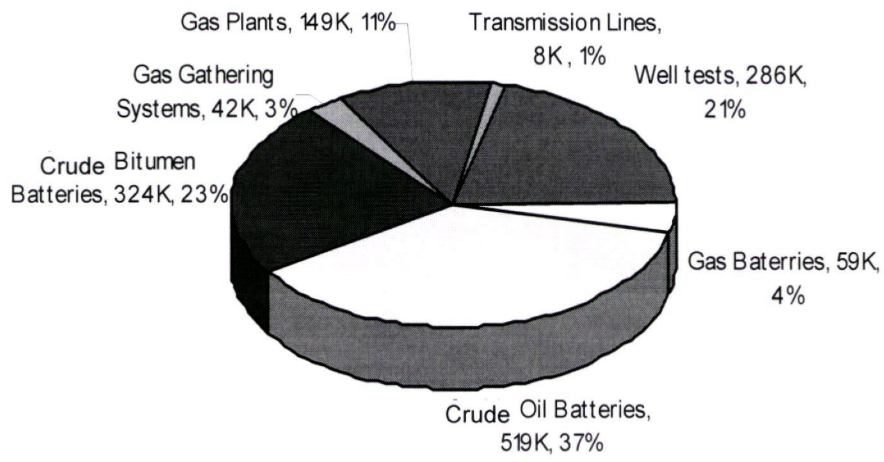

Figure 2.1: Volumes of gas flared and vented in Alberta in various sectors of the upstream oil and gas industry – 2003. (K= $1*10^6$ m^3)
(Source: EUB Statistical Series (ST) 2004-60B)

Inter Governmental Panel for Climate Change (IPCC) has estimated that slightly more than half of the current methane flux to the atmosphere is anthropogenic; primarily from human interactions such as fossil fuel use, waste disposal and agriculture (USEPA, 2004). In 2001, fossil fuels accounted for 83% of energy supply in OECD (Organization for Economic Co-Operation and Development) countries and 76% in the rest of the world (IEA, 2003). The atmospheric concentration of methane in relation to solution gas is of greater concern as large volumes of solution gas are being released to the atmosphere annually in the process of crude oil production.

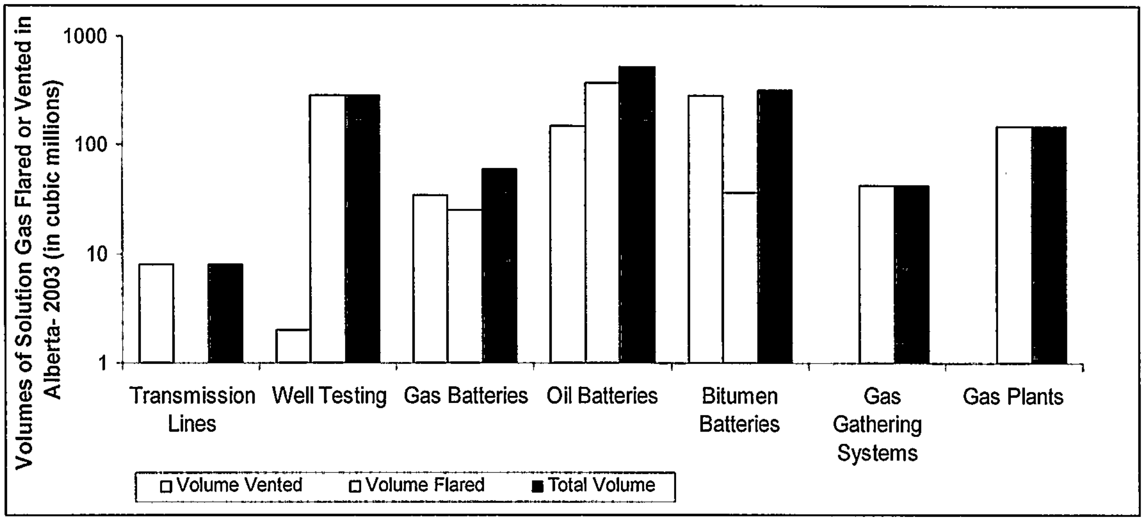

Figure 2.2: Analysis of solution gas flared and vented in various sectors of the upstream oil and gas industry in Alberta - 2003
(Source: EUB Statistical Series (ST) 2004-60B)

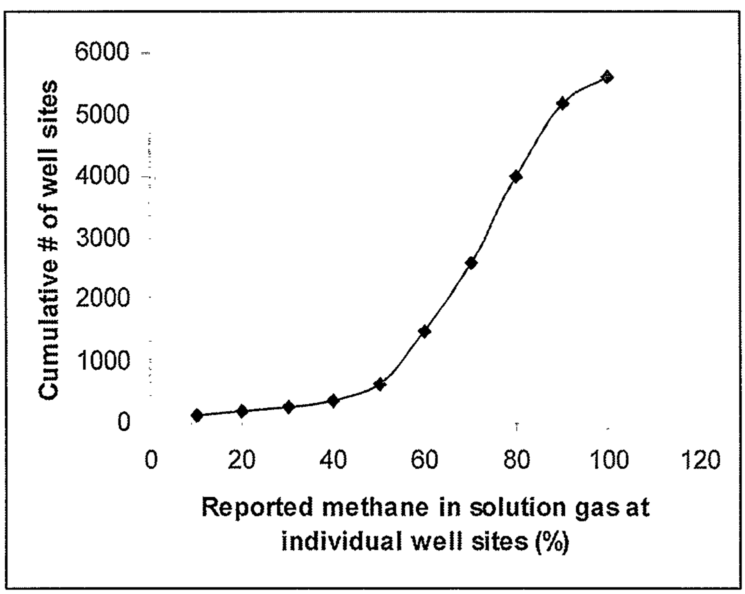

Figure 2.3: Histogram of methane concentration in solution gas in individual oil well sites in Alberta.
[The data is plotted based on solution gas composition analysis for 5614 oil wells in Alberta-1999. Source: Johnson et al. (2001)]

2.3 Composition of Solution gas

Recent studies by Johnson et al. (2001) on categorization of solution gas showed that the methane distribution in individual well sites varies significantly.

When examining the available data on solution gas, the notion of a 'typical solution gas' is recognized as problematic as there is significant site-to-site variability in properties. According to Johnson et al. (2001), the prime constituent of solution gas, methane, has an average composition of 70% and the rest being non-methane volatile organic compounds and other gases such as hydrogen sulphide, nitrogen, helium. They pointed out that the gas composition could greatly vary at individual wells. For example, a composition analysis of emissions from 5614 oil well sites in Alberta found that 98% of wells emit solution gas with a methane concentration higher than 20% (by volume) and 90% of wells with a methane concentration higher than 50% (by volume). The graphical representation of solution gas composition is shown in Figure 2.4. C1-C6 in Figure 2.4 represents solution gas alkanes.

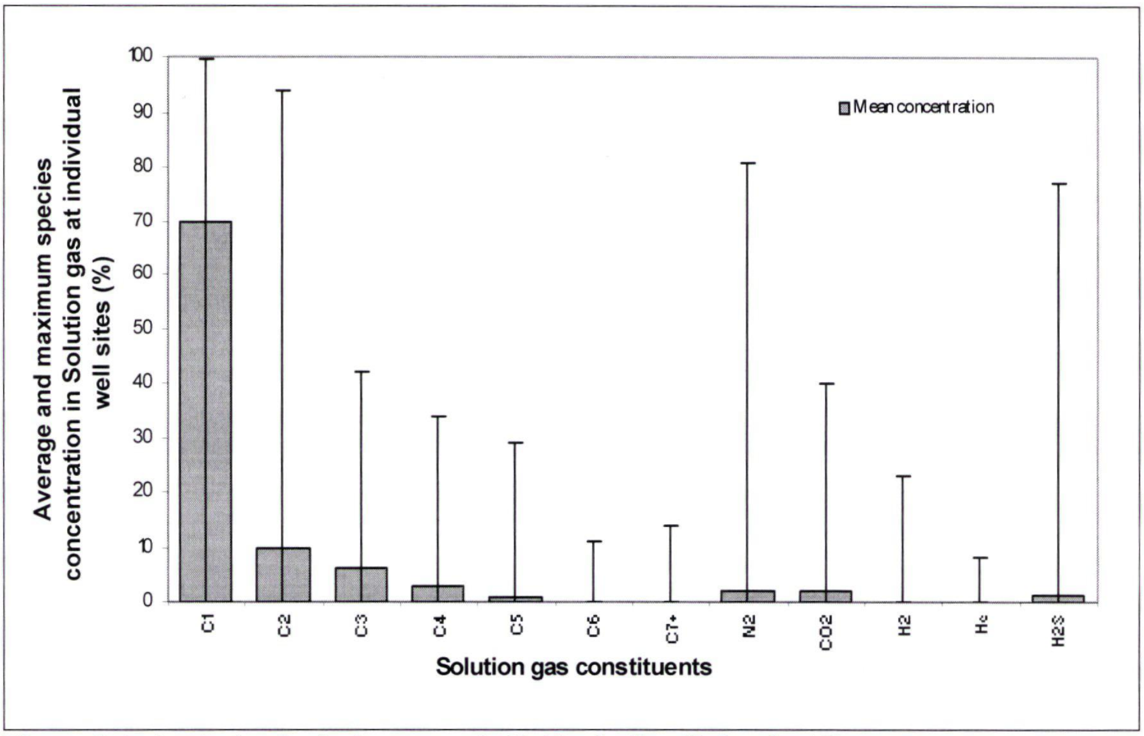

Figure 2.4: Analysis of solution gas at individual oil well sites in Alberta (Source: Johnson et al. 2001).

2.4 Solution gas emission mitigation technologies

Holford and Hettiaratchi (1998) identified seven potential alternatives to solution gas flaring that could be implemented under different field conditions. The potential technologies were as follows:

- Low pressure gas collection (clustering)
- Electrical generation using gas turbines or reciprocating engines
- Electrical generation using "Mini turbines"
- Cogeneration
- Reinjection of gas with produced water
- Oxidation (biological and physical)
- Collection and processing

The adaptation the aforementioned technologies would result in a significant reduction of solution gas volume flared (Holford and Hettiaratchi, 1998).

2.5 Methane oxidation and biofiltration

A biofilter consists of a layer of porous organic or soil media containing microorganisms capable of degrading gaseous contaminants as they pass along the filter depth. The concept of biofiltration addresses biological degradation of gas phase chemicals by active microbial populations attached to a solid medium to end products such as CO_2, H_2O, inorganic salts and biomass. Therefore, in a biofilter column, when a contaminated air stream flows through the filter depth, the contaminants are first sorbed by the solid phase and then metabolized to harmless end products in the presence of microorganisms (Alexander, 1994).

Biological degradation is categorized under a three step process which relies on mechanisms of diffusion and biological degradation of target contaminants (Swanson and Loehr, 1997). First, contaminant constituents of bulk gas adsorbs on the interface between the gas and the aqueous biofilm surrounding the solid medium. Secondly, the contaminants diffuse through the biofilm to a consortium of acclimated microorganisms. Finally, the microorganisms obtain energy from oxidation of contaminants as a primary substrate, or they co-metabolize contaminants via non specific enzymes. Simultaneously, there is diffusion and uptake of nutrients, such as nitrogen and phosporus in available forms, and oxygen within the biofilm. Utilization of contaminants, electron acceptors, and nutrients, continuously maintains concentration gradients driving diffusive transport in the biofilm (Swanson and Loehr, 1997).

Although biofiltration has many different applications, types of active microbial population present in a biofilter column medium varies in accordance with the influent gases being treated. For example, the predominant microbes that are present in biofilters treating volatile organic compounds are heterotrophs, in which most of heterotrophs are recognized as bacteria and fungi (Kosky and Neff 1988; Leson and Winter 1991). Muller (1998) demonstrated that influent gases with inorganic constituents could be treated in the presence of chemoautotrophs while using carbon dioxide as a carbon source. However, in either case, mesophiles and thermophiles predominate, according to the environmental conditions (Leson and Winter 1991).

Methane is a volatile organic compound which could be readily degraded to harmless by-products in the presence of methylotrophs, which is a subset of heterotrophs. Specific bacteria capable of oxidizing methane are known as methanotrophic microorganisms, a subset of methylotrophs, which are also known as obligate methanotrophs or methanotrophs. Methanotrophs are of two types; which are categorized as low methane oxidation capacity and high methane oxidation capacity microbial populations (Bender and Conrad, 1994). The former microbial populations exist at low methane concentrations (low V_{max} and low K_m - high affinity) and the latter at high methane concentrations (high V_{max} and high K_m - low affinity). V_{max} denotes maximum methane oxidation rate and K_m denotes affinity constant of methane. Bowmen et al. (1993) reported different classification of methanotrophs as type I, type II and type X. These types of methanotrophs share the enzyme methane–mono-oxygenase (MMO), an enzyme containing copper and iron, which occurs in two forms; namely soluble sMMO and particulate pMMO (Hanson and Hanson, 1996). pMMO is universal among all methanotrophs, whereas the sMMO is only found in type II and type X (Mancinnelli, 1995). The pMMO and sMMO are distinguished based on biochemical characteristics such as different locations within the cell and structural differences in terms of substrate specificity, oxygen requirements, copper concentration requirements, kinetics, sensitivity to inhibitors etc. (Colby et al., 1977; Dalton, 1980; Stanley et al., 1983; Burrows et al., 1985; Green and Dalton, 1986; Dalton and Higgins, 1987; Fox et al., 1989; and Rosenzweig et al., 1993: cited from Mancinnelli, 1995). The ecological implications of these two MMOs, based on the differences in biochemical characteristics are given in Table 2.1.

Table 2.1: Comparison of ecological implications of sMMO and pMMO

sMMO	pMMO	Reference
Oxidize aromatic, alicyclic hydrocarbons, and dehalogenated hydrocarbons	Cannot oxidize such hydrocarbons as mentioned under sMMO	Colby et al., 1977; Dalton, 1980; Fox et al., 1990; Hanson et al., 1990: Cited from Mancinnelli, 1995
Less energy efficient compared to pMMO – requires more NAD(P)H and therefore limits its ability to co-oxidize substrates other than methane.	More energy efficient compared to sMMO	Burrows et al., 1985; Green and Dalton, 1986; Leak and Dalton, 1986: Cited from Mancinnelli, 1995
Less oxygen required compared to pMMO – K_m for oxygen is 0.1 micro meters – Higher number of type II and type X colonies are present at low oxygen environments, for example, sediments and in soil at depth	More oxygen required compared to sMMO – K_m for oxygen is 17micro meters	Green and Dalton, 1986: Cited from Mancinnelli, 1995
sMMO synthesize only at low copper levels	The synthesis of pMMO requires considerable amount of copper compared to sMMO	Stanley et al., 1983

2.5.1 Pathways of methane oxidation

Methanotrophic microorganisms uptake methane via dissimilatory and assimilatory pathways (refer to Figure 2.5). In dissimilatory pathway, methane is completely converted to carbon dioxide during production of cellular energy. In this process, carbon converts to neither biomass nor cellular material, and produced carbon dioxide will escape to the atmosphere. In the assimilatory pathway, conversion of methane to cellular mass occurs via ribulose monophosphate pathway or serine pathway. Type I and type X methanotrophs follow the former pathway, whereas type II and type X methanotrophs follow the latter pathway.

In both pathways, methane is first oxidized to methanol, which is then oxidized to formaldehyde. The formaldehyde can be used as a reducing power in the metabolic pathway/electron-transport chain, oxidized to formate, or assimilated by the cell via the ribulose monophosphate pathway and/or the serine pathway. The cell then either oxidizes the formate to carbon dioxide or uses it as a reducing power to drive metabolic pathway. The produced carbon dioxide is then released off as a gas or be assimilated via the serine pathway (Mancinnelli, 1995).

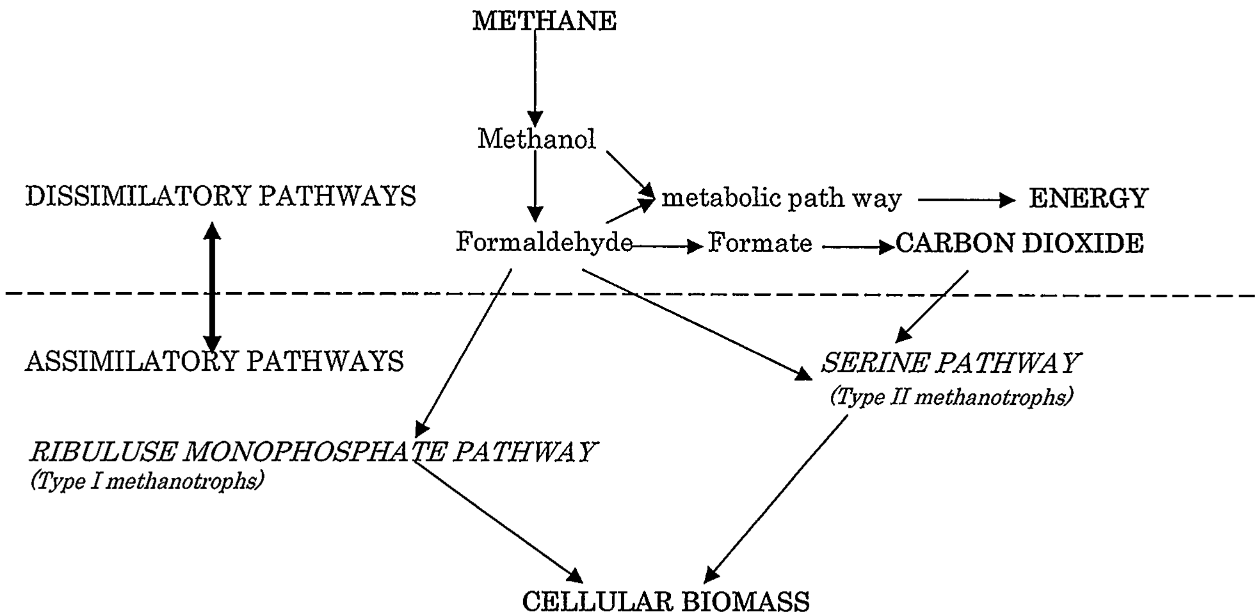

Figure 2.5: Assimilatory and dissimilatory methane oxidation pathways (Source: Mancinnelli, 1995)

2.6 Factors controlling microbial methane oxidation

Environmental factors, such as moisture content, oxygen, pH, temperature, nutrients, and methane concentration affecting methanotrophic activities are discussed below.

2.6.1 Moisture content

Moisture content has been identified as the most important parameter in biofilter column operation (Marsh, 1992). Even though maintaining optimal moisture conditions is crucial, many contingent factors address difficulties of attaining the desired filter performance. Mostly, these adverse conditions exist when biofilter column medium is subjected to extreme wet or dry conditions. Adverse conditions such as high back pressure development and low gas retention time, oxygen transfer problems along the filter bed, creation of anaerobic zones, slow methane degradation, nutrient washing are encountered in over-wet biofilters. Whereas, deactivation of methanotrophs, contraction and consequent medium cracking reducing retention times are recognized as adverse conditions that reduce optimum performance of biofilter columns with low moisture.

Studies on forested soils (Steudler et al., 1989; Keller et al., 1986; Whalen et al., 1991; Mosier et al., 1991, 1993; Koschorreck and Conrad, 1993; Lessard et al., 1994; Castro et al., 1995, and unforested soils (Keller and Reiners, 1994) showed that there is a strong relationship between methane oxidation and the moisture content. Methane oxidation potential of soils in low moisture environments is lower than methane oxidation in higher moisture environments (Figueroa, 1993). The opposing effects of diffusion limitations and water stress lead to occurrence of an optimum moisture content for methane oxidation (De Visscher, 2001). The optimum moisture range for methane oxidation is 10-25% for different soils (Bender, 1992; Boeckx et al., 1996; Whalen and Reeburgh, 1996; Park et al. 2002; Pokhrel, 1999; Stein, 2000; and De Visscher, 2001). Bender (1992, as cited by Humer & Lechner, 1999) showed methanotrophic microorganisms tend to become inactive when the moisture content falls below 13% of the maximum water holding capacity. A maximum oxidation rate at moisture content of 18% was observed by Pokhrel (1998) from experiments performed on silt-clay topsoil samples. However, Park et al. (2002), for sandy loamy soils, obtained higher methane oxidation rates at moisture contents around 13% and lower oxidation rates at moisture contents around 5%.

2.6.2 Oxygen

In dissimilatory pathway, methane converts to carbon dioxide according to the following stoichiometric equation (Croft and Emberton, 1989):

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2\,H_2O + 2108\ \text{kCal mol}^{-1} \qquad (2.1)$$

According to Equation 2.1, type I and type X methanotrophs oxidize one mole of methane to one mole of carbon dioxide while consuming two oxygen moles. However, this stoichiometric equation is not applicable in situations where carbon is converted to biomass in assimilatory pathway, in the presence of type II and type X methanotrophs under less oxygen environments. Bender (1992, as cited by Humer & Lechner, 1999) concluded that methanotrophic activities will be significantly retarded at oxygen concentration below 2% (by volume). These experimental conclusions were based on samples extracted from methane oxidizing paddy fields. Similar observations were reported by Czepiel et al. (1996). Bender and Conrad (1994) concluded that oxygen concentration lower than 3% by volume in the gaseous phase will significantly retard the microbial activity of methanotrophs.

2.6.3 pH

Methanotrophic microorganisms co-metabolize to its end products in a wide pH range of 4-9. However, an optimum activity and growth rate occurs within a pH range of 5.5-8.5 (Figueroa, 1993). Hutsch et al. (1994) reported a significant methane uptake in soil taken from woodlands by adjusting to pH 7.5, and a minimum methane uptake for same soil matrix at pH 4.1. Similar observations were made by Amaral et al. (1998) from the experiments carried out on forest soils at pH range 4.5 to 7.5, of which the optimal pH was recorded near natural pH.

2.6.4 Temperature

Temperature effects on methanotrophic activity were studied by various researchers, mainly using laboratory scale batch incubation experiments.

Microbes, based on temperature effects, could be categorized into three main groups namely, psychrophilic (below 20°C), mesophilic (20°C to 37°C) and thermophelic (above 37°C). Heyer (1990, as cited by Humer & Lechner, 1999) revealed that psychrophilic microorganisms could multiply their cells to an optimum at below 20°C, and limits or cease cell multiplication at around 0°C. Whereas, thermophelic cultures sustain their growth up to a temperature of 55°C, and may tolerate a short term temperature exposure up to 80°C.

Studies to date on temperature interaction effects have shown that methane oxidation has a positive correlation with temperature. For example, Whalen et al. (1990) showed a doubling of methane oxidation rate when temperature is increased from 15°C to 25°C. Similarly, Nozhevnikova et al. (1993) showed an increase of methane oxidation rate by 2.5 times when temperature is increased from 6°C to 25°C. Also, Whalen and Reeburgh (1996) and Visvanathan et al. (1999) reported similar effects of temperature on methane oxidation in soils. LaGrega et al. (1994) explained this phenomenon as an exponentially upward curve yielding to a distinct maximum, and thereafter a downward sloping exponential curve with further temperature increase. Optimum temperatures for methane oxidation reported in literature are within the range of 20°C to 37°C. For example, the optimum temperatures observed by various researchers are: Whalen et al. (1990): 31°C to 36°C, Nesbit (1992): 20°C to 30°C, Boecckx and Van Cleemput (1996): 25°C to 30°C, Whalen and Reeburgh (1996): 25°C to 30°C, and Czepiel et al. (1996): 36°C.

2.6.5 Nutrients

To enhance cellular metabolism of methanotrophic microorganisms, it is necessary to use correct proportions of nutrients and substrates. Many studies to date reveal the effects of nutrient addition on methane oxidation, however proper guidelines are yet to be developed.

Organic media serves mainly as a carrier for microorganisms and improves the soil and substrate properties. Compost organic media usually supply ample quantities of nutrients in the available form to enhance cellular metabolic reactions (Leson and Winer, 1991). However, in most cases, nutrients need to be supplied. Studies by Graham et al. (1993) demonstrated that type I methanotrophs grow more rapidly than type II when mineral nitrogen and copper are introduced to the soil matrix. Furthermore, Stanley et al. (1983) showed the synthesis of MMOs at different copper concentrations, in which, sMMO synthesis occurs at low levels of copper, where as, pMMO synthesis occurs irrespective of available copper.

Kightley et al. (1995) observed a significant increase of methanotrophy when coarse grained soil is amended with nutrients. As reported in literature, methane oxidation increased by 26% in amended soils with anaerobically digested sewage sludge, 27% with an admixture of peat and 41% with an admixture of compost derived from green waste, to that of unamended coarse grained soil. However, addition of phosphate (K_2PO_4) to coarse soils exhibited no effect on methane oxidation (Kightley et al., 1995).

2.7 Inhibition effects

Many studies to date have shown inhibition of methanotrophic activity by extreme moisture and temperature conditions. Visvanathan et al (1999) observed low methane oxidation rates at a moisture content of 7% and a zero oxidation at 1.5%. Nesbit (1992) also observed zero oxidation for air dried soil samples at a moisture content of 1.5%.

Nesbit (1992) showed zero methane oxidation at 5^0C. A quick inhibition effect occurs due to the rise in temperature above optimum temperatures (Visvanathan et al. 1999).

Many studies to date showed that the presence of NH_4^+ (also called "competitive inhibitor") intervenes in the methane oxidation process. Boeckx et al. (1996) found that the addition of small amounts of NH_4^+ to landfill soils increase methane oxidation, and poses significant inhibitory effects at elevated NH_4^+ concentrations. Similar conclusions were made by Bender and Conrad (1995).

Boeckx and Van Cleemput (1996) studied the effects of C/N ratio of organic residuals in relation to NH_4^+. In this study, soil amendments with wheat straw and maize straw at high C/N ratios of 97.2 and 24.8, respectively, showed no inhibition effects and soil amendments with sugar beat leaves and potato leaves at low C/N ratios of 13.5 and 11.3, respectively, exhibited higher levels of inhibitory effects. The possible explanation was that high C/N ratio promotes immobilization of N and thereby lower NH_4^+ concentration. Conversely, organic residues with low C/N ratios promote N mineralization, and thereby increasing NH_4^+ concentration levels resulting in inhibitory effects on methanotrophic activities. NH_4^+ inhibitory effects on soils are numerous, especially in different soil anionic environments like Cl^-, SO_4^{-2}, NO_3^- etc. Studies by Gulledge and Schimel (1998) observed more inhibitory effects due to NH_4Cl as compared with $(NH_4)_2SO_4$. The difference of inhibitory effects between NH_4Cl and $(NH_4)_2SO_4$ was thought to be caused by the presence of Cl^-. In general, NO_3^- ions exhibit no inhibition effects on methane oxidation in contrast to NH_4^+ ions (Boeckx and Van Cleemput, 1996). However, Kightley et al. (1995) observed inhibition of methane oxidation when high concentrations of NH_4NO_3 were added (71 micro mol g^{-1} dry soil) to landfill cover soil.

2.8 Passive Aeration and Active Aeration

Methanotrophic bacteria are obligatory aerobes. The treatment efficiency of a Methano-Biofilter (MBF) column is limited by the amount of oxygen present. MBFs may be aerated either passively or actively. In passively aerated MBFs, oxygen is supplied to the media by diffusing down through the MBF's surface, whereas in actively aerated MBFs, air is injected at the biofilter's inlet.

Studies on passively aerated systems show methane oxidation occurs in a limited soil depth to which oxygen is diffused from the top soil surface of biofilter. However, compared to passively aerated systems, actively aerated systems are expected to oxidize high methane volumes since adequate amount of oxygen is available throughout the depth of the soil column for methane conversion (Stein and Hettiaratchi, 2001).

2.9 Summary

More than one billion cubic meters of solution gas, containing primarily methane, is emitted each year into the atmosphere by the oil industry. Methane is a key greenhouse gas. Methane oxidation in soil biofilters depends on soil texture and other factors such as oxygen, nutrients and inhibitory ions, moisture content, pH and organic carbon content. Methane is oxidized by methanotrophs to harmless end products and new bio-cells while following two different pathways. Since methanotrophs are aerobic organisms, provision of adequate oxygen in properly designed actively aerated biofilter columns containing methanotrophs are expected to oxidize methane at high loading rates through out the depth of column compared to passively aerated systems.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Materials

The soil used in actively aerated biofilter column experiments was a top soil obtained from the University of Calgary grounds. According to sieve and hydrometer analyses (Lambe and Whitman, 1979), the soil consists of 86.2% coarse sand, 11.7% silt sand and 4.1% clay. The graphs and calculations related to soil analyses are provided in appendix A. Other relevant soil properties were; pH = 6.9, organic carbon content = 4.8 %, bulk density = 1026 kg/m^3 and moisture content = 18% (based on dry wt.). The reason for selecting top soil for this research work is that top soil has a high organic carbon content and high amount of methanotrophs. The presence of high levels of organic carbon in soil improves the soil and substrate properties, and help maintaining a sufficient concentration of methanotrophic bacteria.

The soil suitable to grow methanotrophs should consist of 49% to 88% coarse sand, 6.5% to 40.4% silt and 4% to 25% clay (Park et al., 2002; De Visscher, 2001; Hilger et al., 2000; Kightley et al., 1995; Visvanathan et al., 1999). Likewise, Kightley et al. (1994) and De Visscher (2001) reported a required range of organic carbon content of soil as 2% to 5% for methane oxidizing bacteria to grow.

Methane (Praxair – 99% purity) was used to feed the biofilter column. Ethane (Praxair – 99% purity) was used as the non-methane VOC to study the potential interference effect of VOCs on methane oxidation.

3.2 Experimental Apparatus

Six biofilter columns of 1m height and 15.2 cm outer diameter used in this research were constructed with a 76.2 mm thick Plexiglass tube. Gas sampling ports were drilled at 5 cm intervals (first port was located 15 cm above the base of the column) along the biofilter column fitted with 3.8 mm male NPT adapters. A perforated steel plate glued with a fine steel mesh was placed 10 cm above the base of the biofilter column. The biofilter columns were closed at both ends with Plexiglass end caps fitted with rubber O-rings. The end caps were fastened to the biofilter columns with 122 mm ×7.6 mm long threaded rods.

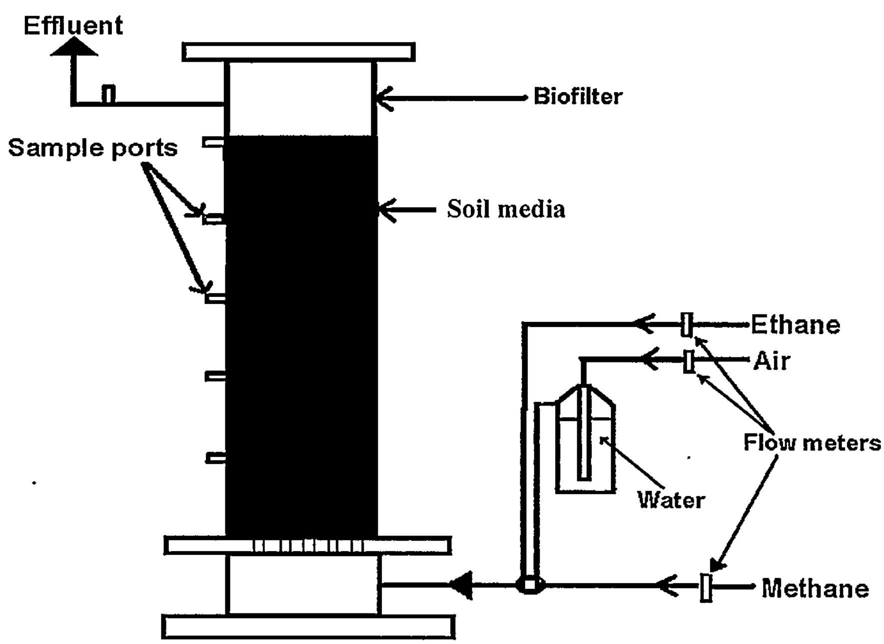

Figure 3.1: Experimental setup of a biofilter column

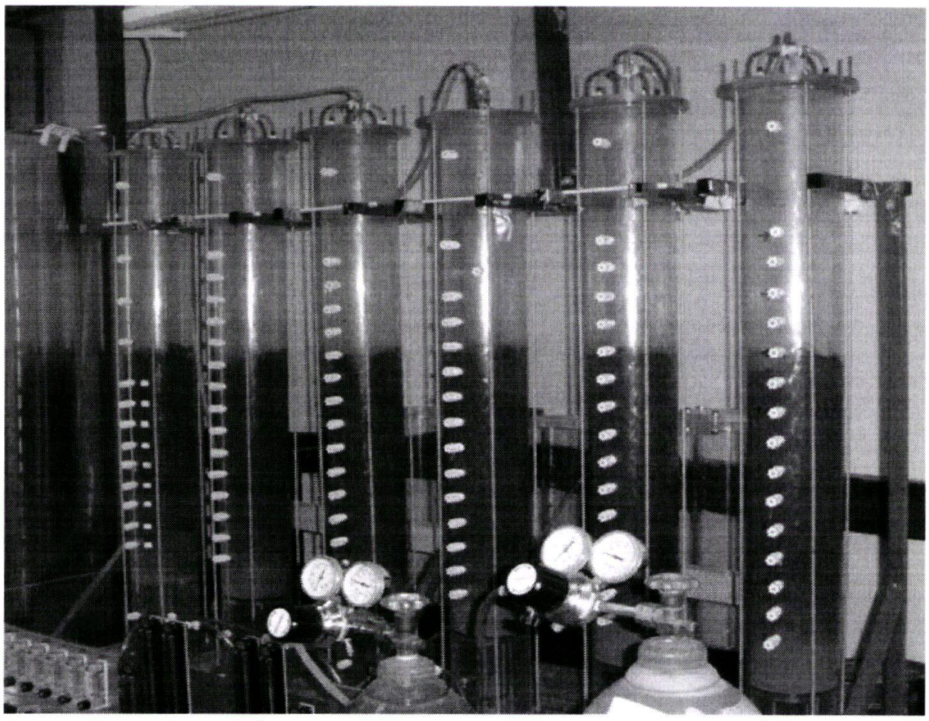

Figure 3.2: Biofilter column apparatus – Photographic view

The biofilter columns used in this research were designed to operate under active aerated conditions. Inlet of the biofilter column was connected to a cross connector to collect air, methane and ethane. Figure 3.1 shows the schematic diagram of an actively aerated biofilter column. A photographic view of biofilter column apparatus is shown in Figure 3.2.

Methane, ethane and air supplied at the inlet were measured using separate flow meters. The descriptions of flow meters used were as follows:

- Air: (Cole-parmer: 32010-15 (Aluminium/Glass) - 6#s)
- Methane: (Cole-parmer: N042-15S- 3#s)
- Ethane (Omega micro rota meter: FL 310 - 2#s and Cole-parmer: N032-41G- 1#)

Calibration of flow meters was done by using a bubble flow meter at a pressure of 2.5 psig and temperature of 22^{0}C. The flow meters and tubing arrangement are shown in Figure 3.3.

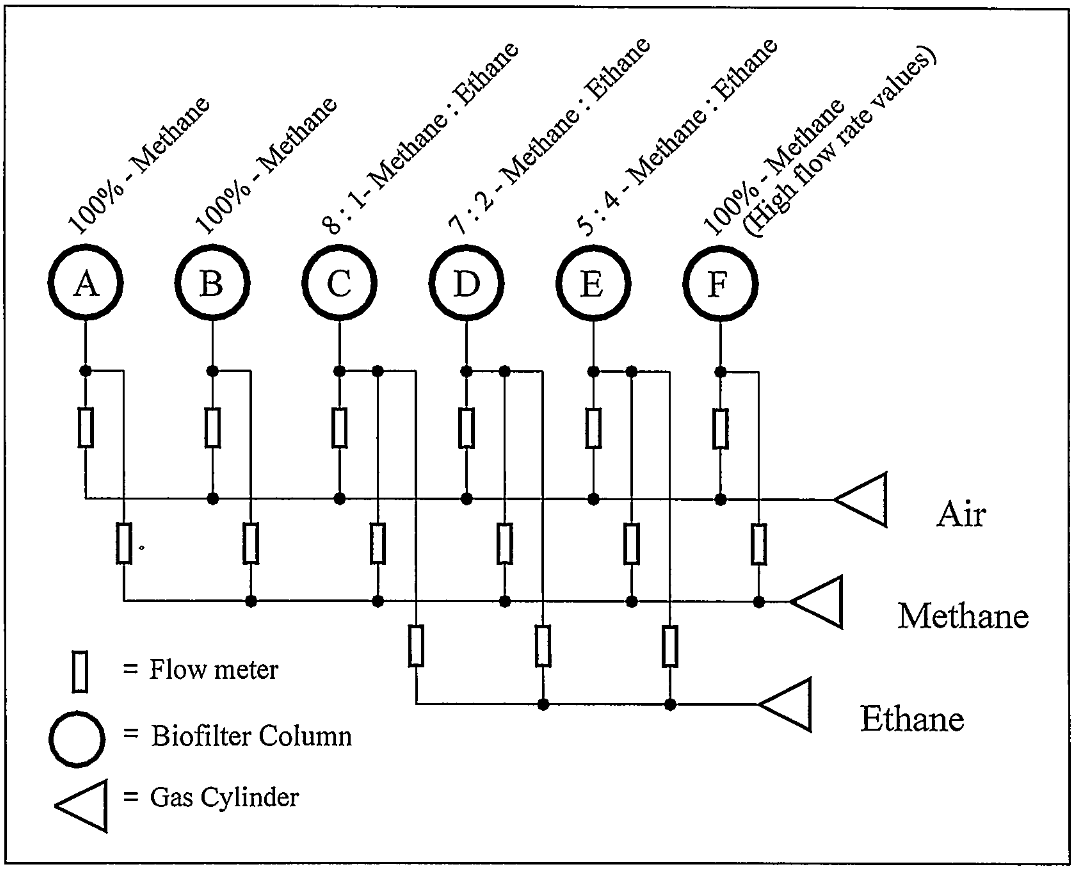

Figure 3.3: The flow meter and tubing arrangement

3.3 Methods

Initially, soil was passed through a 2.5mm sieve to remove large sized particles and then placed in the biofilter columns. The amount of soil filled in each column was 10 Kg. During the filling process, biofilter columns were shaken manually to ensure homogeneous distribution of particles. The columns were filled to a height of approximately 60 cm.

3.3.1 Gas supply and measurement

All gases and air were supplied into the columns through the bottom inlet. The inlet gas pressure was maintained at 2.5 psi. Flow meters were used to control methane, ethane and air flow into the columns. During an experimental run, gas samples (2ml) were collected from sampling port/s, inlet and outlet, and analyzed using a portable Hewlett Packared Micro-Gas Chromatograph. For calibration, "two-point calibration" method was adopted and standard curves were generated using data obtained from Prax-Air gases. In two point calibration, two gas standards (Standard-1: oxygen = 0.29, nitrogen = 78.71, methane = 3.00, carbon dioxide = 8.19, ethane = 10.1; Standard-2: oxygen = 4.9, nitrogen = 70.15, methane = 9.85, carbon dioxide = 15.00) were used.

3.3.2 Methane oxidation efficiency for actively aerated biofilter columns

The methane oxidation efficiency was calculated from the following formula:

$$\text{Methane oxidation efficiency} = \left\{ \frac{\left[C_{m,in} - C_{m,out}\left(\frac{C_{n,in}}{C_{n,out}} \right) \right]}{C_{m,in}} \right\} * 100\%$$

Where,

$C_{m,\,in}$ = Methane concentration at the inlet

$C_{m,\,out}$ = Methane concentration at the outlet

$C_{n,\,in}$ = Nitrogen concentration at the inlet

$C_{n,\,out}$ = Nitrogen concentration at the outlet

Derivation of methane oxidation efficiency formula was primarily based on N_2 loaded volume per unit time taken across actively aerated biofilter columns loaded with methane or methane-ethane mixtures. In actively aerated biofilter columns, considerable volume of air is sent through the inlet. Air is approximately 78% V/V of Nitrogen. Therefore, for the development of methane oxidation efficiency formula, Nitrogen flow rates at the inlet ($Q_{n,in}$) and outlet ($Q_{n,out}$) were taken as equal.

3.3.2.1 Derivation of methane oxidation efficiency formula:

At the inlet,

$$\frac{Q_{n,in}}{Q_{m,in}} = \frac{C_{n,in}}{C_{m,in}} \tag{3.1}$$

At the outlet,

$$\frac{Q_{n,out}}{Q_{m,out}} = \frac{C_{n,out}}{C_{m,out}} \tag{3.2}$$

Where,

$Q_{m,in}$ = Methane flow rate at the inlet

$Q_{m,out}$ = Methane flow rate at the outlet

Since N_2 flow rate at the inlet and outlet are same,

$$Q_{n,in} = Q_{n,out} \tag{3.3}$$

$$\text{Methane oxidation efficiency} = 100 * \left(\frac{Q_{m,in} - Q_{m,out}}{Q_{m,in}}\right) \tag{3.4}$$

From equation (3.1) and (3.3),

$$Q_{n,out} = Q_{m,in}\left(\frac{C_{n,in}}{C_{m,in}}\right) \tag{3.5}$$

From equation (3.2) and (3.5),

$$Q_{m,out} = Q_{m,in}\left(\frac{C_{n,in}}{C_{m,in}}\right)\left(\frac{C_{m,out}}{C_{n,out}}\right) \tag{3.6}$$

Substituting equation (3.6) in equation (3.4) re arranging yields:

$$\text{Methane oxidation efficiency} = \left\{\frac{\left[C_{m,in} - C_{m,out}\left(\frac{C_{n,in}}{C_{n,out}}\right)\right]}{C_{m,in}}\right\} * 100\% \tag{3.7}$$

Similarly, ethane oxidation efficiency formula could be written as follows:

$$\text{Ethane oxidation efficiency} = \left\{\frac{\left[C_{e,in} - C_{e,out}\left(\frac{C_{n,in}}{C_{n,out}}\right)\right]}{C_{e,in}}\right\} * 100\% \tag{3.8}$$

Where,

$C_{e,\ in}$ = Ethane concentration at the inlet

$C_{e,\ out}$ = Ethane concentration at the outlet

3.3.3 Measurement of pH, Bulk density, Moisture and Organic carbon content

Soil pH was determined by mixing soil with distilled water at the ratio of 1:2.5 using HI 9025 Microcomputer pH meter. Bulk density of soil was determined by measuring the mass of known volume of soil. Moisture content of soil samples was determined gravimetrically by drying at 105 ^{0}C for 48 hrs. Organic carbon content of soil samples were determined according to the Loss-On-Ignition method (Nelson and Sommers, 1996).

3.3.4 Batch experiments

Methane incubation experiments were undertaken in 250 ml airtight glass bottles provided with Teflon-silicon septa caps. Each bottle was provided with a methane head space concentration of 6% (15 ml). Approximately 10-15 g of soil sample was used. Gas samples (2ml) were collected from each bottle head space and analyzed for methane, carbon dioxide and oxygen.

3.4 Experimental protocol

3.4.1 Interaction effects of methane and non-methane volatile organics on methane oxidation

3.4.1.1 Non-methane VOC

Ethane was selected as the representative non-methane VOC to study the effect of VOCs on methane oxidation. Based on average concentrations of individual species in solution gas, ethane is considered to be the prominent alkane present while only been second to methane. Studies by Dalton & Stirling (1982) showed the potential nature of enzyme methane monooxygenese (MMO) to oxidize n-alkanes as growth substrates. Previous investigations have shown the primary substrate transformations of ethane to ethanol, acetaldehyde, and methane to methanol, and formaldehyde. However, when both methane and ethane are present, ethane is found to be the secondary substrate and methane the primary substrate, in which ethane co-metabolizes to end products ethanol, acetaldehyde, and acetic acid (Dalton & Stirling, 1982).

3.4.1.2 Gas application rate and ratios

In this research, four methane to ethane ratios were selected to simulate methane composition variations in solution gas at well sites. The selected ratios which represent methane compositions at solution gas well sites were methane/ethane/other gases: 100/0/0, 80/10/10, 70/20/10, and 50/40/10. The corresponding ratios used for the research were methane to ethane: 1:0, 8:1, 7:2 and 5:4, respectively. The methane to ethane ratio 1:0 represents individual solution gas well sites having 100% methane, whereas methane to ethane ratio of 7:2 corresponds to an average methane concentration of 70%. The methane to ethane ratio of 8:1 represents solution gas wells with methane concentration above 70% and below 100%. The methane to ethane ratio 5:4 represented solution gas wells that have methane concentrations below 70%.

The selected gas loading rate into biofilter columns were, methane (99% purity): 6.58-20.00 ml/min (407-1237 $g/m^2/day$), ethane (99% purity): 0.82–10.88 ml/min. (95.36-1262 $g/m^2/day$), and air: 47.2-94.4 ml/min. The air flow rate was determined based on stoichiometry of methane oxidation. Based on stoichiometry, an air volume of 10ml is required to oxidize 1 ml of methane. Therefore, the air flow rates were maintained around 65.8 ml/min (65.8 ml/min. of air flow corresponds to the initial methane loading rate of less than 6.58 ml/min) and then followed by a constant air loading rate of 94.4 ml/min throughout the experiment.

3.4.1.3 Biofilter column experiments

Six biofilter columns (A, B, C, D, E and F) were used in this research. Soil was used as the biofilter column medium.

- Biofilter columns A and B were operated at low methane loading rates, with 100% methane.
- Biofilter columns C, D, and E were operated at low methane loading rates, with methane to ethane flow ratios of 8:1, 7:2, and 5:4, respectively.
- Biofilter column F was operated at a high methane loading rate throughout the experiment. The reason of operating at high methane loading rates was to verify whether biofilter column F yields steady state methane oxidation similar to that of other biofilter columns A to E.

Biofilter columns A to E were operated first at low methane loading rates. Thereafter, the loading rates were increased in steps after reaching steady state methane oxidation for each step. Methane loading rates applied at different stages for biofilter columns A to E are shown in Table 3.1.

Table 3.1: Experimental Protocol

Stage	Biofilter Column								
	A	B	C		D		E		F
			(Methane/Ethane: 8:1)		(Methane/Ethane: 7:2)		(Methane/Ethane: 5:4)		
	Methane (100%) (g/m^2/day)		Methane (g/m^2/day)	Ethane (g/m^2/day)	Methane (g/m^2/day)	Ethane (g/m^2/day)	Methane (g/m^2/day)	Ethane (g/m^2/day)	Methane (100%) (g/m^2/day)
I	≤406.8	≤406.87	≤406.87	N/A	≤406.87	N/A	≤406.87	N/A	2232.23
II	406.87	406.87	406.87	95.36	406.87	217.97	406.87	610.31	2232.23
III	502.10	502.10	502.10	117.68	502.10	268.98	502.10	753.15	2232.23
IV	601.65	601.65	601.65	141.01	601.65	322.31	601.65	902.48	2232.23
V	711.72	711.72	711.72	166.81	711.72	381.28	711.72	1067.57	2232.23
VI	841.95	841.95	841.95	197.10	841.95	536.64	711.72	1261.43	2232.23
VII	841.95	1001.72	1001.72	234.78	1001.72	649.26	711.72	1261.43	2232.23
VIII	841.95	1211.96	1211.96	284.05	1001.72	649.26	711.72	1261.43	2232.23

As shown in Table 3.1, experiments were run in eight stages. The detailed experimental procedure followed for biofilter column experiments is as follows:

- Stage I corresponds to methane and airflow rates of 0 - 406.9 g/m^2/day (0 - 6.58 ml/min) and 47.2-94.4 ml/min., respectively. After achieving a rate of 100% methane oxidation in Stage I, Stage II was commenced.
- In Stage II, 406.9 g/m^2/day of methane was supplied in biofilter columns A to E. Methane to ethane ratios of 8:1, 7:2, and 5:4 were maintained in biofilter column C, D and E, respectively.
- In case of biofilter column F, a methane flow rate of 2232.2 g/m^2/day was maintained throughout the experiment. From Stage II to Stage VIII, the airflow rate was maintained at 94.4 ml/min.
- The biofilter column operating procedure for stages III-VIII was similar to stage II as explained above.

In each stage, inlet and outlet gas samples were collected regularly and analyzed using the portable GC. The inlet and outlet gas compositions were used to calculate methane oxidation rate and efficiency of biofilter columns.

3.4.2 Biofilter column behaviour as a function of depth

3.4.2.1 Gas concentration depth profiles:

As explained in the experimental protocol (refer to Table 3.1), at the end of each experimental stage, gas samples were collected from gas sampling ports of each biofilter column and were analyzed for methane, ethane, carbon dioxide, oxygen and nitrogen using a GC. These data were used to develop gas concentration depth profiles.

3.4.2.2 Moisture and organic carbon depth profiles:

At the end of the experimental run, during the biofilter column dismantling process, three soil samples of biofilter column A, B, and C, each weighing approximately 10-15g were collected from every 100 mm depth. These samples were analyzed to determine the moisture content and organic carbon content. These data were used to develop moisture and organic carbon depth profiles.

3.4.3 Variation of maximum methane oxidation rate along the depth of biofilter column

3.4.3.1 Batch experiments

Batch experiments were carried out to determine methane oxidation kinetics of soil. About 10g of soil from each 100mm depth of the biofilter column A, B, and C were taken during the biofilter column dismantling process and were transferred into 250 ml dark glass bottles. The bottles were sealed with Teflon-silicon septa caps. Methane (15 ml) was injected into the bottle to maintain initial methane headspace concentration of 6% (v/v). Then the bottles were incubated at 22^0C. Gas samples (2 ml) were drawn from the bottles and analyzed for methane, oxygen, carbon dioxide and nitrogen concentration using GC, as explained in section 3.2. The rate of methane utilization with respect to time was calculated and used to estimate the methane oxidation kinetic parameters, maximum oxidation ($V_{max.}$) and Michaelis-Menten constant (K_m) following Michaelis and Menten method (De Visscher, 2001). The constant K_m is the methane concentration at methane oxidation rate equals to half of V_{max} (refer to Figure 3.4)

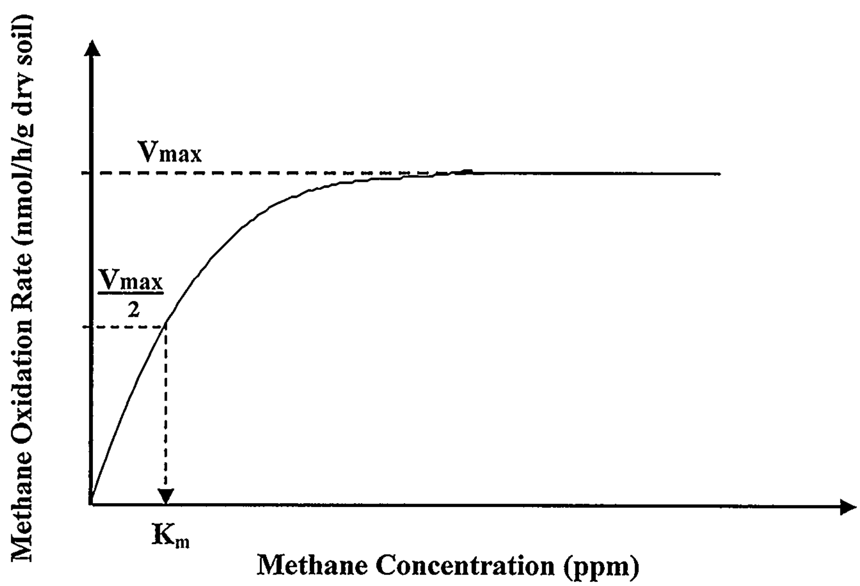

Figure 3.4: Michaelis-Menten curve showing relationship between V_{max} and K_m (Adapted from Reynolds and Richards, 1996)

CHAPTER FOUR: EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Interaction effects of methane and non-methane volatile organics on biofilter column performance

4.1.1 Methane oxidation rate and efficiency

Methane oxidation profiles of biofilter columns A and B are shown in Figure 4.1 and Figure 4.2, respectively. Data relating to methane oxidation and efficiency are presented in appendix B.

The soil column experiments started two months after of soil procurement. Since, the soil used as filter media in biofilter columns were stored in partially closed containers for two months before starting the experiments less amount of methanotrophs could be expected to exist in soils just prior to the commencement of biofilter column experiments. Therefore, a considerable time was required to reach steady state methane oxidation conditions. All six biofilter columns achieved steady state conditions in approximately 95 to 110 days.

During Stage I, all columns showed a profile similar to those seen in Figure 4.1 (c). The steep slope in later part of Stage I indicates a high methanotrophic growth rate. After a period of 99 days, it appears that the methanotrophs in biofilter columns have reached their full potential for methane oxidation; with oxidation profiles exhibiting steady state conditions with a levelled off value of 406.9 $g/m^2/day$ with an oxidation efficiency of 100%.

As indicated in Figures 4.1 and 4.2, biofilter columns A and B, which were treated with only methane, maintained a 100% oxidation efficiency during the methane loading rates between 406.9 $g/m^2/day$ (in Stage II) to 601.7 $g/m^2/day$ (in Stage IV).

However, a drop in methane oxidation steady state efficiency was observed when the methane loading rate was increased to 711.7 $g/m^2/day$ (i.e. in Stage V), in both biofilter columns. Also, a step form drop of methane oxidation rates and efficiencies were observed for further increment of methane loading rates. For example, methane oxidation efficiency in both biofilter columns A and B dropped from 100 % to 84.9% when methane loading rate increased from 711.7 $g/m^2/day$ to 840.9$g/m^2/day$. Further increase in methane loading rate from 840.9 $g/m^2/day$ to 1211.9 9 $g/m^2/day$ in column B resulted in low methane oxidation efficiency of 33.3 %.

The columns A and B showed low methane oxidation efficiencies (Stage VII to Stage VIII) at high loading rates and higher efficiencies (Stage II to Stage VI) at low methane loading rates. The highest methane oxidation rate was 705 g/m^2 /day with loading rates of 711.7 $g/m^2/day$ (Stage V) and 841.0 $g/m^2/day$ (Stage VI).

Biofilter column F, fed with a high methane loading rate, exhibited a gradual decline in methane oxidation efficiency during early stages (Figure 4.3). A low oxidation rate of 5-15% was recorded at steady state conditions and remained low over the entire duration of the experiment. The high methane flow rate to the biofilter column resulted a low methane retention time, which might be a cause for low microbial activity.

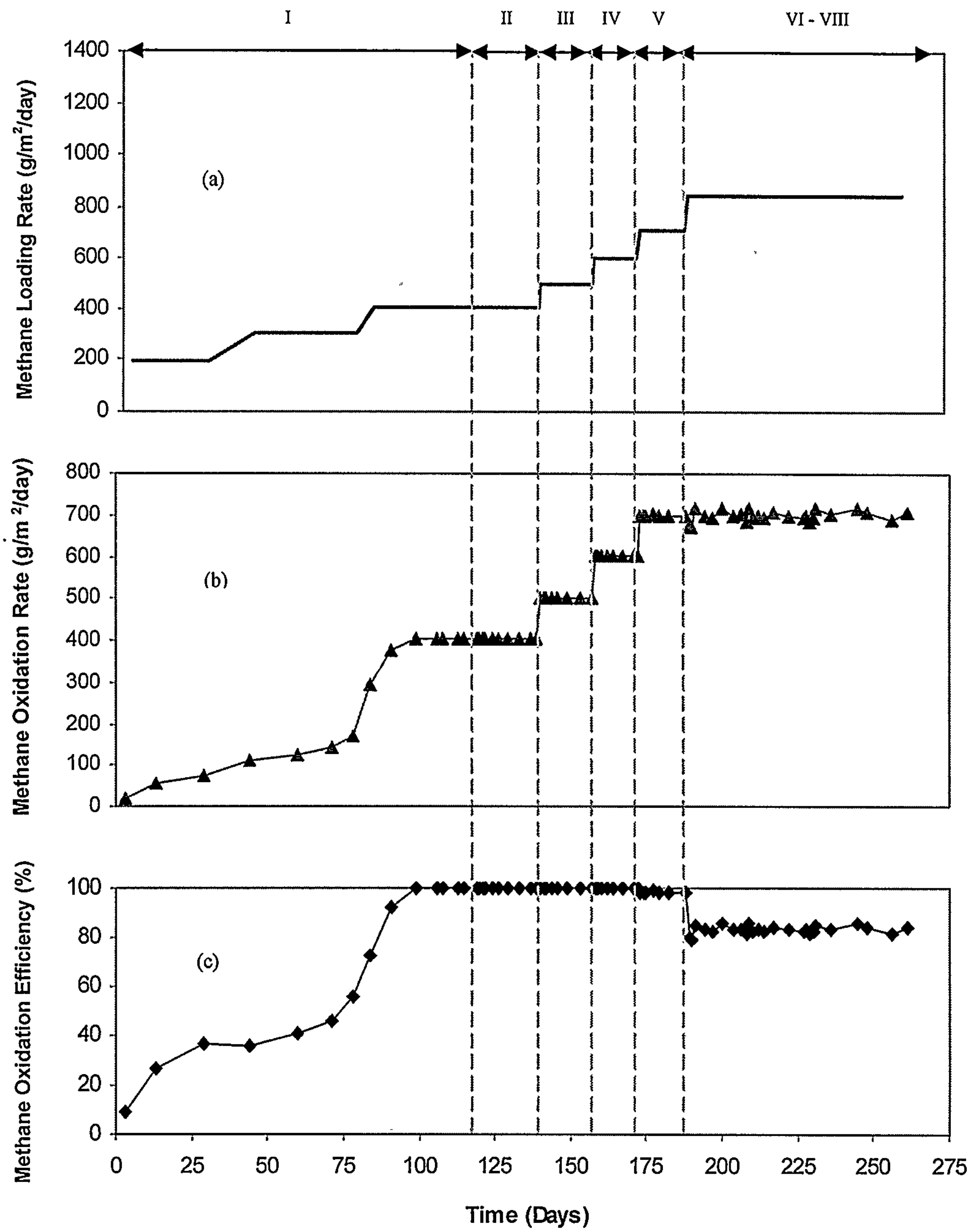

Figure 4.1: Actively aerated biofilter column results: Biofilter column A (100% methane) (a): Methane loading rate, (b): Methane oxidation rate, and (c): Methane oxidation efficiency in relation to time. (Note: Refer to Table 3.1 for information on methane loading rates at different stages).

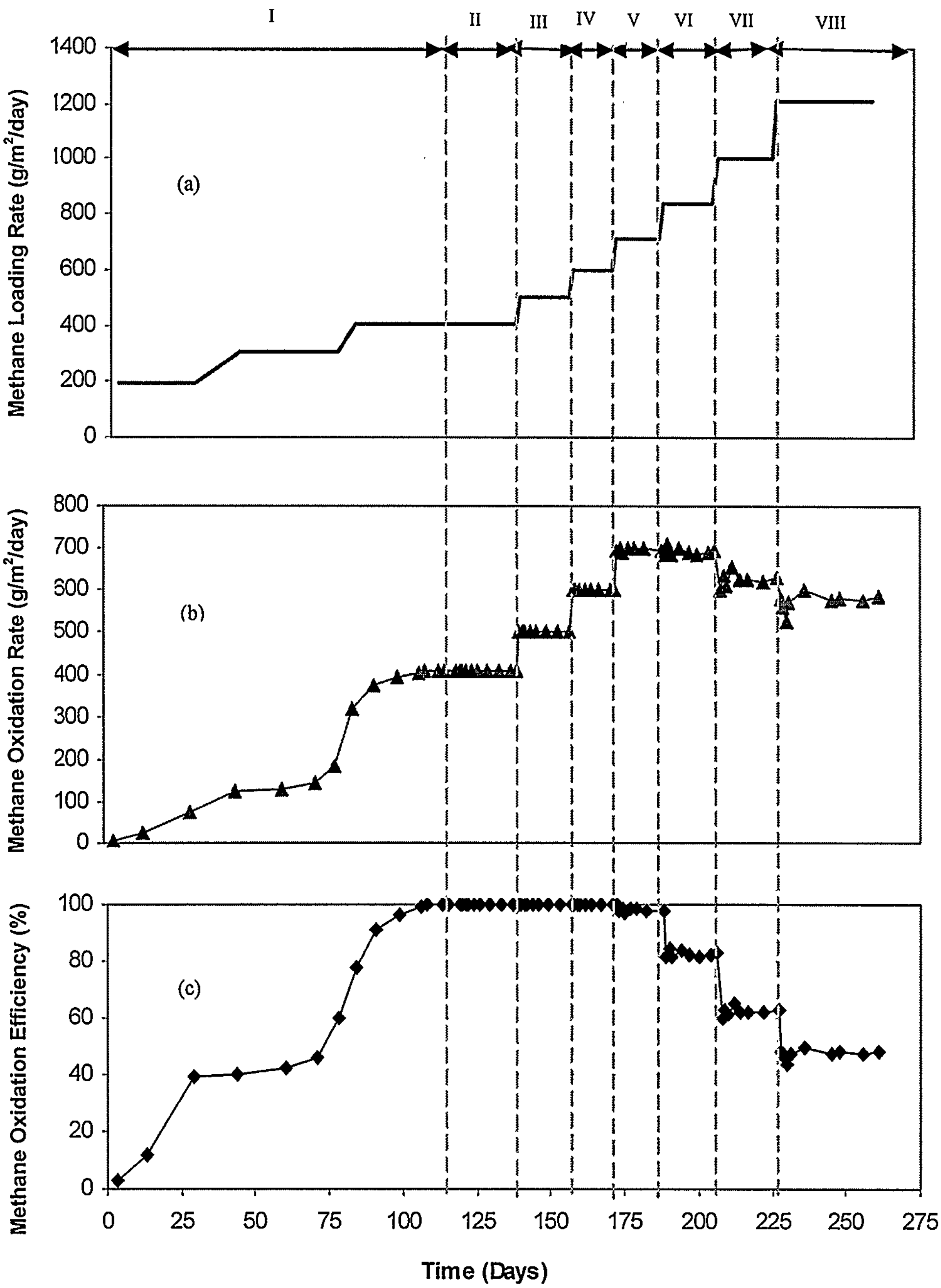

Figure 4.2: Actively aerated biofilter column results: Biofilter column B (100% methane) (a): Methane loading rate, (b): Methane oxidation rate, and (c): Methane oxidation efficiency in relation to time (Note: Refer to Table 3.1 for information on methane loading rates at different stages).

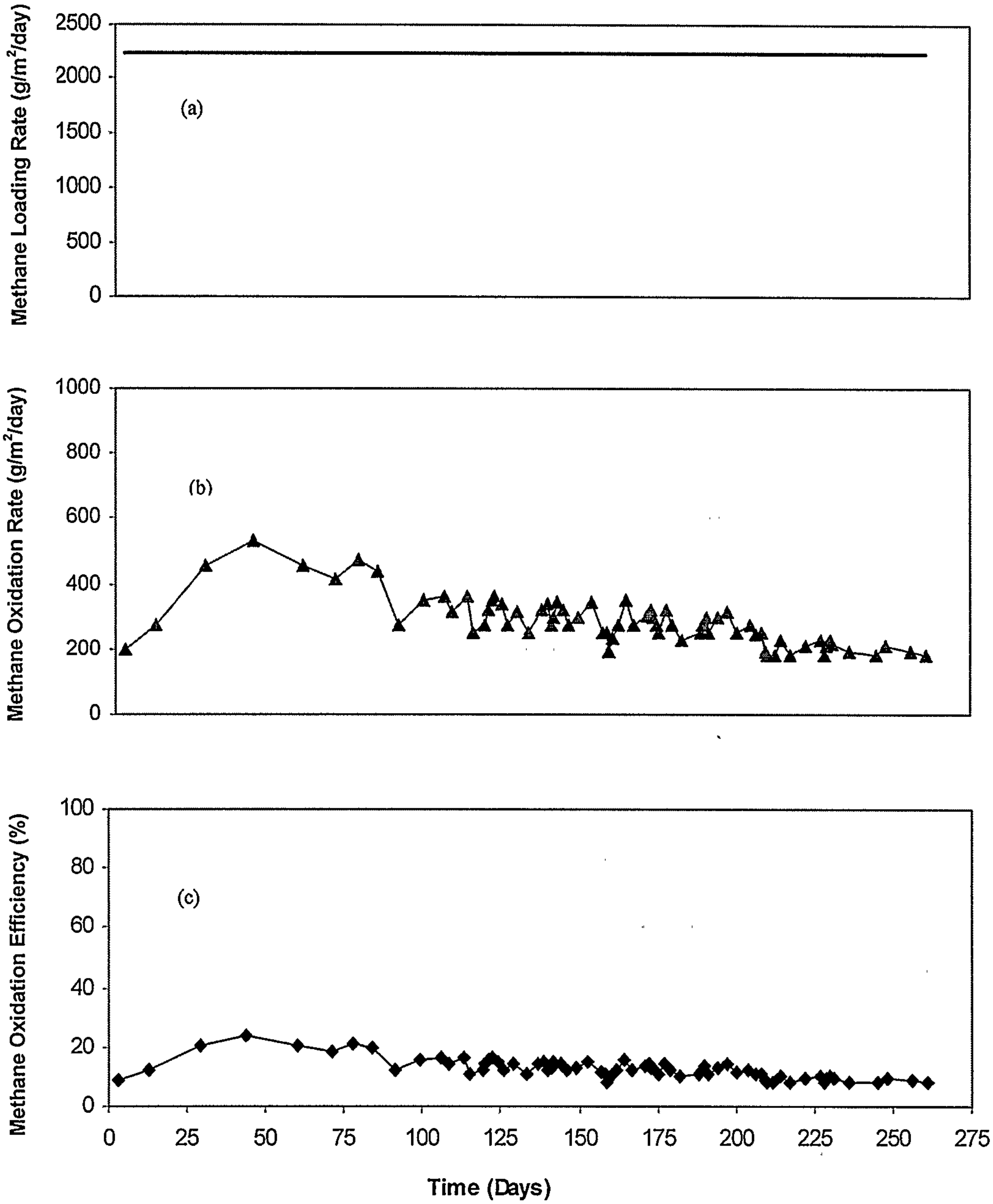

Figure 4.3: Actively aerated biofilter column results: Biofilter column F (100% high methane loading rates)
(a): Methane loading rate, (b): Methane oxidation rate, and (c): Methane oxidation efficiency in relation to time.

4.1.2 Methane - Ethane oxidation rate and efficiency

Methane oxidation rate and efficiency of biofilter columns C to E are shown in Figure 4.4 to Figure 4.9. Data and relevant calculations pertaining to methane-ethane loaded biofilter columns C, D, and E are presented in Appendix B. These figures show patterns of methane oxidation rate and efficiency profiles similar to those observed in columns A and B.

From Stage II onwards, ethane was introduced in to the columns C, D and E. The methane to ethane ratios maintained were 8:1, 7:2 and 5:4 in columns C, D and E, respectively. In the case of column C, the rate of methane oxidation increased by increasing methane loading rates up to 840.9 g/m^2/day. Increasing methane loading rates beyond 840.9 g/m^2/day resulted in a decrease in methane oxidation (Figure 4.4). Whereas, in column D, the methane oxidation rate was increased by increasing loading rates up to 711.7 g/m^2/day, and a further increase in loading rate resulted in a decrease in oxidation (Figure 4.6). However, in column E, reduction in methane oxidation was observed even at a methane loading rate of 406.8 g/m^2/day after introducing ethane at a methane to ethane ratio of 5:4 (Figure 4.8).

A maximum ethane oxidation rate of 115 g/m^2/day was observed at Stage IV in column C (Figure 4.5). Similarly, maximum ethane oxidation rates of 210 g/m^2/d in Stage III and 230 g/m^2/d at Stages II and III were found in columns D and E, respectively (see Figures 4.7 and 4.9).

Both methane and ethane oxidation profiles show a drop in oxidation rates when loading rate was increased in steps, as identified in the experimental protocol. A rapid drop in biofilter column efficiency was observed just after each increment in loading rate.

The rapid drop in oxidation efficiency could be due to disturbances created on existing environment of methanotrophs, which were already acclimatized to existing steady state loading conditions. However, the methane and ethane efficiencies reached constant values over time. This might be due to acclimatization of methanotrophs to a new loading condition.

Similar profiles were observed for ethane oxidation rate and efficiency. Methanotrophs are found to adjust well to a new loading condition over time. Further, quantitative analysis of these results is provided in section 4.1.2.1.

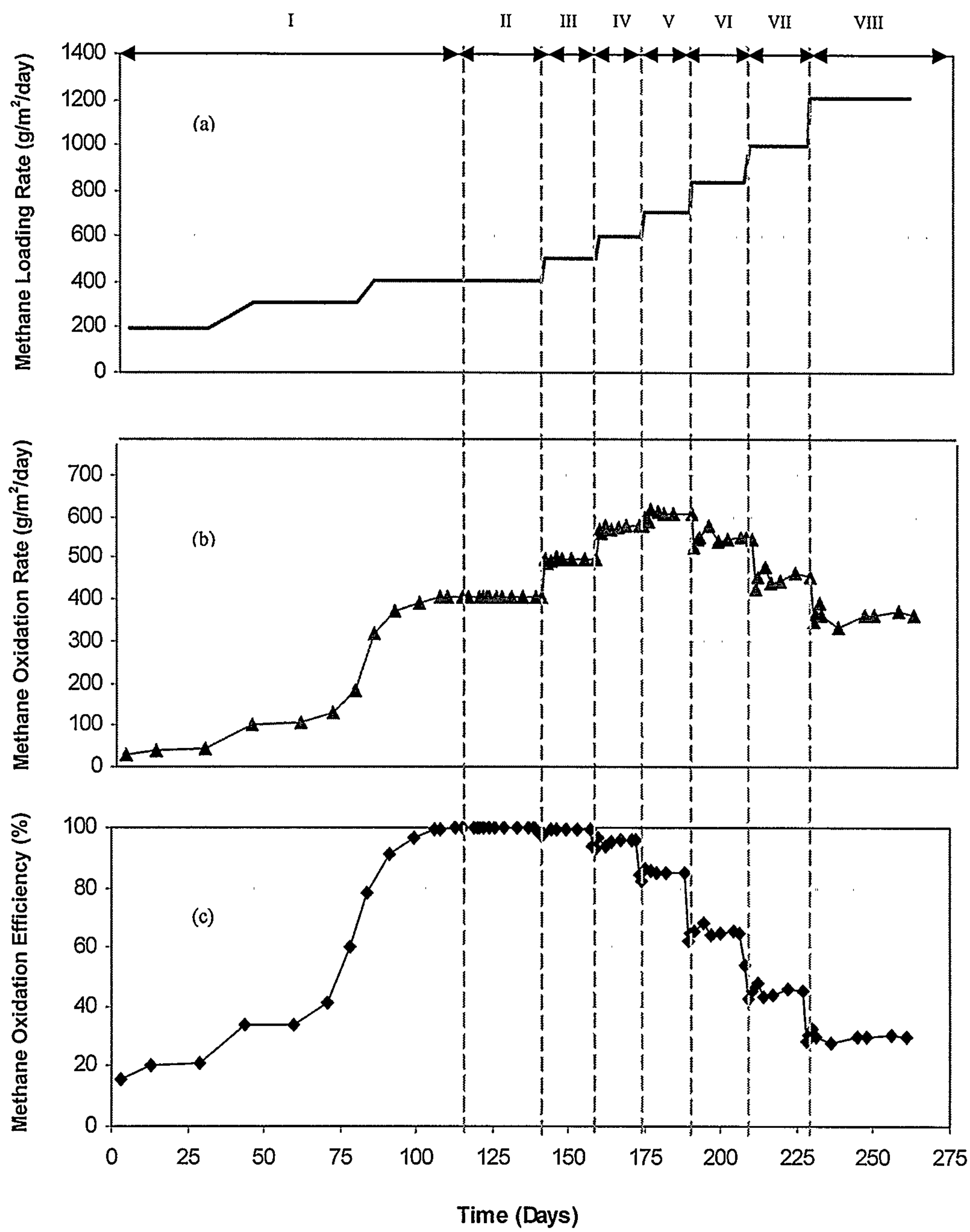

Figure 4.4: Actively aerated biofilter column results: Biofilter column C (Methane:Ethane = 8:1)
(a): Methane loading rate, (b): Methane oxidation rate, and (c): Methane oxidation efficiency in relation to time. (Note: Refer to Table 3.1 for information on methane loading rates at different stages)

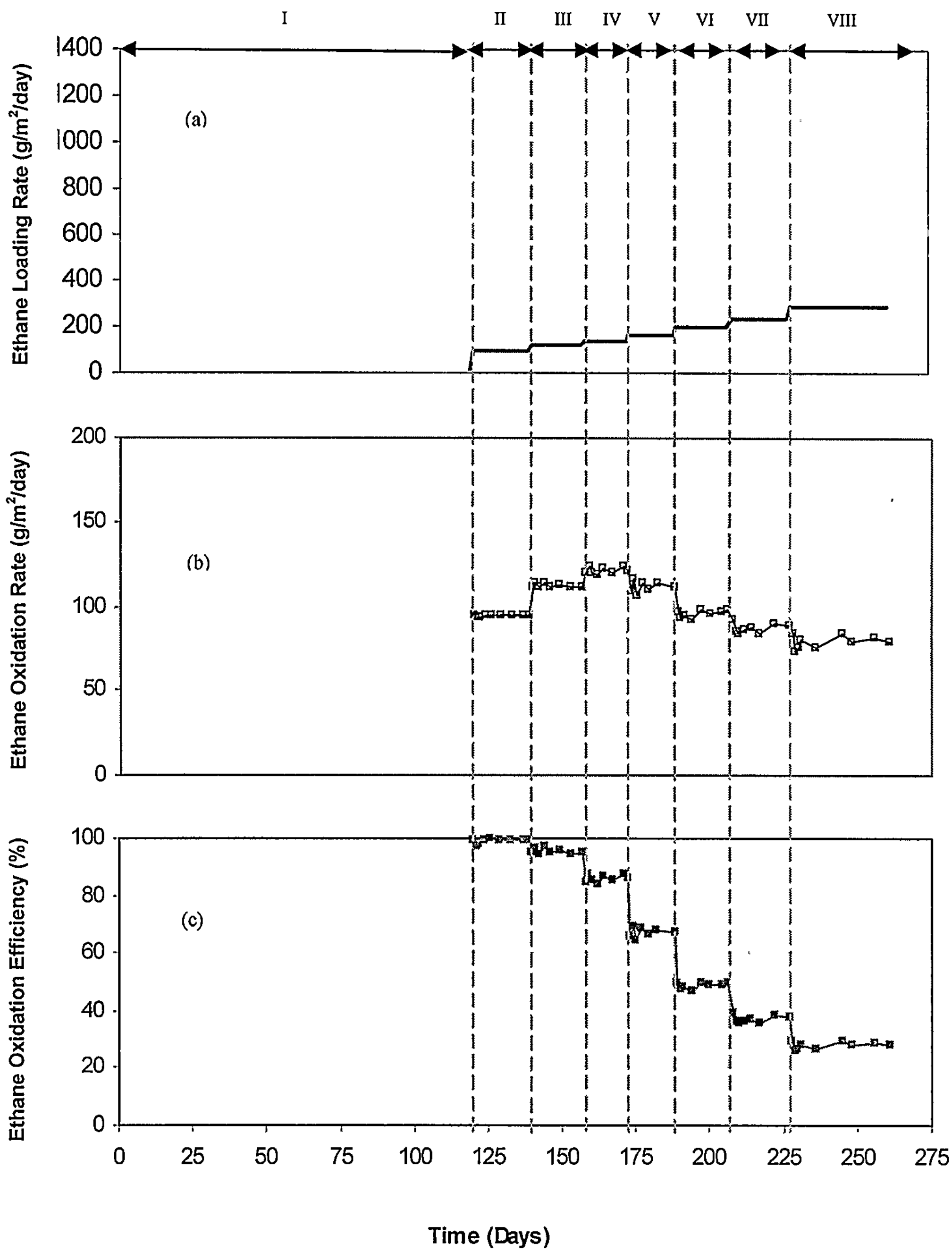

Figure 4.5: Actively aerated biofilter column results: Biofilter column C (Methane:Ethane = 8:1)

(a): Ethane loading rate, (b): Ethane oxidation rate, and (c): Ethane oxidation efficiency in relation to time. (Note: Refer to Table 3.1 for information on methane loading rates at different stages)

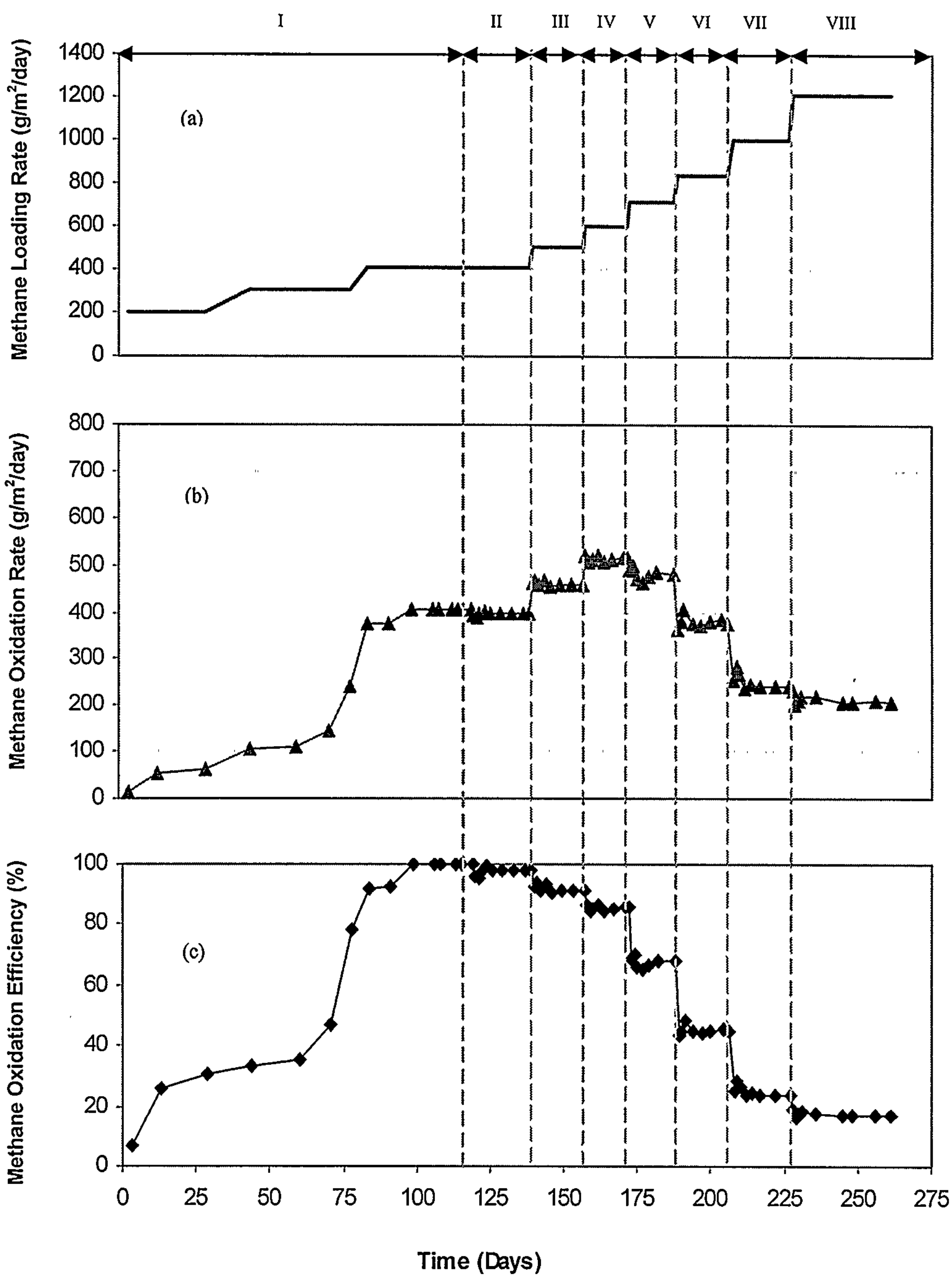

Figure 4.6: Actively aerated biofilter column results: Biofilter column D (Methane: Ethane = 7:2)
(a): Methane loading rate, (b): Methane oxidation rate, and (c): Methane oxidation efficiency in relation to time. (Note: Refer to Table 3.1 for information on methane loading rates at different stages)

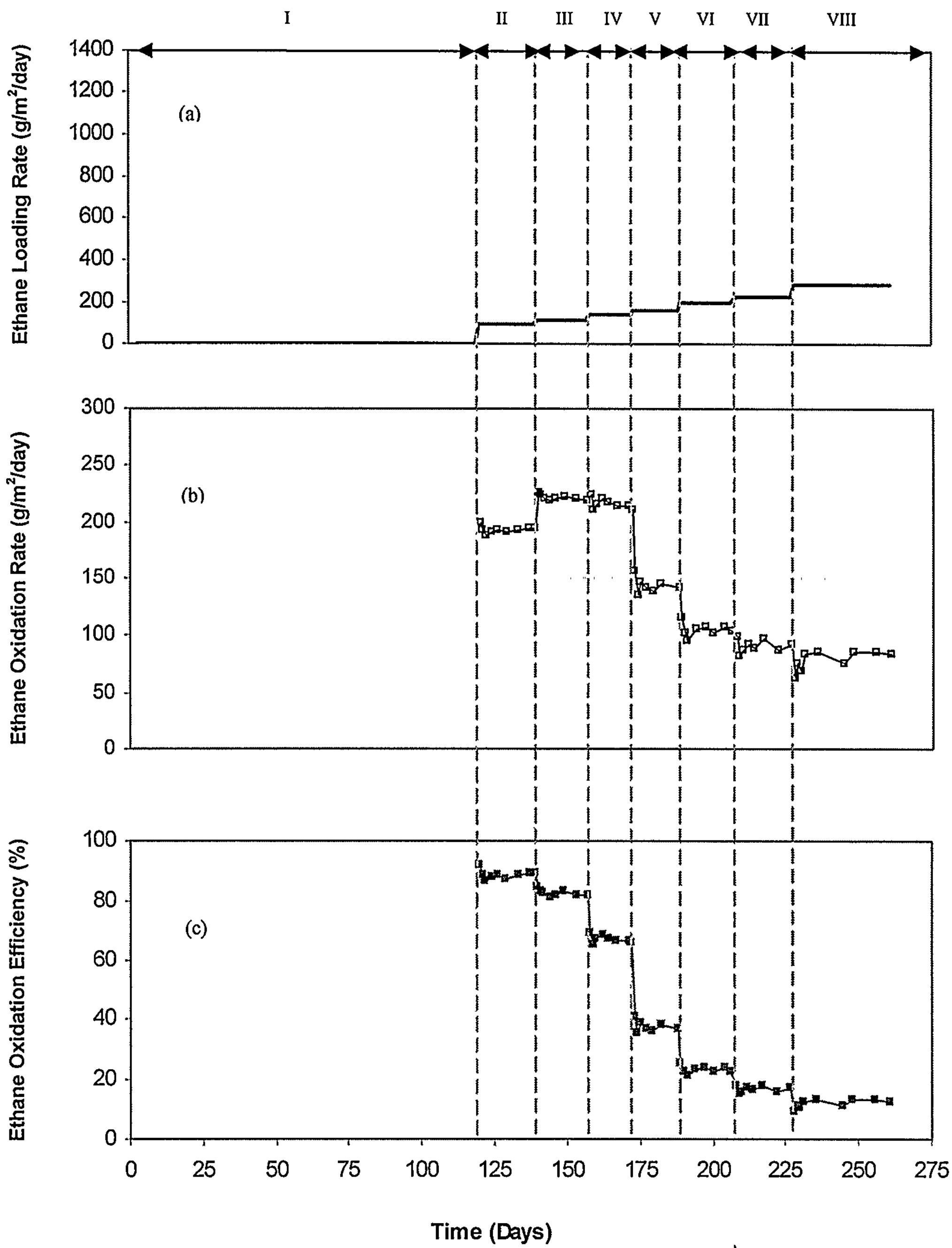

Figure 4.7: Actively aerated biofilter column results: Biofilter column D (Methane:Ethane = 7:2)
(a): Ethane loading rate, (b): Ethane oxidation rate, and (c): Ethane oxidation efficiency in relation to time. (Note: Refer to Table 3.1 for information on methane loading rates at different stages)

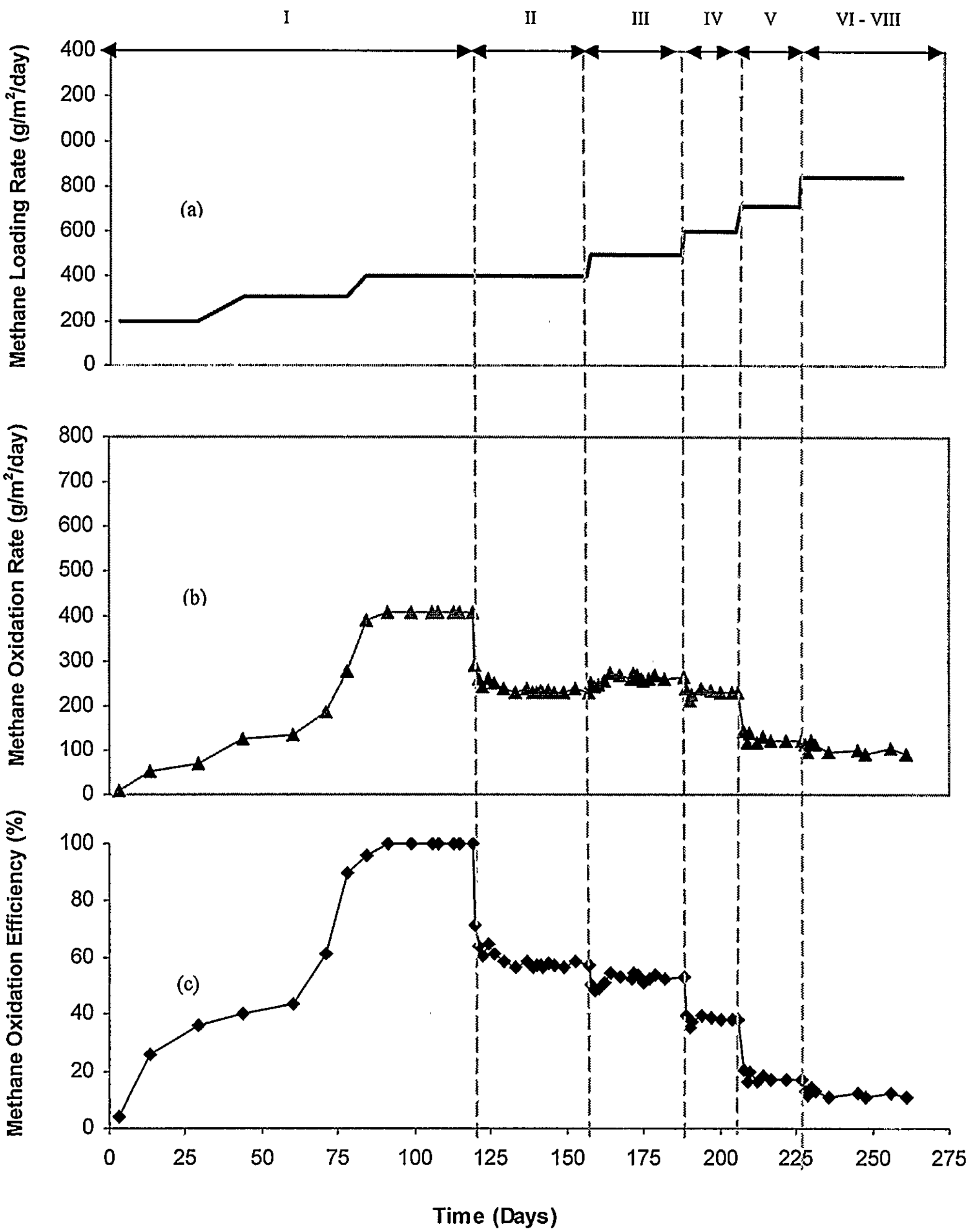

Figure 4.8: Actively aerated biofilter column results: Biofilter column E (Methane:Ethane: 5:4)
(a): Methane loading rate, (b): Methane oxidation rate, and (c): Methane oxidation efficiency in relation to time. (Note: Refer to Table 3.1 for information on methane loading rates at different stages)

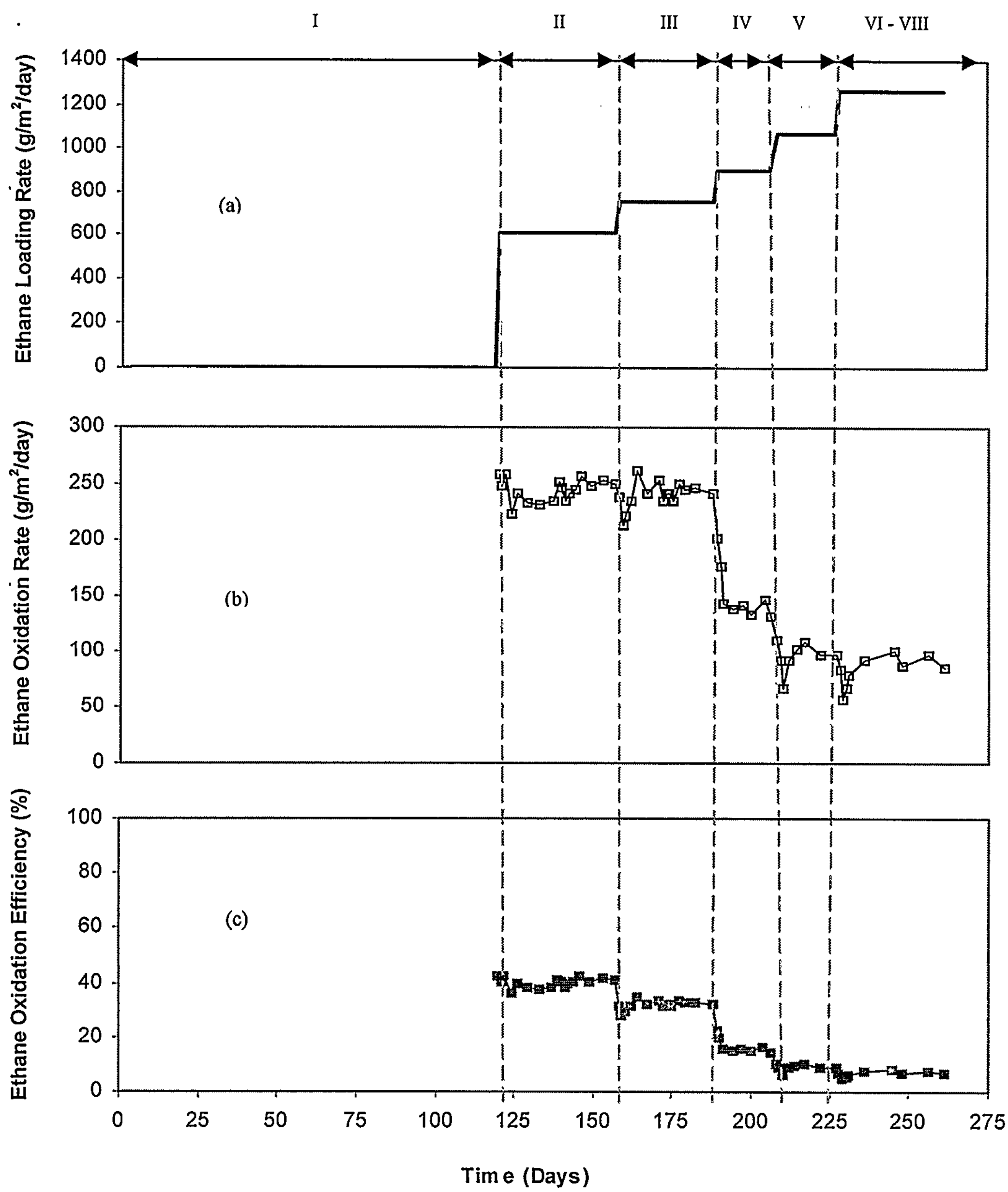

Figure 4.9: Actively aerated biofilter column results: Biofilter column E (Methane:Ethane = 5:4)
(a): Ethane loading rate, (b): Ethane oxidation rate, and (c): Ethane oxidation efficiency in relation to time. (Note: Refer to Table 3.1 for information on methane loading rates at different stages)

4.1.2.1 Analysis of methane and ethane oxidation efficiency results

Table 4.1 provides a summary of steady state oxidation efficiency results observed in biofilter columns fed with methane/ ethane mixtures.

Table 4.1: Methane and ethane oxidation efficiencies at different loading rates

Methane loading rate ($g/m^2/day$)	Biofilter Column B	Biofilter Column C		Biofilter Column D		Biofilter Column E	
	CH_4 (%)	CH_4 (%)	C_2H_6 %)	CH_4 %)	C_2H_6 (%)	CH_4 (%)	C_2H_6 (%)
	M:E=1:0	M:E=8:1		M:E=7:2		M:E=5:4	
406.9 (Stage II)	100.00	100.00	99.20	98.10	89.00	57.20	41.00
502.1 (Stage III)	100.00	99.10	95.20	91.10	82.20	53.10	32.20
601.7 (Stage IV)	100.00	96.10	86.20	85.30	66.10	38.10	15.20
711.7 (Stage V)	98.20	85.10	67.10	67.10	37.10	17.10	9.10
841.0 (Stage VI)	82.20	65.10	49.10	45.10	23.20	11.20	7.10
1001.7 (Stage VII)	41.82	30.89	27.73	18.17	18.08	N/A	N/A
1212.0 (Stage VIII)	33.27	23.94	21.92	15.08	13.97	N/A	N/A

Note: M:E = Methane: Ethane

In Stage I, all columns were fed with methane (methane loading rate of 406.9 $g/m^2/d$). The columns showed a steady state methane oxidation efficiency of 100%. In column B, the methane oxidation efficiency dropped from 100% to 98.2% in Stage V and reached a low of 33% in Stage VIII (1212$g/m^2/day$). In column C, the drop of methane oxidation efficiency was observed beyond 502.1 $g/m^2/day$ (Stage III) and reached a low of 24% at the methane loading rate of 1212 $g/m^2/day$ (Stage VIII).

The columns receiving high ethane concentrations behaved differently. In columns D and E, the oxidation efficiency decreased immediately after introducing ethane in Stage II. A significant reduction in methane oxidation efficiency from 100 to 57.2 % was recorded in column E. Reductions in ethane oxidation efficiency was observed at each increment in ethane loading rates for all columns.

The results revealed that inlet methane to ethane ratio of 8:1 and 7:2 has no effect on methane oxidation performance of biofilters below a methane loading rate of 406.9 g/m^2/day. The methane oxidation rate and oxidation efficiency as a function of methane loading rates (irrespective of ethane loading rates) for biofilter columns B to E are shown in Figures 4.10 and 4.11, respectively.

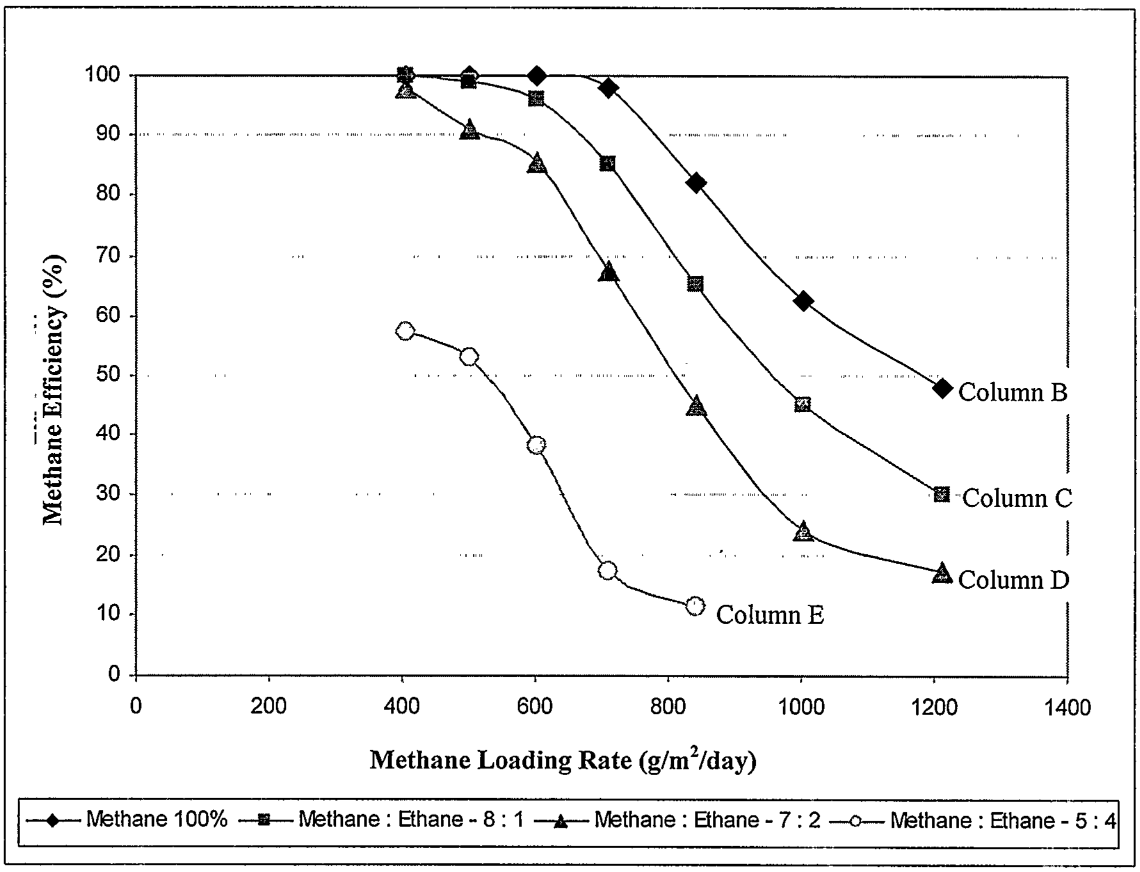

Figure 4.10: Methane oxidation efficiency profiles

Figure 4.11 shows a significant downward shift of oxidation rate curves when methane loading rate increased beyond 600 g/m^2/day. Different values of optimum methane oxidation were found for each biofilter column. This optimum values correspond to biofilter column maximum methane oxidation capacity. In this figure, optimum points between different methane to ethane loading ratios 1:0 and 5:4 w ere found by drawing a line connecting optimum points in each curve.

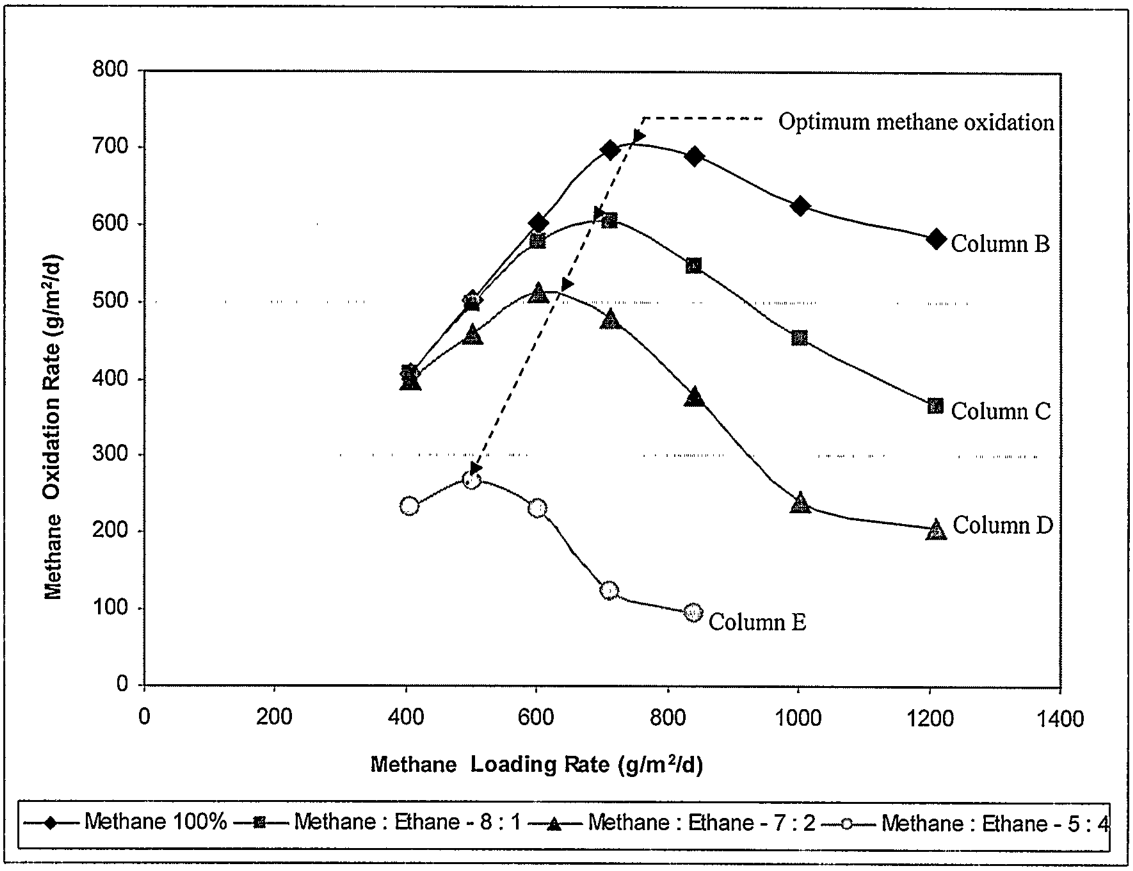

Figure 4.11: Methane oxidation rate variation in relation to methane loading rates – (For biofilter columns A-E)

4.1.2.2 Effect of VOCs on methane oxidation

Table 4.2 shows the overall methane oxidation rate reduction (in percentage) in methane-ethane loaded biofilter columns relative to performance in biofilter column fed with methane only (column B) over the different loading rates (Stage II to Stage VIII).

Table 4.2: Methane oxidation rate reduction in methane-ethane loaded biofilter columns (relative to methane loaded biofilter column B)

Methane Loading Rate ($g/m^2/day$)	Biofilter Column C	Biofilter Column D	Biofilter Column E
	CH_4 Oxidation Rate Reduction (%) relative to Biofilter Column B		
	M:E=8:1	M:E=7:2	M:E=5:4
406.9 (Stage II)	0.0	1.9	42.8
502.1 (Stage III)	0.9	8.9	46.9
601.7 (Stage IV)	3.9	14.7	61.9
711.7 (Stage V)	13.3	31.3	82.6
841.0 (Stage VI)	20.8	45.1	86.3
1001.7 (Stage VII)	27.8	61.6	N/A
1212.0 (Stage VIII)	37.5	64.5	N/A

Note: M:E = Methane:Ethane

The percentage methane oxidation reduction was calculated from:

$$\left(\frac{A_0 - B_0}{A_0}\right) = \left(\frac{X_0 - Y_0}{X_0}\right)$$

Where,

A_0 = Methane oxidation rate of methane loaded biofilter column B

B_0 = Methane oxidation rate of methane - ethane loaded biofilter columns

X_0 = Efficiency of methane loaded biofilter column B

Y_0 = Efficiency of methane - ethane loaded biofilter columns

Table 4.2 indicates that there was no reduction in methane oxidation when methane loading rate was 406.9 g/m^2/day and 601.7 g/m^2/day (for column C) and 406.9 g/m^2/day (for column D). This demonstrates negligible effect of ethane on methane oxidation at relatively low methane loading rates and methane to ethane ratios. However, a relatively high level of ethane affects methane oxidation. For example, the biofilter column E, which had a methane to ethane loading ratio of 5:4, showed a methane oxidation rate reduction of 86.3% at the methane loading rate of 841 g/m^2/day.

4.1.2.3 Ethane oxidation in biofilter columns

The ethane oxidation in methane-ethane fed biofilter columns showed identical oxidation patterns to those of methane oxidation. The ethane oxidation efficiencies of methane-ethane fed biofilter columns at different flow rates are shown in Figure 4.12. According to Figure 4.12, high ethane oxidation occurs (in the range of 65 to 100%) at low methane loading rates in the range of 406.9 g/m^2/day to 601.7 g/m^2/day, and for methane to ethane ratios of 8:1 and 7:2. However, less than 40% ethane oxidation was observed for the same flow rate range for the higher methane to ethane ratio of 5:4. In summary, high ethane oxidation at low loading rates and methane to ethane ratios and less ethane oxidation at high loading rates and ratios were observed.

The observation of high methane and ethane oxidation at low methane loading rates and ethane to methane ratios could be due to the presence of adequate methanotrophic colonies and co- metabolism of ethane. However, increased methane loading flow rates and methane to ethane ratios adversely affects methanotrophic activity and reduces ethane oxidation. Furthermore, when high flow rates are sent through biofilter columns, certain percentage of gas could pass through the biofilter column without degradation because of low retention time, resulting in a lower overall oxidation of ethane and methane.

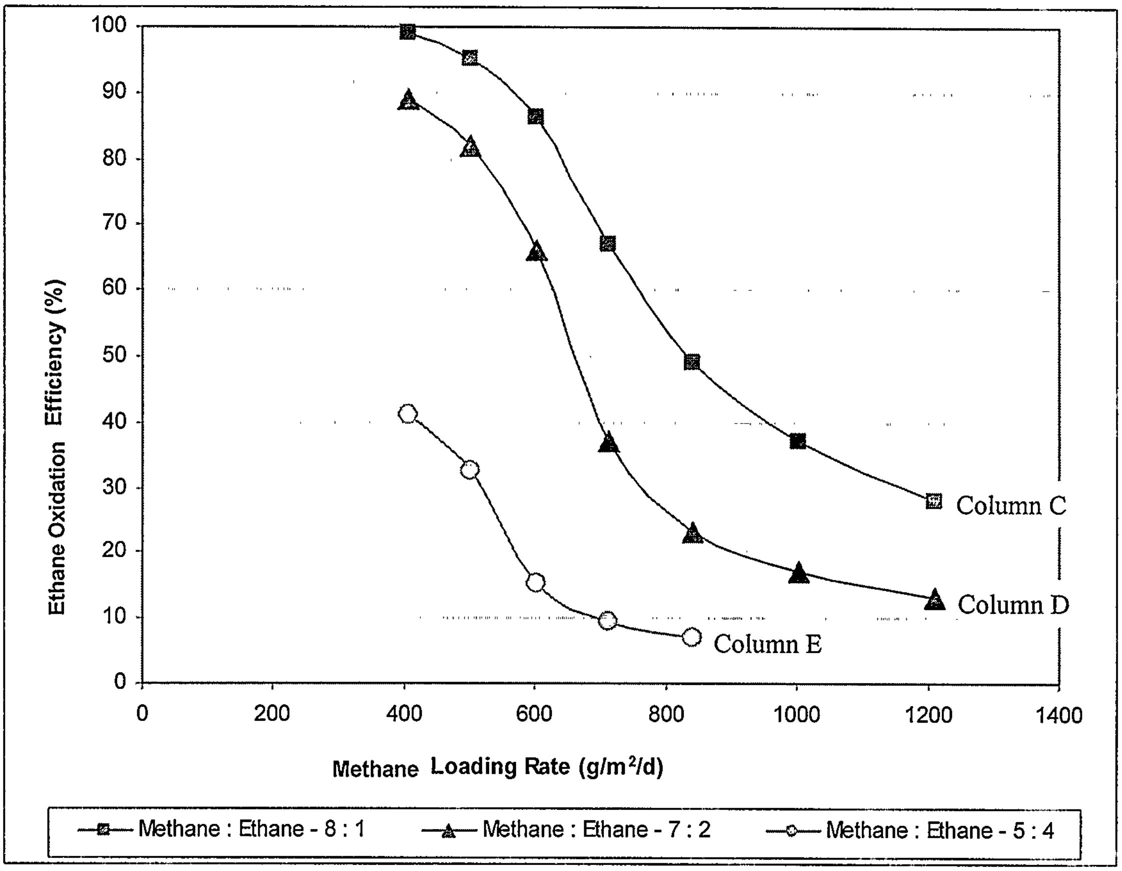

Figure 4.12: Ethane oxidation efficiency as a function of methane loading rates

4.1.3 Absolute methane oxidation Vs. Optimum methane oxidation

The absolute methane oxidation rate refers to the maximum methane oxidation rate at 100% methane oxidation. The optimum methane oxidation rate refers to the potential maximum methane oxidation rate irrespective of efficiency.

The methane oxidation rates and efficiencies as a function of methane loading rates for biofilter columns B to E are presented in Figures 4.13 to 4.16. A summary of optimum and absolute methane oxidation rate values observed for biofilter columns B to E are provided in Table 4.3. Evidently, the absolute methane oxidation rate showed a value of 680 g/m^2/day in column B, whereas the optimum methane oxidation rate was found to be 705 g/m^2/day, with a 96% efficiency.

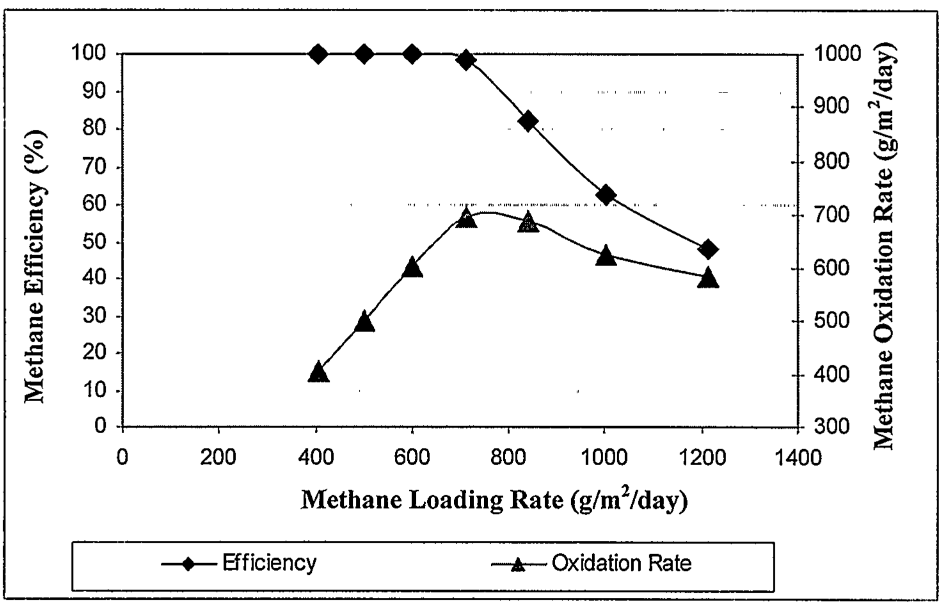

Figure 4.13: Methane oxidation rate and efficiency: Biofilter column B (Methane 100%)

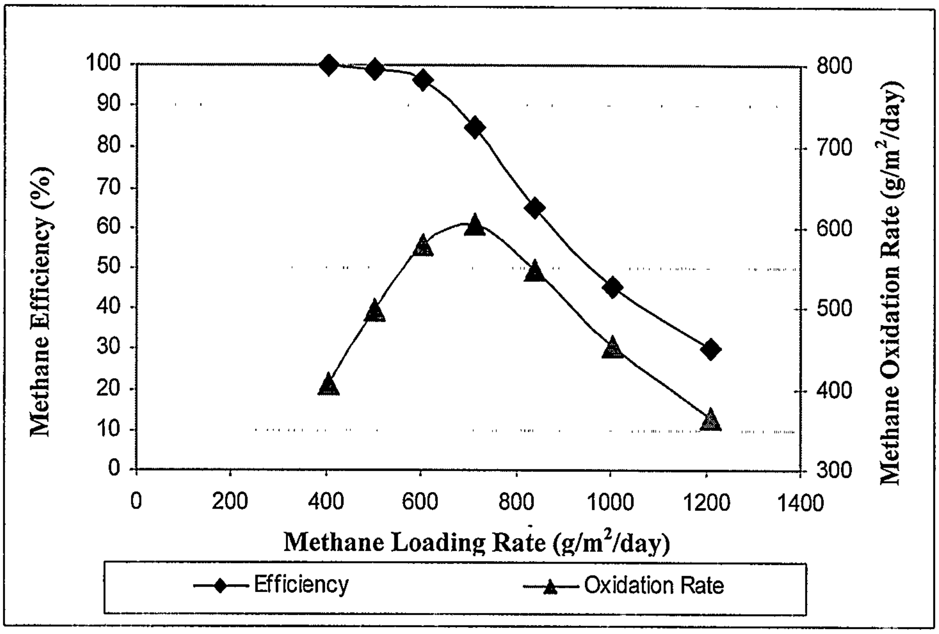

Figure 4.14: Methane – Ethane oxidation rate and efficiency – Biofilter column C (Methane: Ethane = 8:1)

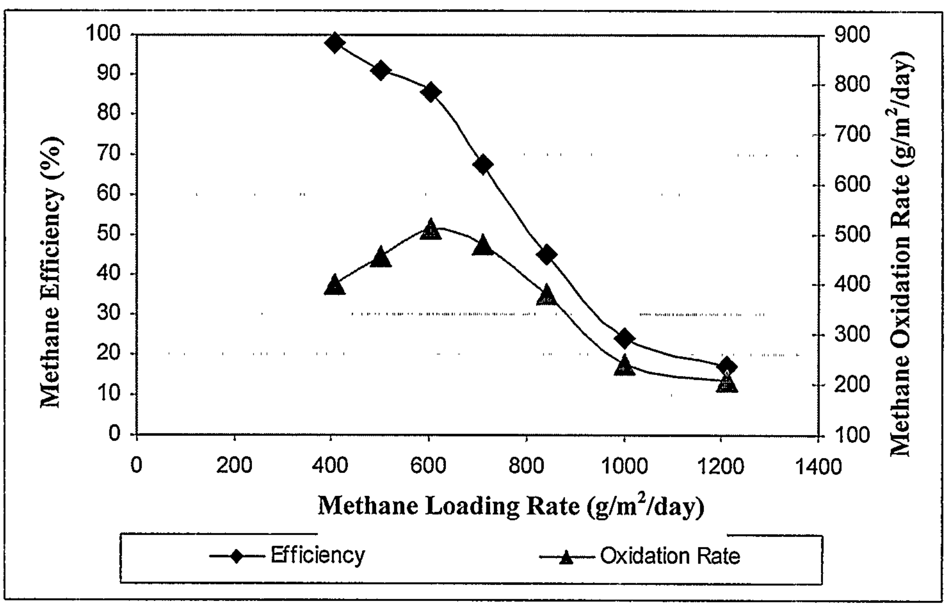

Figure 4.15: Methane – Ethane oxidation rate and efficiency – Biofilter column D (Methane: Ethane = 7:2)

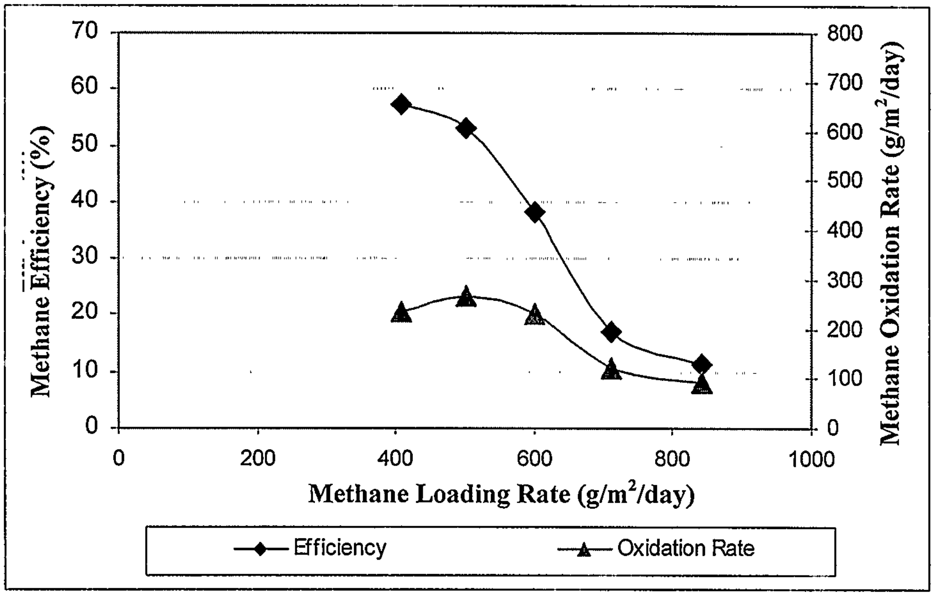

Figure 4.16: Methane – Ethane oxidation rate and efficiency – Biofilter column E (Methane: Ethane = 5:4)

Table 4.3: Optimum and Absolute methane oxidation rates for Columns B to E

	Biofilter Column B	**Biofilter Column C**	**Biofilter Column D**	**Biofilter Column E**
	M:E=1:0	**M:E=8:1**	**M:E=7:2**	**M:E=5:4**
Optimum methane oxidation rate (g/m^2/day)	705	610	515	268
Efficiency at optimum oxidation rate (%)	96	85	82	53
Highest possible methane oxidation rate with absolute efficiency (g/m^2/day)	680	450	<399	<233

Note: M:E=Methane:Ethane

4.1.4 Analysis of biofilter column performance: practical implications

In this section, more detailed explanations of biofilter performance are provided. This analysis would allow extrapolation of results to field scale application of biofilters.

In the previous section, the performance of biofilter columns were discussed with respect to the methane loading rate. However, when considering mixtures of gases, it is more useful to express the loading rates in terms of total VOCs ($g/m^2/day$), and biofilter column performance with respect to total VOC removal rate ($g/m^2/day$). The methane and ethane oxidation rates as a function of total VOCs loading rates are shown in Figure 4.17 and Figure 4.18, respectively. Simultaneous oxidation of methane and ethane took place in columns fed with methane and ethane mixtures.

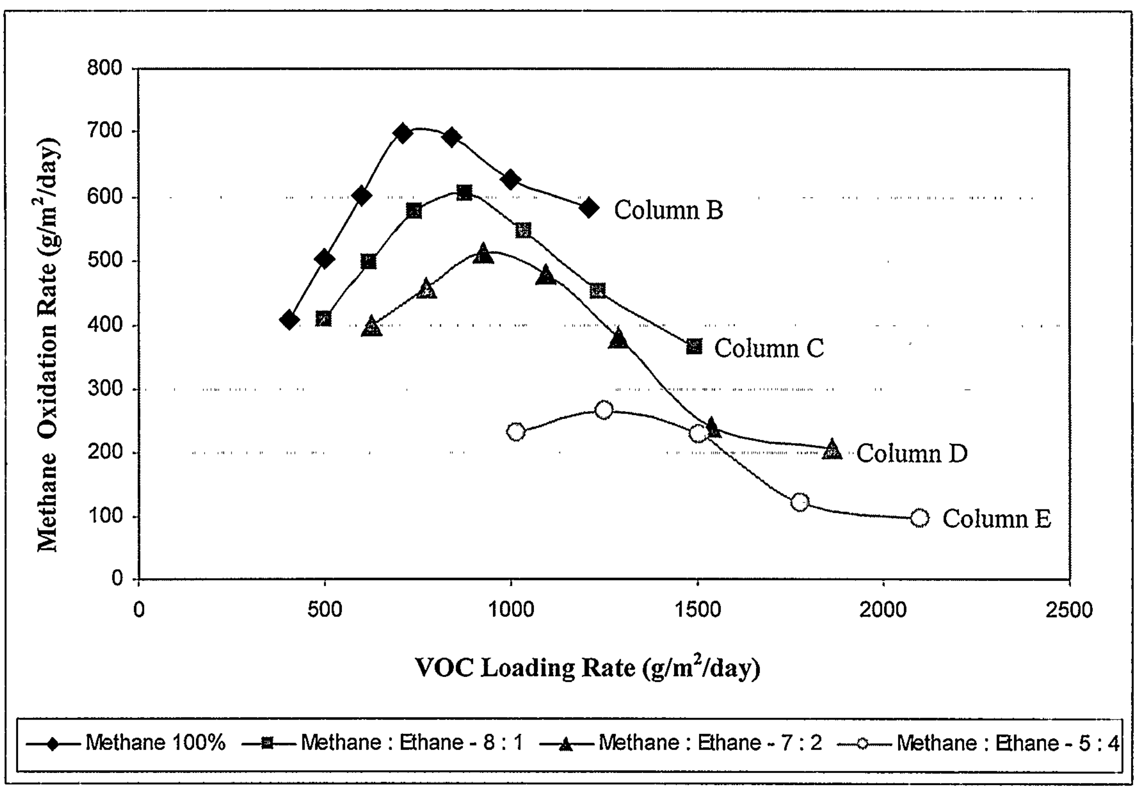

Figure 4.17: Methane oxidation rate in relation to total VOC loading rate

Low methane oxidation was observed in column fed with high methane to ethane ratios. On the other hand, ethane oxidation was high in columns fed with low methane to ethane ratio.

The cumulative oxidation rate of VOCs (both methane and ethane) as a function of total VOC loading rates is shown in Figure 4.19. The VOC oxidation values were within a close range for all columns within the VOC loading rates of 1300 g/m^2/day. The results indicate that any VOC loadings with methane to ethane loading ratios higher than 7:2, oxidize almost the same amount of VOC irrespective of the type of VOC. The optimum VOC oxidation for columns A, B and C were also found within a very close range between 705 g/m^2/day to 725 g/m^2/day. Therefore, in a full field scale application, one could expect to treat 705g/day of VOC (with methane to ethane ratio higher than 7:2) in a 1m×1m (surface area) actively aerated biofilter with soil as a medium.

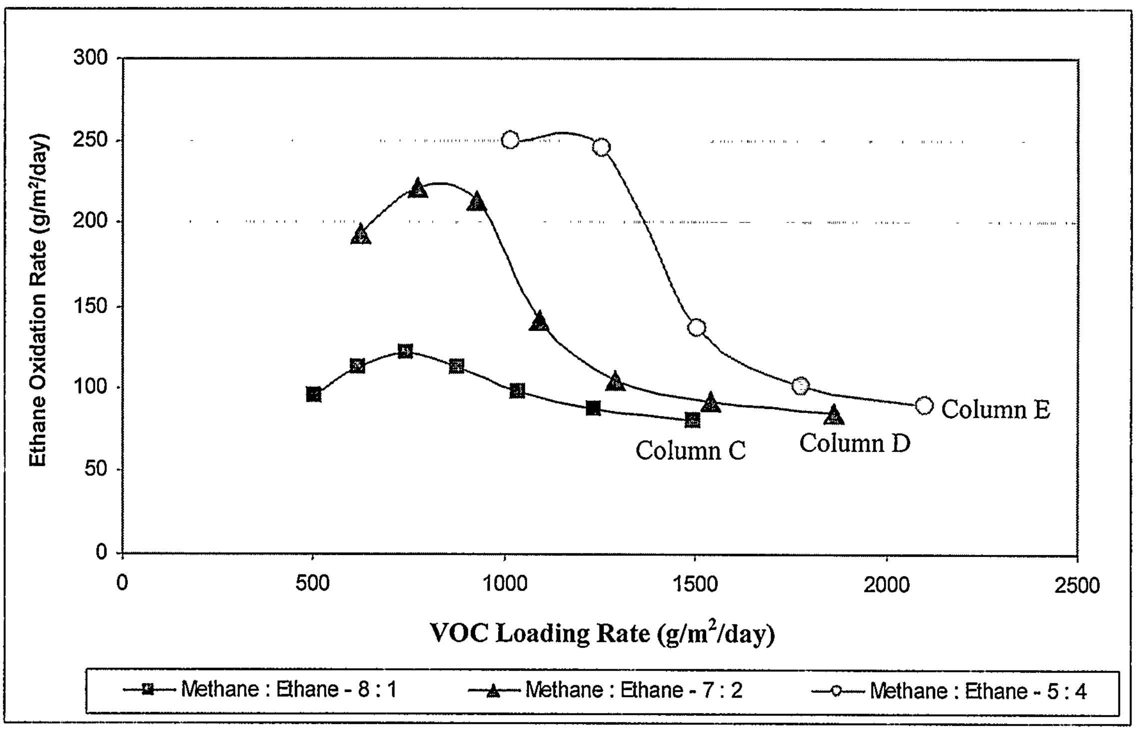

Figure 4.18: Ethane oxidation rate in relation to total VOC loading rate

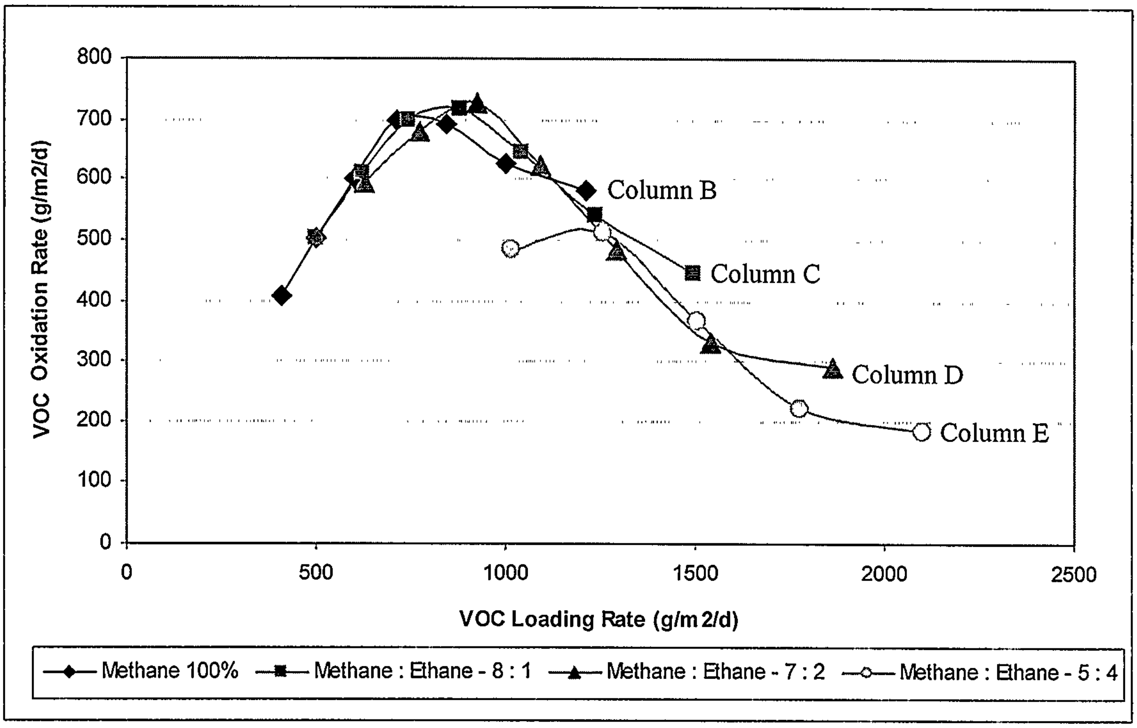

Figure 4.19: Total VOC oxidation in relation to total VOC loading rate

4.2 Biofilter column behaviour as a function of depth

4.2.1 Gas profiles along the biofilter column

The data and relevant figures of gas profiles along the biofilter column depth are presented in appendix C. Sample figures of gas profiles for methane and methane-ethane loaded biofilter columns are presented and explained below.

4.2.1.1 Methane loaded biofilter columns

Figure 4.20 shows the gas concentration profiles corresponding to the biofilter column A for a methane loading rate of 406.9 g/m^2/day. At a height of 250 mm, a change in gradient of gas (oxygen, carbon dioxide and methane) profile was observed. Also, a very low methane oxidation rate was recorded at the bottom of the biofilter column (i.e. from 0 to 100 mm). From height 250 mm to 500 mm, a sharp increase in carbon dioxide concentration and decrease in oxygen concentration were noticed. Once the methane loading rate was increased to 711.7 g/m^2/day, a different pattern of concentration profile was noticed (Figure 4.21).

The methane, oxygen, and carbon dioxide concentration profiles indicate that the methane oxidation zone lies within the biofilter column height from 100 mm to 500 mm. Similar observations were found in other biofilter columns that were fed with low rates of VOCs. However, a decrease in methane oxidation zone thickness was observed when the methane loading rate was increased from 711.7 g/m^2/day to 841 g/m^2/day.

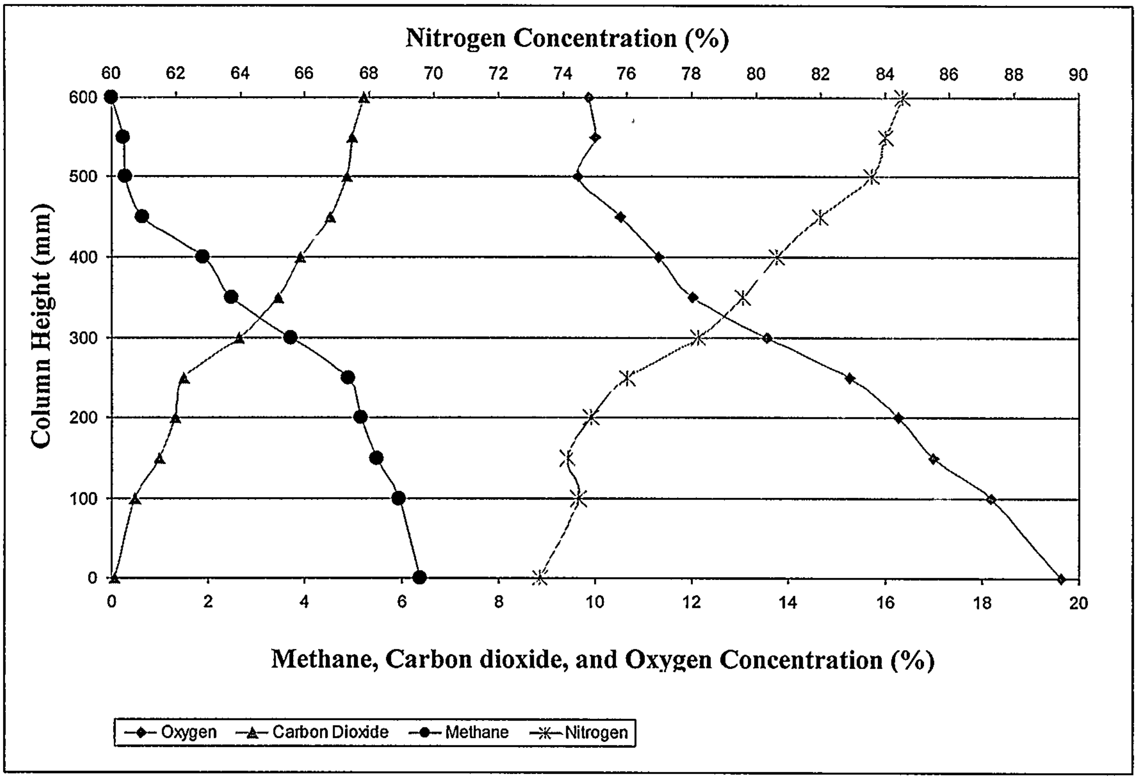

Figure 4.20: Gas profile – Biofilter column A (Stage II, Methane loading rate: 406.9g/m^2/d)

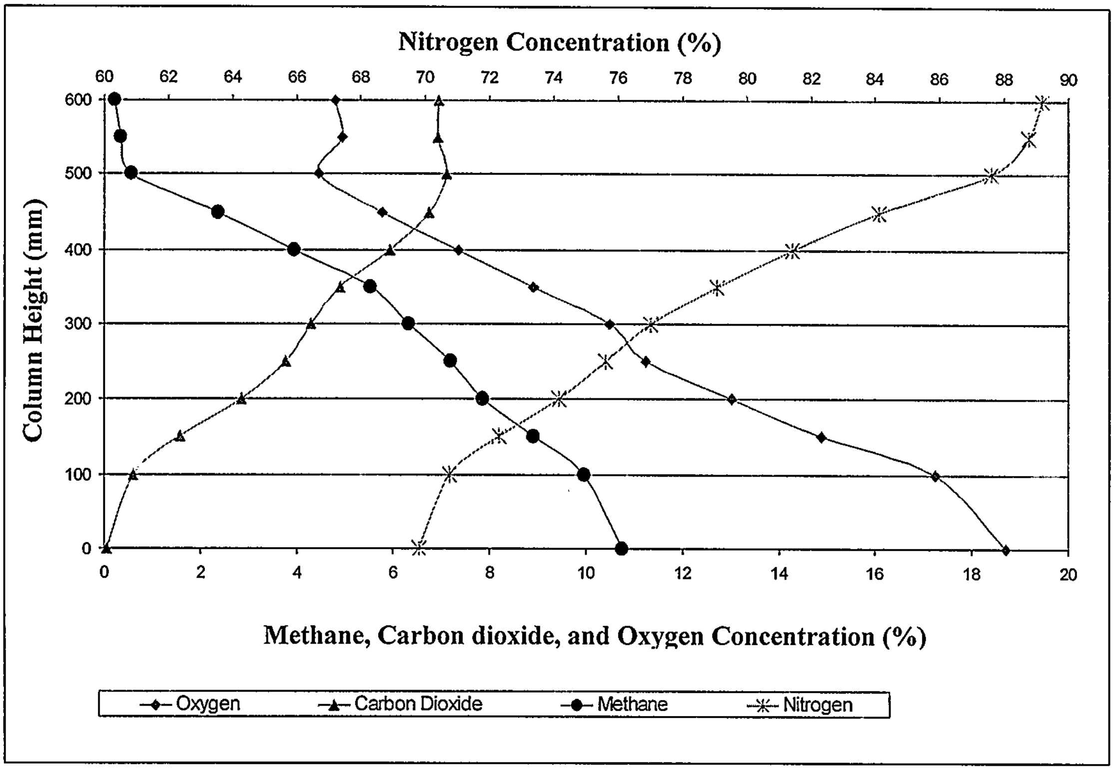

Figure 4.21: Gas profile- Biofilter column A (Stage V: Methane loading rate 711.7 g/m²/d)

Gas concentration profiles of columns A and B demonstrated similar patterns at the methane loading rate range of 606.9 and 711.7 g/m²/d. Both columns exhibited an active methane oxidation zone between 200mm to 500mm (distance measured from the bottom of the column).

4.2.1.2 Columns loaded with methane and ethane mixtures

Methane-ethane loaded biofilter columns also exhibited similar gas profile patterns as observed in methane loaded columns. In addition, the profiles showed that ethane oxidation also takes place in the same zones of methane oxidation (refer to Appendix C).

4.2.2 Active methane oxidation zone behaviour as a function of depth

The behaviour of the active methane oxidation zone was investigated from methane concentration profiles obtained at different loading rates and methane to ethane ratios. As explained before, the active zone of methane oxidation in biofilter column was observed between 100 mm to 500 mm height, with two distinct methane concentration gradients at low methane loading and with a mild concentration gradient at high loading rates. The inactive zone at the top layer of the biofilter column increased and moved downward when methane loading rate was increased. Similar methane profiles in methane-ethane loaded biofilter columns at high loading rates and methane to ethane ratios were observed. Figures 4.22 and 4.23 shows the location of the active methane oxidation zones at various methane loading rates in biofilter column C with methane to ethane ratio of 8:1 and in biofilter column E with methane to ethane ratio of 5:4, respectively.

Downward movement of maximum oxidation zone with increasing loading rate and ethane to methane loading ratios is possibly caused by downward movement of methanotrophs to mid soil layers having favourable environment for methane oxidation. Such movement is possible due to high moisture production at top soil layers at initial stages. In addition, nutrient depletion and relatively low oxygen concentration at the top soil layers could also be possible causes.

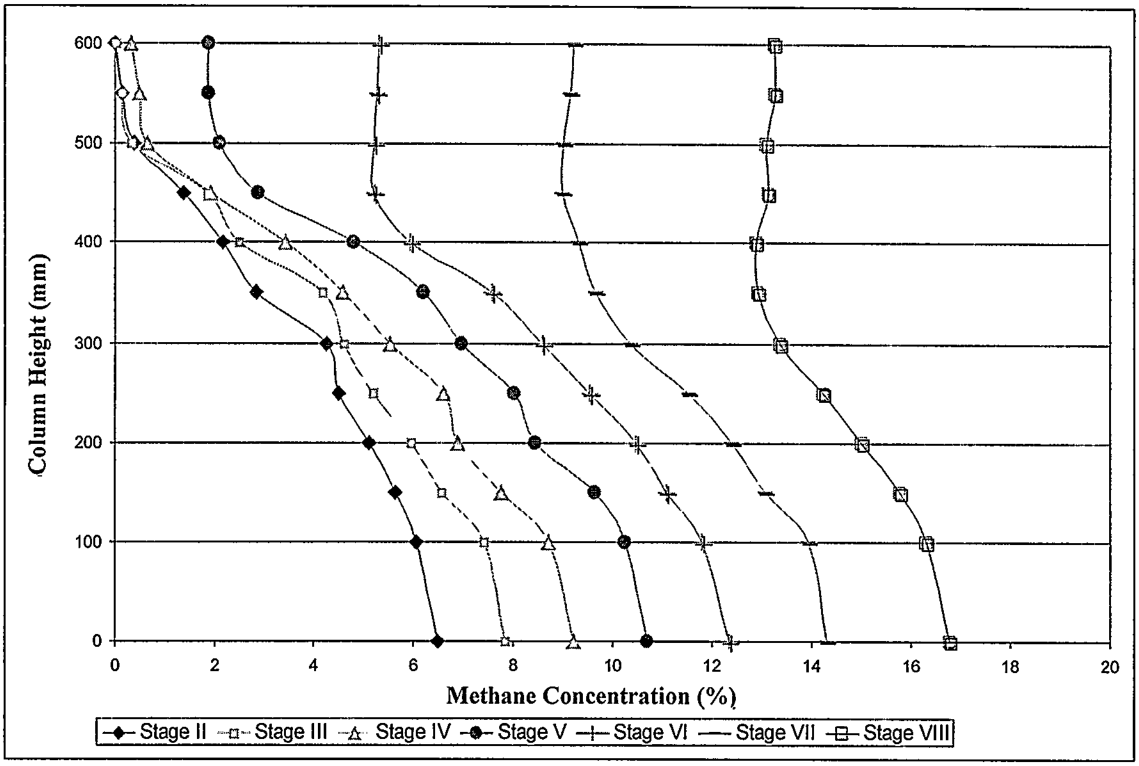

Figure 4.22: Methane concentration depth profile – Biofilter column C

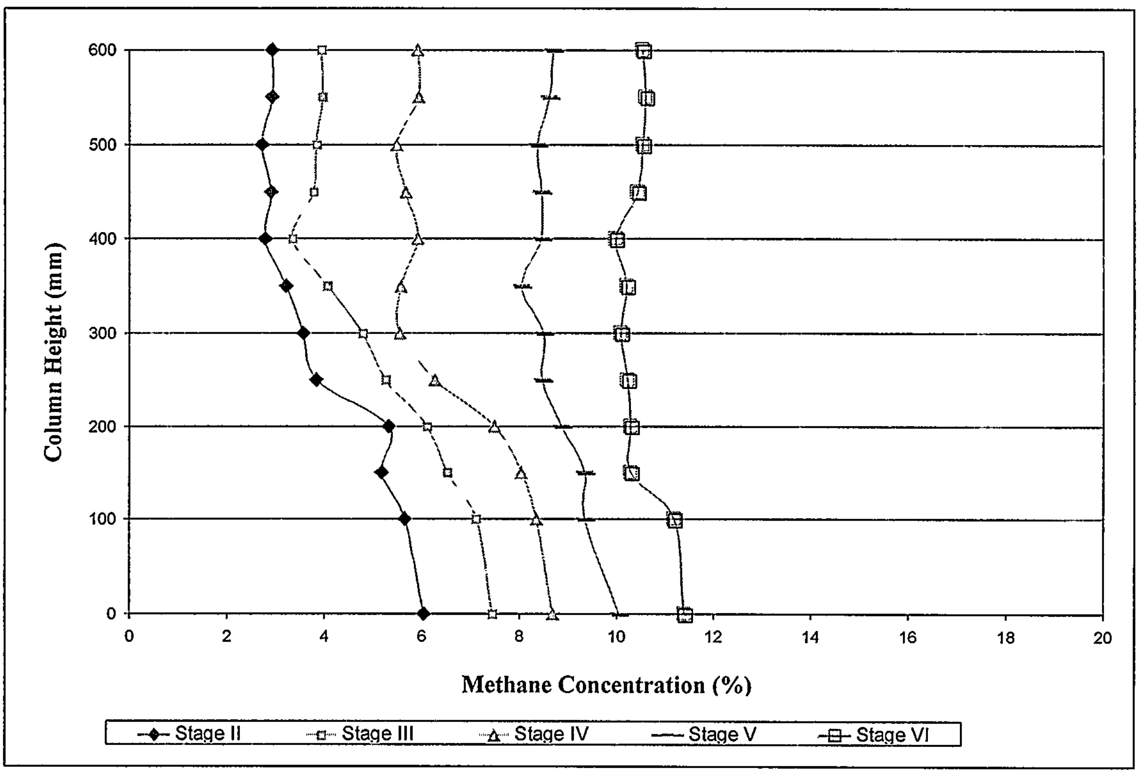

Figure 4.23: Methane concentration depth profile- Biofilter column E

4.2.3 Moisture content variation along the depth of Biofilter column

The moisture content (MC) profiles for methane and methane-ethane loaded biofilter columns are shown in Figure 4.24 and Figure 4.25, respectively. The results are based on soil samples (from 10 cm intervals along the columns) obtained during dismantling of biofilter columns. Experimental data for all columns and associated calculations are presented in Appendix E.

At the commencement of biofilter column experiments, moisture content was maintained at 18% throughout the depth of all columns. However, at the end of experimental runs, all columns exhibited significant increase in moisture content. Results indicated that the methane loaded biofilter columns had higher moisture contents than methane-ethane loaded biofilter columns. In general, higher moisture contents were observed in the zones corresponding to high methane oxidation rates. For example, as indicated in Figure 4.24, in biofilter column A, high moisture contents of 50 to 60% were recorded between the heights 200 mm and 400 mm. High moisture contents results from moisture production by methanotrophs and water vapour carried by the gas flow. Close to the surface, or between heights of 500mm and 600 mm, moisture contents were lower. This could be due to the high air flow rates, resulting in upward moisture movement along the soil biofilter columns. In addition, low moisture contents were observed at the bottom layer between 0 mm and 100 mm.

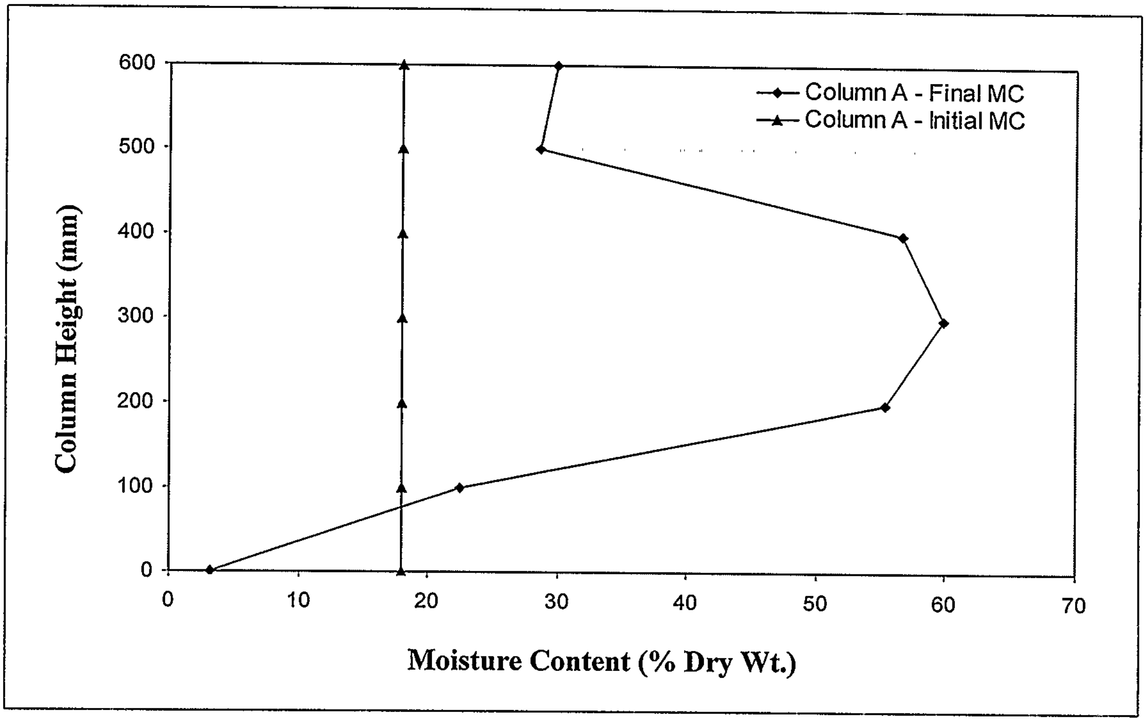

Figure 4.24: Moisture content profile of Biofilter column A

Figure 4.25 shows moisture content profiles of methane and methane-ethane loaded biofilter columns, B and C. In general, biofilter column B showed higher moisture contents compared to biofilter column C. For example, the maximum moisture content in Column B was 55% (corresponding to a column height of 60cm). Whereas, the maximum moisture content in column C was 44% (corresponding to a column height of 60cm).

Both these values are higher than the optimum moisture content of 18% reported in literature indicating a possible cause of reduction in methane oxidation with time. Both biofilter columns showed high moisture content zones between 100 mm and 400 mm, which also corresponded to the zone of high methane oxidation. This result also matched with results obtained from batch experiment as well as organic carbon and gas concentration depth profiles (discussed in more detail in section 4.2.5).

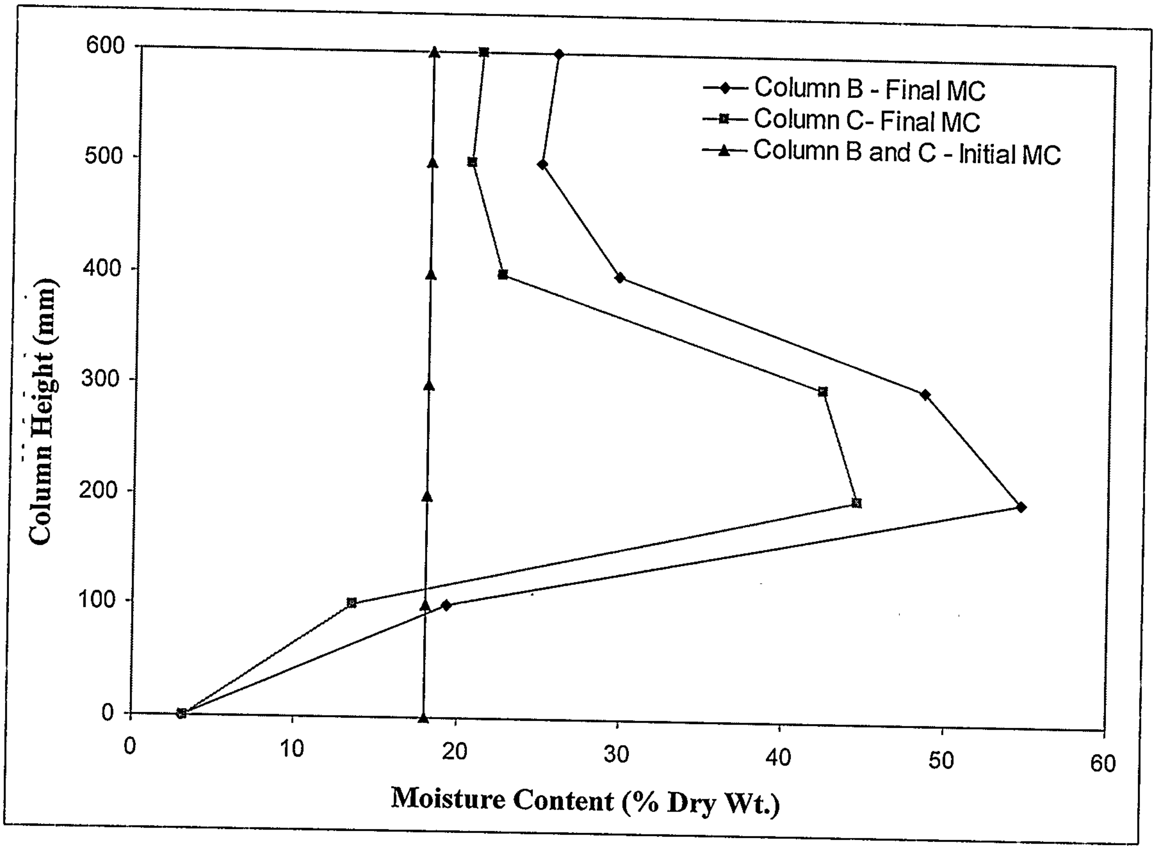

Figure 4.25: Moisture content analysis of Biofilter columns B and C

4.2.4 Organic carbon profile along depth of biofilter column

Organic carbon content in soil indicates the presence of high concentrations of microorganisms, and indirectly indicates the areas with high methane oxidation activity. For example, in biofilter column A, maximum methane oxidation height was observed between 150 mm and 500 mm, whereas the highest value of organic carbon contents was recorded at a height of about 400mm (Figure 4.26).

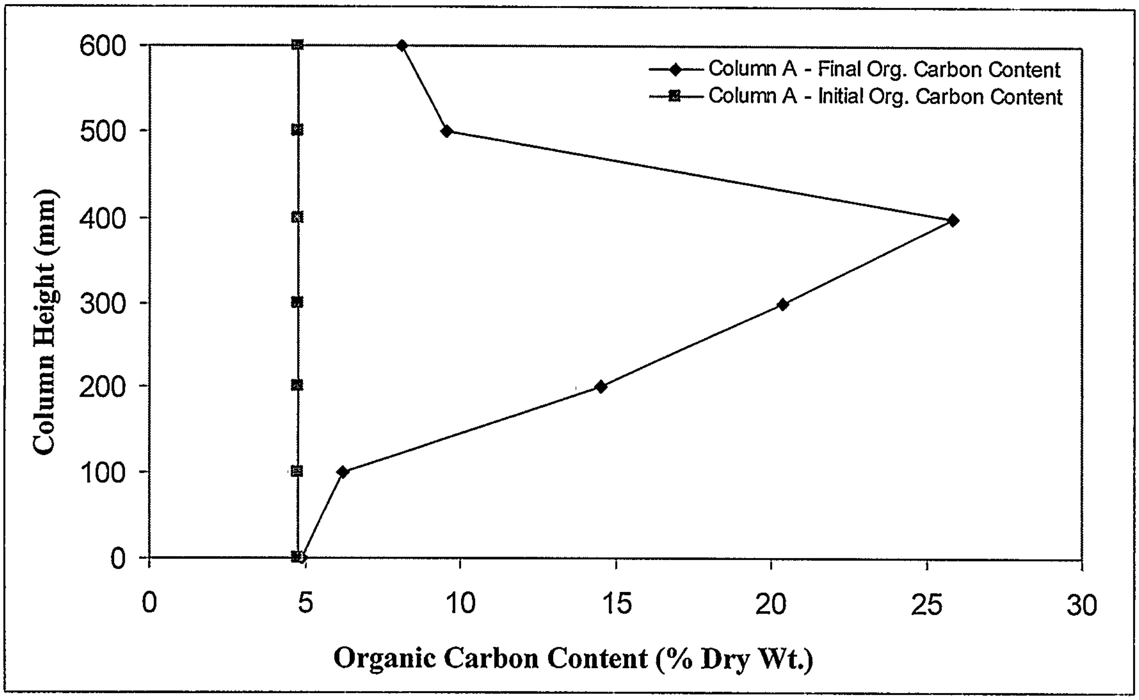

Figure 4.26: Organic carbon contents of biofilter column A.

Organic carbon content of biofilter columns B and C are shown in Figure 4.27. Although both curves show slightly higher values of organic carbon content were observed in biofilter column B compared to biofilter column A. Since organic carbon content is an indication of microbial mass, this observation implies that there was less microbial growth in biofilter column fed with ethane (in column C) in addition to methane compared to methane fed column (in column B). If ethane contributes to the cell division, comparative higher organic carbon contents could have observed in biofilter column B. Several researchers have concluded that ethane, in the presence of methane, will get oxidized, but does not contribute to the cell division of methanotrophs (Leadbetter and Foster, 1958, 1959, 1960 (as cited by Dalton and Stirling, 1982); Berthe-corti and Fetzner, 2002). Organic carbon depth profile indicates the presence of maximum methane oxidation zones, as evidenced by V_{max}, moisture, and gas concentration depth profiles. Organic carbon content in columns B and C occurred at a column height of 400 mm. Incidently, column A's highest organic carbon content was observed at the same height.

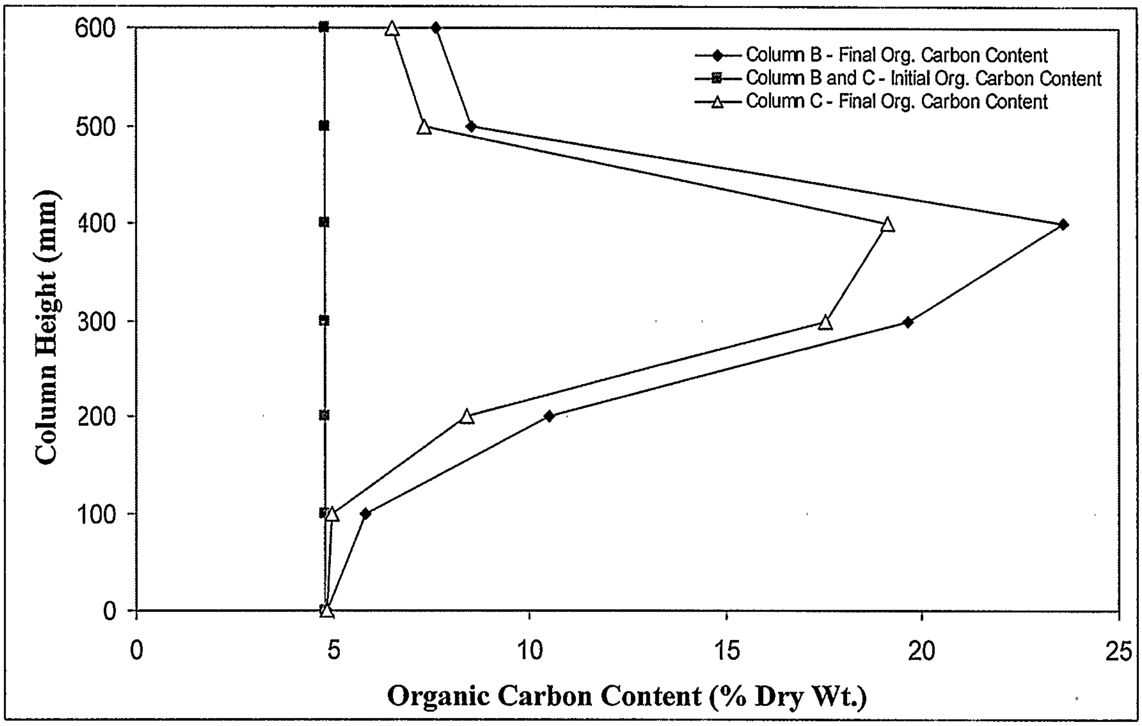

Figure 4.27: Organic carbon content analysis of biofilter columns B and C

4.3 Variation of maximum methane oxidation rate along the depth

4.3.1 Batch experiments

Batch incubation studies were performed on soil samples collected during the biofilter column dismantling process. These batch incubation experiments provide information on areas within biofilter column with high methane oxidation activity. The samples were collected from column A, B and C, every 10cm along the depth of the column.

Similar to observations of Kightley et al. (1995) and Czepiel et al. (1996), the head space methane drawdown curves obtained from the batch incubation experiments demonstrated pseudo-zero order kinetics with a down ward sloping linear curve. Figure 4.28 represents biofilter column A methane drawdown data corresponding to a soil sample obtained at a filter height of 500mm. A similar form of methane drawdown curves was observed in all incubated soil samples used for the batch incubation experiments. These curves are included in Appendix D.

The $V_{max.}$ depth profiles of biofilter column A presented in figure 4.29 indicates that the highest V_{max} occurs at a column height of about 300mm. The magnitude of $V_{max.}$ at this location is 8150 nmol/h/g dry soil. The V_{max} values of passively aerated biofilter columns are in the range of 5.6 to 3400 nmol/h/g dry soil (Bogner et al., 1997). Since methanotrophs are aerobic microorganisms that utilize oxygen to convert methane to carbon dioxide, high V_{max} values could be expected with a properly designed actively aerated biofilter.

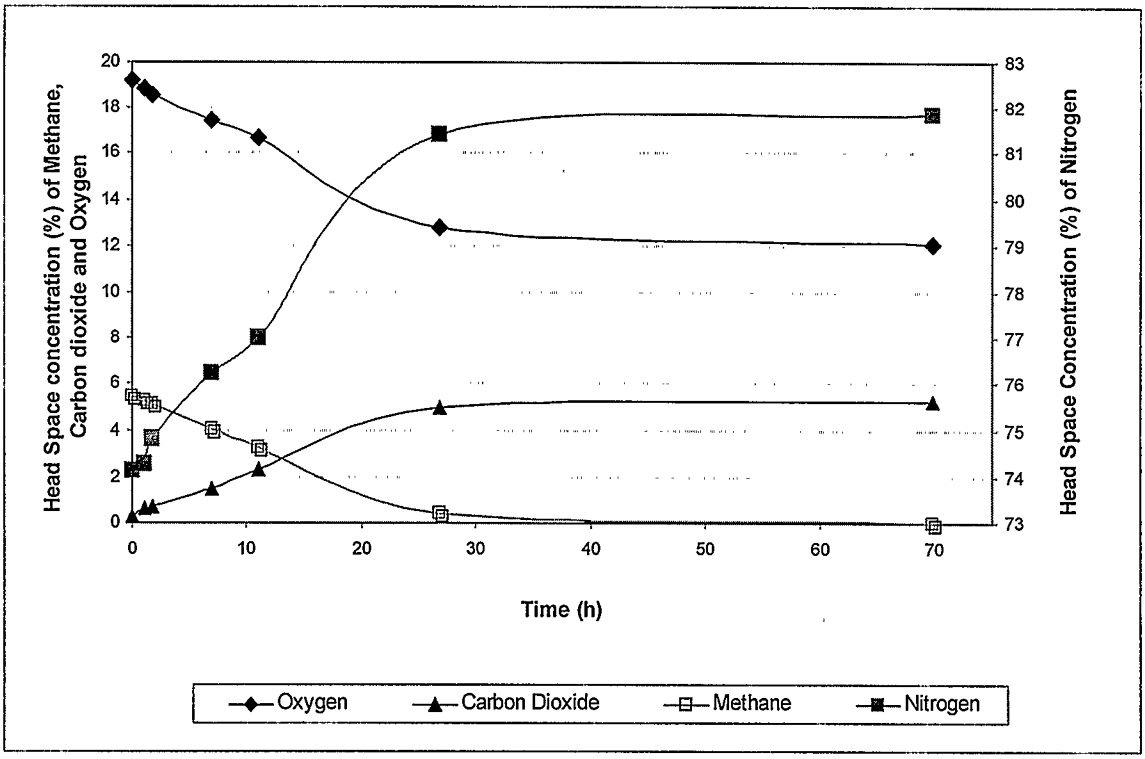

Figure 4.28: Methane drawdown curve for biofilter column A at column height 500mm

Active aeration enhances methanotrophic growth resulting in high methane oxidation. The only other study that reported V_{max} values higher than observed in this research was by Nozhevnikova et al. (1993). They observed a high V_{max} of 25000 nmol/h/g dry soil. This anomaly cannot be explained because of lack of research details in their study.

Further analysis of batch experimental results shows methane oxidation kinetics with high activity (V_{max} in the range of 7500 to 8200 nmol/h/g dry soil) in the depth levels ranging from 200mm to 400mm. However, low V_{max} (in the range of 0 to 1500 nmol/h/g dry soil) was observed in top and near the bottom soil layers. For example, a zero V_{max} value was observed at the bottom of the column. This may be due to inadequate moisture in soils which result in low or no methane degradation. Low moisture content at the bottom of the biofilter column could be due to the bulk moisture movement along the biofilter column resulting from high air loading rates (94.4 ml/min.).

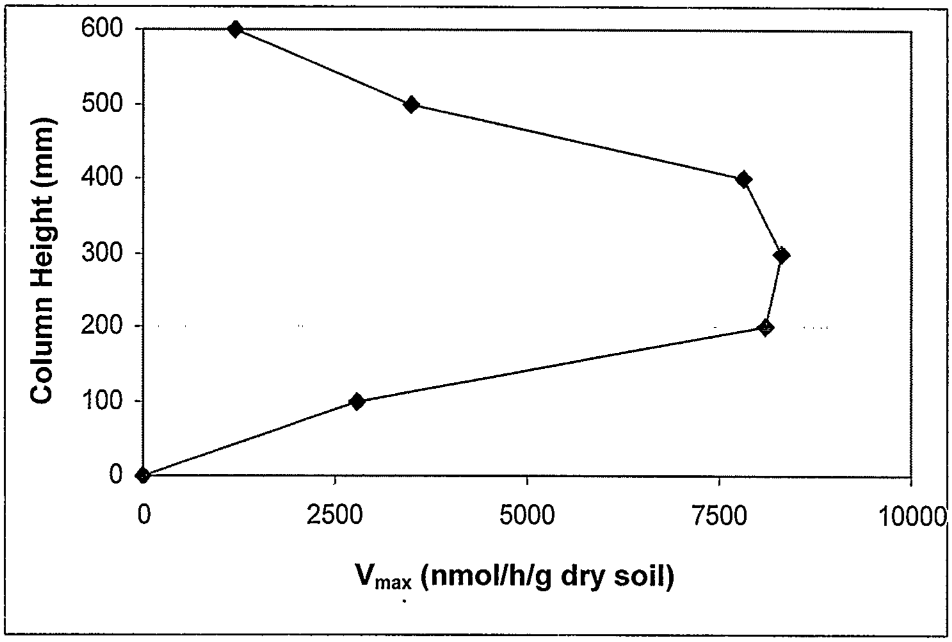

Figure 4.29: V max depth profile for biofilter column A

The effect of non-methane volatile organics (i.e. ethane) on V_{max} along the depth of biofilter columns B and C are presented in figures 4.30 and 4.31, respectively. In column B, high V_{max} values were observed between the column heights of 100 mm and 300 mm. The highest V_{max} of 7600 nmol/h/g dry soil in biofilter column B was recorded at the column height of about 200 mm. However, at the same height, the biofilter column C demonstrated a relatively low microbial activity, with a V_{max} of only 2310 nmol/h/g dry soil. The V_{max} profiles of biofilter columns B and C show that there is a significant reduction of microbial activities when methane is mixed with ethane at high loading rates.

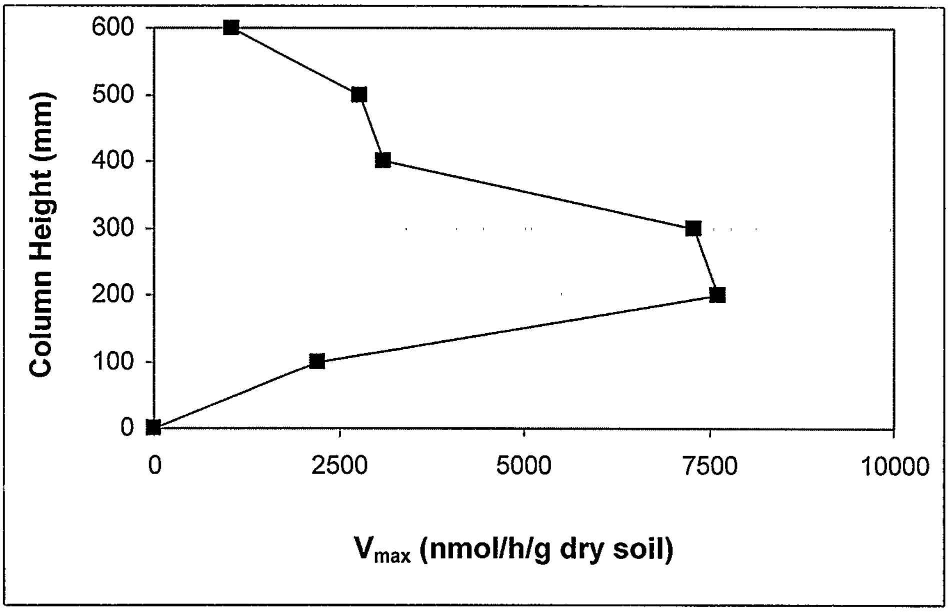

Figure 4.30: V_{max} depth profiles for column B

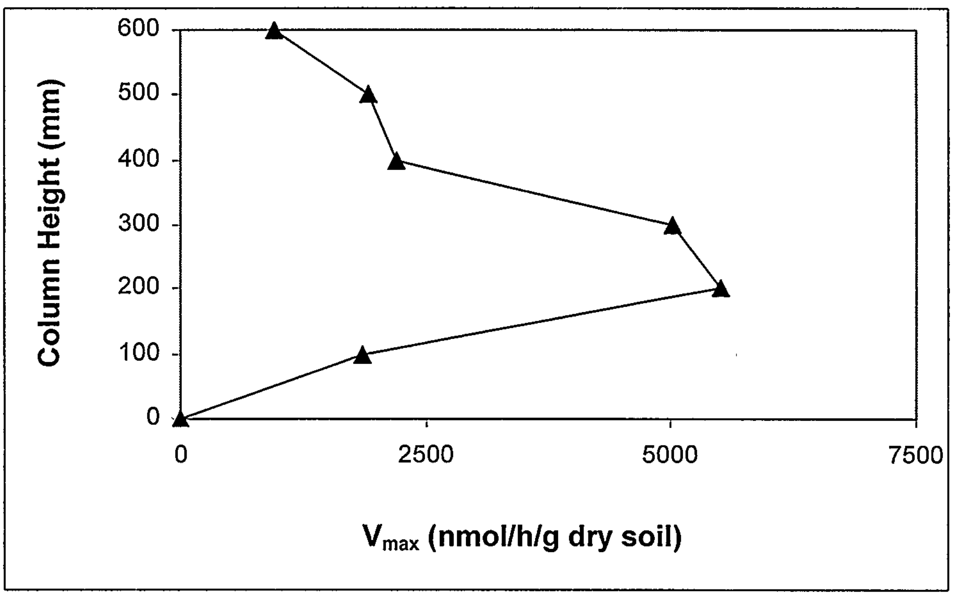

Figure 4.31: V_{max} depth profiles for column C

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions:

In this study, actively aerated biofilter columns were operated to investigate the methane oxidation performance as well as the effect of non-methane VOCs on biofilter column performance. Ethane was used as the surrogate non-methane VOC. The experiments were conducted with various combinations of methane loading rates and methane to ethane ratios.

A maximum methane oxidation rate of 705 $g/m^2/day$ was observed in actively aerated biofilter columns, which is 200-300% higher than those reported for passively aerated biofilter columns. Methane – ethane loaded biofilter columns showed a relatively low optimum oxidation rates than that of biofilter columns loaded with methane alone. The column subjected to higher loading rates exhibited low steady state methane oxidation efficiency. This study confirmed that methane oxidation is not affected in the presence of ethane at very low VOC - methane application rates and ratios. Therefore, it could be concluded that low ethane flow rates can be easily treated with an actively aerated soil biofilter.

Moisture and carbon depth profiles confirmed the existence of a maximum methane oxidation zone that was identified from the gas concentration depth profiles. Furthermore, gas concentration depth profiles demonstrated the adoptability of properly designed actively aerated biofilter in field scale to address variable gas flow rates.

Similar to Leadbetter and Foster (1959, 1960) and Dalton and Stirling (1982), organic carbon content profile obtained in this research work showed that cell multiplication of methanotrophs in presence of ethane may be negligible. However, to support this fact, further microbial research on methane-ethane interactions are needed.

Soil-moisture response experiments showed low oxidation rates and moisture contents at the bottom layers of biofilter column. In active aerated systems, low moisture contents are expected at the filter bottom since the moisture moves upwards along with the gas in the biofilter column. Therefore, in such conditions, less soil methanotrophic activity exists resulting low methane oxidation at the bottom layer of the biofilter column. Similar conclusions were made by Whalen and Reeburgh (1996), Visvanathan et al. (1999), Stein (2000), De Visscher (2001), Park et al. (2002).

The maximum methane oxidation rate (V_{max}) determined for actively aerated biofilter columns was higher compared to the values reported in literature for passively aerated biofilters. A highest maximum methane oxidation rate (V_{max}) of 8150 nmol/h/g dry soil was found in methane loaded actively aerated biofilter column.

5.2 Recommendations:

A series biofilter arrangement is proposed for the treatment of solution gas in field scale. The first biofilter is to remove H_2S in solution gas, followed by treatment of VOCs in the second filter. Design criteria governing the second biofilter corresponds to the research study explained in thesis work. Research on solution gas H_2S shall be conducted before selection of a suitable material and study of biofilter column performance could be finalized. In addition, a study on methane oxidation potential at variable air application flow rates is also recommended. Research results could incorporate in a mathematical model to design actively aerated biofilter for optimum methane oxidation. etc.

REFERENCES

Alberta Energy and Utilities Board, (2004a). "Crude Bitumen Batteries: Monthly Flaring, Venting and Production of Data [CD-ROM].

Alberta Energy and Utilities Board, (2004b). Statistical series 2004-60B: Upstream Petroleum Industry Flaring Report. Calgary, Canada: EUB Press.

Amaral, J. A., Ren, T. and Knowles, R. (1995). "Atmospheric methane consumption by forest soils and extracted bacteria at different pH values." Applied Environmental Microbiology, 64, 2397-2402.

Alexander, M. (1994). "Biodegradation and bioremediation." San Diego, CA: Academic Press.

Apel, W. A., Barnes, J. M., and Barrett, K. B. (1995), "Biofiltration of nitrogen oxides from fuel combustion gas streams" Proceedings, Air and Waste Management Association 88th Annual Meeting & Exhibition.

Bender, M. and Conrad, R. (1994). "Methane oxidation activity in various soils and freshwater sediments: Occurrence, characteristics, vertical profiles and distribution on grain size distribution." Journal of Geophysical Research, 99, 16531-16540.

Bender, M. and Conrad, R. (1995). "Effect of CH_4 concentrations and soil conditions on the induction of CH_4 oxidation activity." Soil Biology and Biochemistry, 27, 1517-1527.

Berthe-corti, L. and Fetzner, S. (2002). "Bacterial Metabolism of n-alkanes and amonnia under oxic, suboxic, and anoxic conditions." Acta Biotechnology, 22(3/4), pp. 299-336.

Boeckx, P., and Van Cleemput, O. (1996). "Methane oxidation in neutral landfill cover soil: influence of moisture content, temperature, and nitrogen turnover." Journal of Environmental Quality, 25, 178-183.

Boeckx, P., Van Cleemput, O. & Villaravo, I. (1996)."Methane oxidation in soils with different textures and land use". Nutrient Cycling in Agroecosystems, 49,(1/3), 91-95.

Boeckx, P., Van Cleemput, O. and Villaravo, I. (1996)."Methane emission from a landfill and methane oxidizing capacity of its covering soil." Soil Biology Biochemistry, 28, 1397-1405.

Bogner, J. E., Medows, M., and Czepiel, P. (1997). " Fluxes of methane between landfills and the atmosphere: natural and engineered controls." Soil use of Management, 13, 268-277.

Burrows, K. J., Cornosh, A., Scott, D., and Higgins, I. G. (1984). " Substrate specifities of the soluble and particulate methane monooxygenese of Methylosinus trichoporium O B3b", Journal of General Microbiology, 130, 3327-3333.

Castro, M. S., Melillo J. M., Steudler, P. A. and Chapman, J. W. (1994). "Soil moisture as a predictor of methane uptake by temperate forest soils." Canadian Journal of Forest Research, 24, 1805-1810.

Castro, M. S., Steudler, P. A. Melillo J. M., Aber, J. D. and Bowden, R. D. (1995). " Factors controlling atmospheric methane consumption by temperate forest soils." Global Biogeochemical Cycles, 9, 1-10.

Colby, J., Stirling, D. I., and Dalton, H. (1977). "The soluble methane mono-oxygenese of Methlococcus capsulatus(Bath). Its ability to oxygenate n-alkanes, n-alkenes, ethers, and alicyclic, aromatic, and heterocyclic compounds." Biochemistry Journal, 165, 395-402.

Croft, B. and Emberton, R. (1989). "Landfill gas and the oxidation of methane in soil." The Technical Aspects of Controlled Waste Management, Oxfordshire, UK: Department of Environment, Wastes Technical Division, Research Report No. CWM 049/89.

Czepiel, P. M., Mosher, B., Crill, P. M., Harris R.C (1996). "Quantifying the effect of oxidation on landfill methane emissions." Journal of Geophysical Research, 101, 16721-16729.

Dalton, H. (1980). "Oxidation of hydrocarbons by methane monooxygenases from a variety of microbes." Advanced Applied Microbiology, 26, 71-87.

Dalton, H. & Stirling, D. I. (1982). "Co-metabolism" Philosophical Transactions of Royal Society of London, B297, 481-496.

Dalton, H., Higgins, I.J. (1987). "Physiology and biochemistry of methylotrophic bacteria." In, H.W. Van Verseveld, J.A. Duine, (Eds.), Microbial growth on Cl compounds (pp. 89-94). Dordrecht: Nijhhoff press.

De Visscher, A. (2001). " Modelling of diffusion and reaction of CH_4 and N_2O in soils". Doctoral dissertation, Gent University, Belgium.

De Visscher, A., Schippers, M. & Van Cleempt, O. (2001). Short-term kinetic response of enhanced methane oxidation in landfill cover soils to environmental factors. Biology & Fertility of Soils, 33, 231-237.

De Visscher, A., Thomas, D., Boecks, P. & Van Cleempt, O. (1999). "Methane oxidation in simulated landfill cover soil environments." Environmental Science & Technology., 33, 1854-1859.

Donner, L. & V. Ramanathan, (1980). " Methane and Nitrous Oxide: Their effects on the terrestrial climate". Journal of Atmospheric Science, 37, 119-124.

Figueroa, R. A. (1993). "Methane oxidation in Landfill top soil." Proceedings: Fourth International Landfill Symposium, CISA, S. Margherita di Paula, Cagliari, Italy. 1, 701-715.

Fox, B. G., Froland, W. A., Dege, & J. E., Lipscomb, J. D. (1990). " Methane monooxygenase from Methlosinus trichosportium OB3b: mechanistic and environmental applications." Journal of Biology Chemistry, 264, 10023-10033.

Graham, D. W., Chaudhary, J. A., Hanson, R. S. & Arnold, R. G. (1993). "Factors effecting competition between type I and type II methanotrophs in two-organism, continuous flow reactors." Microbial Ecology, 25, 1-17.

Green, J. and Dalton, H. (1986). "Steady-state kinetic analysis of soluble methane monooxygenese from Methylococcus capsulatus (Bath)." Biochemical Journal, 236,155-162.

Gullage, J. and Schimel, J. P. (1998). " Low-concentration kinetics of atmospheric CH_4 oxidation in soil and mechanism of NH_4^+ inhibition." Applied Environmental Microbiology, 64, 4291-4298.

Hanson, R. S., and Hanson, T. E. (1996). "Methanotropic bacteria." Microbiological Reviews, 60(2), 439-471.

Hilger, H.A., Wollum, A.G. and Barlaz, M.A. (2000). "Landfill methane oxidation response to vegetation, fertilization, and liming." Journal of Environmental Quality, 29, 1, 324-334.

Holford, M.R. and Hettiaratchi, J.P. (1998). An evaluation of potential technologies for reducing solution gas flaring in Alberta: Report to clean air strategic alliance (CSCA) flaring project team, University of Calgary, Calgary, Alberta, Canada, pp 31.

Humer, M., and Lechner, P. (1999). "Alternative approach to the elimination of greenhouse gases from old landfills." Waste Management, 17, 443-452.

Hutsch, B. W., Webster, C.P. & Powlson, D. S. (1994). " Methane oxidation in soil as affected by land use, soil pH, and N fertilization." Soil Biology Biochemistry, 26, 1613-1622.

International Energy Agency (IEA) (2003). "IEA Statistics: Carbon dioxide emissions from fuel combustion, 1971- 2001." Paris: OECD/IEA.

International Panel on Climate Change (IPCC) (2001)." Climate change 2001: The scientific Basis." Cambridge and New York: Cambridge University Press.

International Panel on Climate Change (IPCC) (2000)."Emissions scenarios." New York: Cambridge University Press.

International Panel on Climate Change (IPCC) (1996)."Climate change 1995: The science of climate change." New York: Cambridge University Press.

Johnson, M.R., Kostiuk, L.W., and Spangelo J. L. (2001). "A characterization of solution gas flaring in Alberta." Journal of Air & Waste Management Association 51, 1167-1177.

Keller, M., Kaplan, W. A. and Wofsy S. C. (1986). "Emission of N_2O, CH_4, and CO_2 from tropical forest soils." Journal of Geophysical Research, 91, 11791-11802.

Keller, M., and Reiners, W.A. (1994). "Soil-atmosphere exchange of nitrous oxide, and methane under secondary succession of pasture to forest in the Atlantic lowlands of Costa Rica." Global Biogeochemical Cycles, 8, 399-409.

Kightley, D., Nedwell, D.B., and Cooper, M. (1995). Capacity for methane oxidation in landfill cover soils measured in laboratory-scale soil microcosms. Applied and Environmental Microbiology, 61, 592-601.

Koschorreck, M. and Conrad, R. (1993). Oxidation of at atmospheric methane in soil: Measurement in the field, in soil cores and in soil samples." Global Biogeochemical Cycles, 7, 109-121.

Kosky, K. F., and Neff, C. R. (1988). "Innovative biological degradation system for hydrocarbon treatment." Proceedings, NWWA/API Petroleum Hydro-carbons and Organic Chemicals in Ground water Conference, 8, 56-61.

LaGrega, M. D., Buckingham, P. L., and Jeffery, C. E. (1994). "Hazardous waste management." New York: McGraw-Hill, Inc.

Lambe, T. W., and Whitman, R. V. (1979). "Soil mechanics, SI version." John Wiley and Sons Inc., pp. 40-43.

Leadbetter, E. R., and Foster, J. W. (1958). " Studies on some methane-utilizing bacteria" Archives Microbiology, 30, 91-118.

Leadbetter, E. R., and Foster, J. W. (1959). "Oxidation products formed from gaseous alkanes by the bacterium Pseudomonas methanica." Archives of Biochemistry Biophysical, 82, 491-492.

Leadbetter, E. R., and Foster, J. W. (1960). "Bacterial oxidation of gaseous alkanes." Archives of Microbiology, 35, 92-104.

Leadbetter, E. R., and Foster, J. W. (1962). "Bacterial oxidation of gaseous alkanes." Archives of Microbiology, 35, 92-104.

Leak, D. J., and Dalton, H. (1986). "Growth yields of methanotrophs." A theoretical analysis, Applied Microbiology Biotechnology, 23, 477-481.

Leson, G. and Winer, A. M. (1991). "Biofilteration: an innovative air pollution control technology for VOC emissions." Journal of Air Waste Management Association (Aug.), 41(8), 1045-1054.

Lessard, R., Rochette, P., Topp, E., Pattey E., Desjardens, R. L. and Beaumont, G. (1994). " Methane and carbon dioxide fluxes from poorly drained adjacent cultivated and forest sites." Canadian Journal of Soil Science, 74, 139-146.

Mancinelli, R. L. (1995). "The regulation of methane oxidation in soil." Annual Review of Microbiology, 49, 581-605.

Marsh, R. (1992). " Biofiltration history, theoretical model and practice." North Western Branch Papers, Institution of Chemical Engineers, 3, 13, 1-14.

Mosier, A. R., Klemedtsson, L. K., Sommerfeld R.A. and Musselman, R. C. (1993). "Methane and nitrous oxide flux in Wyoming substrate meadow." Global Geochemical Cycles, 7, 771-784.

Mosier, A., Scimel, D., Valentine, D., Broson, K., and Parton, W. (1991). "Methane and nitrous oxide fluxes in native, fertilized and cultivated grasslands." Nature, 350, 330-332.

Mueller, J.C. (1998). "Biofilteration of gases – a mature technology for control of wide range of air pollutants." Vancouver, B. C., Canada: British Columbia Research Corporation.

Nelson, D.W. and Sommers, L.E. (1996). Total carbon, organic carbon, and organic matter. In D.L. Sparks and J.M. Bartels (Eds.), Methods of Soil Analysis, Part 3, Chemical methods–SSSA Book Series no. 5, (pp. 961-1010). Maidison, Wisconsin, U.S.A: Soil Science Society of America, Inc. and American Society of Agronomy, Inc.

Nesbit, S.P.B. (1992). "A laboratory study of factors influencing methane uptake by soils." Agriculture, ecosystem and Environment, 41, 39-54.

Nozhevnikova, A., Lifshitz, A.B., Lebedev, V.S. and Zavarzin, G.A. (1993). "Emission of methane into the atmosphere from landfills in the former USSR." Chesosphere, 26, 401-417.

Park, S., Brown, K.W., and Thomas, J.C., (2002). "The effect of various environmental and design parameters on methane oxidation in a model biofilter." Waste Management & Research, 20, 434-444.

Pokhrel, D. (1998). "Microbial methane oxidation studies in laboratory scale experiments." Master of Engineering thesis, Asian Institute of Technology, Bangkok, Thailand.

Reynolds, T.D., and Richards, P.A., (1996). "Unit operations and processes in environmental engineering." (2nd ed.). Boston: PWS Publishing Company.

Rozenzweig, A. C., Fredrick, C. A., Lippard, and S. J., Nordlund, P. (1993). "Crystal structure of a bacterial nonheme iron hydroxylase that catalyzes the biological oxidation of methane." Nature, 366, 537-543.

Stanley, S. H., Prior, S. D., Leak, D. J. and Dalton, H. (1983). "Copper stress underlies the fundamental change in intercellular location of methane monooxygenase in methane oxidizing organisms: studies in batch and continuous cultures." Biotechnology Letters, 5, 487-492.

Stein, V. B., and Hettiaratchi, J. P. A. (2001). "Methane oxidation in three Alberta soils: Infuence of soil parameters and methane flux rates." Environmental Technology, 22, 101-111.

Stein, V.B. (2000). "Methane oxidation in soils as a tool for reducing greenhouse gas emissions." Master of Science thesis, The University of Calgary, Calgary, Alberta, Canada.

Steudler, P. A., Bowden, R. D., Melillo, J. M. and Aber J. D. (1989). "Influence of N fertilization on CH_4 uptake in temperate forest soils." Nature, 341, 314-316.

Strosher, M. (1996). Investigations of flare gas emissions in Alberta: Final report to Environment Canada Conservation and Protection, Alberta Energy and Utilities Board, and Canadian Association of Petroleum Producers. Calgary, Canada: Alberta Research Council.

Swanson, W. J., and Loehr, R. C. (1997). "Biofilteration: Fundamentals, design and operations principles, and applications." Journal of Environmental Engineering, 123(6), 538-546.

The World Bank (2004), "Public policy for the private sector: A regulatory frame work and incentives for gas utilization." Note number 279. Retrieved from http://rru.worldbank.org/PublicPolicyJournal.

U.S. EPA (2004). Inventory of U.S Greenhouse Gas Emissions and Sinks: 1990-2002. USA EPA/30/R/04/003.

Visvanathan, C., Pokhrel, D., Cheimchaisri, W., Hettiaratchi, J.P.A. and Wu, J.S. (1999) "Methanptrophic activities in trophical landfill cover soils: effects of temperature, moisture content and methane concentration." Waste Management & Research, 17(4) 313-323.

Whalen, S. C., Reeburgh, W. and Sandbeck, K. (1990). "Rapid methane oxidation in a landfill cover soil." Applied and Environmental Microbiology, 56(11), 3405-3411.

Whalen, S. C., Reeburgh, W. S. and Kiser, K. S. (1991). "Methane consumption and emission by taiga." Global Biogeochemical Cycles, 5, 261-273.

Whalen, S.C. and Reeburgh, W. S. (1996). " Moisture and temperature sensitivity of CH_4 oxidation in boreal soils." Soil Biology Biochemistry, 28, 1271-1281.

Wuebbles, D. J. and Hayhoe, K. (2000). "Atmospheric methane: Trends and impacts. In Ham, J.V., Baede, A.P.M., Meyer, L.A., and Ybema, R. (Eds.). Non-Carbon dioxide Greenhouse Gases: Scientific Understanding, Control And Implementation, proceedings of the second international symposium, Netherlands (pp. 30-35). Netherlands: Kluwer academic publishers.

APPENDIX A: SIEVE AND HYDROMETER ANALYSIS DATA AND CALCULATIONS

Sieve Analysis Results

Experiment 1:

Sieve #	Wt. Retained	Cum. Wt.	Cum. WT. %	% Finer	Sieve size (mm)
2.5mm	25.93	25.93	14.78	85.22	2.5
10	1.01	26.94	15.35	84.65	2.0
20	9.02	35.96	20.49	79.51	0.840
40	16.01	51.97	29.62	70.38	0.425
50	19.56	71.53	40.76	59.24	0.300
100	28.05	99.58	56.75	43.25	0.150
200	34.34	133.92	76.32	23.68	0.074
Pan	41.56	175.48	100.00	0	

Soil wt. = 175.48g

Experiment 2:

Sieve #	Wt. Retained	Cum. Wt.	Cum. WT. %	% Finer	Sieve size (mm)
2.5mm	22.12	22.12	12.63	87.37	2.5
10	1.52	23.64	13.50	86.50	2.0
20	8.81	32.45	18.53	81.47	0.840
40	16.85	49.3	28.15	71.85	0.425
50	19.23	68.53	39.13	60.87	0.300
100	28.68	97.21	55.51	44.49	0.150
200	35.23	132.44	75.63	24.37	0.074
Pan	42.68	175.12	100.00	0	

Soil wt. = 175.12g

Experiment 3:

Sieve #	Wt. Retained	Cum. Wt.	Cum. WT. %	% Finer	Sieve size (mm)
2.5mm	21.23	21.23	12.13	87.87	2.5
10	1.68	22.91	13.09	86.91	2.0
20	8.85	31.76	18.15	81.85	0.840
40	16.25	48.01	27.43	72.57	0.425
50	20.1	68.11	38.92	61.08	0.300
100	28.65	96.76	55.29	44.71	0.150
200	37.25	134.01	76.57	23.43	0.074
Pan	41	175.01	100.00	0	

Soil wt. = 175.01g

Hydrometer Analysis Results

Experiment 1:

Soil Wt. = 46.7g

Time(min)	Hydrometer Reading	Percent finer	Diameter(mm)
0.5	40	73.98	0.052681
1	31	54.48	0.041429
2	23	37.15	0.031691
4	21	32.82	0.022813
8	20	30.65	0.016272
15	18	26.32	0.012086
30	17	24.16	0.008617
60	16	21.99	0.006143
120	15	19.82	0.004379
240	14	17.66	0.003121
480	13	15.49	0.002224
1440	11	11.16	0.001304
2880	10	8.99	0.000929

Experiment 2:

Soil Wt. = 48.0g

Time(min)	Hydrometer Reading	Percent finer	Diameter(mm)
0.5	41	74.09	0.051983
1	33	57.22	0.040538
2	23	36.15	0.031691
4	19	27.72	0.023209
8	18	25.61	0.016550
15	16	21.39	0.012286
30	15	19.29	0.008758
60	14	17.18	0.006241
120	13	15.07	0.004448
240	13	15.07	0.003145
480	12	12.96	0.002241
1440	10	8.75	0.001313
2880	10	8.75	0.000929

Experiment 3:

Soil Wt. = 52.0g

Time(min)	Hydrometer Reading	Percent finer	Diameter(mm)
0.5	41	68.39	0.051983
1	32	50.88	0.040986
2	24	35.31	0.031401
4	22	31.42	0.022612
8	19	25.58	0.016412
15	17	21.69	0.012187
30	16	19.75	0.008688
60	15	17.80	0.006193
120	14	15.86	0.004413
240	13	13.91	0.003145
480	13	13.91	0.002224
1440	12	11.97	0.001294

Sieve and Hydrometer Combined Analysis

Experiment 1:

Analysis	D(mm)	Percent finer	% Finer Adjusted
Sieve	2.5	85.22	85.22
Sieve	2.0	84.65	84.65
Sieve	0.840	79.51	79.51
Sieve	0.425	70.38	70.38
Sieve	0.300	59.24	59.24
Sieve	0.150	43.25	43.25
Sieve	0.074	23.68	23.68
Hydrometer	0.052681	73.98	17.52
Hydrometer	0.041429	54.48	12.90
Hydrometer	0.031691	37.15	8.80
Hydrometer	0.022813	32.82	7.77
Hydrometer	0.016272	30.65	7.26
Hydrometer	0.012086	26.32	6.23
Hydrometer	0.008617	24.16	5.72
Hydrometer	0.006143	21.99	5.21
Hydrometer	0.004379	19.82	4.69
Hydrometer	0.003121	17.66	4.18
Hydrometer	0.002224	15.49	3.67
Hydrometer	0.001304	11.16	2.64

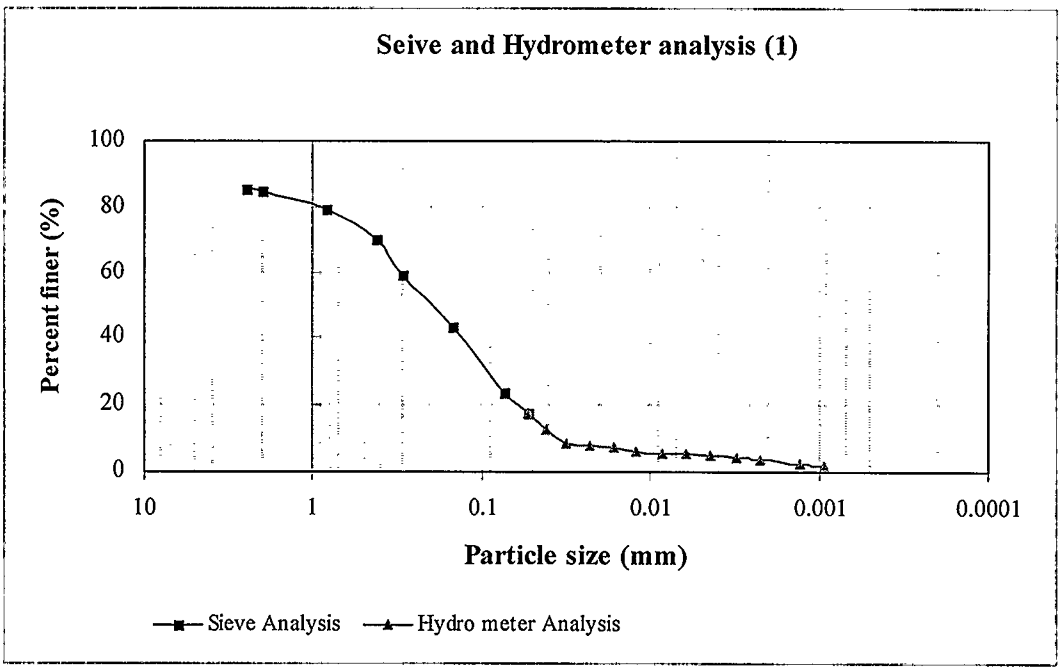

Figure A-1: Sieve and Hydrometer analysis - Sample 1

Experiment 2:

Analysis	D(mm)	Percent finer	% Finer Adjusted
Sieve	2.5	87.37	87.37
Sieve	2.0	86.50	86.50
Sieve	0.840	81.47	81.47
Sieve	0.425	71.85	71.85
Sieve	0.300	60.87	60.87
Sieve	0.150	44.49	44.49
Sieve	0.074	24.37	24.37
Hydrometer	0.051983	74.09	18.06
Hydrometer	0.040538	57.22	13.95
Hydrometer	0.031691	36.15	8.81
Hydrometer	0.023209	27.72	6.75
Hydrometer	0.016550	25.61	6.24
Hydrometer	0.012286	21.39	5.21
Hydrometer	0.008758	19.29	4.70
Hydrometer	0.006241	17.18	4.19
Hydrometer	0.004448	15.07	3.67
Hydrometer	0.003145	15.07	3.67
Hydrometer	0.002241	12.96	3.16
Hydrometer	0.001313	8.75	2.13

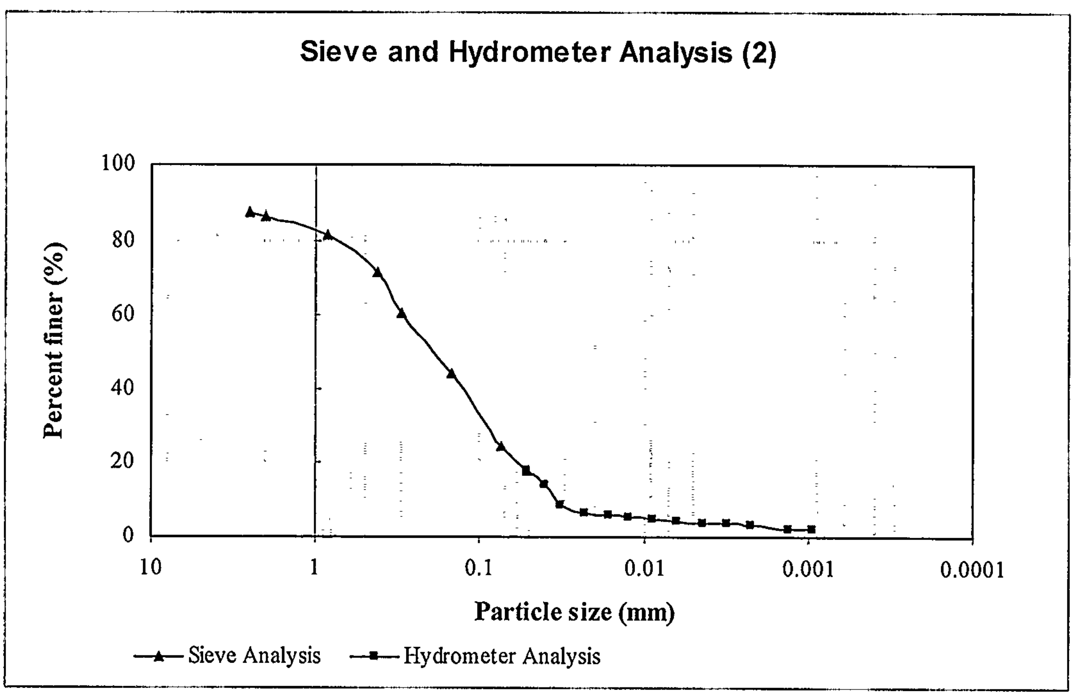

Figure A-2: Sieve and Hydrometer analysis - Sample 2

Experiment 3:

Analysis	D(mm)	Percent finer	% Finer Adjusted
Sieve	2.5	87.87	87.87
Sieve	2.0	86.91	86.91
Sieve	0.840	81.85	81.85
Sieve	0.425	72.57	72.57
Sieve	0.300	61.08	61.08
Sieve	0.150	44.71	44.71
Sieve	0.074	23.43	23.43
Hydrometer	0.051983	68.39	16.02
Hydrometer	0.040986	50.88	11.92
Hydrometer	0.031401	35.31	8.27
Hydrometer	0.022612	31.42	7.36
Hydrometer	0.016412	25.58	5.99
Hydrometer	0.012187	21.69	5.08
Hydrometer	0.008688	19.75	4.63
Hydrometer	0.006193	17.80	4.17
Hydrometer	0.004413	15.86	3.71
Hydrometer	0.003145	13.91	3.26
Hydrometer	0.002224	13.91	3.26

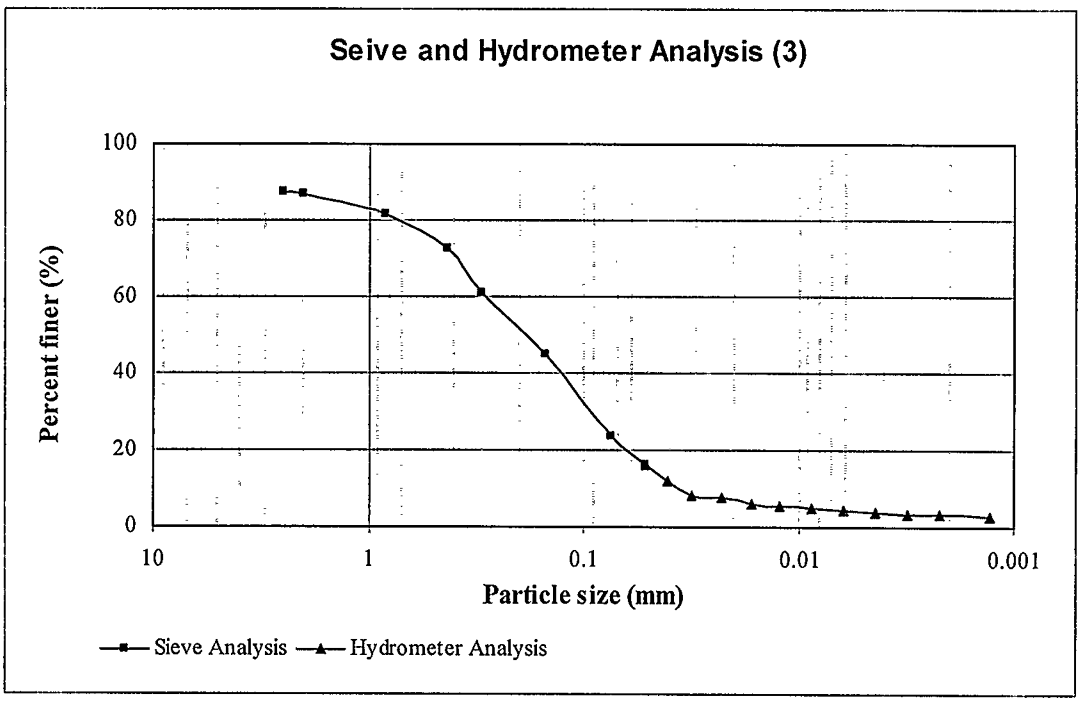

Figure A-3: Sieve and Hydrometer analysis - Sample 3

Sample	Percentage passing (%)		
	< 2 mm sieve size	< 0.05 mm sieve size	< 0.002 mm sieve size
Sample – 1	84.65	13.42	3.50
Sample – 2	86.50	13.95	3.50
Sample – 3	86.91	13.44	3.60

Soil Type	Sample - 1	Sample - 2	Sample - 3
Coarse sand Range: (2-0.05) mm	84.31	11.59	4.09
Silt Range:(0.05-.002) mm	83.87	12.08	4.05
Clay Range: (< 0.002 mm)	84.54	11.32	4.14

Soil classification results:

Coarse sand: 86.24%

Silt: 11.66%

Clay: 4.09%

APPENDIX B: METHANE OXIDATION PROFILE DATA AND CALCULATIONS

Column A: Gas Chromatograph - Average readings (contd.)

Date	Inlet					Outlet				
	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane
D/M/Y	%	%	%	%	%	%	%	%	%	%
3/8/2004	18.730	73.251	0.067	9.051	N/A	5.137	86.888	6.165	0.000	N/A
3/11/2004	19.693	72.171	0.094	8.847	N/A	6.095	87.716	5.333	0.000	N/A
3/15/2004	19.746	71.933	0.041	8.738	N/A	6.211	87.534	6.094	0.000	N/A
3/16/2004	18.462	71.932	0.089	8.894	N/A	5.228	87.366	5.784	0.000	N/A
3/17/2004	18.733	72.385	0.051	10.878	N/A	3.538	88.294	6.332	0.249	N/A
3/18/2004	18.899	72.246	0.084	10.709	N/A	3.406	88.668	6.397	0.232	N/A
3/19/2004	19.748	72.902	0.065	11.174	N/A	3.848	87.729	6.100	0.221	N/A
3/21/2004	19.555	72.194	0.053	11.441	N/A	4.096	89.126	6.714	0.124	N/A
3/23/2004	19.768	73.193	0.041	10.718	N/A	4.831	87.386	6.252	0.241	N/A
3/26/2004	19.647	73.403	0.061	11.376	N/A	3.571	87.799	6.893	0.272	N/A
4/1/2004	18.595	73.524	0.069	10.771	N/A	4.544	87.886	6.220	0.228	N/A
4/2/2004	18.890	71.647	0.041	12.690	N/A	4.105	84.723	6.224	2.966	N/A
4/3/2004	19.300	72.157	0.047	13.235	N/A	5.415	84.220	5.988	3.158	N/A
4/4/2004	18.725	72.898	0.057	13.086	N/A	3.926	86.569	6.283	2.277	N/A
4/7/2004	19.478	73.148	0.074	13.003	N/A	3.734	86.957	6.073	2.589	N/A
4/10/2004	18.626	72.914	0.056	13.593	N/A	4.618	85.646	6.318	2.819	N/A
4/13/2004	19.186	73.347	0.093	12.876	N/A	3.194	87.118	6.637	2.219	N/A
4/17/2004	19.819	73.368	0.074	12.742	N/A	4.770	85.811	6.551	2.481	N/A
4/19/2004	18.811	73.075	0.085	13.097	N/A	4.101	85.389	6.444	2.519	N/A
4/21/2004	18.410	73.258	0.081	13.236	N/A	4.595	84.783	6.537	2.830	N/A
4/22/2004	19.707	72.894	0.080	12.763	N/A	4.249	86.176	6.748	2.179	N/A
4/23/2004	19.277	73.124	0.045	12.708	N/A	4.299	85.823	6.823	2.601	N/A
4/25/2004	19.239	73.229	0.051	12.766	N/A	3.746	86.044	6.743	2.510	N/A
4/27/2004	19.608	71.935	0.094	13.046	N/A	4.364	85.379	5.969	2.734	N/A
4/30/2004	18.676	73.583	0.069	12.667	N/A	3.310	85.628	6.953	2.323	N/A
5/5/2004	18.582	73.558	0.073	13.166	N/A	4.833	85.578	6.873	2.565	N/A
5/10/2004	19.558	73.426	0.061	13.079	N/A	4.026	86.127	6.019	2.675	N/A
5/11/2005	19.212	72.352	0.052	13.057	N/A	3.436	85.142	6.271	2.571	N/A
5/12/2004	19.121	72.435	0.070	13.095	N/A	4.114	84.680	6.367	2.826	N/A
5/13/2004	19.212	71.775	0.061	12.607	N/A	4.168	86.614	6.520	2.683	N/A
5/14/2004	18.724	72.286	0.081	12.926	N/A	3.777	87.062	6.120	2.295	N/A
5/19/2004	19.203	72.885	0.055	12.639	N/A	4.261	85.353	6.015	2.417	N/A
5/28/2004	18.976	73.032	0.045	12.991	N/A	3.568	86.193	7.042	2.216	N/A
5/31/2004	19.496	73.143	0.084	13.564	N/A	3.246	86.893	6.586	2.520	N/A
6/8/2004	18.423	72.203	0.093	12.637	N/A	4.583	85.002	6.267	2.675	N/A
6/13/2004	19.315	73.522	0.094	12.894	N/A	4.547	86.550	6.102	2.431	N/A

Column A: Gas Chromatograph - Average readings

Date	Inlet					Outlet				
	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane
D/M/Y	%	%	%	%	%	%	%	%	%	%
9/29/2003	19.709	72.042	0.044	2.731	N/A	15.047	75.906	1.747	2.620	N/A
10/9/2003	19.100	72.155	0.051	1.825	N/A	13.646	75.489	2.580	1.395	N/A
10/25/2003	19.038	71.896	0.066	2.526	N/A	14.456	77.389	2.398	1.714	N/A
11/9/2003	19.339	70.647	0.067	4.884	N/A	12.680	76.958	1.735	3.399	N/A
11/25/2003	18.787	73.200	0.051	4.010	N/A	13.581	77.060	2.841	2.499	N/A
12/6/2003	19.317	71.478	0.081	4.488	N/A	13.758	75.414	2.659	2.574	N/A
12/13/2003	19.772	71.709	0.055	4.556	N/A	13.016	77.959	3.318	2.203	N/A
12/19/2003	19.496	70.988	0.018	6.338	N/A	11.273	80.749	2.961	1.956	N/A
12/26/2003	19.464	72.947	0.070	5.691	N/A	9.479	82.486	4.430	0.470	N/A
1/3/2004	18.945	72.731	0.040	5.794	N/A	8.765	82.747	4.665	0.000	N/A
1/10/2004	19.193	71.993	0.075	5.335	N/A	8.834	84.619	3.908	0.000	N/A
1/12/2004	18.931	72.223	0.025	5.484	N/A	7.659	84.477	4.765	0.000	N/A
1/17/2004	18.543	71.768	0.069	6.114	N/A	8.694	82.885	4.373	0.000	N/A
1/19/2004	18.809	72.758	0.044	6.193	N/A	8.846	83.929	4.140	0.000	N/A
1/23/2004	19.798	73.382	0.072	5.670	N/A	9.383	84.450	4.347	0.000	N/A
1/24/2004	19.244	72.045	0.059	5.691	N/A	9.194	83.386	4.423	0.000	N/A
1/25/2004	19.202	72.123	0.081	5.827	N/A	8.905	83.832	4.669	0.000	N/A
1/26/2004	19.688	73.184	0.035	5.792	N/A	9.148	82.756	4.843	0.000	N/A
1/28/2004	18.724	72.176	0.064	6.061	N/A	9.860	83.052	4.210	0.000	N/A
1/30/2004	19.091	73.311	0.089	5.670	N/A	9.328	83.325	4.160	0.000	N/A
2/2/2004	18.788	72.944	0.070	5.930	N/A	9.216	84.209	4.500	0.000	N/A
2/6/2004	19.082	72.539	0.045	6.534	N/A	9.563	84.053	4.705	0.000	N/A
2/10/2004	18.522	72.011	0.053	6.046	N/A	9.873	83.469	4.815	0.000	N/A
2/12/2004	18.608	71.943	0.048	5.888	N/A	8.527	82.762	4.605	0.000	N/A
2/13/2004	18.965	72.360	0.086	8.062	N/A	7.715	85.601	5.298	0.000	N/A
2/14/2004	19.249	72.482	0.062	7.688	N/A	7.465	84.703	5.550	0.000	N/A
2/15/2004	19.754	72.518	0.078	7.290	N/A	7.162	84.723	4.909	0.000	N/A
2/17/2004	19.068	72.729	0.055	7.638	N/A	8.174	84.392	5.090	0.000	N/A
2/19/2004	19.616	73.290	0.083	7.198	N/A	7.777	85.160	4.838	0.000	N/A
2/22/2004	18.886	72.144	0.051	7.470	N/A	6.900	85.773	4.872	0.000	N/A
2/26/2004	19.666	72.002	0.090	7.736	N/A	8.005	84.988	4.706	0.000	N/A
3/1/2004	18.825	72.323	0.082	7.736	N/A	7.375	85.334	4.704	0.000	N/A
3/2/2004	19.509	73.013	0.057	9.336	N/A	5.400	87.785	5.832	0.000	N/A
3/3/2004	18.982	72.038	0.076	9.671	N/A	5.121	85.991	5.980	0.000	N/A
3/4/2004	19.550	73.341	0.068	9.175	N/A	5.696	86.907	6.190	0.000	N/A
3/6/2004	19.418	73.283	0.038	9.224	N/A	5.429	87.346	6.050	0.000	N/A

Column A: Oxidation rate and Efficiency results

Date	Cum Days	Application Rate				Methane : Ethane Volume Ratio	Efficiency		Oxidation Rate			
		Methane		Ethane			Methane	Ethane	Methane		Ethane	
D/M/Y		ml/mt	g/m2/d	ml/mt	g/m2/d		%	%	ml/mt	g/m2/d	ml/mt	g/m2/d
9/29/2003	3	3.19	197.25	0.00	0.00	1:0	8.9	N/A	0.29	17.64	N/A	N/A
10/9/2003	13	3.19	197.25	0.00	0.00	1:0	26.9	N/A	0.86	53.10	N/A	N/A
10/25/2003	29	3.19	197.25	0.00	0.00	1:0	37.0	N/A	1.18	72.91	N/A	N/A
11/9/2003	44	4.99	308.55	0.00	0.00	1:0	36.1	N/A	1.80	111.41	N/A	N/A
11/25/2003	60	4.99	308.55	0.00	0.00	1:0	40.8	N/A	2.04	125.90	N/A	N/A
12/6/2003	71	4.99	308.55	0.00	0.00	1:0	45.6	N/A	2.28	140.81	N/A	N/A
12/13/2003	78	4.99	308.55	0.00	0.00	1:0	55.5	N/A	2.77	171.31	N/A	N/A
12/19/2003	84	6.58	406.87	0.00	0.00	1:0	72.9	N/A	4.80	296.52	N/A	N/A
12/26/2003	91	6.58	406.87	0.00	0.00	1:0	92.7	N/A	6.10	377.18	N/A	N/A
1/3/2004	99	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
1/10/2004	106	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
1/12/2004	108	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
1/17/2004	113	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
1/19/2004	115	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
1/23/2004	119	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
1/24/2004	120	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
1/25/2004	121	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
1/26/2004	122	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
1/28/2004	124	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
1/30/2004	126	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
2/2/2004	129	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
2/6/2004	133	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
2/10/2004	137	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
2/12/2004	139	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
2/13/2004	140	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.10	N/A	N/A
2/14/2004	141	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.10	N/A	N/A
2/15/2004	142	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.10	N/A	N/A
2/17/2004	144	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.10	N/A	N/A
2/19/2004	146	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.10	N/A	N/A
2/22/2004	149	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.10	N/A	N/A
2/26/2004	153	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.10	N/A	N/A
3/1/2004	157	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.10	N/A	N/A
3/2/2004	158	9.73	601.65	0.00	0.00	1:0	100.0	N/A	9.73	601.65	N/A	N/A
3/3/2004	159	9.73	601.65	0.00	0.00	1:0	100.0	N/A	9.73	601.65	N/A	N/A
3/4/2004	160	9.73	601.65	0.00	0.00	1:0	100.0	N/A	9.73	601.65	N/A	N/A
3/6/2004	162	9.73	601.65	0.00	0.00	1:0	100.0	N/A	9.73	601.65	N/A	N/A

Column A: Oxidation rate and Efficiency results (contd.)

Date	Cum Days	Application Rate				Methane : Ethane Volume Ratio	Efficiency		Oxidation Rate			
		Methane		Ethane			Methane	Ethane	Methane		Ethane	
D/M/Y		ml/mt	g/m2/d	ml/mt	g/m2/d		%	%	ml/mt	g/m2/d	ml/mt	g/m2/d
3/8/2004	164	9.73	602	0	0	1:0	100.0	N/A	9.73	601.650	N/A	N/A
3/11/2004	167	9.73	602	0	0	1:0	100.0	N/A	9.73	601.650	N/A	N/A
3/15/2004	171	9.73	602	0	0	1:0	100.0	N/A	9.73	601.650	N/A	N/A
3/16/2004	172	9.73	602	0	0	1:0	100.0	N/A	9.73	601.650	N/A	N/A
3/17/2004	173	11.51	712	0	0	1:0	98.1	N/A	11.29	698.364	N/A	N/A
3/18/2004	174	11.51	712	0	0	1:0	98.2	N/A	11.31	699.154	N/A	N/A
3/19/2004	175	11.51	712	0	0	1:0	98.4	N/A	11.32	700.001	N/A	N/A
3/21/2004	177	11.51	712	0	0	1:0	99.1	N/A	11.41	705.481	N/A	N/A
3/23/2004	179	11.51	712	0	0	1:0	98.1	N/A	11.29	698.293	N/A	N/A
3/26/2004	182	11.51	712	0	0	1:0	98.0	N/A	11.28	697.489	N/A	N/A
4/1/2004	188	11.51	712	0	0	1:0	98.2	N/A	11.31	699.126	N/A	N/A
4/2/2004	189	13.60	841	0	0	1:0	80.2	N/A	10.91	674.703	N/A	N/A
4/3/2004	190	13.60	841	0	0	1:0	79.6	N/A	10.82	669.018	N/A	N/A
4/4/2004	191	13.60	841	0	0	1:0	85.4	N/A	11.61	717.751	N/A	N/A
4/7/2004	194	13.60	841	0	0	1:0	83.3	N/A	11.32	700.125	N/A	N/A
4/10/2004	197	13.60	841	0	0	1:0	82.3	N/A	11.20	692.472	N/A	N/A
4/13/2004	200	13.60	841	0	0	1:0	85.5	N/A	11.63	718.928	N/A	N/A
4/17/2004	204	13.60	841	0	0	1:0	83.4	N/A	11.34	700.966	N/A	N/A
4/19/2004	206	13.60	841	0	0	1:0	83.5	N/A	11.36	702.530	N/A	N/A
4/21/2004	208	13.60	841	0	0	1:0	81.5	N/A	11.09	685.576	N/A	N/A
4/22/2004	209	13.60	841	0	0	1:0	85.6	N/A	11.64	719.517	N/A	N/A
4/23/2004	210	13.60	841	0	0	1:0	82.6	N/A	11.23	694.322	N/A	N/A
4/25/2004	212	13.60	841	0	0	1:0	83.3	N/A	11.32	700.217	N/A	N/A
4/27/2004	214	13.60	841	0	0	1:0	82.3	N/A	11.20	692.447	N/A	N/A
4/30/2004	217	13.60	841	0	0	1:0	84.2	N/A	11.46	708.425	N/A	N/A
5/5/2004	222	13.60	841	0	0	1:0	83.3	N/A	11.32	700.125	N/A	N/A
5/10/2004	227	13.60	841	0	0	1:0	82.6	N/A	11.23	694.339	N/A	N/A
5/11/2005	228	13.60	841	0	0	1:0	83.3	N/A	11.32	700.226	N/A	N/A
5/12/2004	229	13.60	841	0	0	1:0	81.5	N/A	11.09	685.719	N/A	N/A
5/13/2004	230	13.60	841	0	0	1:0	82.4	N/A	11.20	692.640	N/A	N/A
5/14/2004	231	13.60	841	0	0	1:0	85.3	N/A	11.59	716.961	N/A	N/A
5/19/2004	236	13.60	841	0	0	1:0	83.7	N/A	11.38	703.598	N/A	N/A
5/28/2004	245	13.60	841	0	0	1:0	85.5	N/A	11.63	719.408	N/A	N/A
5/31/2004	248	13.60	841	0	0	1:0	84.4	N/A	11.47	709.459	N/A	N/A
6/8/2004	256	13.60	841	0	0	1:0	82.0	N/A	11.15	689.756	N/A	N/A
6/13/2004	261	13.60	841	0	0	1:0	84.0	N/A	11.42	706.272	N/A	N/A

Column B: Gas Chromatograph - Average readings

Date	Inlet					Outlet				
	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane
D/M/Y	%	%	%	%	%	%	%	%	%	%
9/29/2003	18.187	72.297	0.064	2.773	N/A	15.435	73.763	1.108	2.749	N/A
10/9/2003	19.319	72.437	0.050	2.972	N/A	14.869	75.877	2.050	2.751	N/A
10/25/2003	18.064	70.704	0.039	2.414	N/A	14.115	75.881	2.612	1.581	N/A
11/9/2003	18.292	72.535	0.077	4.684	N/A	13.819	76.334	2.698	2.955	N/A
11/25/2003	19.516	72.425	0.059	4.800	N/A	13.787	78.030	2.888	2.974	N/A
12/6/2003	18.226	72.950	0.013	3.953	N/A	12.076	76.104	2.925	2.215	N/A
12/13/2003	19.062	72.441	0.073	4.962	N/A	11.966	78.149	3.031	2.148	N/A
12/19/2003	19.170	72.351	0.059	6.271	N/A	10.899	80.452	4.209	1.547	N/A
12/26/2003	17.717	73.477	0.008	5.581	N/A	10.238	82.864	3.910	0.564	N/A
1/3/2004	18.042	72.028	0.062	5.641	N/A	9.070	84.075	3.889	0.240	N/A
1/10/2004	18.456	73.164	0.062	6.547	N/A	9.836	84.513	3.978	0.058	N/A
1/12/2004	19.485	72.263	0.089	6.457	N/A	9.045	83.239	4.390	0.000	N/A
1/17/2004	19.591	73.492	0.068	6.345	N/A	9.411	84.278	4.204	0.000	N/A
1/19/2004	19.709	72.231	0.050	6.445	N/A	9.647	83.508	4.540	0.000	N/A
1/23/2004	18.699	73.256	0.089	5.590	N/A	8.510	83.698	4.182	0.000	N/A
1/24/2004	19.502	73.176	0.077	5.901	N/A	8.434	83.556	4.582	0.000	N/A
1/25/2004	18.666	73.586	0.070	6.417	N/A	9.749	84.389	4.662	0.000	N/A
1/26/2004	19.277	73.630	0.075	5.815	N/A	9.651	83.110	4.803	0.000	N/A
1/28/2004	18.665	72.378	0.057	5.738	N/A	8.430	83.619	4.536	0.000	N/A
1/30/2004	19.086	71.679	0.046	5.887	N/A	9.406	83.347	4.237	0.000	N/A
2/2/2004	18.764	73.073	0.039	6.171	N/A	9.493	83.248	4.503	0.000	N/A
2/6/2004	18.999	73.554	0.035	5.990	N/A	8.518	83.507	4.841	0.000	N/A
2/10/2004	19.097	73.444	0.067	5.743	N/A	8.508	84.661	4.607	0.000	N/A
2/12/2004	19.235	73.455	0.053	5.691	N/A	9.696	83.772	4.486	0.000	N/A
2/13/2004	18.732	72.219	0.091	7.800	N/A	8.100	85.804	5.264	0.000	N/A
2/14/2004	19.596	72.259	0.046	7.424	N/A	7.404	85.161	5.070	0.000	N/A
2/15/2004	19.583	73.049	0.068	7.937	N/A	7.137	85.064	5.393	0.000	N/A
2/17/2004	19.447	71.685	0.067	8.046	N/A	7.017	85.855	4.653	0.000	N/A
2/19/2004	18.811	73.544	0.056	7.908	N/A	6.989	84.551	5.168	0.000	N/A
2/22/2004	19.235	71.885	0.043	7.325	N/A	8.058	84.400	5.077	0.000	N/A
2/26/2004	18.587	71.775	0.086	7.860	N/A	8.186	85.743	4.965	0.000	N/A
3/1/2004	18.657	71.678	0.090	8.069	N/A	7.396	86.139	4.651	0.000	N/A
3/2/2004	19.383	72.647	0.074	9.351	N/A	6.297	85.970	5.968	0.000	N/A
3/3/2004	19.079	72.373	0.090	9.200	N/A	6.503	86.218	6.159	0.000	N/A
3/4/2004	19.758	72.487	0.069	9.284	N/A	6.235	86.267	5.605	0.000	N/A
3/6/2004	18.818	72.223	0.053	9.092	N/A	6.219	86.142	6.039	0.000	N/A

Column B: Gas Chromatograph - Average readings (contd.)

Date	Inlet					Outlet				
	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane
D/M/Y	%	%	%	%	%	%	%	%	%	%
3/8/2004	18.848	73.448	0.086	9.087	N/A	6.374	87.514	5.347	0.000	N/A
3/11/2004	19.297	73.103	0.035	9.156	N/A	5.100	85.941	5.481	0.000	N/A
3/15/2004	18.370	72.180	0.047	9.350	N/A	5.762	86.870	6.105	0.000	N/A
3/16/2004	19.176	72.616	0.058	9.515	N/A	6.054	86.732	5.525	0.000	N/A
3/17/2004	19.597	72.446	0.052	10.574	N/A	4.522	88.370	6.695	0.255	N/A
3/18/2004	18.648	73.020	0.048	10.830	N/A	4.402	88.543	7.030	0.229	N/A
3/19/2004	18.631	73.507	0.043	10.641	N/A	3.604	87.856	6.861	0.349	N/A
3/21/2004	19.502	72.964	0.045	11.156	N/A	4.220	88.970	6.552	0.192	N/A
3/23/2004	18.803	72.728	0.071	10.731	N/A	4.677	88.436	6.269	0.216	N/A
3/26/2004	19.005	72.226	0.044	10.674	N/A	4.752	88.907	6.543	0.248	N/A
4/1/2004	18.988	72.411	0.087	11.405	N/A	4.531	87.859	6.309	0.277	N/A
4/2/2004	18.911	72.868	0.072	13.245	N/A	3.799	85.332	6.418	2.859	N/A
4/3/2004	18.572	73.491	0.047	13.364	N/A	4.107	86.445	6.109	2.460	N/A
4/4/2004	19.704	71.829	0.060	13.017	N/A	3.834	86.182	6.187	2.928	N/A
4/7/2004	18.589	73.529	0.050	12.806	N/A	3.442	86.819	6.427	2.517	N/A
4/10/2004	18.889	72.931	0.051	13.526	N/A	3.845	84.810	6.238	2.854	N/A
4/13/2004	19.513	72.719	0.094	13.447	N/A	4.878	85.905	6.160	2.939	N/A
4/17/2004	18.861	72.217	0.068	12.706	N/A	3.869	86.134	6.657	2.675	N/A
4/19/2004	19.365	73.277	0.035	13.064	N/A	4.334	86.430	5.979	2.678	N/A
4/21/2004	18.366	73.117	0.055	16.105	N/A	5.583	80.448	5.670	7.043	N/A
4/22/2004	19.582	72.701	0.055	16.041	N/A	5.415	81.753	5.662	6.629	N/A
4/23/2004	18.642	72.998	0.077	15.319	N/A	4.947	81.117	5.495	6.595	N/A
4/25/2004	18.531	71.971	0.044	15.437	N/A	4.482	81.515	5.894	6.075	N/A
4/27/2004	18.352	73.310	0.072	15.993	N/A	5.890	81.177	5.719	6.665	N/A
4/30/2004	19.189	72.015	0.048	15.513	N/A	5.755	81.367	6.082	6.560	N/A
5/5/2004	19.157	72.272	0.048	15.592	N/A	5.651	81.231	5.990	6.620	N/A
5/10/2004	19.482	72.200	0.086	15.253	N/A	4.681	80.627	5.370	6.322	N/A
5/11/2005	18.855	72.634	0.089	19.236	N/A	5.994	76.834	4.825	10.557	N/A
5/12/2004	18.653	72.559	0.080	18.698	N/A	7.137	76.310	4.633	10.574	N/A
5/13/2004	19.122	73.139	0.061	18.826	N/A	7.345	75.549	5.187	10.982	N/A
5/14/2004	19.780	72.893	0.041	19.500	N/A	5.593	77.537	5.334	10.941	N/A
5/19/2004	18.356	73.474	0.093	18.789	N/A	5.795	77.073	5.417	9.915	N/A
5/28/2004	19.166	73.239	0.061	18.784	N/A	6.102	76.600	5.567	10.310	N/A
5/31/2004	19.289	72.319	0.056	19.445	N/A	5.667	77.221	5.315	10.765	N/A
6/8/2004	18.570	72.682	0.035	18.746	N/A	6.784	77.870	5.218	10.514	N/A
6/13/2004	19.392	73.239	0.071	19.509	N/A	5.559	77.727	5.227	10.662	N/A

Column B: Oxidation rate and Efficiency results

Date	Cum Days	Inflow Rate				Methane : Ethane Volume Ratio	Efficiency		Oxidation Rate			
		Methane		Ethane			Methane	Ethane	Methane		Ethane	
D/M/Y		ml/mt	g/m2/d	ml/mt	g/m2/d		%	%	ml/mt	g/m2/d	ml/mt	g/m2/d
9/29/2003	3	3.19	197.25	0.00	0.00	1:0	2.8	N/A	0.09	5.6	N/A	N/A
10/9/2003	13	3.19	197.25	0.00	0.00	1:0	11.6	N/A	0.37	22.9	N/A	N/A
10/25/2003	29	3.19	197.25	0.00	0.00	1:0	39.0	N/A	1.24	76.9	N/A	N/A
11/9/2003	44	4.99	308.55	0.00	0.00	1:0	40.0	N/A	2.00	123.6	N/A	N/A
11/25/2003	60	4.99	308.55	0.00	0.00	1:0	42.5	N/A	2.12	131.1	N/A	N/A
12/6/2003	71	4.99	308.55	0.00	0.00	1:0	46.3	N/A	2.31	142.8	N/A	N/A
12/13/2003	78	4.99	308.55	0.00	0.00	1:0	59.9	N/A	2.99	184.8	N/A	N/A
12/19/2003	84	6.58	406.87	0.00	0.00	1:0	77.8	N/A	5.12	316.6	N/A	N/A
12/26/2003	91	6.58	406.87	0.00	0.00	1:0	91.0	N/A	5.99	370.4	N/A	N/A
1/3/2004	99	6.58	406.87	0.00	0.00	1:0	96.4	N/A	6.34	392.0	N/A	N/A
1/10/2004	106	6.58	406.87	0.00	0.00	1:0	99.2	N/A	6.53	403.8	N/A	N/A
1/12/2004	108	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.9	N/A	N/A
1/17/2004	113	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.9	N/A	N/A
1/19/2004	115	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.9	N/A	N/A
1/23/2004	119	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.9	N/A	N/A
1/24/2004	120	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.9	N/A	N/A
1/25/2004	121	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.9	N/A	N/A
1/26/2004	122	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.9	N/A	N/A
1/28/2004	124	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.9	N/A	N/A
1/30/2004	126	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.9	N/A	N/A
2/2/2004	129	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.9	N/A	N/A
2/6/2004	133	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.9	N/A	N/A
2/10/2004	137	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.9	N/A	N/A
2/12/2004	139	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.9	N/A	N/A
2/13/2004	140	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.1	N/A	N/A
2/14/2004	141	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.1	N/A	N/A
2/15/2004	142	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.1	N/A	N/A
2/17/2004	144	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.1	N/A	N/A
2/19/2004	146	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.1	N/A	N/A
2/22/2004	149	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.1	N/A	N/A
2/26/2004	153	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.1	N/A	N/A
3/1/2004	157	8.12	502.10	0.00	0.00	1:0	100.0	N/A	8.12	502.1	N/A	N/A
3/2/2004	158	9.73	601.65	0.00	0.00	1:0	100.0	N/A	9.73	601.7	N/A	N/A
3/3/2004	159	9.73	601.65	0.00	0.00	1:0	100.0	N/A	9.73	601.7	N/A	N/A
3/4/2004	160	9.73	601.65	0.00	0.00	1:0	100.0	N/A	9.73	601.7	N/A	N/A
3/6/2004	162	9.73	601.65	0.00	0.00	1:0	100.0	N/A	9.73	601.7	N/A	N/A

Column B: Oxidation rate and Efficiency results (contd.)

Date	Cum Days	Inflow Rate				Methane : Ethane Volume Ratio	Efficiency		Oxidation Rate			
		Methane		Ethane			Methane	Ethane	Methane		Ethane	
D/M/Y		ml/mt	g/m2/d	ml/mt	g/m2/d		%	%	ml/mt	g/m2/d	ml/mt	g/m2/d
3/8/2004	164	9.73	601.65	0.00	0.00	1:0	100.0	N/A	9.73	601.7	N/A	N/A
3/11/2004	167	9.73	601.65	0.00	0.00	1:0	100.0	N/A	9.73	601.7	N/A	N/A
3/15/2004	171	9.73	601.65	0.00	0.00	1:0	100.0	N/A	9.73	601.7	N/A	N/A
3/16/2004	172	9.73	601.65	0.00	0.00	1:0	100.0	N/A	9.73	601.7	N/A	N/A
3/17/2004	173	11.51	711.72	0.00	0.00	1:0	98.0	N/A	11.28	697.6	N/A	N/A
3/18/2004	174	11.51	711.72	0.00	0.00	1:0	98.3	N/A	11.31	699.3	N/A	N/A
3/19/2004	175	11.51	711.72	0.00	0.00	1:0	97.3	N/A	11.19	692.2	N/A	N/A
3/21/2004	177	11.51	711.72	0.00	0.00	1:0	98.6	N/A	11.35	701.7	N/A	N/A
3/23/2004	179	11.51	711.72	0.00	0.00	1:0	98.3	N/A	11.32	699.9	N/A	N/A
3/26/2004	182	11.51	711.72	0.00	0.00	1:0	98.1	N/A	11.29	698.3	N/A	N/A
4/1/2004	188	11.51	711.72	0.00	0.00	1:0	98.0	N/A	11.28	697.5	N/A	N/A
4/2/2004	189	13.60	840.95	0.00	0.00	1:0	81.6	N/A	11.09	686.0	N/A	N/A
4/3/2004	190	13.60	840.95	0.00	0.00	1:0	84.4	N/A	11.47	709.4	N/A	N/A
4/4/2004	191	13.60	840.95	0.00	0.00	1:0	81.3	N/A	11.05	683.3	N/A	N/A
4/7/2004	194	13.60	840.95	0.00	0.00	1:0	83.4	N/A	11.34	701.0	N/A	N/A
4/10/2004	197	13.60	840.95	0.00	0.00	1:0	81.9	N/A	11.13	688.4	N/A	N/A
4/13/2004	200	13.60	840.95	0.00	0.00	1:0	81.5	N/A	11.08	685.4	N/A	N/A
4/17/2004	204	13.60	840.95	0.00	0.00	1:0	82.4	N/A	11.20	692.5	N/A	N/A
4/19/2004	206	13.60	840.95	0.00	0.00	1:0	82.6	N/A	11.24	694.8	N/A	N/A
4/21/2004	208	16.20	1001.72	0.00	0.00	1:0	60.3	N/A	9.76	603.6	N/A	N/A
4/22/2004	209	16.20	1001.72	0.00	0.00	1:0	63.3	N/A	10.25	633.6	N/A	N/A
4/23/2004	210	16.20	1001.72	0.00	0.00	1:0	61.3	N/A	9.92	613.6	N/A	N/A
4/25/2004	212	16.20	1001.72	0.00	0.00	1:0	65.3	N/A	10.57	653.7	N/A	N/A
4/27/2004	214	16.20	1001.72	0.00	0.00	1:0	62.4	N/A	10.10	624.8	N/A	N/A
4/30/2004	217	16.20	1001.72	0.00	0.00	1:0	62.6	N/A	10.14	626.8	N/A	N/A
5/5/2004	222	16.20	1001.72	0.00	0.00	1:0	62.2	N/A	10.08	623.3	N/A	N/A
5/10/2004	227	16.20	1001.72	0.00	0.00	1:0	62.9	N/A	10.19	629.9	N/A	N/A
5/11/2005	228	19.60	1211.96	0.00	0.00	1:0	48.1	N/A	9.43	583.2	N/A	N/A
5/12/2004	229	19.60	1211.96	0.00	0.00	1:0	46.2	N/A	9.06	560.3	N/A	N/A
5/13/2004	230	19.60	1211.96	0.00	0.00	1:0	43.5	N/A	8.53	527.5	N/A	N/A
5/14/2004	231	19.60	1211.96	0.00	0.00	1:0	47.3	N/A	9.26	572.7	N/A	N/A
5/19/2004	236	19.60	1211.96	0.00	0.00	1:0	49.7	N/A	9.74	602.3	N/A	N/A
5/28/2004	245	19.60	1211.96	0.00	0.00	1:0	47.5	N/A	9.31	575.9	N/A	N/A
5/31/2004	248	19.60	1211.96	0.00	0.00	1:0	48.2	N/A	9.44	583.6	N/A	N/A
6/8/2004	256	19.60	1211.96	0.00	0.00	1:0	47.7	N/A	9.34	577.5	N/A	N/A
6/13/2004	261	19.60	1211.96	0.00	0.00	1:0	48.5	N/A	9.51	587.8	N/A	N/A

Column C: Gas Chromatograph - Average readings

Date	Inlet					Outlet				
	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane
D/M/Y	%	%	%	%	%	%	%	%	%	%
9/29/2003	19.100	72.430	0.057	2.387	N/A	20.326	76.642	1.162	2.136	N/A
10/9/2003	17.804	71.728	0.049	2.935	N/A	19.252	74.646	0.668	2.445	N/A
10/25/2003	18.887	72.137	0.040	2.777	N/A	19.480	75.458	1.216	2.290	N/A
11/9/2003	19.267	72.274	0.035	4.477	N/A	17.719	75.962	2.163	3.127	N/A
11/25/2003	19.489	73.045	0.058	4.103	N/A	17.290	75.951	1.463	2.825	N/A
12/6/2003	19.276	72.663	0.066	4.633	N/A	17.863	77.889	2.051	2.908	N/A
12/13/2003	19.480	73.339	0.082	4.136	N/A	15.523	78.122	2.608	1.761	N/A
12/19/2003	19.452	73.352	0.060	5.735	N/A	13.210	80.328	4.203	1.373	N/A
12/26/2003	19.757	72.080	0.051	6.479	N/A	10.399	83.506	4.166	0.680	N/A
1/3/2004	19.223	72.739	0.083	5.324	N/A	11.378	84.015	3.639	0.224	N/A
1/10/2004	18.295	73.125	0.059	5.967	N/A	10.911	82.007	5.040	0.059	N/A
1/12/2004	18.993	72.247	0.090	5.967	N/A	11.279	83.059	4.881	0.030	N/A
1/17/2004	19.345	73.176	0.059	6.114	N/A	10.261	84.479	4.308	0.000	N/A
1/19/2004	19.712	72.242	0.093	6.362	N/A	11.135	83.834	4.366	0.000	N/A
1/23/2004	18.336	71.858	0.084	6.389	N/A	10.934	84.190	4.496	0.000	N/A
1/24/2004	18.349	72.089	0.077	5.850	0.707	7.611	85.789	5.878	0.000	0.008
1/25/2004	19.149	72.280	0.052	6.203	0.805	8.360	85.534	6.008	0.000	0.024
1/26/2004	19.714	73.060	0.051	6.553	0.739	8.036	83.901	5.985	0.000	0.016
1/28/2004	18.538	73.555	0.042	5.745	0.763	9.036	85.684	5.363	0.000	0.007
1/30/2004	19.222	72.451	0.079	6.079	0.779	8.586	83.942	5.877	0.000	0.003
2/2/2004	19.796	72.380	0.051	6.571	0.740	8.047	84.869	5.511	0.000	0.007
2/6/2004	19.732	71.959	0.082	5.819	0.628	8.432	84.602	5.676	0.000	0.007
2/10/2004	18.780	72.912	0.037	6.540	0.685	7.596	84.847	6.060	0.000	0.004
2/12/2004	19.542	71.848	0.044	6.261	0.765	8.771	85.578	5.697	0.000	0.008
2/13/2004	18.967	71.758	0.074	7.297	0.818	5.606	86.549	6.569	0.130	0.048
2/14/2004	19.610	71.808	0.086	8.073	1.012	5.513	85.466	6.416	0.266	0.045
2/15/2004	18.388	72.986	0.060	7.137	1.003	5.262	86.394	6.982	0.167	0.068
2/17/2004	19.608	71.949	0.050	7.365	0.887	5.750	86.638	6.767	0.057	0.033
2/19/2004	18.897	73.089	0.091	7.425	0.978	5.507	86.927	7.360	0.066	0.057
2/22/2004	19.766	72.061	0.049	7.716	0.838	4.891	87.209	6.672	0.082	0.040
2/26/2004	18.673	72.547	0.067	7.489	0.867	5.861	87.340	7.177	0.088	0.060
3/1/2004	19.801	73.561	0.072	7.535	0.990	5.453	87.110	6.560	0.079	0.057
3/2/2004	19.217	72.176	0.035	9.569	1.160	3.627	87.001	8.074	0.665	0.216
3/3/2004	18.605	72.453	0.070	9.054	1.106	3.401	86.459	7.665	0.729	0.168
3/4/2004	19.087	71.659	0.072	9.000	1.113	2.287	87.539	7.603	0.401	0.200
3/6/2004	19.060	73.569	0.062	9.568	1.060	2.671	87.599	7.246	0.654	0.202

Column C: Gas Chromatograph - Average readings (contd.)

Date	Inlet					Outlet				
	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane
D/M/Y	%	%	%	%	%	%	%	%	%	%
3/8/2004	18.346	71.903	0.093	8.750	1.166	3.151	87.957	7.805	0.520	0.187
3/11/2004	19.790	72.153	0.070	9.084	1.051	2.939	87.804	7.540	0.417	0.190
3/15/2004	18.662	72.998	0.050	9.092	1.126	2.478	88.252	8.259	0.426	0.172
3/16/2004	19.692	72.972	0.042	9.077	1.035	2.451	86.592	7.892	0.431	0.170
3/17/2004	18.406	72.454	0.082	11.423	1.322	3.008	86.356	7.757	2.148	0.542
3/18/2004	19.102	72.393	0.070	11.241	1.307	3.259	85.063	7.574	2.330	0.468
3/19/2004	19.013	72.993	0.036	10.672	1.412	1.760	87.307	8.301	1.740	0.604
3/21/2004	19.594	72.046	0.059	10.774	1.275	2.075	85.559	8.181	1.798	0.479
3/23/2004	18.386	71.928	0.054	11.435	1.348	2.009	86.668	8.240	2.068	0.549
3/26/2004	19.741	71.905	0.082	11.271	1.396	2.100	85.187	7.915	1.988	0.527
4/1/2004	19.739	73.330	0.076	10.672	1.315	2.091	86.325	8.175	1.872	0.511
4/2/2004	19.090	71.753	0.059	12.884	1.648	4.297	80.026	6.676	5.412	0.931
4/3/2004	19.107	73.503	0.088	13.484	1.604	4.435	80.506	6.451	5.238	0.927
4/4/2004	18.588	72.327	0.065	13.478	1.655	3.688	81.470	7.287	5.258	0.965
4/7/2004	18.981	72.091	0.041	12.877	1.561	3.479	81.883	7.115	4.603	0.945
4/10/2004	18.840	72.785	0.041	12.915	1.560	4.227	80.687	6.987	5.124	0.872
4/13/2004	18.451	72.362	0.069	13.140	1.604	4.331	80.905	6.649	5.199	0.922
4/17/2004	19.124	72.042	0.055	12.771	1.628	3.544	81.827	6.607	5.004	0.939
4/19/2004	19.018	72.848	0.052	12.953	1.666	4.376	82.693	6.720	5.128	0.954
4/21/2004	18.415	72.637	0.055	15.815	1.963	5.254	78.550	6.582	7.827	1.290
4/22/2004	19.596	72.136	0.071	15.334	1.842	7.682	75.110	5.063	9.202	1.223
4/23/2004	18.582	72.082	0.077	15.982	1.953	6.335	75.332	5.397	9.126	1.313
4/25/2004	19.375	73.043	0.084	15.793	1.990	6.163	77.947	5.518	8.787	1.345
4/27/2004	18.994	73.263	0.071	16.051	1.990	6.634	75.585	5.810	9.345	1.291
4/30/2004	18.815	72.272	0.047	15.667	1.947	6.586	76.698	5.321	9.283	1.331
5/5/2004	19.041	72.120	0.051	15.217	1.930	6.165	77.451	5.840	8.787	1.278
5/10/2004	19.474	71.771	0.068	15.330	1.994	7.698	76.236	5.459	8.940	1.324
5/11/2005	19.797	72.161	0.041	19.567	2.287	9.436	70.289	4.618	13.598	1.574
5/12/2004	19.664	72.521	0.072	18.670	2.286	9.269	70.156	4.300	12.605	1.645
5/13/2004	19.044	73.545	0.068	19.535	2.260	8.620	70.733	4.784	12.709	1.597
5/14/2004	19.821	73.417	0.036	19.116	2.383	9.573	71.677	4.363	13.129	1.672
5/19/2004	19.027	73.006	0.043	18.725	2.427	9.927	70.144	4.250	13.037	1.717
5/28/2004	19.367	71.865	0.034	19.343	2.333	9.744	71.766	4.868	13.522	1.646
5/31/2004	18.403	72.371	0.054	19.271	2.252	8.741	71.184	4.307	13.293	1.594
6/8/2004	19.143	71.702	0.035	19.240	2.342	9.639	70.427	4.449	13.112	1.642
6/13/2004	18.848	72.202	0.052	19.175	2.324	9.150	71.208	4.452	13.283	1.655

Column C: Oxidation rate and Efficiency results

Date	Cum Days	Application Rate				Methane : Ethane Volume Ratio	Efficiency		Oxidation Rate			
		Methane		Ethane			Methane	Ethane	Methane		Ethane	
D/M/Y		ml/mt	g/m2/d	ml/mt	g/m2/d		%	%	ml/mt	g/m2/d	ml/mt	g/m2/d
9/29/2003	3	3.19	197.25	0.00	0.00	1:0	15.4	N/A	0.49	30.43	N/A	N/A
10/9/2003	13	3.19	197.25	0.00	0.00	1:0	19.9	N/A	0.64	39.35	N/A	N/A
10/25/2003	29	3.19	197.25	0.00	0.00	1:0	21.2	N/A	0.68	41.76	N/A	N/A
11/9/2003	44	4.99	308.55	0.00	0.00	1:0	33.5	N/A	1.67	103.51	N/A	N/A
11/25/2003	60	4.99	308.55	0.00	0.00	1:0	33.8	N/A	1.69	104.26	N/A	N/A
12/6/2003	71	4.99	308.55	0.00	0.00	1:0	41.4	N/A	2.07	127.88	N/A	N/A
12/13/2003	78	4.99	308.55	0.00	0.00	1:0	60.0	N/A	3.00	185.26	N/A	N/A
12/19/2003	84	6.58	406.87	0.00	0.00	1:0	78.1	N/A	5.14	317.95	N/A	N/A
12/26/2003	91	6.58	406.87	0.00	0.00	1:0	90.9	N/A	5.98	369.99	N/A	N/A
1/3/2004	99	6.58	406.87	0.00	0.00	1:0	96.4	N/A	6.34	392.07	N/A	N/A
1/10/2004	106	6.58	406.87	0.00	0.00	1:0	99.1	N/A	6.52	403.30	N/A	N/A
1/12/2004	108	6.58	406.87	0.00	0.00	1:0	99.6	N/A	6.55	405.08	N/A	N/A
1/17/2004	113	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
1/19/2004	115	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
1/23/2004	119	6.58	406.87	0.00	0.00	1:0	100.0	N/A	6.58	406.87	N/A	N/A
1/24/2004	120	6.58	406.87	0.82	95.36	8:1	100.0	99.0	6.58	406.87	0.81	94.41
1/25/2004	121	6.58	406.87	0.82	95.36	8:1	100.0	97.5	6.58	406.87	0.80	93.00
1/26/2004	122	6.58	406.87	0.82	95.36	8:1	100.0	98.1	6.58	406.87	0.81	93.56
1/28/2004	124	6.58	406.87	0.82	95.36	8:1	100.0	99.2	6.58	406.87	0.82	94.63
1/30/2004	126	6.58	406.87	0.82	95.36	8:1	100.0	99.7	6.58	406.87	0.82	95.03
2/2/2004	129	6.58	406.87	0.82	95.36	8:1	100.0	99.2	6.58	406.87	0.82	94.63
2/6/2004	133	6.58	406.87	0.82	95.36	8:1	100.0	99.1	6.58	406.87	0.82	94.51
2/10/2004	137	6.58	406.87	0.82	95.36	8:1	100.0	99.5	6.58	406.87	0.82	94.84
2/12/2004	139	6.58	406.87	0.82	95.36	8:1	100.0	99.1	6.58	406.87	0.82	94.52
2/13/2004	140	8.12	502.10	1.02	117.68	8:1	98.5	95.1	8.00	494.69	0.97	111.94
2/14/2004	141	8.12	502.10	1.02	117.68	8:1	97.2	96.2	7.90	488.20	0.98	113.25
2/15/2004	142	8.12	502.10	1.02	117.68	8:1	98.0	94.3	7.96	492.16	0.96	110.92
2/17/2004	144	8.12	502.10	1.02	117.68	8:1	99.4	96.9	8.07	498.86	0.98	114.02
2/19/2004	146	8.12	502.10	1.02	117.68	8:1	99.3	95.1	8.06	498.35	0.97	111.94
2/22/2004	149	8.12	502.10	1.02	117.68	8:1	99.1	96.1	8.05	497.68	0.98	113.09
2/26/2004	153	8.12	502.10	1.02	117.68	8:1	99.0	94.2	8.04	497.18	0.96	110.91
3/1/2004	157	8.12	502.10	1.02	117.68	8:1	99.1	95.1	8.05	497.63	0.97	111.93
3/2/2004	158	9.73	601.65	1.22	141.01	8:1	94.2	84.5	9.17	566.97	1.03	119.19
3/3/2004	159	9.73	601.65	1.22	141.01	8:1	93.3	87.2	9.07	561.08	1.06	123.01
3/4/2004	160	9.73	601.65	1.22	141.01	8:1	96.4	85.3	9.38	579.71	1.04	120.23
3/6/2004	162	9.73	601.65	1.22	141.01	8:1	94.3	84.0	9.17	567.09	1.02	118.48

Column C: Oxidation rate and Efficiency results (contd.)

Date	Cum Days	Application Rate				Methane : Ethane Volume Ratio	Efficiency		Oxidation Rate			
		Methane		Ethane			Methane	Ethane	Methane		Ethane	
D/M/Y		ml/mt	g/m2/d	ml/mt	g/m2/d		%	%	ml/mt	g/m2/d	ml/mt	g/m2/d
3/8/2004	164	9.73	601.65	1.22	141.01	8:1	95.1	86.9	9.26	572.42	1.06	122.47
3/11/2004	167	9.73	601.65	1.22	141.01	8:1	96.2	85.1	9.36	578.98	1.04	120.02
3/15/2004	171	9.73	601.65	1.22	141.01	8:1	96.1	87.3	9.35	578.35	1.06	123.14
3/16/2004	172	9.73	601.65	1.22	141.01	8:1	96.0	86.1	9.34	577.60	1.05	121.45
3/17/2004	173	11.51	711.72	1.44	166.81	8:1	84.2	65.6	9.69	599.41	0.94	109.46
3/18/2004	174	11.51	711.72	1.44	166.81	8:1	82.4	69.5	9.48	586.20	1.00	115.98
3/19/2004	175	11.51	711.72	1.44	166.81	8:1	86.4	64.2	9.94	614.69	0.92	107.14
3/21/2004	177	11.51	711.72	1.44	166.81	8:1	86.0	68.4	9.89	611.73	0.98	114.03
3/23/2004	179	11.51	711.72	1.44	166.81	8:1	85.0	66.2	9.78	604.88	0.95	110.45
3/26/2004	182	11.51	711.72	1.44	166.81	8:1	85.1	68.1	9.80	605.76	0.98	113.61
4/1/2004	188	11.51	711.72	1.44	166.81	8:1	85.1	67.0	9.80	605.68	0.96	111.76
4/2/2004	189	13.60	840.95	1.70	197.10	8:1	62.3	49.4	8.48	524.20	0.84	97.29
4/3/2004	190	13.60	840.95	1.70	197.10	8:1	64.5	47.2	8.78	542.67	0.80	93.09
4/4/2004	191	13.60	840.95	1.70	197.10	8:1	65.4	48.3	8.89	549.70	0.82	95.10
4/7/2004	194	13.60	840.95	1.70	197.10	8:1	68.5	46.7	9.32	576.29	0.79	92.04
4/10/2004	197	13.60	840.95	1.70	197.10	8:1	64.2	49.6	8.73	539.99	0.84	97.70
4/13/2004	200	13.60	840.95	1.70	197.10	8:1	64.6	48.6	8.79	543.37	0.83	95.79
4/17/2004	204	13.60	840.95	1.70	197.10	8:1	65.5	49.2	8.91	550.84	0.84	97.01
4/19/2004	206	13.60	840.95	1.70	197.10	8:1	65.1	49.5	8.86	547.66	0.84	97.62
4/21/2004	208	16.20	1001.72	2.03	234.78	8:1	54.2	39.3	8.79	543.28	0.79	92.15
4/22/2004	209	16.20	1001.72	2.03	234.78	8:1	42.4	36.2	6.86	424.38	0.73	85.05
4/23/2004	210	16.20	1001.72	2.03	234.78	8:1	45.4	35.7	7.35	454.42	0.72	83.78
4/25/2004	212	16.20	1001.72	2.03	234.78	8:1	47.9	36.7	7.75	479.43	0.74	86.06
4/27/2004	214	16.20	1001.72	2.03	234.78	8:1	43.6	37.1	7.06	436.44	0.75	87.15
4/30/2004	217	16.20	1001.72	2.03	234.78	8:1	44.2	35.6	7.16	442.43	0.72	83.50
5/5/2004	222	16.20	1001.72	2.03	234.78	8:1	46.2	38.4	7.49	463.10	0.78	90.06
5/10/2004	227	16.20	1001.72	2.03	234.78	8:1	45.1	37.5	7.31	451.78	0.76	88.05
5/11/2005	228	19.60	1211.96	2.45	284.05	8:1	28.7	29.4	5.62	347.29	0.72	83.38
5/12/2004	229	19.60	1211.96	2.45	284.05	8:1	30.2	25.6	5.92	366.16	0.63	72.79
5/13/2004	230	19.60	1211.96	2.45	284.05	8:1	32.4	26.5	6.34	392.12	0.65	75.31
5/14/2004	231	19.60	1211.96	2.45	284.05	8:1	29.7	28.1	5.81	359.39	0.69	79.86
5/19/2004	236	19.60	1211.96	2.45	284.05	8:1	27.5	26.4	5.40	333.70	0.65	74.86
5/28/2004	245	19.60	1211.96	2.45	284.05	8:1	30.0	29.4	5.88	363.56	0.72	83.41
5/31/2004	248	19.60	1211.96	2.45	284.05	8:1	29.9	28.0	5.85	362.04	0.69	79.55
6/8/2004	256	19.60	1211.96	2.45	284.05	8:1	30.6	28.6	6.00	371.04	0.70	81.27
6/13/2004	261	19.60	1211.96	2.45	284.05	8:1	29.8	27.8	5.83	360.72	0.68	78.92

Column D: Gas Chromatograph - Average readings

Date	Inlet					Outlet				
	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane
D/M/Y	%	%	%	%	%	%	%	%	%	%
9/29/2003	19.648	71.923	0.075	2.613	N/A	23.564	76.100	0.911	2.578	N/A
10/9/2003	19.251	73.106	0.012	2.091	N/A	21.943	74.739	0.439	1.581	N/A
10/25/2003	19.572	71.718	0.053	3.061	N/A	22.449	76.140	1.783	2.261	N/A
11/9/2003	17.624	72.378	0.051	4.803	N/A	21.145	76.903	1.538	3.389	N/A
11/25/2003	19.786	73.364	0.044	4.456	N/A	19.795	76.875	1.968	3.020	N/A
12/6/2003	19.777	71.958	0.057	4.098	N/A	18.759	77.802	2.642	2.343	N/A
12/13/2003	18.065	71.578	0.071	4.183	N/A	17.350	78.145	2.422	0.999	N/A
12/19/2003	17.634	73.292	0.051	5.613	N/A	11.974	82.516	5.079	0.500	N/A
12/26/2003	18.718	71.671	0.088	6.467	N/A	12.940	82.410	4.453	0.544	N/A
1/3/2004	18.949	72.742	0.057	5.828	N/A	11.154	83.896	5.007	0.000	N/A
1/10/2004	19.149	73.158	0.087	5.835	N/A	12.061	83.705	5.722	0.000	N/A
1/12/2004	19.779	73.624	0.059	5.788	N/A	10.933	83.941	5.054	0.000	N/A
1/17/2004	18.939	71.990	0.093	5.715	N/A	11.321	84.301	5.168	0.000	N/A
1/19/2004	19.291	73.575	0.045	5.702	N/A	10.756	83.062	4.853	0.000	N/A
1/23/2004	18.674	72.374	0.067	6.554	N/A	10.730	84.557	5.098	0.000	N/A
1/24/2004	19.755	72.677	0.042	5.866	1.816	5.218	84.954	7.195	0.258	0.178
1/25/2004	18.950	73.480	0.080	6.001	1.877	5.134	84.632	7.103	0.328	0.247
1/26/2004	18.348	73.227	0.062	5.944	1.685	6.016	85.830	7.337	0.170	0.272
1/28/2004	18.993	71.801	0.085	6.283	1.746	5.116	84.844	7.934	0.076	0.254
1/30/2004	18.368	73.417	0.038	6.074	1.686	5.411	86.655	7.145	0.151	0.228
2/2/2004	19.378	72.853	0.049	6.320	1.808	5.285	86.163	7.585	0.149	0.267
2/6/2004	19.299	72.959	0.058	5.770	1.749	5.719	85.560	7.374	0.128	0.229
2/10/2004	19.118	71.834	0.059	6.075	1.874	5.784	86.004	7.693	0.144	0.244
2/12/2004	18.332	73.457	0.081	6.381	1.813	4.875	85.031	7.747	0.139	0.229
2/13/2004	18.737	73.036	0.066	8.047	2.282	1.526	86.701	8.770	0.729	0.427
2/14/2004	18.832	71.660	0.042	7.606	2.124	1.794	85.965	8.499	0.587	0.425
2/15/2004	19.056	73.473	0.060	7.292	2.133	1.891	86.706	8.299	0.755	0.447
2/17/2004	19.407	72.720	0.069	7.515	2.200	2.333	86.449	9.124	0.615	0.488
2/19/2004	18.912	73.557	0.089	8.120	2.152	1.677	85.134	9.107	0.906	0.445
2/22/2004	18.862	72.232	0.064	8.099	2.222	1.686	85.362	8.709	0.838	0.447
2/26/2004	19.617	71.992	0.071	8.000	2.220	2.309	86.115	8.541	0.859	0.482
3/1/2004	19.764	71.659	0.071	7.850	2.181	2.023	86.753	8.999	0.854	0.485
3/2/2004	19.485	72.484	0.043	9.679	2.670	-0.159	87.064	9.900	1.585	0.983
3/3/2004	18.815	73.601	0.047	9.650	2.778	0.602	86.296	8.950	1.751	1.132
3/4/2004	18.477	73.297	0.071	9.267	2.588	0.432	85.692	9.148	1.586	0.991
3/6/2004	18.865	71.720	0.042	9.292	2.581	0.121	85.756	9.347	1.527	0.977

Column D: Gas Chromatograph - Average readings (contd.)

Date	Inlet					Outlet				
	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane
D/M/Y	%	%	%	%	%	%	%	%	%	%
3/8/2004	18.869	72.905	0.050	9.581	2.685	-0.174	85.270	9.010	1.763	1.025
3/11/2004	19.786	73.615	0.090	9.024	2.673	0.653	86.396	9.512	1.598	1.051
3/15/2004	19.390	73.378	0.057	8.984	2.751	0.781	86.454	9.190	1.530	1.090
3/16/2004	18.540	73.217	0.092	9.304	2.655	1.083	86.026	9.255	1.596	1.076
3/17/2004	19.484	73.010	0.058	11.379	3.246	3.397	82.256	7.685	4.019	2.149
3/18/2004	19.030	73.181	0.066	10.842	3.268	3.972	80.789	8.200	3.576	2.336
3/19/2004	18.981	72.441	0.062	11.419	3.153	4.624	81.124	7.722	4.318	2.166
3/21/2004	19.411	72.160	0.084	10.869	3.257	5.112	80.794	6.979	4.229	2.289
3/23/2004	19.552	73.412	0.061	10.912	3.103	3.768	80.328	7.065	3.977	2.162
3/26/2004	19.722	72.196	0.079	11.194	3.203	4.329	81.575	7.962	4.056	2.243
4/1/2004	18.844	72.857	0.051	10.914	3.256	3.926	81.874	7.205	3.959	2.304
4/2/2004	19.746	72.249	0.068	12.638	3.880	8.546	74.245	5.321	7.370	2.964
4/3/2004	19.292	72.958	0.079	13.333	3.879	9.003	74.579	5.655	7.464	3.066
4/4/2004	19.603	73.018	0.076	13.010	3.819	7.540	75.067	5.926	6.879	3.093
4/7/2004	18.808	73.509	0.041	12.820	3.871	8.129	75.366	5.738	7.286	3.042
4/10/2004	19.506	72.674	0.087	13.227	3.868	8.933	76.156	5.107	7.726	3.087
4/13/2004	19.720	73.297	0.062	13.041	3.687	8.538	75.789	6.009	7.400	2.950
4/17/2004	18.915	73.081	0.093	13.058	3.806	7.960	74.954	6.225	7.296	2.973
4/19/2004	19.768	72.975	0.060	12.927	3.790	8.761	74.767	5.447	7.336	2.986
4/21/2004	18.400	72.161	0.035	15.871	4.602	11.324	70.604	3.897	11.595	3.676
4/22/2004	19.258	72.024	0.055	16.182	4.468	11.234	70.940	4.656	11.418	3.730
4/23/2004	19.228	71.870	0.070	15.216	4.576	11.440	69.060	3.860	10.741	3.677
4/25/2004	18.403	72.468	0.044	15.969	4.588	12.851	69.760	3.963	11.736	3.656
4/27/2004	18.539	73.047	0.067	15.619	4.449	12.215	68.742	4.043	11.088	3.495
4/30/2004	19.286	72.869	0.073	15.984	4.515	12.582	70.269	4.221	11.696	3.565
5/5/2004	19.071	73.145	0.088	15.845	4.433	12.981	68.423	3.910	11.280	3.474
5/10/2004	18.995	71.823	0.063	15.329	4.496	12.298	69.700	3.970	11.285	3.617
5/11/2005	18.854	73.369	0.085	19.089	5.486	13.576	65.683	3.156	13.822	4.437
5/12/2004	18.493	73.057	0.042	18.918	5.555	13.105	66.133	3.596	14.289	4.443
5/13/2004	19.265	71.933	0.072	18.918	5.405	13.258	65.491	3.123	14.234	4.396
5/14/2004	19.349	71.870	0.055	19.183	5.412	12.381	66.121	3.189	14.450	4.336
5/19/2004	18.905	72.809	0.050	18.776	5.493	13.456	66.840	3.484	14.141	4.381
5/28/2004	19.135	73.101	0.068	19.596	5.461	13.115	65.511	2.939	14.554	4.323
5/31/2004	18.599	73.084	0.042	18.618	5.530	13.044	65.249	2.928	13.799	4.289
6/8/2004	18.936	72.647	0.059	18.984	5.566	12.604	66.493	3.445	14.385	4.427
6/13/2004	19.662	72.321	0.064	19.150	5.473	13.929	66.603	3.289	14.636	4.385

Column D: Oxidation rate and Efficiency results

Date	Cum Days	Application Rate				Methane : Ethane Volume Ratio	Efficiency		Oxidation Rate			
		Methane		Ethane			Methane	Ethane	Methane		Ethane	
D/M/Y		ml/mt	g/m2/d	ml/mt	g/m2/d		%	%	ml/mt	g/m2/d	ml/mt	g/m2/d
9/29/2003	3	3.19	197.25	0.00	0.00	1:0	7	N/A	0.22	13.35	N/A	N/A
10/9/2003	13	3.19	197.25	0.00	0.00	1:0	26	N/A	0.83	51.38	N/A	N/A
10/25/2003	29	3.19	197.25	0.00	0.00	1:0	30	N/A	0.97	60.03	N/A	N/A
11/9/2003	44	4.99	308.55	0.00	0.00	1:0	34	N/A	1.68	103.62	N/A	N/A
11/25/2003	60	4.99	308.55	0.00	0.00	1:0	35	N/A	1.76	108.96	N/A	N/A
12/6/2003	71	4.99	308.55	0.00	0.00	1:0	47	N/A	2.35	145.36	N/A	N/A
12/13/2003	78	4.99	308.55	0.00	0.00	1:0	78	N/A	3.90	241.04	N/A	N/A
12/19/2003	84	6.58	406.87	0.00	0.00	1:0	92	N/A	6.06	374.65	N/A	N/A
12/26/2003	91	6.58	406.87	0.00	0.00	1:0	93	N/A	6.10	377.11	N/A	N/A
1/3/2004	99	6.58	406.87	0.00	0.00	1:0	100	N/A	6.58	406.87	N/A	N/A
1/10/2004	106	6.58	406.87	0.00	0.00	1:0	100	N/A	6.58	406.87	N/A	N/A
1/12/2004	108	6.58	406.87	0.00	0.00	1:0	100	N/A	6.58	406.87	N/A	N/A
1/17/2004	113	6.58	406.87	0.00	0.00	1:0	100	N/A	6.58	406.87	N/A	N/A
1/19/2004	115	6.58	406.87	0.00	0.00	1:0	100	N/A	6.58	406.87	N/A	N/A
1/23/2004	119	6.58	406.87	0.00	0.00	1:0	100	N/A	6.58	406.87	N/A	N/A
1/24/2004	120	6.58	406.87	1.88	217.97	7:2	96	92	6.33	391.55	1.72	199.71
1/25/2004	121	6.58	406.87	1.88	217.97	7:2	95	89	6.27	387.56	1.67	193.04
1/26/2004	122	6.58	406.87	1.88	217.97	7:2	98	86	6.42	396.96	1.62	187.96
1/28/2004	124	6.58	406.87	1.88	217.97	7:2	99	88	6.51	402.73	1.65	191.12
1/30/2004	126	6.58	406.87	1.88	217.97	7:2	98	89	6.44	398.32	1.67	193.04
2/2/2004	129	6.58	406.87	1.88	217.97	7:2	98	88	6.45	398.77	1.65	190.77
2/6/2004	133	6.58	406.87	1.88	217.97	7:2	98	89	6.46	399.19	1.67	193.59
2/10/2004	137	6.58	406.87	1.88	217.97	7:2	98	89	6.45	398.84	1.68	194.25
2/12/2004	139	6.58	406.87	1.88	217.97	7:2	98	89	6.46	399.23	1.67	194.18
2/13/2004	140	8.12	502.10	2.32	268.98	7:2	92	84	7.50	463.76	1.95	226.57
2/14/2004	141	8.12	502.10	2.32	268.98	7:2	94	83	7.60	469.79	1.93	224.12
2/15/2004	142	8.12	502.10	2.32	268.98	7:2	91	82	7.41	458.07	1.91	221.19
2/17/2004	144	8.12	502.10	2.32	268.98	7:2	93	81	7.56	467.54	1.89	218.83
2/19/2004	146	8.12	502.10	2.32	268.98	7:2	90	82	7.34	453.70	1.91	220.98
2/22/2004	149	8.12	502.10	2.32	268.98	7:2	91	83	7.41	458.14	1.93	223.22
2/26/2004	153	8.12	502.10	2.32	268.98	7:2	91	82	7.39	457.01	1.90	220.17
3/1/2004	157	8.12	502.10	2.32	268.98	7:2	91	82	7.39	456.96	1.89	219.53
3/2/2004	158	9.73	601.65	2.78	322.31	7:2	86	69	8.40	519.61	1.93	223.48
3/3/2004	159	9.73	601.65	2.78	322.31	7:2	85	65	8.22	508.52	1.81	210.25
3/4/2004	160	9.73	601.65	2.78	322.31	7:2	85	67	8.31	513.57	1.87	216.70
3/6/2004	162	9.73	601.65	2.78	322.31	7:2	86	68	8.39	518.95	1.90	220.30

Column D: Oxidation rate and Efficiency results (contd.)

Date	Cum Days	Application Rate				Methane : Ethane Volume Ratio	Efficiency		Oxidation Rate			
		Methane		Ethane			Methane	Ethane	Methane		Ethane	
D/M/Y		ml/mt	g/m2/d	ml/mt	g/m2/d		%	%	ml/mt	g/m2/d	ml/mt	g/m2/d
3/8/2004	164	9.73	601.65	2.78	322.31	7:2	84	67	8.20	507.01	1.87	217.08
3/11/2004	167	9.73	601.65	2.78	322.31	7:2	85	67	8.26	510.88	1.85	214.34
3/15/2004	171	9.73	601.65	2.78	322.31	7:2	86	66	8.32	514.66	1.84	213.90
3/16/2004	172	9.73	601.65	2.78	322.31	7:2	85	66	8.31	513.82	1.82	211.12
3/17/2004	173	11.51	711.72	3.29	381.28	7:2	69	41	7.90	488.62	1.36	157.20
3/18/2004	174	11.51	711.72	3.29	381.28	7:2	70	35	8.07	499.08	1.16	134.46
3/19/2004	175	11.51	711.72	3.29	381.28	7:2	66	39	7.62	471.40	1.27	147.39
3/21/2004	177	11.51	711.72	3.29	381.28	7:2	65	37	7.51	464.42	1.22	141.96
3/23/2004	179	11.51	711.72	3.29	381.28	7:2	67	36	7.68	474.64	1.19	138.48
3/26/2004	182	11.51	711.72	3.29	381.28	7:2	68	38	7.82	483.50	1.25	144.97
4/1/2004	188	11.51	711.72	3.29	381.28	7:2	68	37	7.79	481.98	1.22	141.15
4/2/2004	189	13.60	840.95	3.89	450.51	7:2	43	26	5.88	363.73	1.00	115.57
4/3/2004	190	13.60	840.95	3.89	450.51	7:2	45	23	6.15	380.41	0.88	102.19
4/4/2004	191	13.60	840.95	3.89	450.51	7:2	49	21	6.61	408.42	0.82	95.62
4/7/2004	194	13.60	840.95	3.89	450.51	7:2	45	23	6.06	374.76	0.91	105.20
4/10/2004	197	13.60	840.95	3.89	450.51	7:2	44	24	6.02	372.17	0.93	107.37
4/13/2004	200	13.60	840.95	3.89	450.51	7:2	45	23	6.14	379.45	0.88	101.92
4/17/2004	204	13.60	840.95	3.89	450.51	7:2	46	24	6.19	382.81	0.93	107.48
4/19/2004	206	13.60	840.95	3.89	450.51	7:2	45	23	6.07	375.16	0.90	104.07
4/21/2004	208	16.20	1001.72	4.63	536.64	7:2	25	18	4.10	253.78	0.85	98.51
4/22/2004	209	16.20	1001.72	4.63	536.64	7:2	28	15	4.59	284.10	0.71	81.86
4/23/2004	210	16.20	1001.72	4.63	536.64	7:2	27	16	4.30	265.79	0.76	87.82
4/25/2004	212	16.20	1001.72	4.63	536.64	7:2	24	17	3.83	236.95	0.80	92.50
4/27/2004	214	16.20	1001.72	4.63	536.64	7:2	25	17	3.98	246.10	0.77	88.73
4/30/2004	217	16.20	1001.72	4.63	536.64	7:2	24	18	3.91	241.64	0.84	97.24
5/5/2004	222	16.20	1001.72	4.63	536.64	7:2	24	16	3.87	239.36	0.75	87.01
5/10/2004	227	16.20	1001.72	4.63	536.64	7:2	24	17	3.91	241.86	0.79	91.82
5/11/2005	228	19.60	1211.96	5.60	649.26	7:2	19	10	3.75	231.69	0.54	62.68
5/12/2004	229	19.60	1211.96	5.60	649.26	7:2	17	12	3.25	200.75	0.65	75.67
5/13/2004	230	19.60	1211.96	5.60	649.26	7:2	17	11	3.40	210.36	0.60	69.17
5/14/2004	231	19.60	1211.96	5.60	649.26	7:2	18	13	3.55	219.63	0.72	83.75
5/19/2004	236	19.60	1211.96	5.60	649.26	7:2	18	13	3.52	217.62	0.73	85.19
5/28/2004	245	19.60	1211.96	5.60	649.26	7:2	17	12	3.36	207.57	0.65	75.67
5/31/2004	248	19.60	1211.96	5.60	649.26	7:2	17	13	3.33	205.86	0.74	85.26
6/8/2004	256	19.60	1211.96	5.60	649.26	7:2	17	13	3.37	208.60	0.73	85.04
6/13/2004	261	19.60	1211.96	5.60	649.26	7:2	17	13	3.33	206.17	0.73	84.47

Column E: Gas Chromatograph - Average readings

Date	Inlet					Outlet				
	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane
D/M/Y	%	%	%	%	%	%	%	%	%	%
9/29/2003	19.324	73.231	0.187	2.796	N/A	23.924	75.923	0.037	2.780	N/A
10/9/2003	19.193	73.629	0.182	2.843	N/A	22.572	77.291	0.346	2.215	N/A
10/25/2003	18.701	72.492	0.186	2.574	N/A	21.821	77.776	0.782	1.762	N/A
11/9/2003	18.076	72.911	0.176	3.761	N/A	19.490	77.693	1.284	2.396	N/A
11/25/2003	18.579	72.591	0.165	4.286	N/A	19.195	77.680	1.145	2.587	N/A
12/6/2003	17.936	73.008	0.143	4.013	N/A	16.415	79.539	2.523	1.695	N/A
12/13/2003	19.154	72.322	0.145	4.410	N/A	14.927	80.320	3.766	0.508	N/A
12/19/2003	19.734	72.585	0.138	5.636	N/A	10.052	83.806	5.086	0.283	N/A
12/26/2003	17.972	73.417	0.134	6.373	N/A	9.949	84.036	4.932	0.000	N/A
1/3/2004	19.413	72.838	0.184	6.452	N/A	9.934	84.435	6.250	0.000	N/A
1/10/2004	19.299	73.371	0.132	6.385	N/A	9.479	83.841	5.399	0.000	N/A
1/12/2004	19.793	73.128	0.174	6.139	N/A	9.569	83.973	5.974	0.000	N/A
1/17/2004	19.271	72.970	0.186	6.250	N/A	8.639	82.993	6.186	0.000	N/A
1/19/2004	19.715	72.162	0.164	6.576	N/A	8.959	83.051	5.968	0.000	N/A
1/23/2004	19.314	72.984	0.155	5.803	N/A	9.683	84.496	5.318	0.000	N/A
1/24/2004	18.335	73.548	0.144	5.705	5.169	4.016	79.974	7.945	1.775	3.240
1/25/2004	18.343	72.141	0.144	6.455	5.091	5.076	78.348	6.820	2.534	3.285
1/26/2004	18.955	71.908	0.172	6.359	5.215	5.942	78.845	6.835	2.769	3.297
1/28/2004	19.282	72.682	0.168	5.637	5.131	7.050	78.485	6.324	2.162	3.513
1/30/2004	18.965	72.508	0.177	5.759	5.199	5.520	78.292	7.126	2.391	3.388
2/2/2004	18.941	73.547	0.181	6.237	5.234	7.593	78.020	6.753	2.760	3.429
2/6/2004	18.393	72.850	0.179	5.643	5.161	7.844	78.593	6.421	2.659	3.460
2/10/2004	18.644	72.985	0.188	5.626	5.189	6.834	78.559	6.722	2.511	3.432
2/12/2004	19.360	73.399	0.158	6.146	5.134	6.534	77.695	6.329	2.850	3.186
2/13/2004	19.648	71.677	0.143	5.992	5.136	6.789	78.576	6.666	2.817	3.360
2/14/2004	19.119	73.321	0.177	6.563	5.085	7.104	78.653	6.369	2.996	3.351
2/15/2004	19.821	72.789	0.182	6.208	5.150	6.625	77.549	6.069	2.867	3.310
2/17/2004	19.701	72.897	0.187	6.161	5.151	5.930	78.129	6.560	2.796	3.300
2/19/2004	19.714	71.767	0.181	5.909	5.084	6.129	78.818	6.482	2.796	3.230
2/22/2004	18.781	72.213	0.140	6.161	5.211	6.538	77.778	6.267	2.902	3.333
2/26/2004	18.720	72.529	0.169	5.951	5.242	6.760	78.165	6.597	2.673	3.303
3/1/2004	19.014	72.754	0.160	6.281	5.101	6.926	78.111	6.538	2.896	3.231
3/2/2004	18.860	72.183	0.155	7.473	6.342	5.932	75.623	6.534	3.896	4.547
3/3/2004	19.065	72.745	0.132	8.072	6.319	7.080	75.381	6.334	4.303	4.697
3/4/2004	18.772	73.463	0.135	7.556	6.347	7.164	76.202	6.520	3.980	4.643
3/6/2004	19.424	73.196	0.179	7.347	6.437	6.064	76.951	6.186	3.759	4.653

Column E: Gas Chromatograph - Average readings (contd.)

Date	Inlet					Outlet				
	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane
D/M/Y	%	%	%	%	%	%	%	%	%	%
3/8/2004	19.251	73.458	0.158	8.090	6.407	4.342	78.028	7.671	3.922	4.447
3/11/2004	19.729	72.679	0.131	7.816	6.434	5.676	77.334	7.431	3.881	4.645
3/15/2004	18.435	72.040	0.145	7.419	6.469	4.913	76.690	7.288	3.763	4.566
3/16/2004	18.949	72.875	0.167	7.723	6.451	5.933	76.173	7.300	3.698	4.637
3/17/2004	18.652	72.228	0.183	7.806	6.332	5.713	76.536	7.354	3.830	4.554
3/18/2004	18.580	73.026	0.182	7.222	6.477	5.481	77.781	6.470	3.663	4.684
3/19/2004	19.373	72.268	0.183	7.589	6.297	5.478	76.258	6.667	3.905	4.568
3/21/2004	18.426	73.455	0.137	7.240	6.362	5.711	76.098	6.944	3.591	4.402
3/23/2004	19.618	73.188	0.186	7.781	6.411	5.594	77.851	7.381	3.818	4.595
3/26/2004	19.182	71.793	0.175	7.707	6.445	4.772	76.845	7.403	3.928	4.632
4/1/2004	19.044	72.999	0.165	7.659	6.433	4.622	77.270	7.316	3.807	4.622
4/2/2004	18.840	71.938	0.169	9.119	7.598	6.794	73.148	5.158	5.598	5.997
4/3/2004	19.191	72.095	0.184	9.649	7.673	9.669	73.249	5.059	6.349	6.264
4/4/2004	18.803	72.316	0.134	9.116	7.764	9.305	71.514	4.397	5.631	6.453
4/7/2004	19.243	73.557	0.183	9.417	7.625	9.885	73.027	5.033	5.642	6.416
4/10/2004	19.480	72.046	0.164	9.519	7.598	10.133	71.660	5.048	5.804	6.372
4/13/2004	19.773	73.512	0.186	9.665	7.652	9.967	72.319	4.489	5.897	6.418
4/17/2004	19.803	72.531	0.152	9.469	7.703	8.905	72.182	4.694	5.822	6.423
4/19/2004	19.335	72.630	0.132	9.280	7.666	10.681	71.527	4.670	5.666	6.454
4/21/2004	19.067	72.198	0.182	11.505	9.130	12.620	67.173	2.612	8.529	7.625
4/22/2004	18.757	72.072	0.152	11.267	9.026	13.922	66.161	1.897	8.664	7.576
4/23/2004	19.273	72.809	0.148	11.027	9.172	15.058	66.073	2.190	8.042	7.805
4/25/2004	18.630	72.309	0.172	11.086	9.053	14.133	67.461	2.523	8.652	7.723
4/27/2004	19.445	72.472	0.163	10.947	9.056	12.961	66.616	2.607	8.194	7.530
4/30/2004	19.246	73.618	0.130	10.679	9.139	13.022	68.112	2.922	8.177	7.591
5/5/2004	18.917	73.146	0.169	10.685	9.112	14.744	67.274	2.428	8.145	7.615
5/10/2004	19.195	72.079	0.185	10.903	9.194	14.790	65.964	2.438	8.280	7.656
5/11/2005	19.324	72.865	0.174	12.840	10.845	13.981	64.998	2.030	9.941	9.030
5/12/2004	18.360	72.146	0.163	13.557	10.822	14.925	62.983	1.133	10.505	9.020
5/13/2004	19.268	72.598	0.146	13.336	10.783	14.354	63.981	2.387	10.046	9.005
5/14/2004	18.489	73.372	0.183	12.852	10.788	14.220	64.443	1.538	9.792	8.882
5/19/2004	19.658	72.924	0.129	13.389	10.747	14.962	64.854	1.639	10.572	8.867
5/28/2004	18.331	72.715	0.188	12.955	10.874	13.827	64.320	1.966	10.084	8.853
5/31/2004	18.751	72.870	0.146	13.393	10.716	15.008	64.005	1.374	10.504	8.767
6/8/2004	19.527	73.301	0.133	13.098	10.683	14.536	63.654	1.935	9.992	8.569
6/13/2004	19.302	71.698	0.171	13.478	10.717	14.221	63.762	2.150	10.690	8.885

Column E: Oxidation rate and Efficiency results

Date	Cum Days	Application Rate				Methane : Ethane Volume Ratio	Efficiency		Oxidation Rate			
		Methane		Ethane			Methane	Ethane	Methane		Ethane	
D/M/Y		ml/mt	g/m2/d	ml/mt	g/m2/d		%	%	ml/mt	g/m2/d	ml/mt	g/m2/d
9/29/2003	3	3.19	197	0.00	0	1:0	4.093	N/A	0.13	8.07	N/A	N/A
10/9/2003	13	3.19	197	0.00	0	1:0	25.793	N/A	0.82	50.88	N/A	N/A
10/25/2003	29	3.19	197	0.00	0	1:0	36.187	N/A	1.15	71.38	N/A	N/A
11/9/2003	44	4.99	309	0.00	0	1:0	40.206	N/A	2.01	124.06	N/A	N/A
11/25/2003	60	4.99	309	0.00	0	1:0	43.605	N/A	2.18	134.55	N/A	N/A
12/6/2003	71	4.99	309	0.00	0	1:0	61.237	N/A	3.06	188.95	N/A	N/A
12/13/2003	78	4.99	309	0.00	0	1:0	89.632	N/A	4.47	276.56	N/A	N/A
12/19/2003	84	6.58	407	0.00	0	1:0	95.658	N/A	6.29	389.21	N/A	N/A
12/26/2003	91	6.58	407	0.00	0	1:0	100.000	N/A	6.58	406.87	N/A	N/A
1/3/2004	99	6.58	407	0.00	0	1:0	100.000	N/A	6.58	406.87	N/A	N/A
1/10/2004	106	6.58	407	0.00	0	1:0	100.000	N/A	6.58	406.87	N/A	N/A
1/12/2004	108	6.58	407	0.00	0	1:0	100.000	N/A	6.58	406.87	N/A	N/A
1/17/2004	113	6.58	407	0.00	0	1:0	100.000	N/A	6.58	406.87	N/A	N/A
1/19/2004	115	6.58	407	0.00	0	1:0	100.000	N/A	6.58	406.87	N/A	N/A
1/23/2004	119	6.58	407	0.00	0	1:0	100.000	N/A	6.58	406.87	N/A	N/A
1/24/2004	120	6.58	407	5.26	610	5:4	71.386	42.350	4.70	290.45	2.23	258.47
1/25/2004	121	6.58	407	5.26	610	5:4	63.850	40.590	4.20	259.79	2.14	247.72
1/26/2004	122	6.58	407	5.26	610	5:4	60.292	42.331	3.97	245.31	2.23	258.35
1/28/2004	124	6.58	407	5.26	610	5:4	64.480	36.584	4.24	262.35	1.93	223.27
1/30/2004	126	6.58	407	5.26	610	5:4	61.545	39.654	4.05	250.41	2.09	242.01
2/2/2004	129	6.58	407	5.26	610	5:4	58.284	38.231	3.84	237.14	2.01	233.33
2/6/2004	133	6.58	407	5.26	610	5:4	56.321	37.856	3.71	229.15	1.99	231.04
2/10/2004	137	6.58	407	5.26	610	5:4	58.530	38.560	3.85	238.14	2.03	235.33
2/12/2004	139	6.58	407	5.26	610	5:4	56.190	41.367	3.70	228.62	2.18	252.47
2/13/2004	140	6.58	407	5.26	610	5:4	57.121	40.329	3.76	232.41	2.12	246.13
2/14/2004	141	6.58	407	5.26	610	5:4	57.451	38.564	3.78	233.75	2.03	235.36
2/15/2004	142	6.58	407	5.26	610	5:4	56.654	39.685	3.73	230.51	2.09	242.20
2/17/2004	144	6.58	407	5.26	610	5:4	57.658	40.232	3.79	234.59	2.12	245.54
2/19/2004	146	6.58	407	5.26	610	5:4	56.911	42.152	3.74	231.55	2.22	257.26
2/22/2004	149	6.58	407	5.26	610	5:4	56.265	40.613	3.70	228.93	2.14	247.86
2/26/2004	153	6.58	407	5.26	610	5:4	58.314	41.525	3.84	237.26	2.19	253.43
3/1/2004	157	6.58	407	5.26	610	5:4	57.051	41.010	3.75	232.12	2.16	250.29
3/2/2004	158	8.12	502	6.50	753	5:4	50.235	31.560	4.08	252.23	2.05	237.69
3/3/2004	159	8.12	502	6.50	753	5:4	48.561	28.267	3.94	243.82	1.84	212.89
3/4/2004	160	8.12	502	6.50	753	5:4	49.225	29.480	4.00	247.16	1.92	222.03
3/6/2004	162	8.12	502	6.50	753	5:4	51.336	31.234	4.17	257.76	2.03	235.24

Column E: Oxidation rate and Efficiency results (contd.)

Date	Cum Days	Application Rate				Methane : Ethane Volume Ratio	Efficiency		Oxidation Rate			
		Methane		Ethane			Methane	Ethane	Methane		Ethane	
D/M/Y		ml/mt	g/m2/d	ml/mt	g/m2/d		%	%	ml/mt	g/m2/d	ml/mt	g/m2/d
3/8/2004	164	8.12	502.10	6.50	753.15	5:4	54.364	34.651	4.414	272.960	2.251	260.972
3/11/2004	167	8.12	502.10	6.50	753.15	5:4	53.338	32.151	4.331	267.808	2.089	242.144
3/15/2004	171	8.12	502.10	6.50	753.15	5:4	52.357	33.699	4.251	262.883	2.189	253.802
3/16/2004	172	8.12	502.10	6.50	753.15	5:4	54.186	31.228	4.400	272.066	2.029	235.192
3/17/2004	173	8.12	502.10	6.50	753.15	5:4	53.694	32.128	4.360	269.596	2.087	241.970
3/18/2004	174	8.12	502.10	6.50	753.15	5:4	52.378	32.112	4.253	262.988	2.086	241.850
3/19/2004	175	8.12	502.10	6.50	753.15	5:4	51.234	31.251	4.160	257.244	2.030	235.365
3/21/2004	177	8.12	502.10	6.50	753.15	5:4	52.121	33.221	4.232	261.698	2.158	250.202
3/23/2004	179	8.12	502.10	6.50	753.15	5:4	53.869	32.625	4.374	270.475	2.119	245.714
3/26/2004	182	8.12	502.10	6.50	753.15	5:4	52.389	32.851	4.254	263.043	2.134	247.416
4/1/2004	188	8.12	502.10	6.50	753.15	5:4	53.035	32.122	4.306	266.287	2.087	241.925
4/2/2004	189	9.73	601.65	7.78	902.48	5:4	39.624	22.367	3.855	238.398	1.741	201.857
4/3/2004	190	9.73	601.65	7.78	902.48	5:4	35.238	19.654	3.429	212.010	1.530	177.373
4/4/2004	191	9.73	601.65	7.78	902.48	5:4	37.532	15.954	3.652	225.811	1.242	143.981
4/7/2004	194	9.73	601.65	7.78	902.48	5:4	39.654	15.251	3.858	238.578	1.187	137.637
4/10/2004	197	9.73	601.65	7.78	902.48	5:4	38.695	15.685	3.765	232.809	1.221	141.553
4/13/2004	200	9.73	601.65	7.78	902.48	5:4	37.981	14.734	3.696	228.513	1.147	132.971
4/17/2004	204	9.73	601.65	7.78	902.48	5:4	38.221	16.222	3.719	229.957	1.263	146.400
4/19/2004	206	9.73	601.65	7.78	902.48	5:4	38.007	14.510	3.698	228.669	1.129	130.949
4/21/2004	208	11.51	711.72	9.21	1067.57	5:4	20.321	10.234	2.339	144.628	0.942	109.256
4/22/2004	209	11.51	711.72	9.21	1067.57	5:4	16.238	8.564	1.869	115.568	0.789	91.427
4/23/2004	210	11.51	711.72	9.21	1067.57	5:4	19.636	6.233	2.260	139.753	0.574	66.542
4/25/2004	212	11.51	711.72	9.21	1067.57	5:4	16.352	8.562	1.882	116.380	0.788	91.406
4/27/2004	214	11.51	711.72	9.21	1067.57	5:4	18.564	9.535	2.137	132.123	0.878	101.793
4/30/2004	217	11.51	711.72	9.21	1067.57	5:4	17.233	10.221	1.984	122.650	0.941	109.117
5/5/2004	222	11.51	711.72	9.21	1067.57	5:4	17.121	9.124	1.971	121.853	0.840	97.405
5/10/2004	227	11.51	711.72	9.21	1067.57	5:4	17.020	9.014	1.959	121.134	0.830	96.231
5/11/2005	228	13.60	840.95	10.88	1261.43	5:4	13.212	6.652	1.797	111.106	0.724	83.910
5/12/2004	229	13.60	840.95	10.88	1261.43	5:4	11.233	4.521	1.528	94.464	0.492	57.029
5/13/2004	230	13.60	840.95	10.88	1261.43	5:4	14.523	5.233	1.975	122.131	0.569	66.010
5/14/2004	231	13.60	840.95	10.88	1261.43	5:4	13.252	6.258	1.802	111.443	0.681	78.940
5/19/2004	236	13.60	840.95	10.88	1261.43	5:4	11.212	7.235	1.525	94.287	0.787	91.264
5/28/2004	245	13.60	840.95	10.88	1261.43	5:4	12.003	7.954	1.632	100.939	0.865	100.334
5/31/2004	248	13.60	840.95	10.88	1261.43	5:4	10.711	6.861	1.457	90.074	0.746	86.546
6/8/2004	256	13.60	840.95	10.88	1261.43	5:4	12.152	7.634	1.653	102.192	0.831	96.297
6/13/2004	261	13.60	840.95	10.88	1261.43	5:4	10.817	6.782	1.471	90.966	0.738	85.550

Column F: Gas Chromatograph - Average readings

Date	Inlet					Outlet				
	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane
D/M/Y	%	%	%	%	%	%	%	%	%	%
9/29/2003	19.253	71.782	0.094	35.758	N/A	9.943	58.262	2.533	26.428	N/A
10/9/2003	19.629	72.303	0.042	35.973	N/A	9.697	58.951	3.340	25.743	N/A
10/25/2003	18.715	72.227	0.071	35.282	N/A	8.041	63.152	4.020	24.580	N/A
11/9/2003	19.466	72.717	0.005	34.499	N/A	6.809	62.624	4.339	22.621	N/A
11/25/2003	19.139	72.975	0.075	34.791	N/A	7.871	63.264	3.784	24.030	N/A
12/6/2003	19.335	73.446	0.034	33.859	N/A	7.810	63.040	4.023	23.679	N/A
12/13/2003	19.781	72.805	0.085	36.007	N/A	7.426	63.359	3.685	24.654	N/A
12/19/2003	18.522	72.501	0.029	34.479	N/A	8.365	63.426	3.518	24.245	N/A
12/26/2003	18.393	72.183	0.071	36.089	N/A	9.290	60.415	3.562	26.475	N/A
1/3/2004	18.444	72.380	0.062	35.204	N/A	9.244	60.416	3.188	24.794	N/A
1/10/2004	18.396	70.970	0.059	35.916	N/A	7.471	59.964	3.299	25.419	N/A
1/12/2004	17.700	71.894	0.067	35.043	N/A	8.614	61.029	3.770	25.513	N/A
1/17/2004	19.369	72.509	0.085	35.689	N/A	8.257	61.033	3.098	25.164	N/A
1/19/2004	18.338	71.657	0.080	36.021	N/A	10.383	60.305	3.129	26.909	N/A
1/23/2004	19.741	71.782	0.071	35.901	N/A	10.188	59.113	3.415	25.911	N/A
1/24/2004	18.545	71.823	0.059	35.305	N/A	8.887	60.777	3.608	25.587	N/A
1/25/2004	18.393	73.469	0.047	35.279	N/A	8.799	61.647	3.080	24.977	N/A
1/26/2004	18.863	73.467	0.084	35.796	N/A	9.446	61.630	3.395	25.121	N/A
1/28/2004	18.854	72.531	0.075	35.228	N/A	8.650	61.408	3.379	25.282	N/A
1/30/2004	19.718	72.176	0.058	35.649	N/A	10.039	59.455	2.927	25.737	N/A
2/2/2004	19.637	72.518	0.047	35.883	N/A	8.626	59.916	3.093	25.428	N/A
2/6/2004	18.510	73.617	0.085	35.003	N/A	9.829	60.397	3.381	25.490	N/A
2/10/2004	18.879	72.626	0.051	34.860	N/A	8.671	59.956	3.467	24.645	N/A
2/12/2004	19.040	72.609	0.059	35.481	N/A	9.146	60.906	3.616	25.228	N/A
2/13/2004	19.222	73.619	0.040	34.673	N/A	10.132	59.851	2.734	24.703	N/A
2/14/2004	19.388	72.107	0.063	35.205	N/A	9.843	60.795	3.279	25.748	N/A
2/15/2004	18.468	73.344	0.062	35.805	N/A	9.007	60.361	3.376	24.939	N/A
2/17/2004	19.286	73.234	0.042	35.392	N/A	9.314	60.313	3.518	24.964	N/A
2/19/2004	19.486	72.656	0.057	35.628	N/A	9.843	60.870	3.504	26.159	N/A
2/22/2004	18.388	73.106	0.053	34.611	N/A	9.996	59.732	2.905	24.528	N/A
2/26/2004	18.561	72.280	0.056	34.976	N/A	8.333	60.682	3.483	24.852	N/A
3/1/2004	18.650	73.596	0.064	35.634	N/A	9.370	59.470	3.313	25.523	N/A
3/2/2004	18.557	73.268	0.050	35.447	N/A	10.559	60.483	3.344	25.974	N/A
3/3/2004	19.733	73.584	0.091	35.145	N/A	9.699	59.999	3.718	24.484	N/A
3/4/2004	19.372	72.158	0.060	36.051	N/A	10.193	60.879	3.566	26.595	N/A
3/6/2004	18.858	72.525	0.038	35.554	N/A	9.396	60.770	2.875	26.111	N/A

Column F: Gas Chromatograph - Average readings

Date	Inlet					Outlet				
	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane	Oxygen	Nitrogen	Carbon Dioxide	Methane	Ethane
D/M/Y	%	%	%	%	%	%	%	%	%	%
3/8/2004	19.482	72.311	0.057	35.214	N/A	9.123	61.655	3.823	25.325	N/A
3/11/2004	18.606	72.903	0.045	34.686	N/A	10.389	59.030	2.824	24.612	N/A
3/15/2004	19.240	73.072	0.090	35.288	N/A	8.966	60.113	3.289	25.093	N/A
3/16/2004	19.478	72.173	0.037	34.650	N/A	8.931	60.255	3.429	24.723	N/A
3/17/2004	18.967	72.750	0.043	35.081	N/A	9.133	59.444	3.374	24.871	N/A
3/18/2004	19.768	72.454	0.066	35.381	N/A	9.360	59.730	2.759	25.552	N/A
3/19/2004	18.562	72.551	0.089	34.908	N/A	10.743	59.630	2.716	25.465	N/A
3/21/2004	19.356	72.557	0.073	34.694	N/A	8.686	59.978	3.248	24.562	N/A
3/23/2004	19.759	72.964	0.087	35.223	N/A	9.850	60.116	3.371	25.432	N/A
3/26/2004	19.789	72.029	0.042	35.473	N/A	10.911	59.529	2.650	26.317	N/A
4/1/2004	18.408	71.721	0.087	34.893	N/A	9.451	58.994	2.570	25.476	N/A
4/2/2004	19.202	71.888	0.093	35.461	N/A	10.043	59.889	3.240	25.890	N/A
4/3/2004	19.740	72.818	0.094	35.470	N/A	10.238	59.458	3.391	25.091	N/A
4/4/2004	19.188	73.618	0.054	34.749	N/A	9.838	59.302	3.455	24.843	N/A
4/7/2004	18.421	72.264	0.059	35.585	N/A	10.157	60.563	3.592	25.870	N/A
4/10/2004	18.570	71.724	0.041	35.576	N/A	8.603	61.443	3.560	26.137	N/A
4/13/2004	18.695	73.109	0.039	34.873	N/A	10.194	59.446	2.728	25.136	N/A
4/17/2004	19.060	71.712	0.056	34.809	N/A	10.367	59.040	2.742	25.111	N/A
4/19/2004	19.752	71.689	0.038	35.376	N/A	10.073	59.189	3.072	25.999	N/A
4/21/2004	19.655	71.675	0.063	35.217	N/A	9.310	58.698	3.048	25.601	N/A
4/22/2004	19.175	71.835	0.052	35.158	N/A	10.326	58.676	3.159	26.259	N/A
4/23/2004	18.508	73.323	0.090	35.178	N/A	11.144	59.459	2.933	26.210	N/A
4/25/2004	18.431	72.585	0.037	35.261	N/A	11.298	59.279	2.456	26.481	N/A
4/27/2004	18.356	72.298	0.053	35.645	N/A	10.084	58.915	2.713	26.073	N/A
4/30/2004	18.692	73.335	0.063	35.485	N/A	10.548	58.553	2.573	26.000	N/A
5/5/2004	19.138	73.146	0.074	35.780	N/A	9.944	58.569	2.347	25.966	N/A
5/10/2004	19.757	72.932	0.049	36.025	N/A	9.655	58.673	2.851	26.014	N/A
5/11/2005	18.675	72.264	0.075	35.334	N/A	10.552	58.056	3.090	26.049	N/A
5/12/2004	19.502	71.939	0.081	34.697	N/A	10.517	58.990	3.051	25.731	N/A
5/13/2004	19.598	72.686	0.045	34.740	N/A	11.022	59.861	3.124	25.682	N/A
5/14/2004	19.134	72.817	0.066	35.691	N/A	10.927	58.611	3.313	25.954	N/A
5/19/2004	18.849	71.951	0.054	34.637	N/A	10.717	59.509	2.510	26.204	N/A
5/28/2004	19.446	72.565	0.077	34.635	N/A	11.273	58.299	2.947	25.591	N/A
5/31/2004	19.014	73.164	0.071	36.037	N/A	10.125	58.641	2.678	26.133	N/A
6/8/2004	18.664	72.279	0.045	35.480	N/A	10.877	58.390	3.064	26.207	N/A
6/13/2004	19.373	71.662	0.093	34.873	N/A	11.469	59.215	2.963	26.475	N/A

Column F: Oxidation rate and Efficiency results

Date	Cum Days	Application Rate				Methane : Ethane Volume Ratio	Efficiency		Oxidation Rate			
		Methane		Ethane			Methane	Ethane	Methane		Ethane	
D/M/Y		ml/mt	g/m2/d	ml/mt	g/m2/d		%	%	ml/mt	g/m2/d	ml/mt	g/m2/d
9/29/2003	3	36.10	2232.2	0.00	0.0	1:0	8.94	N/A	3.23	199.58	N/A	N/A
10/9/2003	13	36.10	2232.2	0.00	0.0	1:0	12.23	N/A	4.42	273.02	N/A	N/A
10/25/2003	29	36.10	2232.2	0.00	0.0	1:0	20.32	N/A	7.34	453.61	N/A	N/A
11/9/2003	44	36.10	2232.2	0.00	0.0	1:0	23.86	N/A	8.61	532.63	N/A	N/A
11/25/2003	60	36.10	2232.2	0.00	0.0	1:0	20.33	N/A	7.34	453.77	N/A	N/A
12/6/2003	71	36.10	2232.2	0.00	0.0	1:0	18.52	N/A	6.69	413.48	N/A	N/A
12/13/2003	78	36.10	2232.2	0.00	0.0	1:0	21.32	N/A	7.70	475.93	N/A	N/A
12/19/2003	84	36.10	2232.2	0.00	0.0	1:0	19.62	N/A	7.08	437.99	N/A	N/A
12/26/2003	91	36.10	2232.2	0.00	0.0	1:0	12.35	N/A	4.46	275.70	N/A	N/A
1/3/2004	99	36.10	2232.2	0.00	0.0	1:0	15.62	N/A	5.64	348.76	N/A	N/A
1/10/2004	106	36.10	2232.2	0.00	0.0	1:0	16.24	N/A	5.86	362.45	N/A	N/A
1/12/2004	108	36.10	2232.2	0.00	0.0	1:0	14.23	N/A	5.14	317.67	N/A	N/A
1/17/2004	113	36.10	2232.2	0.00	0.0	1:0	16.23	N/A	5.86	362.38	N/A	N/A
1/19/2004	115	36.10	2232.2	0.00	0.0	1:0	11.23	N/A	4.06	250.77	N/A	N/A
1/23/2004	119	36.10	2232.2	0.00	0.0	1:0	12.36	N/A	4.46	275.84	N/A	N/A
1/24/2004	120	36.10	2232.2	0.00	0.0	1:0	14.36	N/A	5.18	320.46	N/A	N/A
1/25/2004	121	36.10	2232.2	0.00	0.0	1:0	15.62	N/A	5.64	348.76	N/A	N/A
1/26/2004	122	36.10	2232.2	0.00	0.0	1:0	16.35	N/A	5.90	364.86	N/A	N/A
1/28/2004	124	36.10	2232.2	0.00	0.0	1:0	15.23	N/A	5.50	340.06	N/A	N/A
1/30/2004	126	36.10	2232.2	0.00	0.0	1:0	12.36	N/A	4.46	275.84	N/A	N/A
2/2/2004	129	36.10	2232.2	0.00	0.0	1:0	14.24	N/A	5.14	317.76	N/A	N/A
2/6/2004	133	36.10	2232.2	0.00	0.0	1:0	11.24	N/A	4.06	250.84	N/A	N/A
2/10/2004	137	36.10	2232.2	0.00	0.0	1:0	14.36	N/A	5.18	320.57	N/A	N/A
2/12/2004	139	36.10	2232.2	0.00	0.0	1:0	15.23	N/A	5.50	340.06	N/A	N/A
2/13/2004	140	36.10	2232.2	0.00	0.0	1:0	12.36	N/A	4.46	275.99	N/A	N/A
2/14/2004	141	36.10	2232.2	0.00	0.0	1:0	13.25	N/A	4.78	295.86	N/A	N/A
2/15/2004	142	36.10	2232.2	0.00	0.0	1:0	15.37	N/A	5.55	343.03	N/A	N/A
2/17/2004	144	36.10	2232.2	0.00	0.0	1:0	14.35	N/A	5.18	320.35	N/A	N/A
2/19/2004	146	36.10	2232.2	0.00	0.0	1:0	12.36	N/A	4.46	275.93	N/A	N/A
2/22/2004	149	36.10	2232.2	0.00	0.0	1:0	13.26	N/A	4.79	296.08	N/A	N/A
2/26/2004	153	36.10	2232.2	0.00	0.0	1:0	15.37	N/A	5.55	343.03	N/A	N/A
3/1/2004	157	36.10	2232.2	0.00	0.0	1:0	11.36	N/A	4.10	253.67	N/A	N/A
3/2/2004	158	36.10	2232.2	0.00	0.0	1:0	11.23	N/A	4.06	250.77	N/A	N/A
3/3/2004	159	36.10	2232.2	0.00	0.0	1:0	14.56	N/A	5.26	325.03	N/A	N/A
3/4/2004	160	36.10	2232.2	0.00	0.0	1:0	12.56	N/A	4.53	280.39	N/A	N/A
3/6/2004	162	36.10	2232.2	0.00	0.0	1:0	12.35	N/A	4.46	275.77	N/A	N/A

Column F: Oxidation rate and Efficiency results (contd.)

Date	Cum Days	Application Rate				Methane : Ethane Volume Ratio	Efficiency		Oxidation Rate			
		Methane		Ethane			Methane	Ethane	Methane		Ethane	
D/M/Y		ml/mt	g/m2/d	ml/mt	g/m2/d		%	%	ml/mt	g/m2/d	ml/mt	g/m2/d
3/8/2004	164	36.10	2232.2	0.00	0.0	1:0	15.65	N/A	5.65	349.43	N/A	N/A
3/11/2004	167	36.10	2232.2	0.00	0.0	1:0	12.37	N/A	4.46	276.04	N/A	N/A
3/15/2004	171	36.10	2232.2	0.00	0.0	1:0	13.56	N/A	4.90	302.78	N/A	N/A
3/16/2004	172	36.10	2232.2	0.00	0.0	1:0	14.54	N/A	5.25	324.50	N/A	N/A
3/17/2004	173	36.10	2232.2	0.00	0.0	1:0	13.23	N/A	4.78	295.41	N/A	N/A
3/18/2004	174	36.10	2232.2	0.00	0.0	1:0	12.40	N/A	4.47	276.68	N/A	N/A
3/19/2004	175	36.10	2232.2	0.00	0.0	1:0	11.24	N/A	4.06	250.97	N/A	N/A
3/21/2004	177	36.10	2232.2	0.00	0.0	1:0	14.36	N/A	5.18	320.46	N/A	N/A
3/23/2004	179	36.10	2232.2	0.00	0.0	1:0	12.37	N/A	4.46	276.04	N/A	N/A
3/26/2004	182	36.10	2232.2	0.00	0.0	1:0	10.23	N/A	3.69	228.45	N/A	N/A
4/1/2004	188	36.10	2232.2	0.00	0.0	1:0	11.23	N/A	4.06	250.77	N/A	N/A
4/2/2004	189	36.10	2232.2	0.00	0.0	1:0	12.36	N/A	4.46	275.99	N/A	N/A
4/3/2004	190	36.10	2232.2	0.00	0.0	1:0	13.37	N/A	4.83	298.38	N/A	N/A
4/4/2004	191	36.10	2232.2	0.00	0.0	1:0	11.25	N/A	4.06	251.10	N/A	N/A
4/7/2004	194	36.10	2232.2	0.00	0.0	1:0	13.26	N/A	4.79	295.90	N/A	N/A
4/10/2004	197	36.10	2232.2	0.00	0.0	1:0	14.24	N/A	5.14	317.80	N/A	N/A
4/13/2004	200	36.10	2232.2	0.00	0.0	1:0	11.35	N/A	4.10	253.45	N/A	N/A
4/17/2004	204	36.10	2232.2	0.00	0.0	1:0	12.38	N/A	4.47	276.33	N/A	N/A
4/19/2004	206	36.10	2232.2	0.00	0.0	1:0	10.99	N/A	3.97	245.21	N/A	N/A
4/21/2004	208	36.10	2232.2	0.00	0.0	1:0	11.23	N/A	4.06	250.77	N/A	N/A
4/22/2004	209	36.10	2232.2	0.00	0.0	1:0	8.56	N/A	3.09	191.17	N/A	N/A
4/23/2004	210	36.10	2232.2	0.00	0.0	1:0	8.12	N/A	2.93	181.32	N/A	N/A
4/25/2004	212	36.10	2232.2	0.00	0.0	1:0	8.04	N/A	2.90	179.52	N/A	N/A
4/27/2004	214	36.10	2232.2	0.00	0.0	1:0	10.24	N/A	3.70	228.54	N/A	N/A
4/30/2004	217	36.10	2232.2	0.00	0.0	1:0	8.23	N/A	2.97	183.78	N/A	N/A
5/5/2004	222	36.10	2232.2	0.00	0.0	1:0	9.36	N/A	3.38	209.03	N/A	N/A
5/10/2004	227	36.10	2232.2	0.00	0.0	1:0	10.24	N/A	3.70	228.51	N/A	N/A
5/11/2005	228	36.10	2232.2	0.00	0.0	1:0	8.24	N/A	2.97	183.85	N/A	N/A
5/12/2004	229	36.10	2232.2	0.00	0.0	1:0	9.56	N/A	3.45	213.42	N/A	N/A
5/13/2004	230	36.10	2232.2	0.00	0.0	1:0	10.23	N/A	3.69	228.45	N/A	N/A
5/14/2004	231	36.10	2232.2	0.00	0.0	1:0	9.66	N/A	3.49	215.54	N/A	N/A
5/19/2004	236	36.10	2232.2	0.00	0.0	1:0	8.53	N/A	3.08	190.43	N/A	N/A
5/28/2004	245	36.10	2232.2	0.00	0.0	1:0	8.03	N/A	2.90	179.29	N/A	N/A
5/31/2004	248	36.10	2232.2	0.00	0.0	1:0	9.52	N/A	3.44	212.58	N/A	N/A
6/8/2004	256	36.10	2232.2	0.00	0.0	1:0	8.56	N/A	3.09	191.17	N/A	N/A
6/13/2004	261	36.10	2232.2	0.00	0.0	1:0	8.12	N/A	2.93	181.35	N/A	N/A

APPENDIX C: DATA FOR DETERMINING GAS PROFILES AND RESULTS OF ANALYSIS

COLUMN A: DEPTH PROFILES CORRESPONDED TO STAGE II

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	19.631	18.182	16.986	16.262	15.256	13.554	12.011	11.319	10.533	9.660	10.006	9.859
N2	73.304	74.477	74.160	74.879	75.983	78.184	79.559	80.625	81.964	83.574	84.011	84.539
CO2	0.065	0.473	0.992	1.307	1.481	2.639	3.442	3.896	4.526	4.875	4.970	5.217
CH4	6.372	5.943	5.483	5.160	4.891	3.709	2.477	1.875	0.631	0.294	0.232	0.000
C2H6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

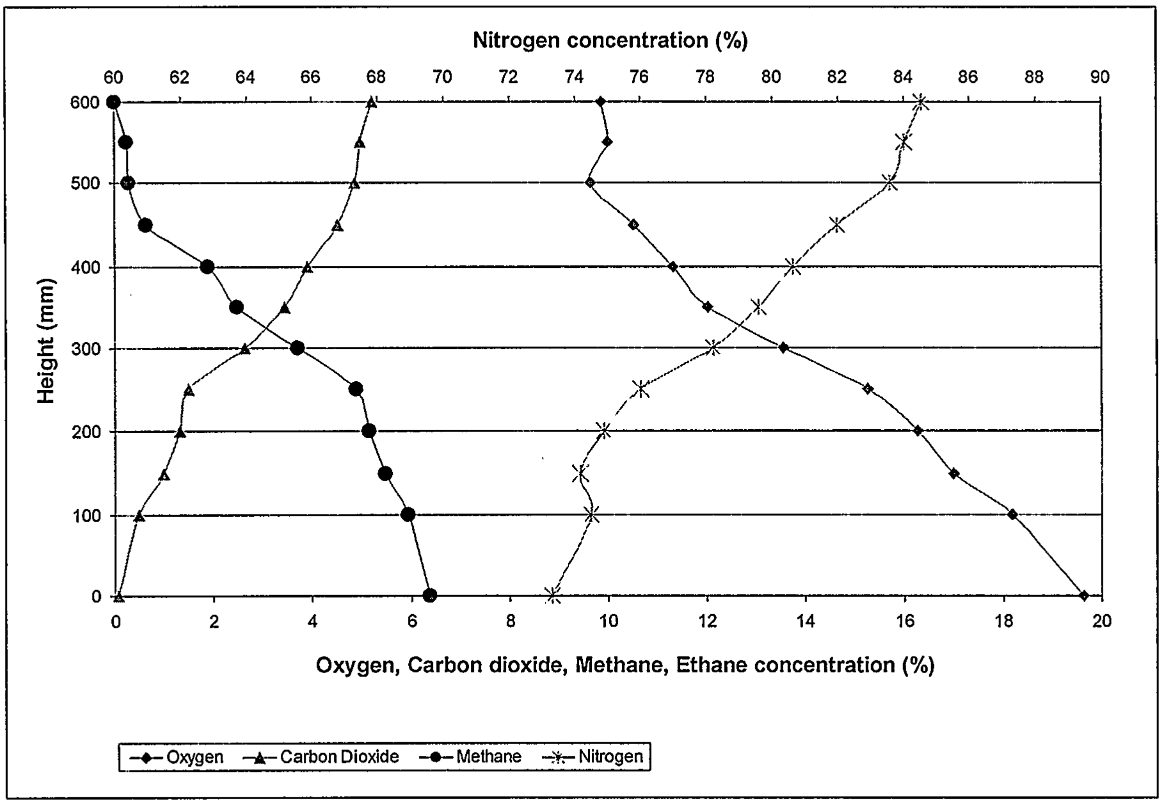

Figure C-1: Gas concentration depth profile – Column A/Stage II

COLUMN A: DEPTH PROFILES CORRESPONDED TO STAGE III

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	19.343	17.482	16.663	15.423	13.709	12.933	11.158	10.298	9.139	8.071	8.482	8.285
N2	72.244	72.988	73.588	75.059	76.094	76.867	79.170	80.798	81.960	85.026	85.472	86.092
CO2	0.064	0.948	1.309	1.728	2.741	3.327	3.803	4.536	4.818	5.379	5.479	5.552
CH4	7.940	6.994	6.183	5.813	5.045	4.582	3.667	2.605	1.773	0.532	0.224	0.000
C2H6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

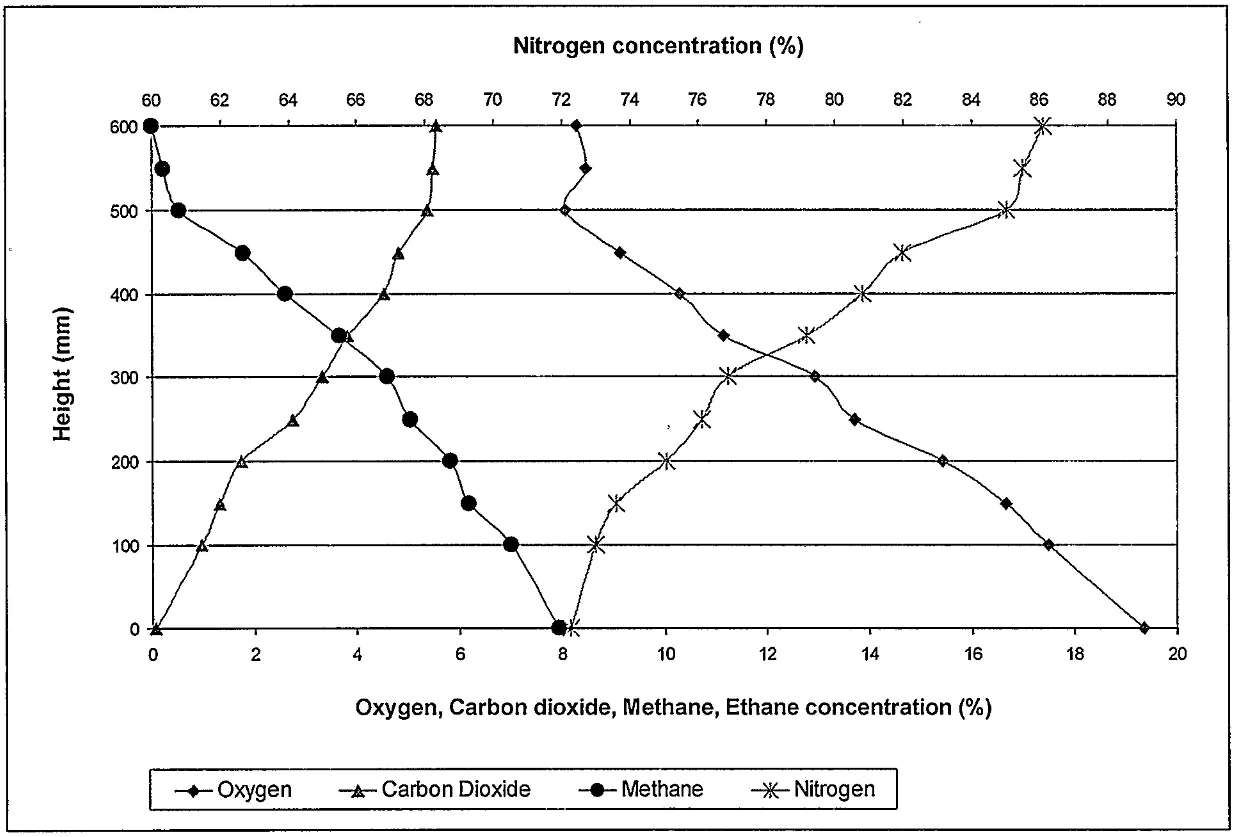

Figure C-2: Gas concentration depth profile – Column A/Stage III

COLUMN A: DEPTH PROFILES CORRESPONDED TO STAGE IV

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	19.058	18.167	15.978	14.749	12.933	11.917	10.361	8.784	7.325	6.372	6.663	6.452
N2	71.125	71.499	72.402	74.156	75.715	76.796	78.492	81.291	83.866	86.637	87.331	87.642
CO2	0.163	0.452	1.616	2.362	3.029	3.556	4.013	4.948	6.180	6.583	6.141	6.311
CH4	9.184	8.927	7.855	7.004	6.544	5.560	5.078	2.912	1.919	0.186	0.158	0.000
C2H6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

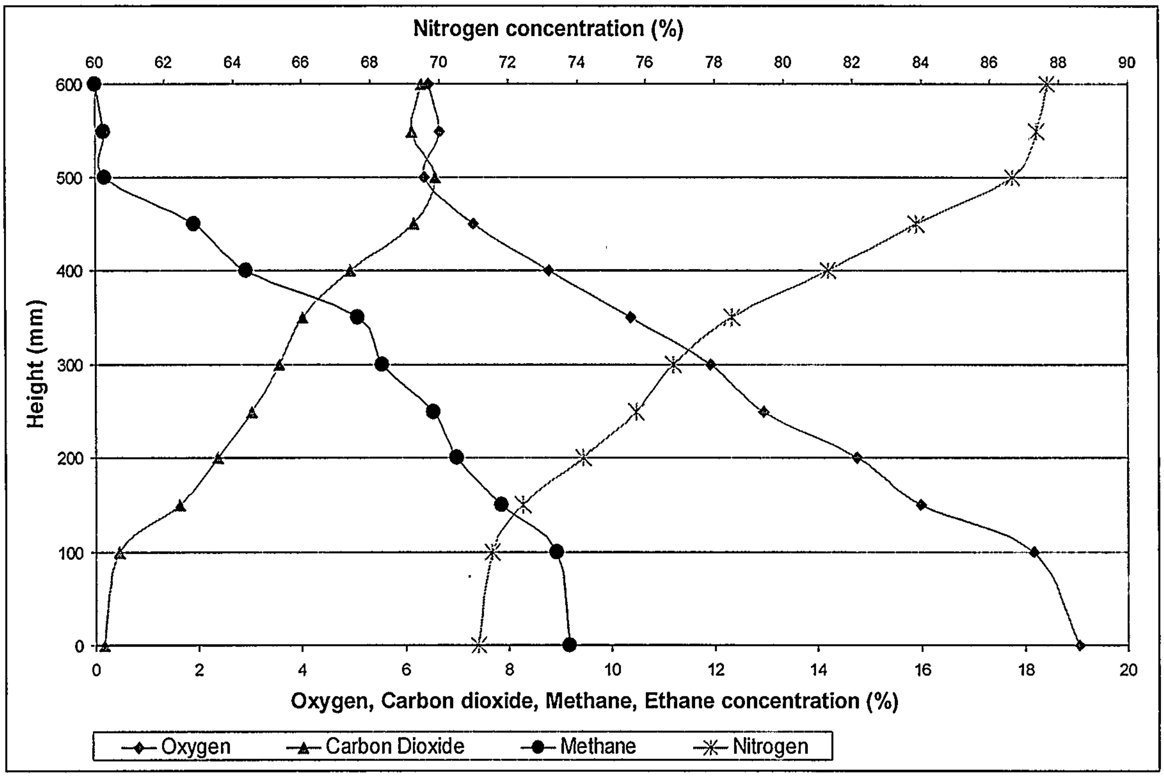

Figure C-3: Gas concentration depth profile – Column A/Stage IV

COLUMN A: DEPTH PROFILES CORRESPONDED TO STAGE V

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	18.710	17.243	14.883	13.014	11.227	10.489	8.910	7.357	5.761	4.448	4.936	4.796
N2	69.803	70.764	72.300	74.143	75.593	77.018	79.070	81.403	84.095	87.599	88.756	89.171
CO2	0.062	0.611	1.589	2.847	3.768	4.297	4.896	5.927	6.740	7.114	6.932	6.935
CH4	10.753	9.950	8.912	7.846	7.195	6.315	5.519	3.939	2.374	0.570	0.349	0.228
C2H6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

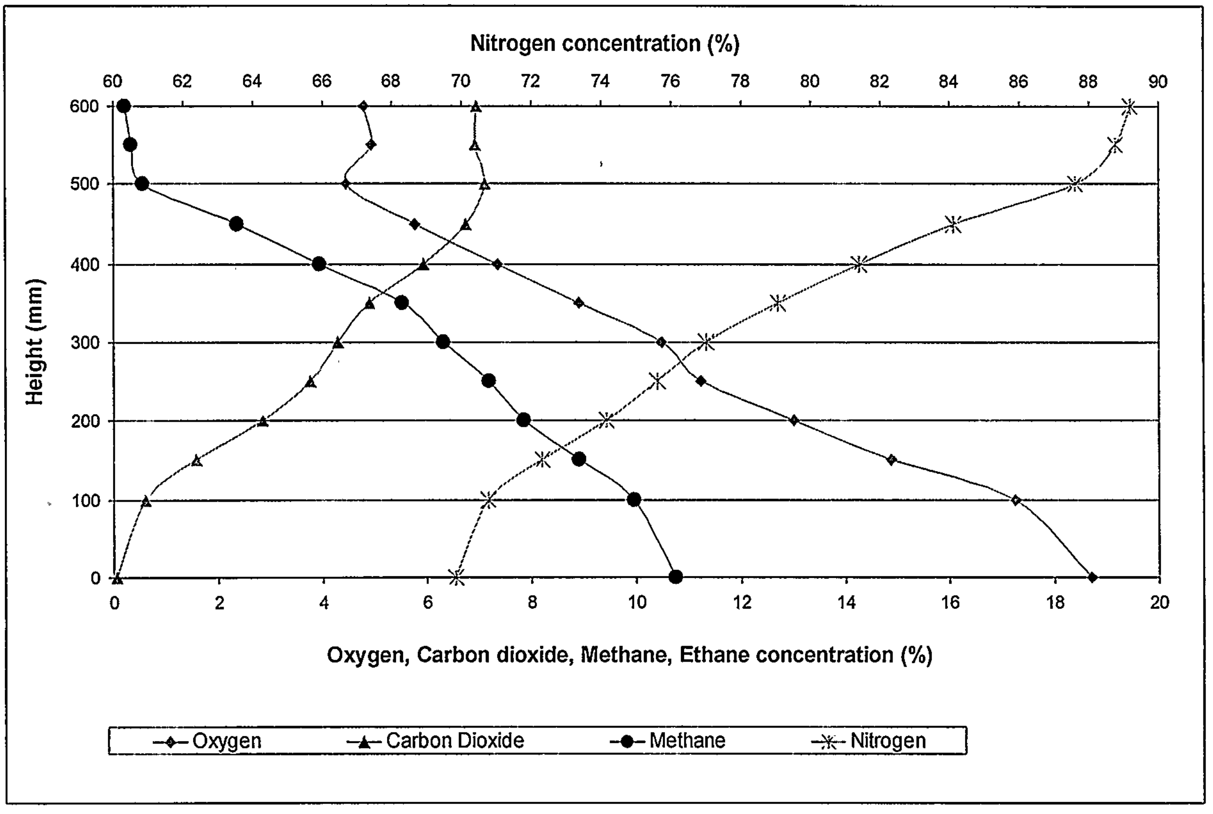

Figure C-4: Gas concentration depth profile – Column A/Stage V

COLUMN A: DEPTH PROFILES CORRESPONDED TO STAGE V (INTERMEDIATE)

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	18.299	16.842	13.950	12.544	10.367	8.318	6.250	5.205	4.247	4.588	5.226	5.023
N2	68.480	69.301	71.635	73.368	75.652	77.179	80.252	82.461	84.507	85.380	86.008	86.513
CO2	0.031	1.018	2.148	3.649	4.626	5.225	6.425	6.943	7.651	6.819	6.744	6.914
CH4	12.540	12.092	10.506	10.005	8.075	7.317	5.663	4.875	3.403	2.993	3.035	2.699
C2H6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

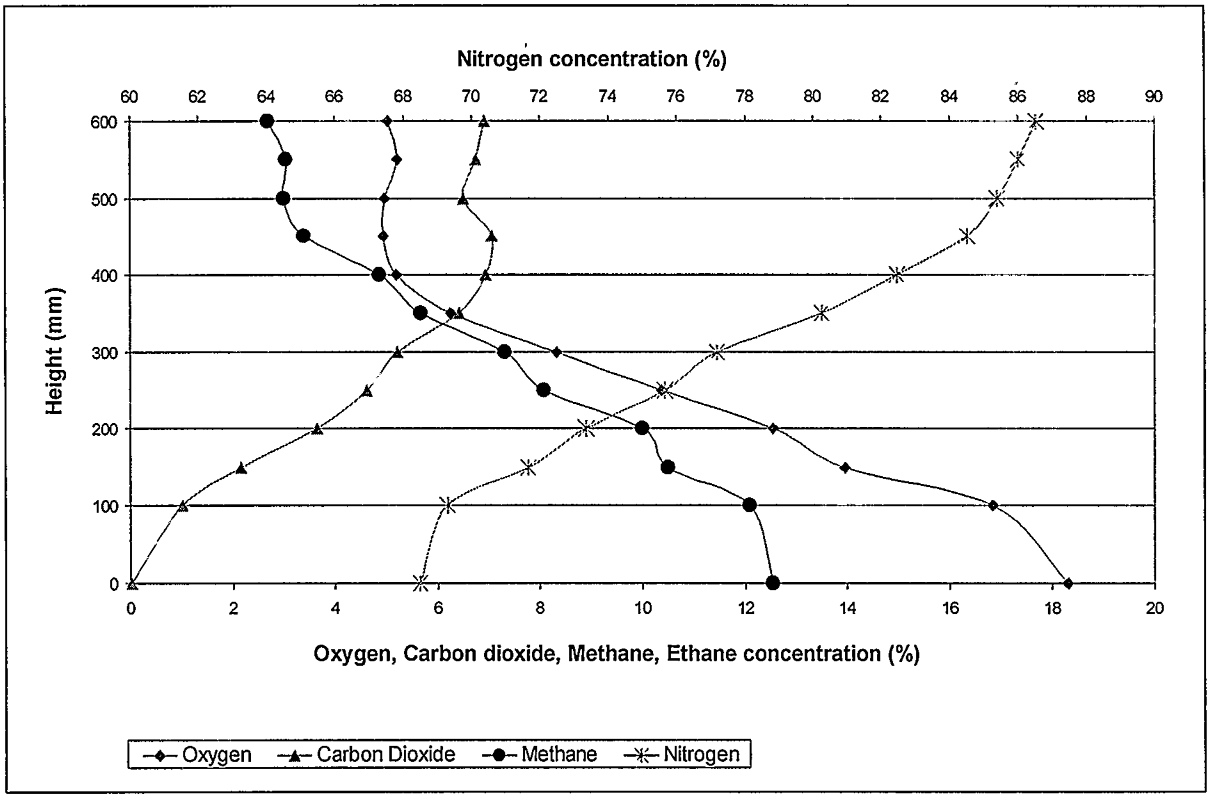

Figure C-5: Gas concentration depth profile – Column A/Stage V (Intermediate)

COLUMN A: DEPTH PROFILES CORRESPONDED TO STAGE V (FINAL)

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	17.841	16.236	14.548	11.563	10.208	9.465	6.854	5.126	4.592	4.962	5.744	5.660
N2	66.887	67.804	69.097	71.912	73.405	74.344	76.935	79.399	81.761	82.277	82.884	83.008
CO2	-0.156	0.956	1.735	3.862	4.411	4.970	5.865	6.777	6.860	6.762	6.285	6.401
CH4	14.629	14.141	13.331	11.754	11.316	9.988	9.352	7.412	6.152	6.545	6.320	6.282
C2H6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

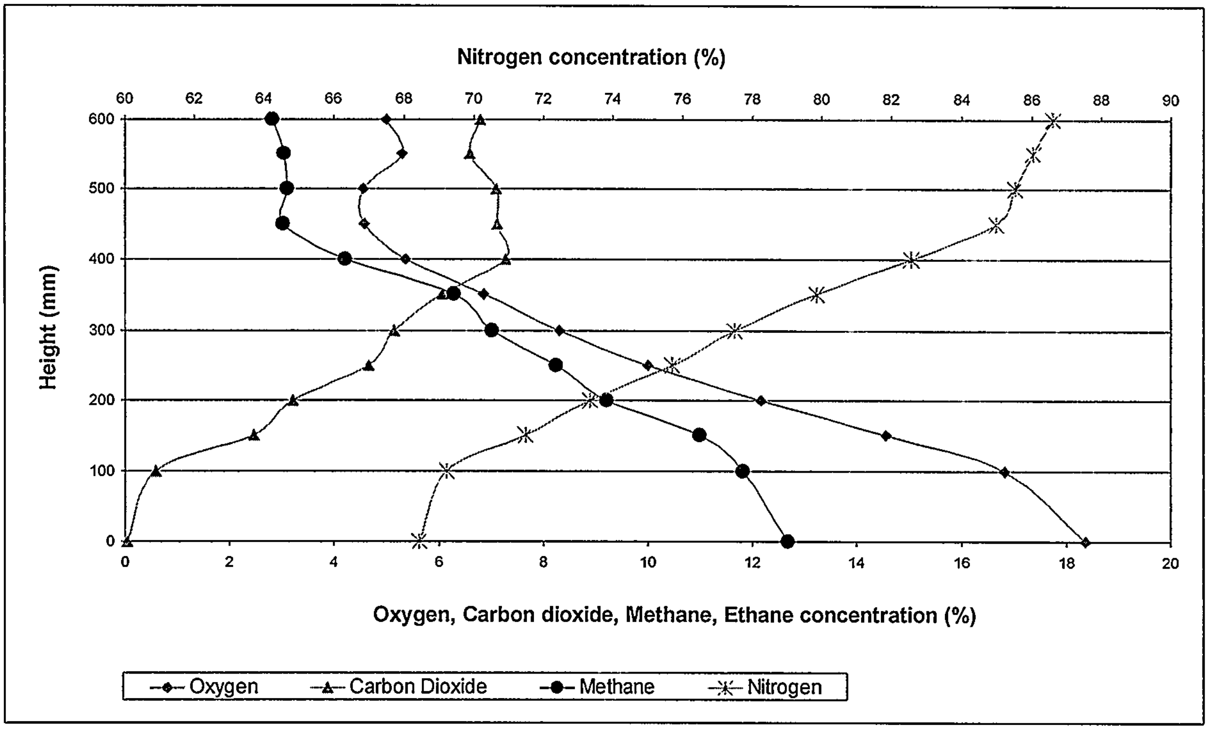

Figure C-6: Gas concentration depth profile – Column A/Stage V (Final)

COLUMN B: DEPTH PROFILES CORRESPONDED TO STAGE II

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	19.559	18.093	16.748	15.725	15.369	13.260	11.475	10.565	9.859	9.854	10.001	9.833
N2	73.338	74.504	74.353	75.313	75.437	78.094	79.639	80.799	82.804	83.914	84.132	84.532
CO2	0.055	0.880	1.317	1.705	2.128	2.984	4.072	4.288	4.681	4.879	4.784	4.966
CH4	6.418	5.910	5.200	4.572	4.591	3.168	2.189	1.758	0.602	0.170	0.214	0.000
C2H6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

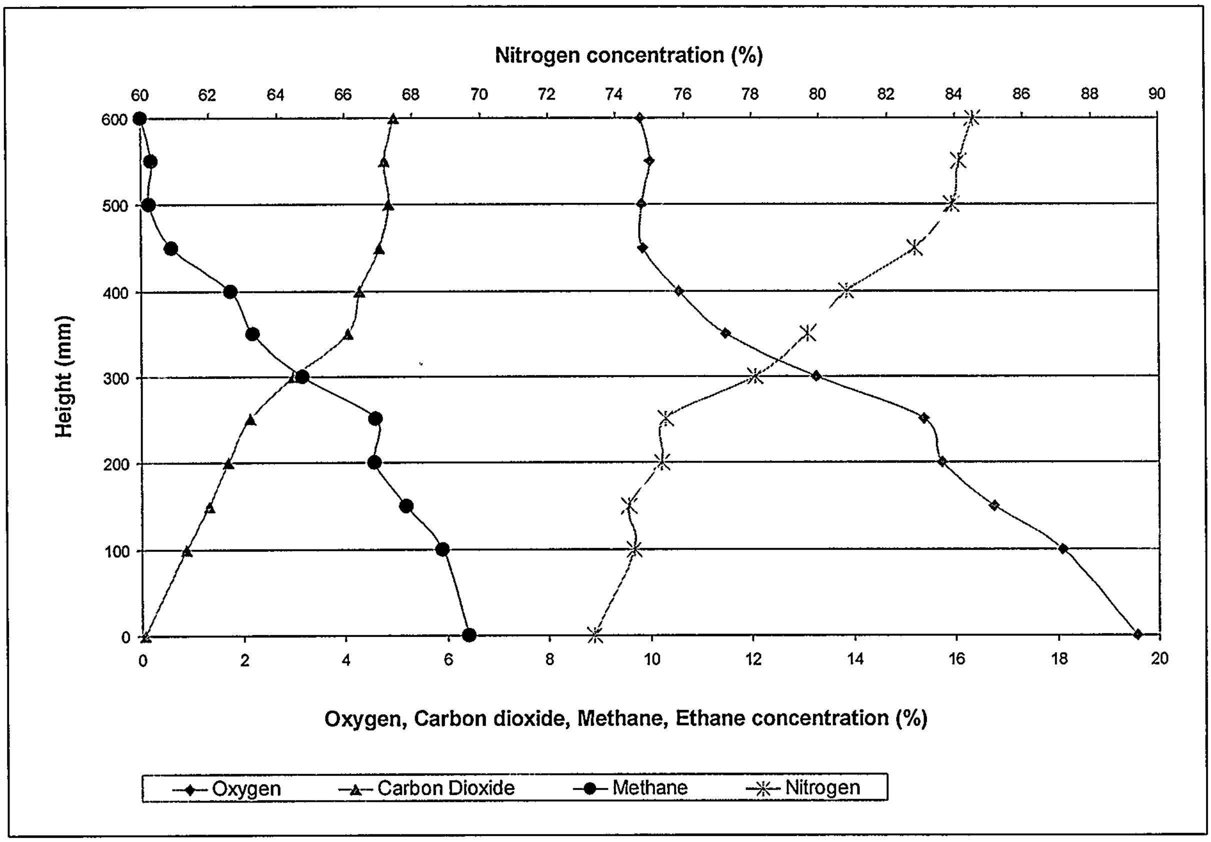

Figure C-7: Gas concentration depth profile – Column B/Stage II

COLUMN B: DEPTH PROFILES CORRESPONDED TO STAGE III

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	19.355	17.959	16.388	14.621	14.264	12.511	11.322	10.315	9.045	8.312	8.624	8.306
N2	72.272	72.971	74.416	74.928	76.112	76.915	79.234	80.473	82.847	85.118	85.482	86.152
CO2	0.089	0.382	1.670	2.241	2.902	2.951	3.753	4.844	4.770	5.724	5.320	5.565
CH4	7.873	7.397	6.285	5.658	4.993	4.348	3.847	2.719	1.133	0.291	0.305	0.000
C2H6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

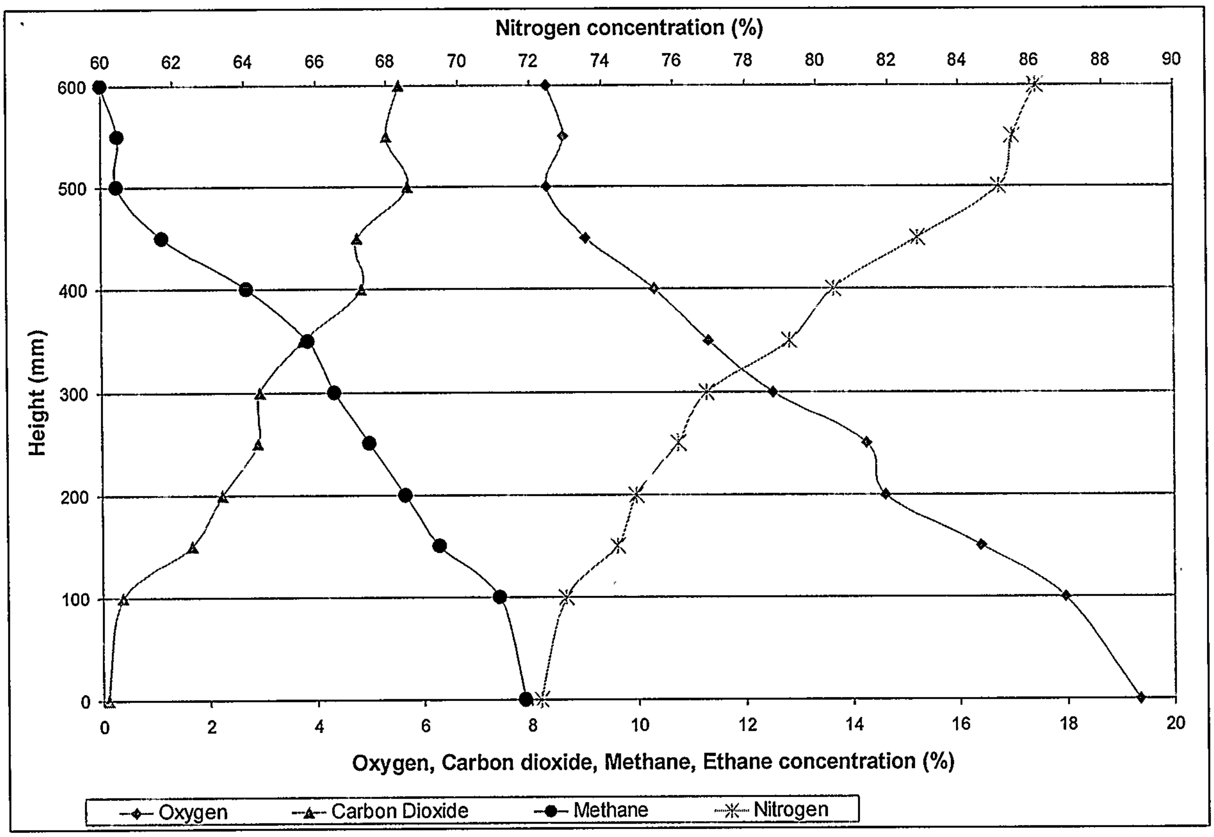

Figure C-8: Gas concentration depth profile – Column B/Stage III

COLUMN B: DEPTH PROFILES CORRESPONDED TO STAGE IV

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	19.086	17.502	16.249	14.435	13.193	11.880	10.690	8.428	7.823	6.905	6.761	6.598
N2	71.163	71.884	73.176	74.594	75.880	77.040	78.174	81.214	83.691	86.201	86.999	87.648
CO2	0.034	0.944	1.331	2.608	3.634	3.684	4.659	5.473	5.451	6.007	6.109	6.383
CH4	9.307	8.553	8.128	6.956	6.492	5.352	4.388	2.990	1.509	0.377	0.213	0.000
C2H6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

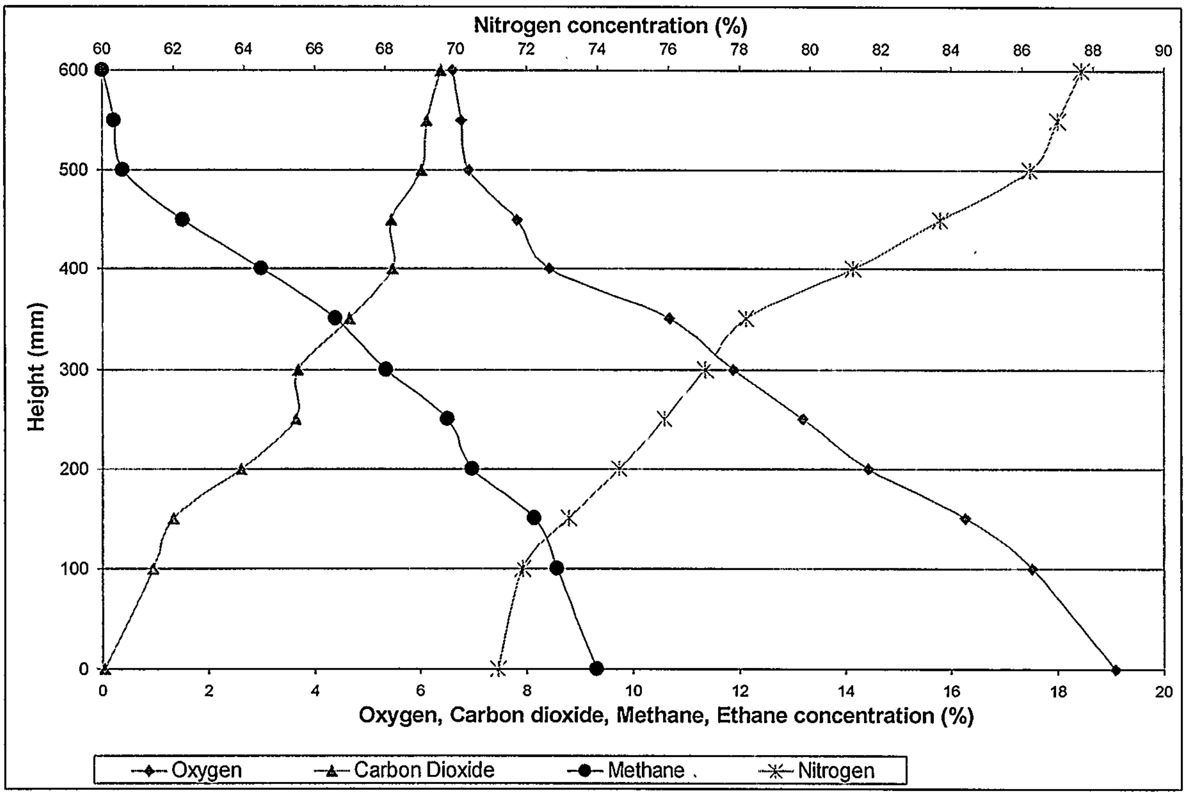

Figure C-9: Gas concentration depth profile – Column B/Stage IV

COLUMN B: DEPTH PROFILES CORRESPONDED TO STAGE V

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	18.655	17.028	14.761	13.100	11.335	10.118	8.284	6.772	5.824	4.613	5.213	4.844
N2	69.744	70.722	71.955	73.780	75.771	77.658	79.350	81.930	84.475	87.646	88.308	89.024
CO2	0.065	1.032	1.659	3.431	3.878	4.651	5.440	5.946	6.420	7.296	6.805	7.002
CH4	10.706	10.232	9.007	8.002	7.056	6.565	5.350	3.709	2.184	0.867	0.591	0.199
C2H6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

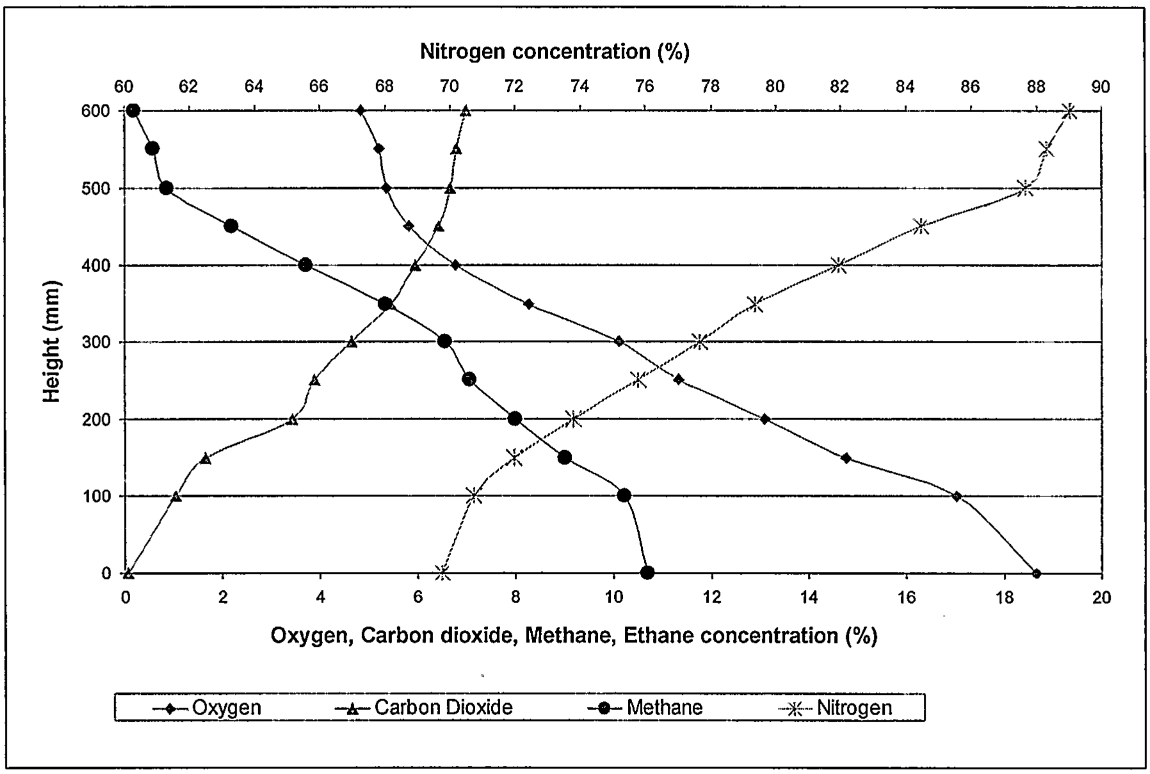

Figure C-10: Gas concentration depth profile – Column B/Stage V

COLUMN B: DEPTH PROFILES CORRESPONDED TO STAGE VI

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	18.325	16.652	13.903	11.553	9.849	8.013	6.433	5.846	4.349	4.540	5.244	4.970
N2	68.618	69.375	71.534	73.756	75.639	77.262	80.229	81.510	84.985	85.615	86.022	86.665
CO2	0.059	0.919	1.960	3.597	5.057	5.159	6.563	6.645	7.489	7.163	6.695	6.812
CH4	12.639	12.098	10.984	9.469	8.114	7.261	5.873	4.908	3.610	3.210	3.070	2.710
C2H6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

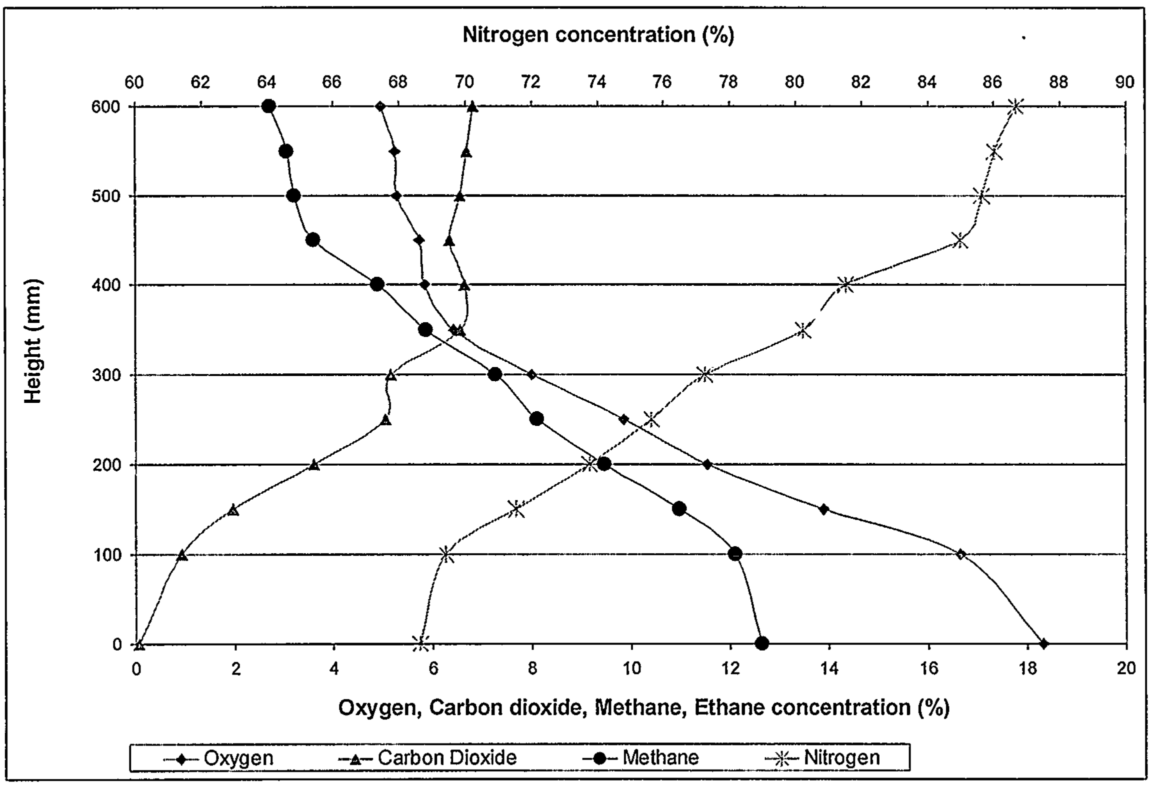

Figure C-11: Gas concentration depth profile – Column B/Stage VI

COLUMN B: DEPTH PROFILES CORRESPONDED TO STAGE VII

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	17.925	16.316	14.999	12.397	9.956	8.041	6.365	5.980	5.539	5.819	5.995	6.018
N2	66.835	67.765	68.441	71.109	72.849	75.581	78.251	80.568	81.496	81.598	82.329	82.068
CO2	0.085	0.725	1.631	3.270	4.617	5.645	5.999	5.925	6.277	6.162	6.143	6.217
CH4	14.730	14.167	12.971	12.019	10.697	9.862	7.946	6.961	6.637	6.447	6.672	6.637
C2H6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

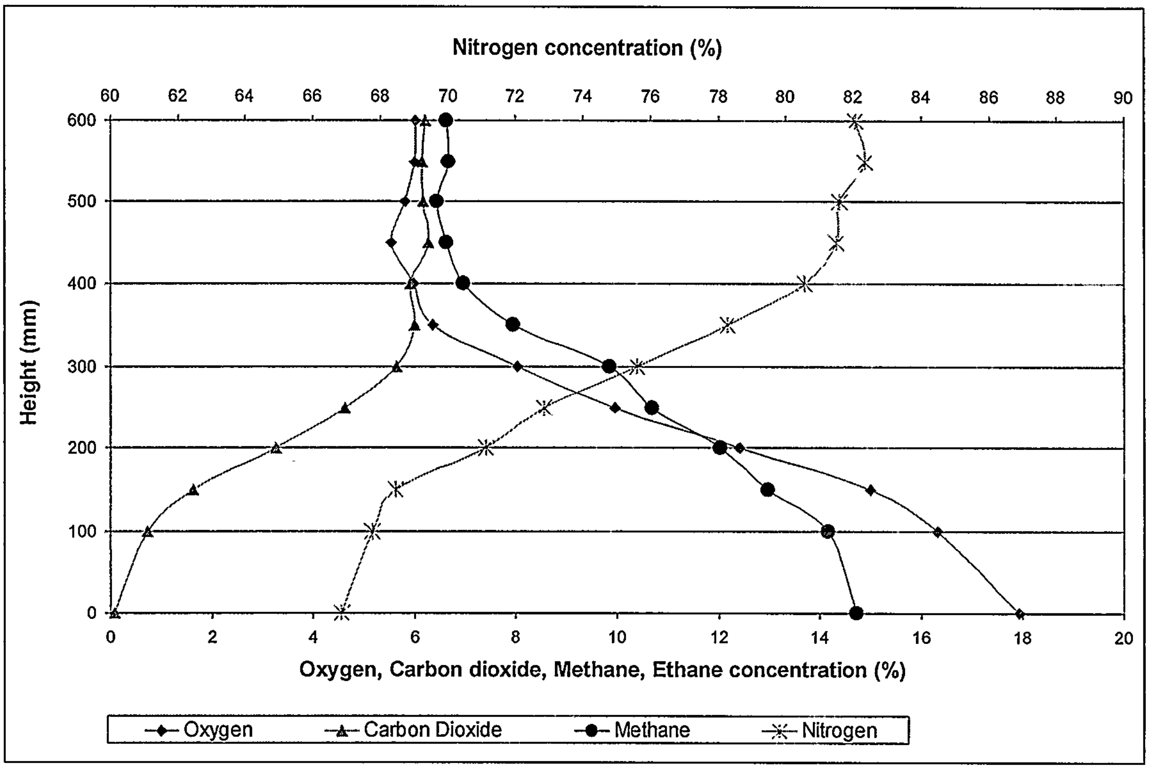

Figure C-12: Gas concentration depth profile – Column B/Stage VII

COLUMN B: DEPTH PROFILES CORRESPONDED TO STAGE VIII

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	17.309	15.358	12.558	10.267	8.673	6.737	6.398	6.267	6.032	6.348	6.990	7.350
N2	64.967	65.727	67.971	69.995	72.099	74.458	77.461	76.612	77.056	76.873	77.582	77.973
CO2	0.014	0.754	2.319	3.534	5.171	5.726	6.463	6.065	5.765	5.539	5.655	5.349
CH4	17.150	16.614	15.218	13.978	12.795	11.963	11.313	10.940	10.780	11.035	10.819	10.758
C2H6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

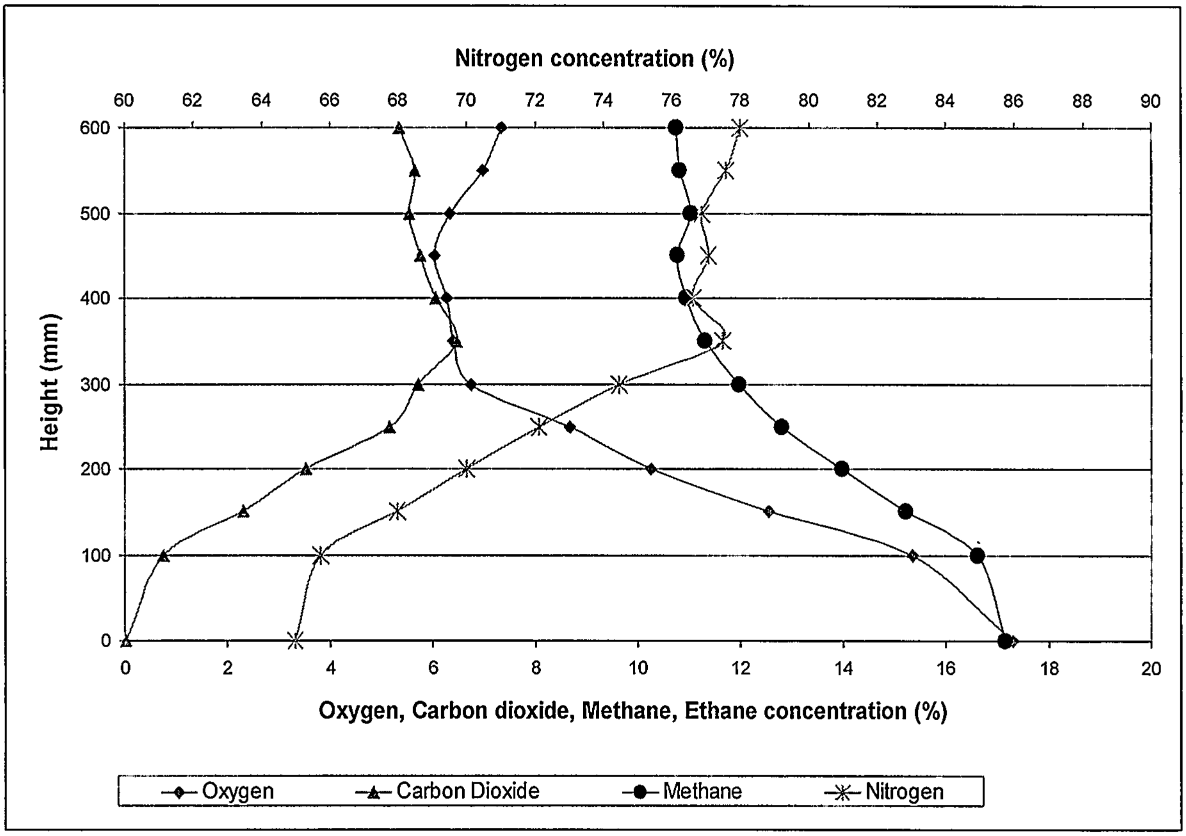

Figure C-13: Gas concentration depth profile – Column B/Stage VIII

COLUMN C: DEPTH PROFILES CORRESPONDED TO STAGE II

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	19.377	18.570	17.300	16.475	16.167	14.857	13.394	12.075	10.969	9.370	9.270	9.073
N2	72.643	73.369	74.106	75.526	76.051	76.656	79.182	80.944	82.474	85.273	85.446	86.000
CO2	0.078	0.613	1.228	1.829	2.691	3.179	4.229	4.968	4.984	6.522	6.177	6.496
CH4	6.486	6.051	5.643	5.099	4.502	4.257	2.827	2.173	1.385	0.381	0.144	0.000
C2H6	0.794	0.715	0.652	0.505	0.567	0.523	0.317	0.217	0.161	0.095	0.019	0.056

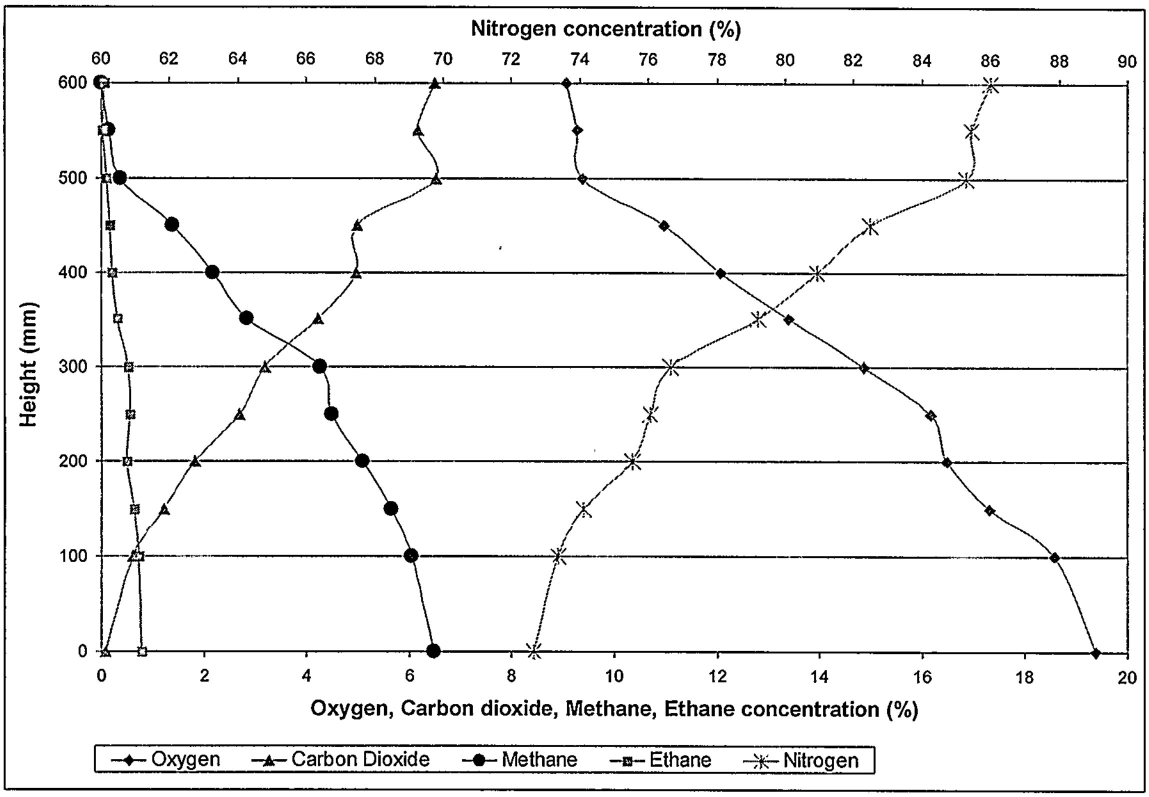

Figure C-14: Gas concentration depth profile – Column C/Stage II

COLUMN C: DEPTH PROFILES CORRESPONDED TO STAGE III

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	19.202	18.607	16.997	16.170	14.860	13.730	12.456	10.074	8.320	5.864	6.210	5.915
N2	71.485	72.047	73.294	74.393	75.418	76.549	78.453	81.057	83.625	86.685	87.246	87.471
CO2	0.064	0.369	0.889	1.891	2.308	3.388	4.427	5.634	6.573	7.340	7.289	7.314
CH4	7.845	7.421	6.561	5.960	5.184	4.593	4.175	2.483	1.873	0.332	0.151	0.021
C2H6	0.940	0.863	0.799	0.767	0.694	0.533	0.508	0.343	0.196	0.044	0.060	0.028

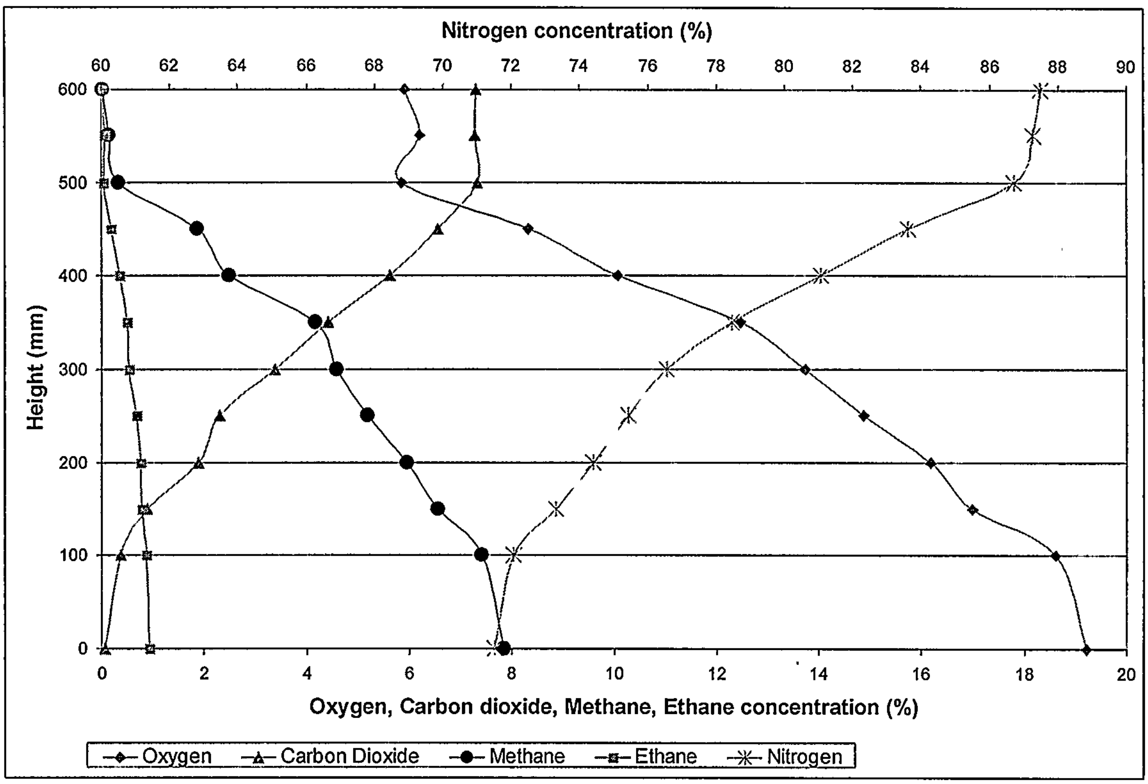

Figure C-15: Gas concentration depth profile – Column C/Stage III

COLUMN C: DEPTH PROFILES CORRESPONDED TO STAGE IV

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	18.833	18.077	16.086	14.014	13.242	11.549	10.848	8.297	6.227	3.335	3.526	3.310
N2	70.258	70.946	72.053	74.192	75.657	76.683	78.716	81.432	84.091	87.453	88.029	88.363
CO2	0.081	0.417	1.312	3.062	3.779	4.560	5.360	6.311	7.118	8.449	8.260	8.317
CH4	9.216	8.713	7.767	6.897	6.614	5.536	4.587	3.416	1.917	0.652	0.488	0.323
C2H6	1.131	1.041	0.913	0.795	0.725	0.662	0.613	0.482	0.313	0.230	0.190	0.179

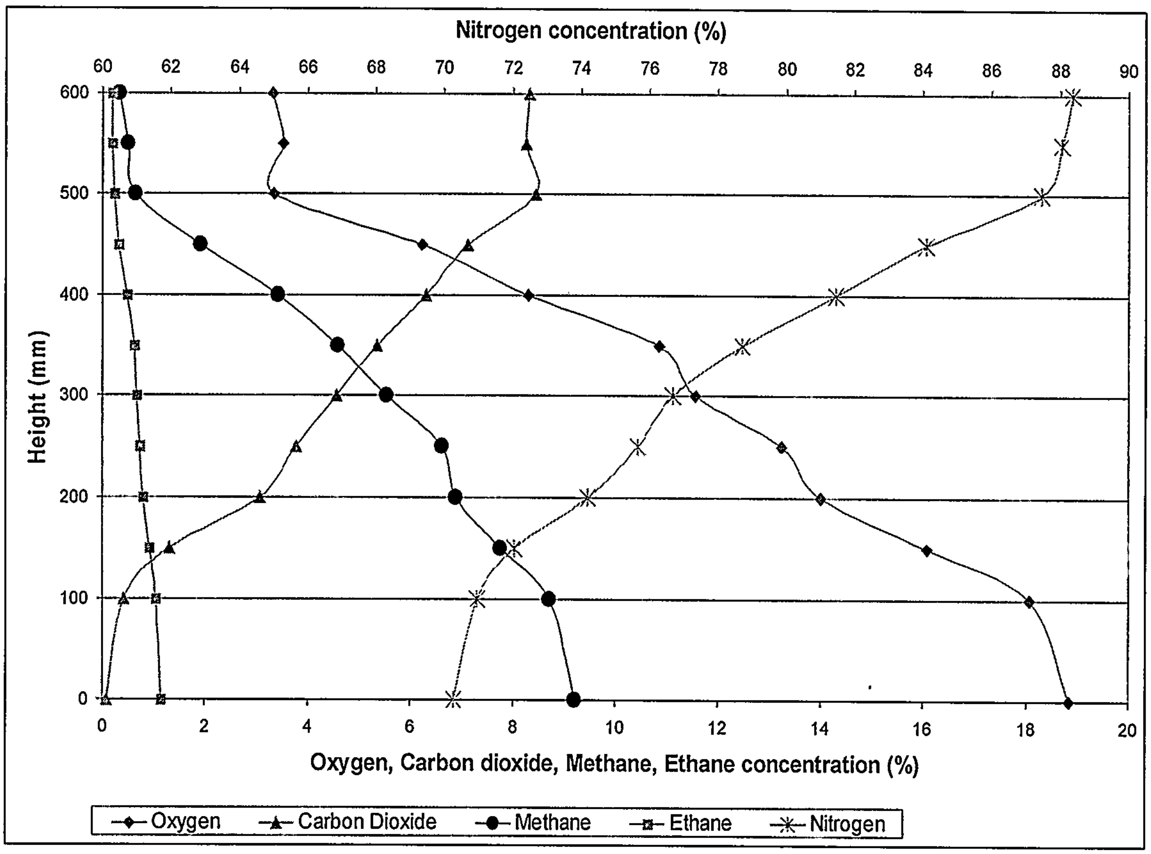

Figure C-16: Gas concentration depth profile – Column C/Stage IV

COLUMN C: DEPTH PROFILES CORRESPONDED TO STAGE V

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	18.534	17.423	16.083	13.956	12.884	11.184	9.679	6.115	3.972	2.242	2.767	2.820
N2	68.971	69.524	70.609	72.227	74.119	75.475	77.351	81.114	83.573	86.167	87.062	86.885
CO2	0.071	0.437	1.283	2.623	4.096	4.937	5.169	6.933	7.682	8.456	8.423	8.407
CH4	10.689	10.253	9.645	8.456	8.018	6.969	6.197	4.804	2.869	2.117	1.885	1.877
C2H6	1.294	1.174	1.040	0.981	0.918	0.833	0.814	0.626	0.658	0.443	0.511	0.529

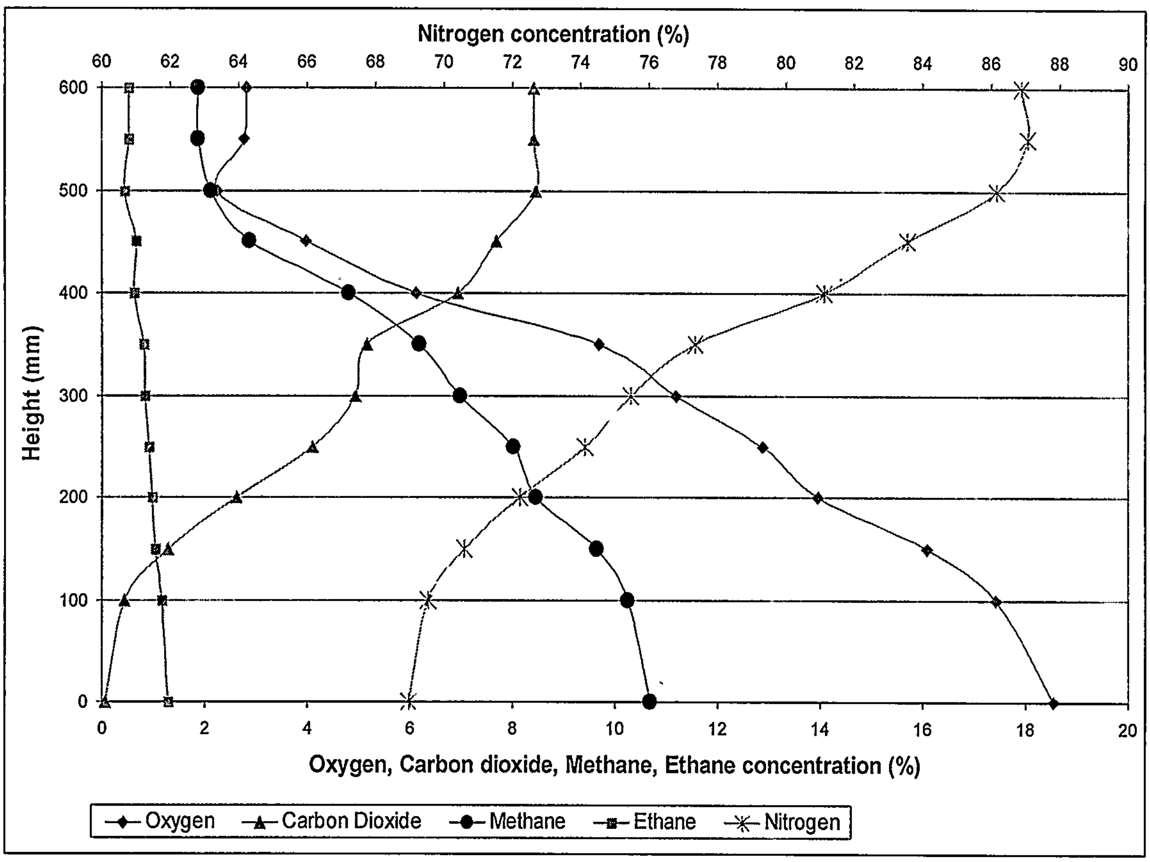

Figure C-17: Gas concentration depth profile – Column C/Stage V

COLUMN C: DEPTH PROFILES CORRESPONDED TO STAGE VI

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	17.980	17.129	15.740	13.777	12.066	10.370	8.240	5.926	3.853	4.498	5.016	4.915
N2	67.339	68.107	69.121	70.966	72.608	74.704	77.185	79.275	81.428	82.197	82.500	82.577
CO2	0.086	0.489	1.903	3.074	3.663	4.539	6.061	7.214	7.557	7.439	7.384	7.261
CH4	12.335	11.791	11.084	10.478	9.548	8.595	7.585	5.947	5.214	5.205	5.262	5.302
C2H6	1.475	1.346	1.255	0.907	0.605	0.815	0.674	0.833	0.884	0.811	0.953	0.900

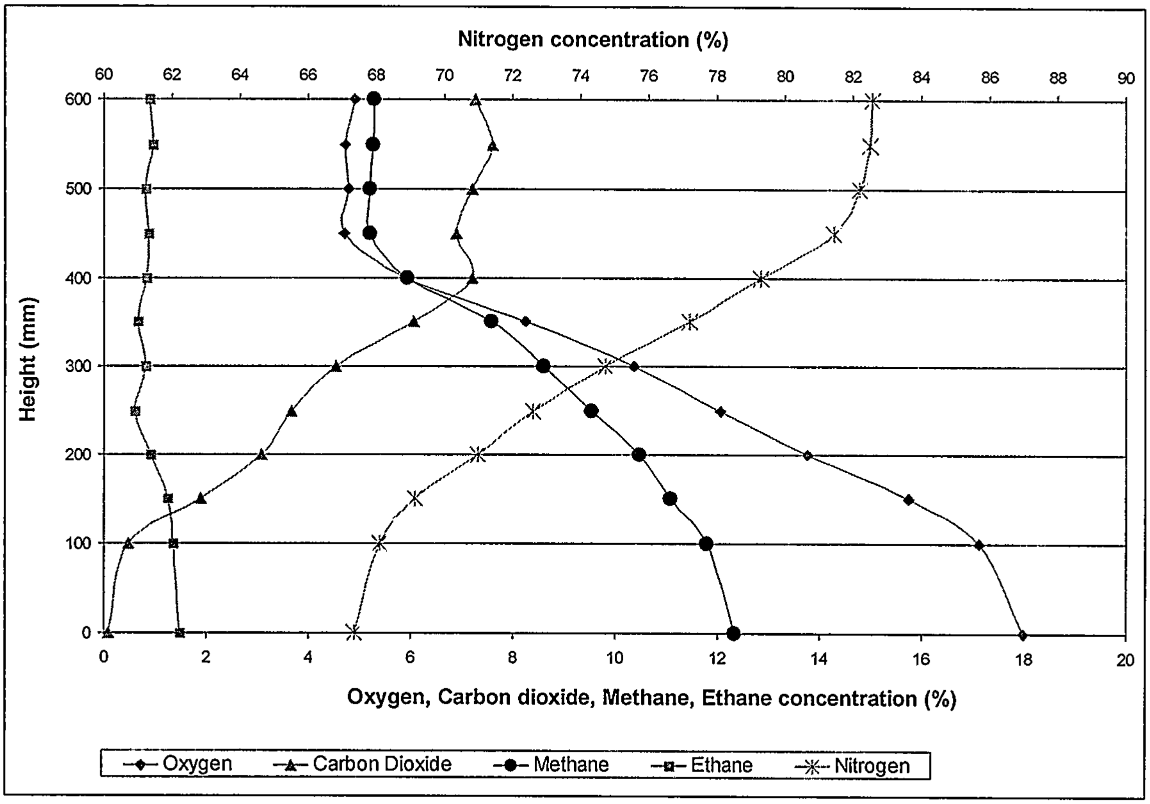

Figure C-18: Gas concentration depth profile – Column C/Stage VI

COLUMN C: DEPTH PROFILES CORRESPONDED TO STAGE VII

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	17.679	16.631	15.157	12.377	11.272	9.009	7.934	6.172	5.902	6.810	7.648	7.651
N2	65.620	66.089	67.359	69.849	71.357	72.758	74.536	76.395	77.273	77.073	77.250	77.166
CO2	0.066	0.772	1.730	2.868	4.297	5.429	5.602	6.592	6.618	6.505	6.098	6.026
CH4	14.306	13.945	13.069	12.405	11.539	10.370	9.670	9.328	8.998	9.024	9.160	9.210
C2H6	1.796	1.570	1.399	1.041	0.825	1.106	1.046	1.275	1.203	0.897	1.248	1.280

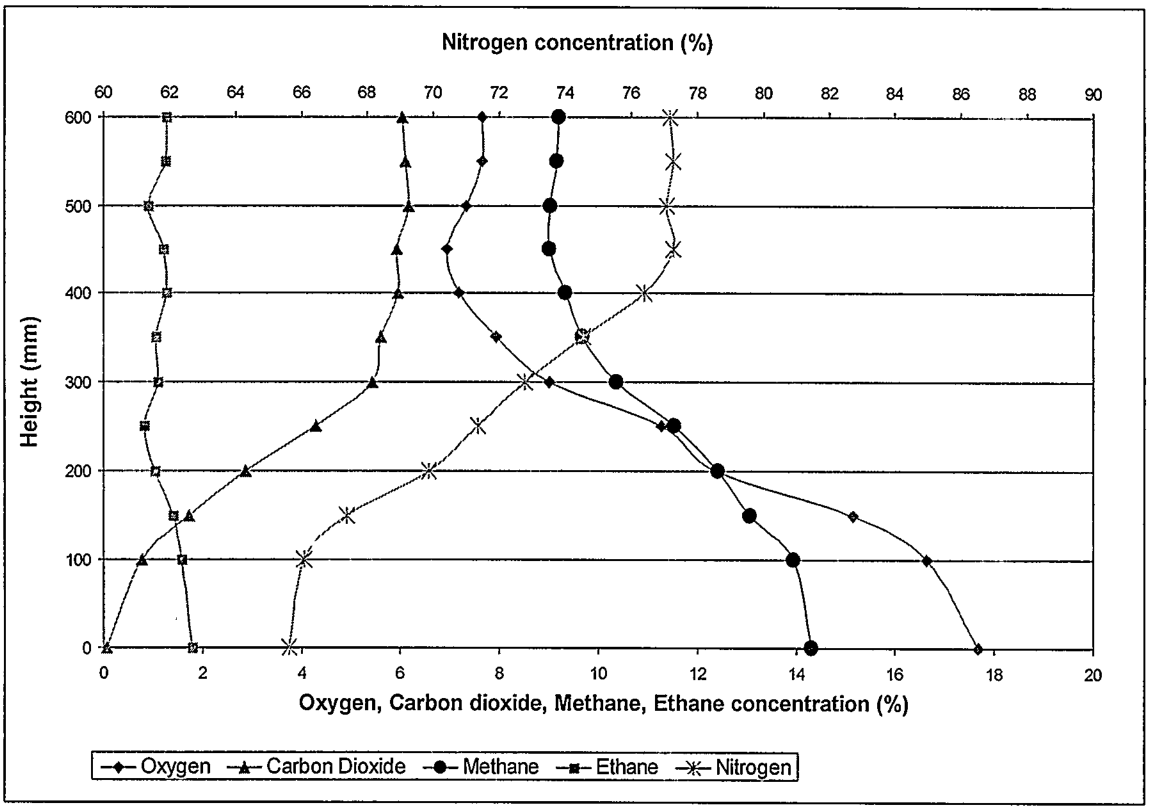

Figure C-19: Gas concentration depth profile – Column C/Stage VII

COLUMN C: DEPTH PROFILES CORRESPONDED TO STAGE VIII

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	16.967	15.619	13.418	12.500	10.580	9.685	8.661	8.361	8.656	9.116	9.669	9.702
N2	63.591	64.033	65.252	66.209	68.378	70.619	70.925	71.657	71.703	71.796	71.753	71.799
CO2	0.048	0.994	1.806	3.093	4.236	4.590	5.445	4.913	4.979	5.044	4.987	4.985
CH4	16.784	16.315	15.786	15.017	14.242	13.367	12.931	12.888	13.134	13.090	13.276	13.260
C2H6	2.055	1.948	1.480	1.406	1.757	1.182	1.125	1.124	1.063	1.217	1.606	1.719

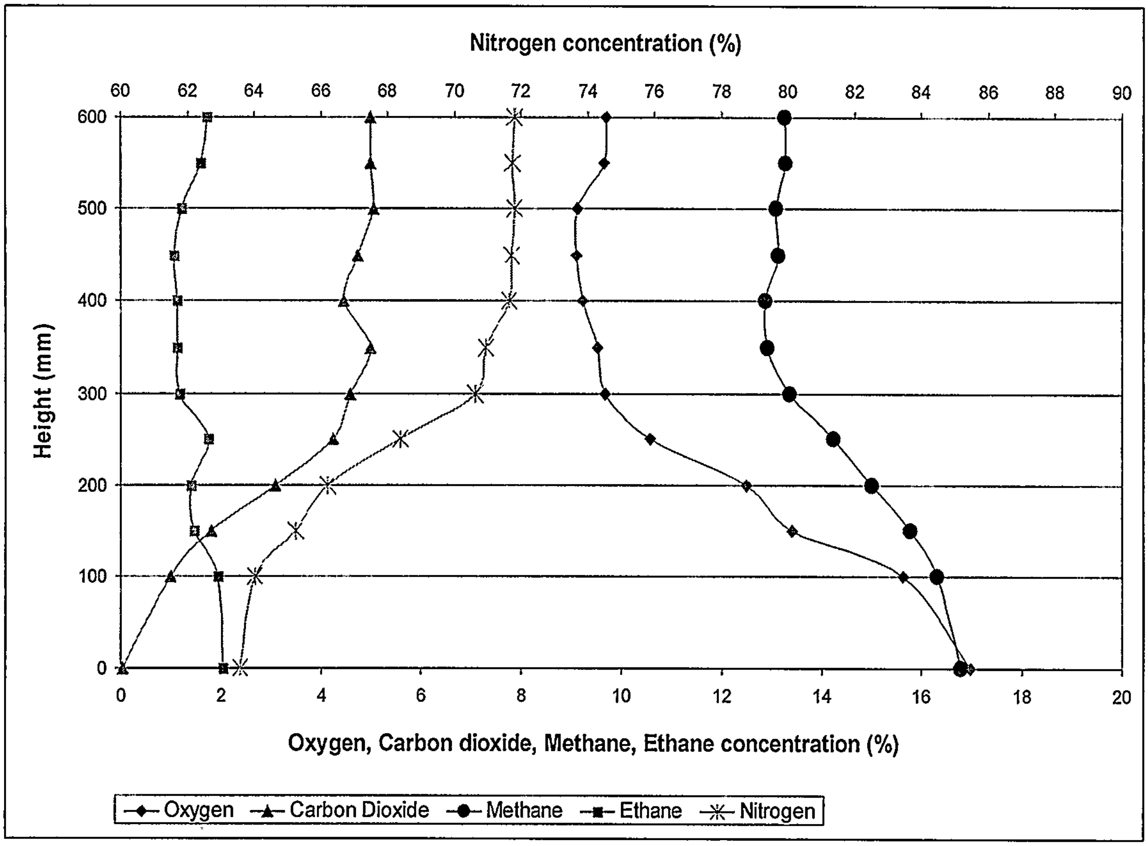

Figure C-20: Gas concentration depth profile – Column C/Stage VIII

COLUMN D: DEPTH PROFILES CORRESPONDED TO STAGE II

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	19.411	18.600	17.393	16.750	15.966	15.699	12.234	10.659	8.473	6.541	6.317	6.058
N2	72.120	72.530	73.800	75.181	75.642	76.390	79.296	81.203	83.059	85.581	86.178	86.400
CO2	0.069	0.468	1.764	2.357	2.839	3.188	4.592	5.867	6.491	7.814	7.887	7.936
CH4	6.302	5.772	5.320	4.652	4.315	4.209	3.233	2.228	1.468	0.393	0.172	0.073
C2H6	1.822	1.727	1.282	1.299	1.252	1.185	0.997	0.762	0.618	0.187	0.346	0.274

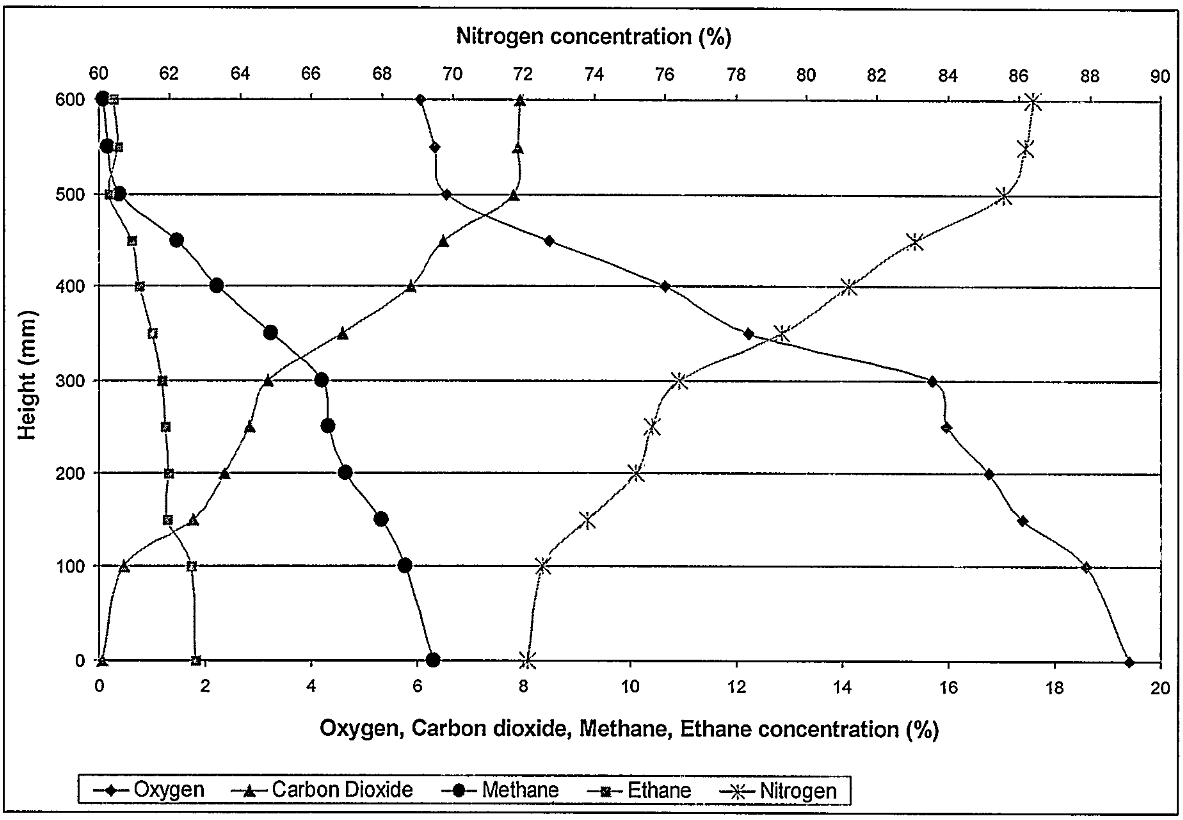

Figure C-21: Gas concentration depth profile – Column D/Stage II

COLUMN D: DEPTH PROFILES CORRESPONDED TO STAGE III

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	18.869	18.341	16.594	15.113	14.009	12.669	11.351	8.769	5.789	3.752	3.078	2.764
N2	70.544	70.995	72.314	74.336	75.552	76.925	78.353	80.637	83.104	85.345	86.869	87.056
CO2	0.061	0.663	1.866	2.799	4.066	4.649	5.159	6.978	7.356	8.833	9.053	9.197
CH4	7.769	7.035	6.748	5.854	5.214	4.577	4.345	3.011	1.881	1.226	0.901	0.782
C2H6	2.102	1.788	1.731	1.567	1.019	1.241	0.635	0.872	0.778	0.505	0.489	0.348

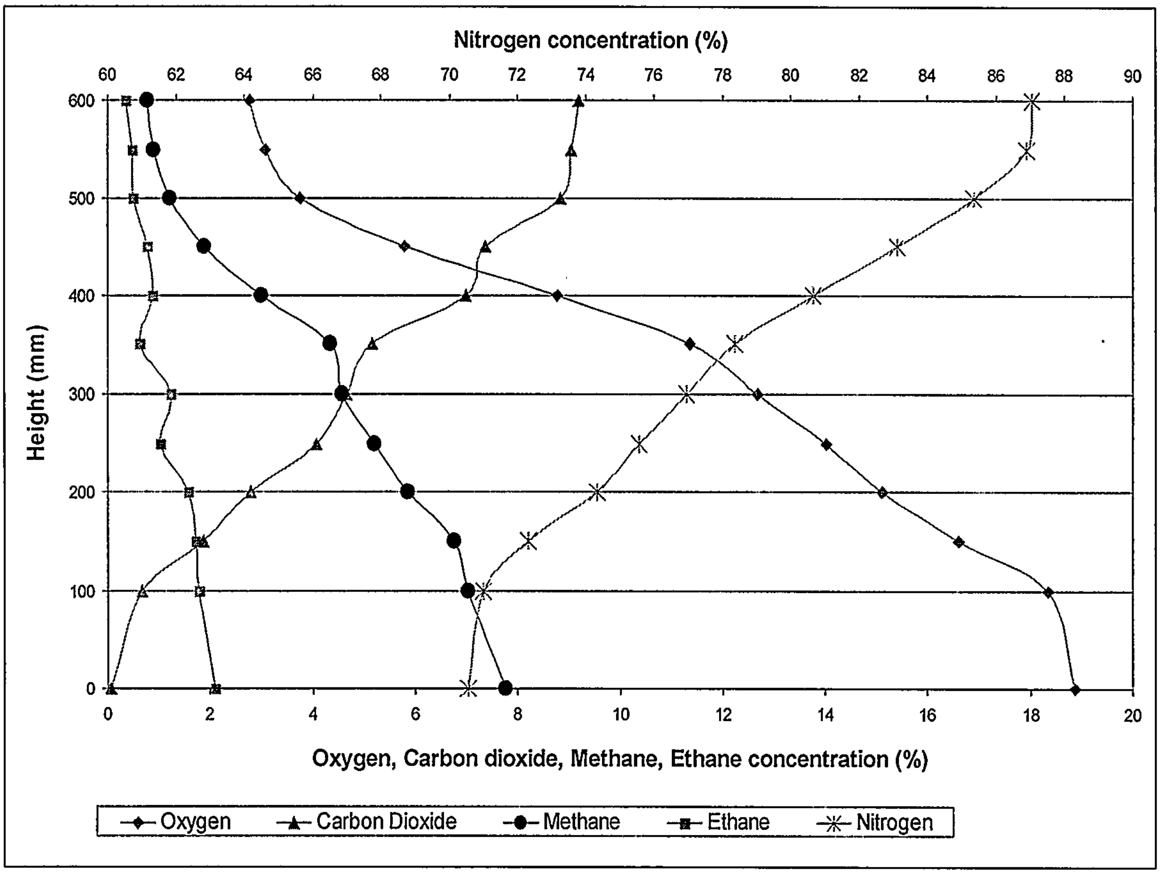

Figure C-22: Gas concentration depth profile – Column D/Stage III

COLUMN D: DEPTH PROFILES CORRESPONDED TO STAGE IV

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	18.440	17.878	16.255	14.733	13.980	11.894	10.020	7.288	4.114	0.958	0.812	1.034
N2	69.321	69.941	71.164	72.280	74.108	75.818	77.154	79.720	82.791	86.087	86.752	86.554
CO2	0.028	0.776	1.854	2.422	3.867	4.878	5.634	6.711	8.395	9.868	9.791	9.610
CH4	9.161	8.557	8.110	7.130	6.433	5.883	5.544	3.774	3.276	1.559	1.487	1.608
C2H6	2.441	2.298	2.238	1.699	2.069	1.300	1.294	1.192	0.817	0.937	1.014	0.980

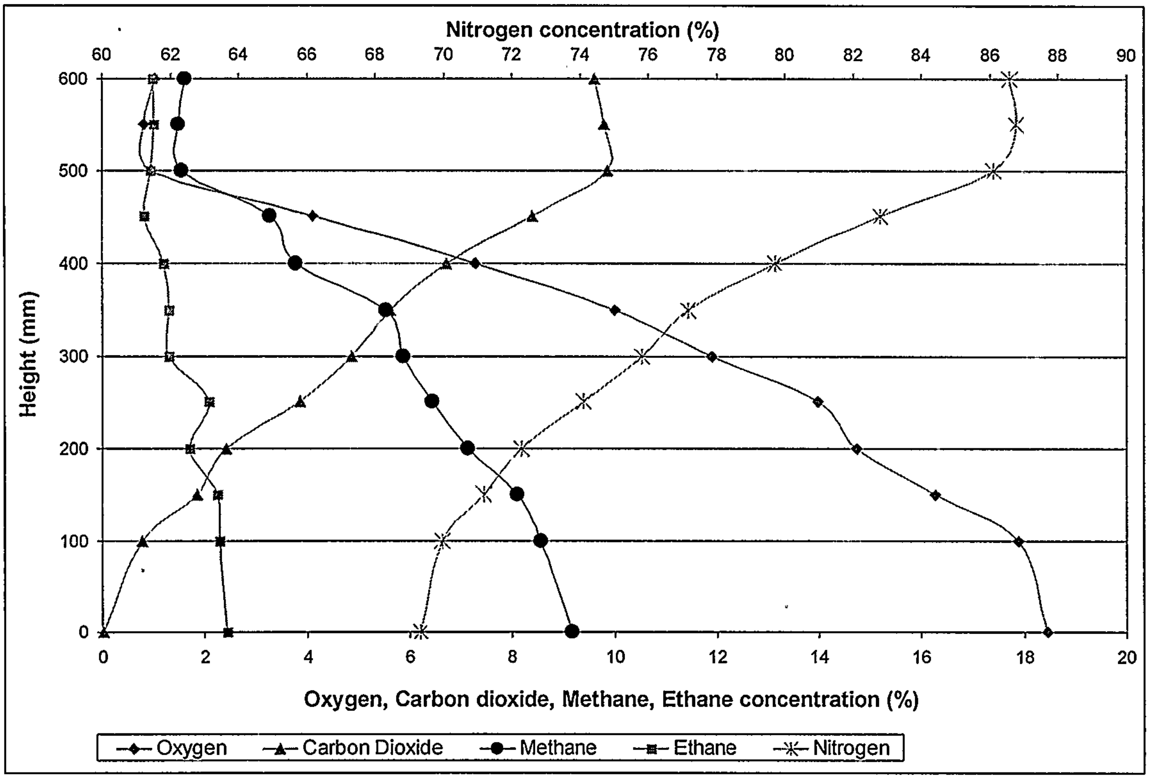

Figure C-23: Gas concentration depth profile – Column D/Stage IV

COLUMN D: DEPTH PROFILES CORRESPONDED TO STAGE V

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	18.274	17.568	16.563	15.197	13.355	11.264	9.145	6.969	4.020	4.136	4.593	4.742
N2	67.804	68.328	68.956	70.591	72.424	74.281	76.007	78.204	81.434	81.440	81.934	81.890
CO2	0.091	0.336	1.201	2.247	3.925	4.515	5.880	6.772	8.456	8.199	7.969	8.069
CH4	10.401	10.097	9.624	8.959	7.798	7.551	6.100	5.471	4.148	4.154	4.091	4.152
C2H6	2.881	2.815	2.488	2.183	2.042	2.073	2.399	1.853	2.312	1.910	2.291	2.191

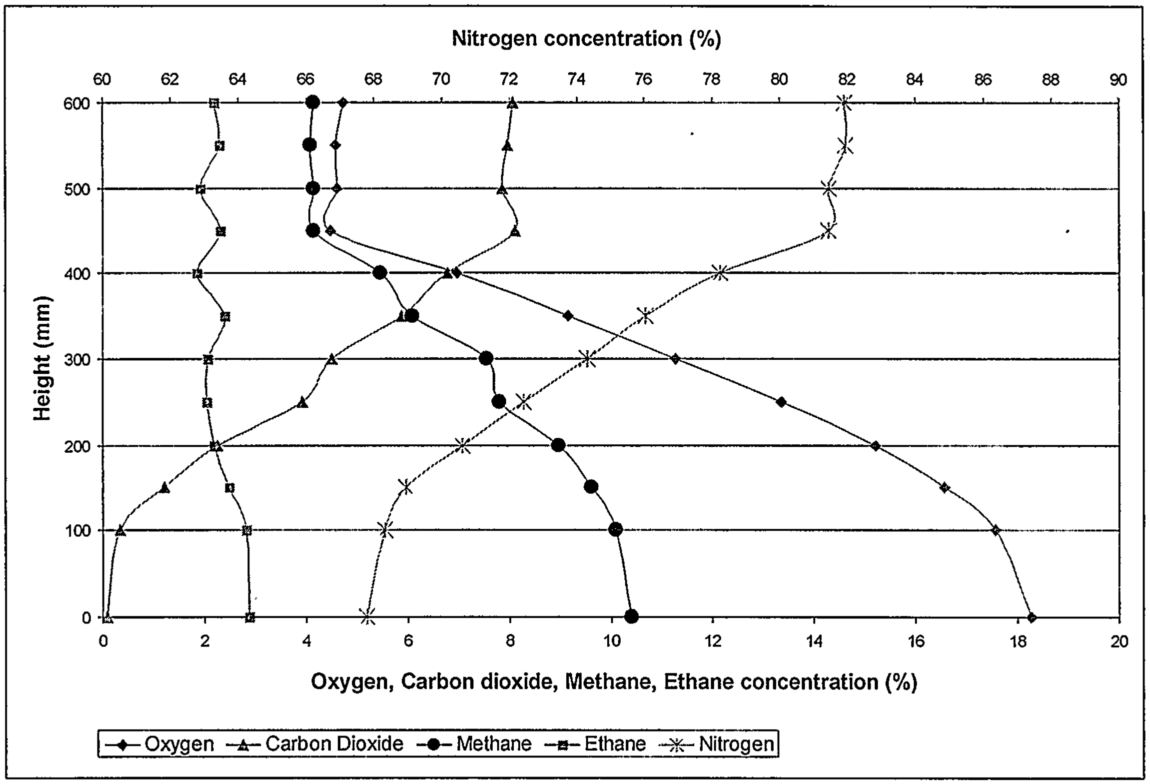

Figure C-24: Gas concentration depth profile – Column D/Stage V

COLUMN D: DEPTH PROFILES CORRESPONDED TO STAGE VI

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	17.629	17.069	15.671	14.604	13.087	11.505	9.034	8.524	8.655	8.599	9.075	8.941
N2	66.196	66.496	68.227	69.082	69.816	72.066	74.131	75.545	76.015	75.595	76.154	76.083
CO2	0.012	0.575	1.290	2.161	3.580	4.178	5.829	5.717	6.375	5.994	6.136	6.163
CH4	12.141	11.766	10.877	10.741	9.774	8.849	8.199	7.435	7.505	7.720	7.655	7.582
C2H6	3.335	3.440	2.771	2.624	2.642	2.896	2.692	2.622	2.949	2.653	3.050	3.043

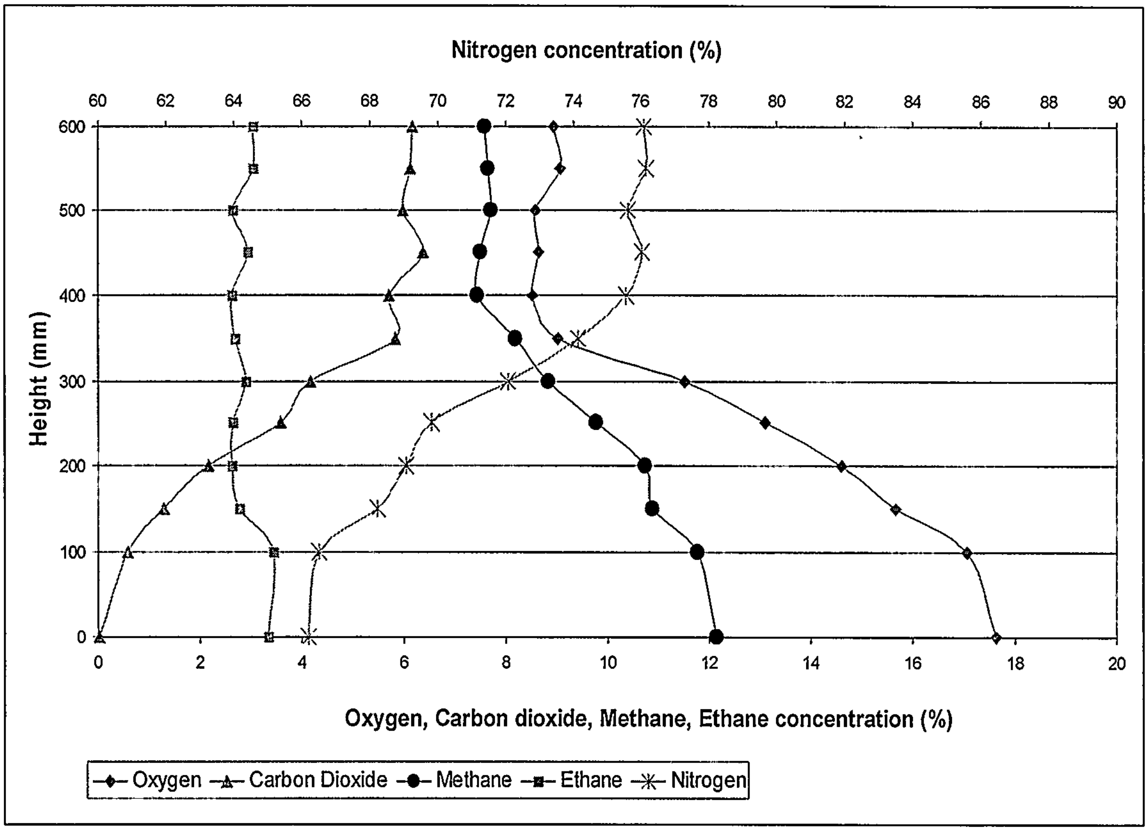

Figure C-25: Gas concentration depth profile – Column D/Stage VI

COLUMN D: DEPTH PROFILES CORRESPONDED TO STAGE VII

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	17.089	16.357	15.016	13.429	13.097	12.397	11.821	12.032	11.746	12.015	12.782	13.137
N2	64.093	64.946	66.176	67.563	69.015	70.496	70.673	70.394	70.023	70.392	70.490	70.209
CO2	0.044	0.510	1.638	2.819	4.011	4.551	4.655	4.439	4.054	4.600	4.473	4.400
CH4	14.077	13.498	13.213	12.695	11.931	11.444	11.516	11.614	11.269	11.438	11.608	11.673
C2H6	3.829	3.877	3.445	3.757	3.039	3.485	3.415	3.012	3.542	3.178	3.549	3.629

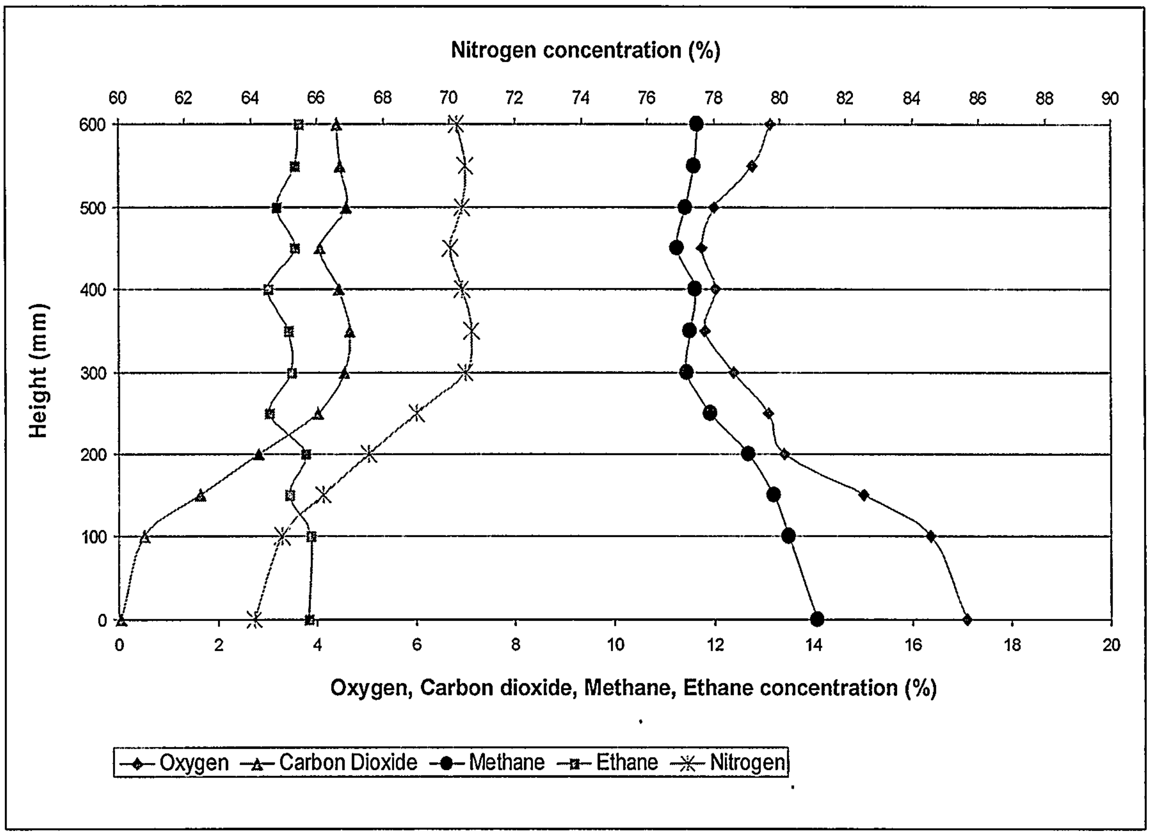

Figure C-26: Gas concentration depth profile – Column D/Stage VII

COLUMN D: DEPTH PROFILES CORRESPONDED TO STAGE VIII

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	16.620	15.282	13.128	12.475	12.458	12.560	12.108	12.471	12.469	12.884	13.762	13.795
N2	61.749	62.739	63.997	66.018	67.057	66.526	66.645	66.731	66.538	66.430	66.640	66.615
CO2	0.149	1.248	2.637	3.761	4.230	3.980	4.245	3.970	3.988	3.854	3.887	3.912
CH4	16.257	15.994	15.413	14.591	14.297	14.100	14.141	14.038	14.216	14.210	14.648	14.590
C2H6	4.498	4.396	3.921	3.808	4.250	4.148	4.049	4.303	4.126	4.073	4.379	4.264

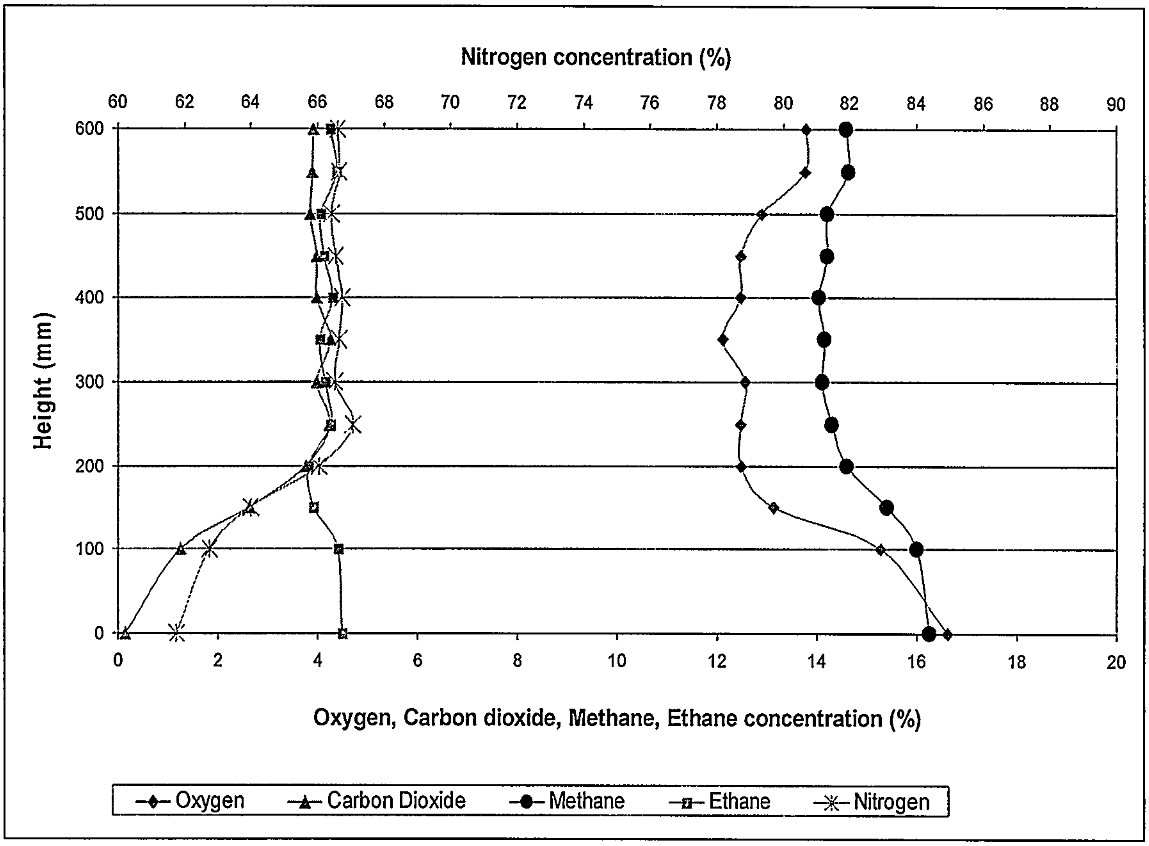

Figure C-27: Gas concentration depth profile – Column D/Stage VIII

COLUMN E: DEPTH PROFILES CORRESPONDED TO STAGE II

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	18.804	17.956	17.037	15.153	11.884	9.064	7.464	6.530	6.695	6.981	7.079	7.073
N2	69.669	70.196	70.969	72.237	74.849	76.625	78.195	78.651	78.652	79.223	79.668	79.518
CO2	0.052	0.570	1.183	2.432	4.555	5.405	6.614	6.949	6.711	7.187	7.093	7.065
CH4	6.043	5.655	5.174	5.316	3.836	3.561	3.229	2.789	2.909	2.733	2.933	2.927
C2H6	4.772	4.548	4.612	4.235	3.552	3.396	2.949	2.874	3.186	2.883	3.306	3.345

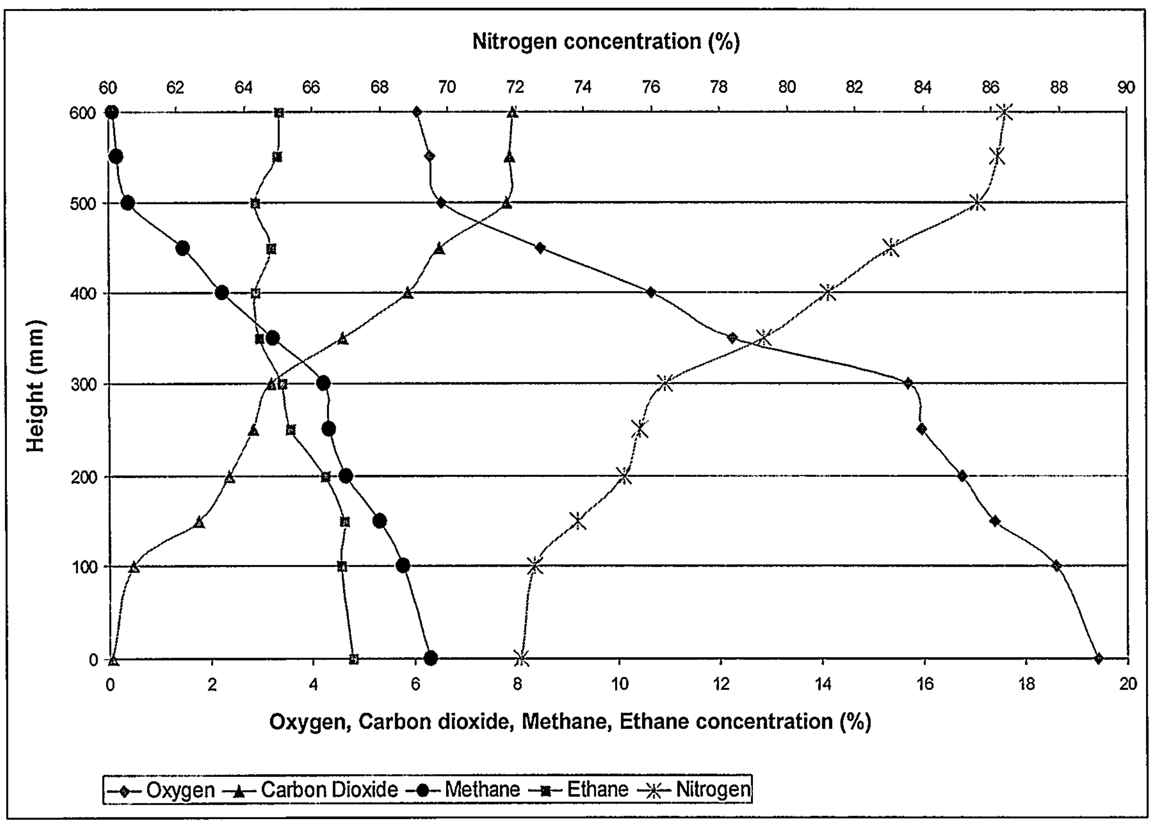

Figure C-28: Gas concentration depth profile – Column E/Stage II

COLUMN E: DEPTH PROFILES CORRESPONDED TO STAGE III

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	18.223	17.432	16.499	13.518	11.815	8.569	5.433	5.220	5.018	5.974	6.206	5.948
N2	67.923	68.790	69.561	71.253	72.947	75.087	77.646	77.653	77.493	77.521	77.742	77.930
CO2	0.096	0.914	1.301	2.866	4.421	5.737	7.517	7.734	7.379	7.466	7.338	7.442
CH4	7.444	7.126	6.517	6.108	5.270	4.793	4.066	3.347	3.784	3.849	3.954	3.939
C2H6	5.902	5.817	5.675	5.304	5.254	4.868	4.044	4.338	4.349	4.223	4.643	4.596

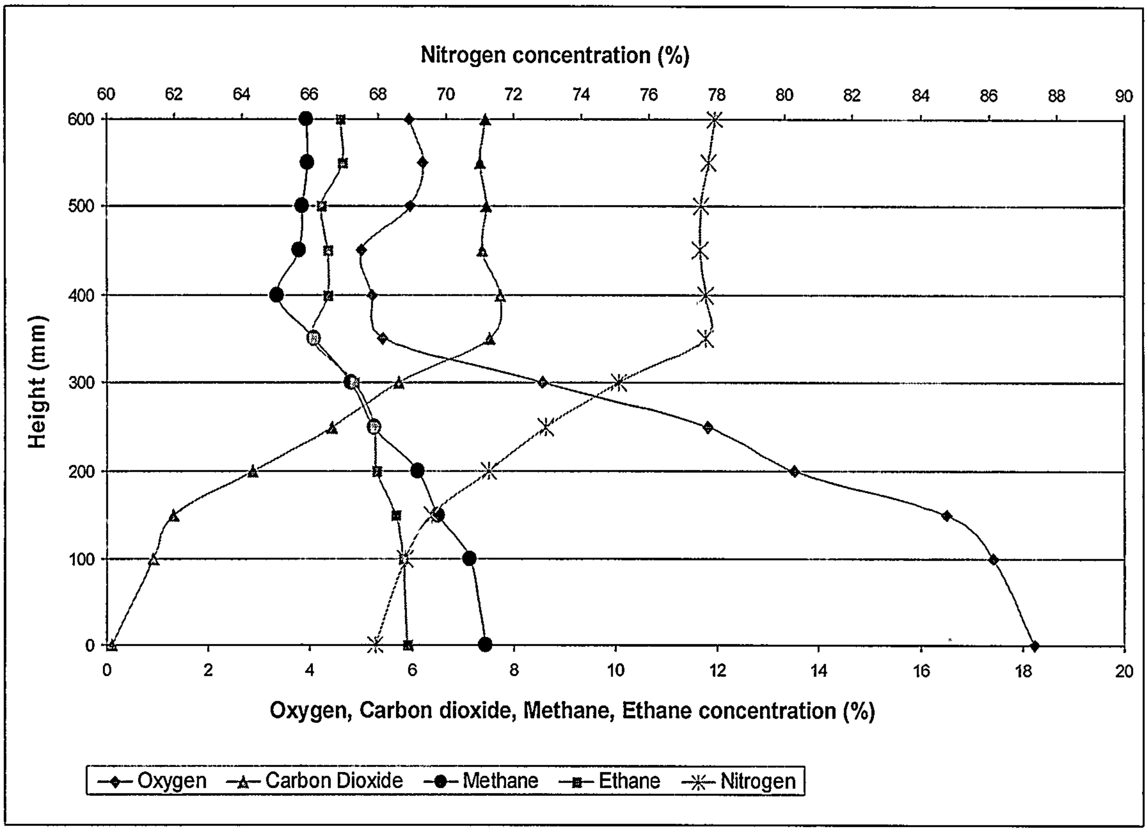

Figure C-29: Gas concentration depth profile – Column E/Stage III

COLUMN E: DEPTH PROFILES CORRESPONDED TO STAGE IV

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	17.740	16.792	15.981	14.305	11.537	8.737	8.906	9.266	9.756	10.230	10.561	10.652
N2	66.205	67.029	67.108	68.780	71.087	72.903	72.400	72.353	72.785	73.139	72.889	72.955
CO2	0.092	0.684	1.201	2.086	3.662	5.619	5.299	4.973	4.629	5.157	5.016	4.991
CH4	8.685	8.356	8.042	7.488	6.283	5.561	5.570	5.932	5.673	5.500	5.948	5.927
C2H6	6.971	6.754	6.605	6.050	6.308	6.362	6.341	5.949	5.896	6.155	6.511	6.417

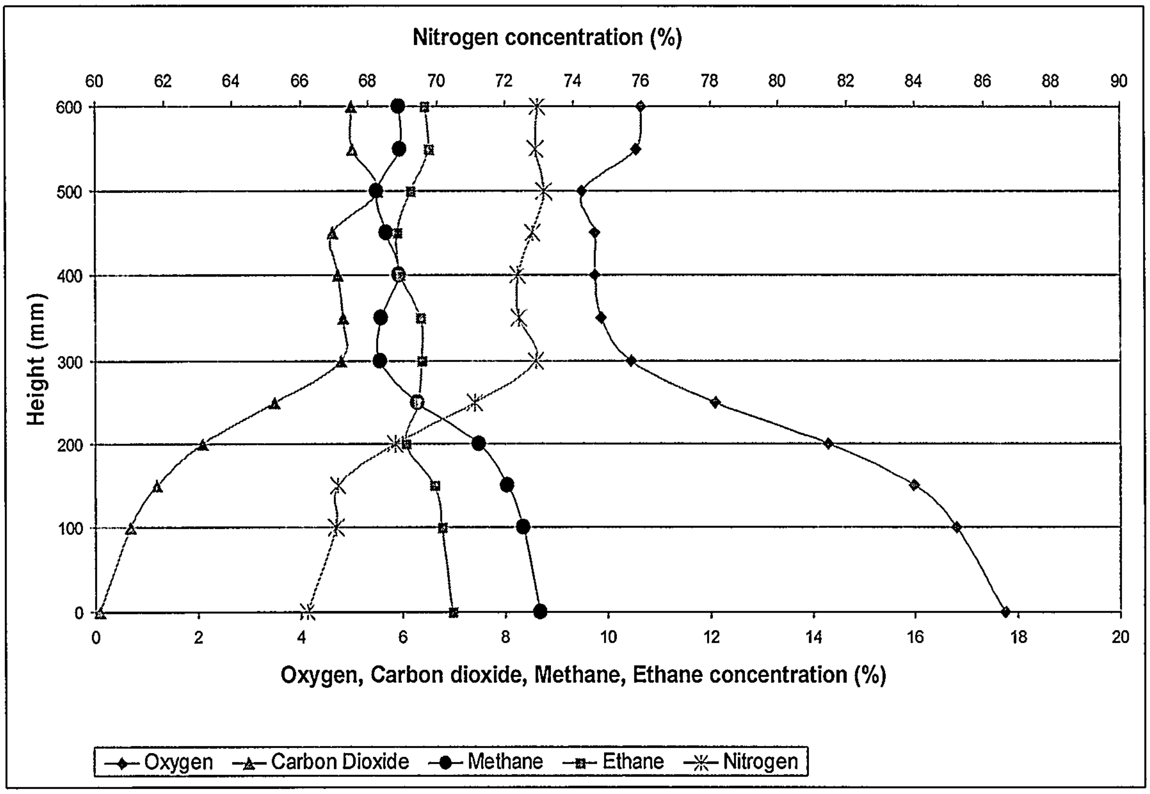

Figure C-30: Gas concentration depth profile – Column E/Stage IV

COLUMN E: DEPTH PROFILES CORRESPONDED TO STAGE V

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	17.274	16.295	14.906	13.658	12.668	13.078	12.765	13.407	13.491	14.155	14.433	14.680
N2	64.340	64.706	65.364	66.631	67.670	67.771	67.543	67.810	67.398	67.653	68.092	67.948
CO2	0.096	0.547	1.343	2.708	3.191	2.803	2.780	2.920	2.528	2.740	2.974	2.837
CH4	10.058	9.342	9.340	8.871	8.482	8.496	8.040	8.466	8.472	8.371	8.629	8.716
C2H6	8.029	7.842	7.797	7.280	7.489	7.221	7.031	7.025	7.073	7.380	7.613	7.623

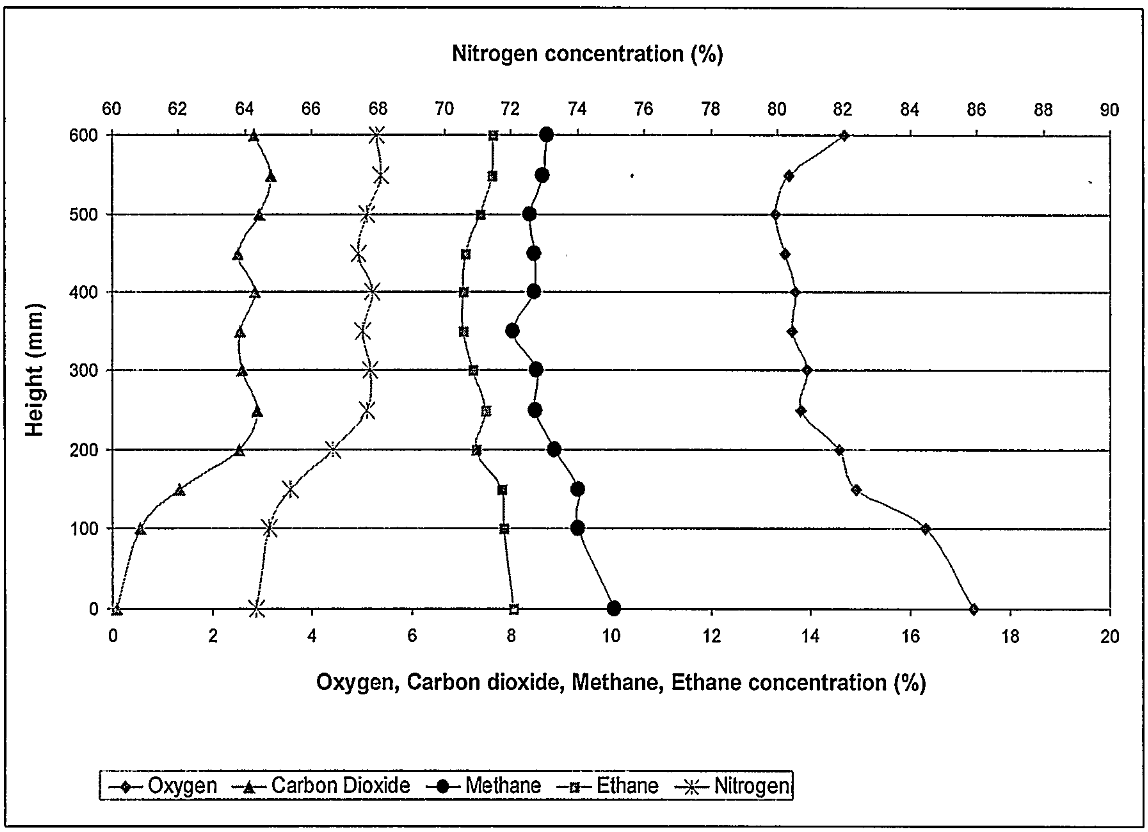

Figure C-31: Gas concentration depth profile – Column E/Stage V

COLUMN E: DEPTH PROFILES CORRESPONDED TO STAGE VI

Gas	Height (mm)											
	0	100	150	200	250	300	350	400	450	500	550	600
O2	16.617	15.596	14.574	13.682	13.420	13.570	13.830	13.611	13.799	13.793	14.374	15.385
N2	62.121	63.153	64.209	64.848	65.054	64.804	64.820	64.847	65.153	65.198	65.249	65.072
CO2	0.147	1.064	1.436	2.054	2.197	2.049	2.208	2.531	2.647	2.502	2.602	2.348
CH4	11.401	11.194	10.308	10.302	10.229	10.103	10.210	9.983	10.437	10.549	10.603	10.538
C2H6	9.080	8.988	8.443	8.785	8.588	8.548	8.350	8.624	8.735	8.588	8.814	8.836

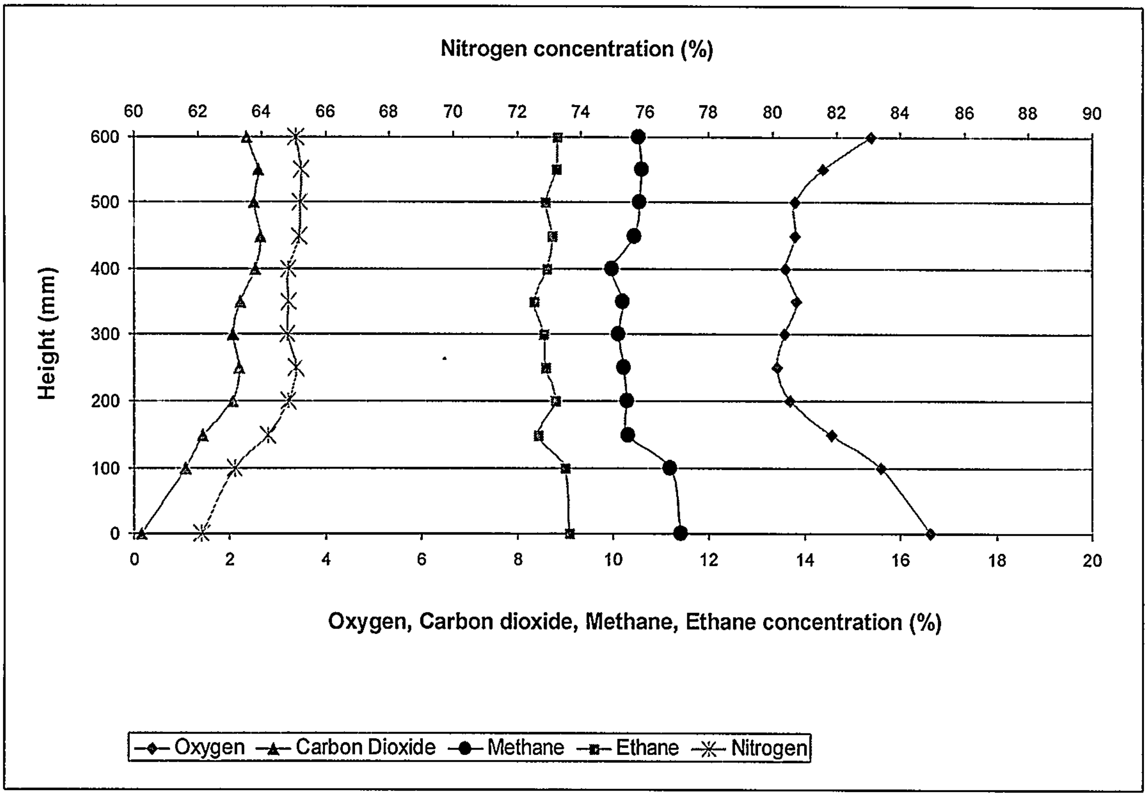

Figure C-32: Gas concentration depth profile – Column E/Stage VI

OVERALL METHANE OXIDATION DEPTH PROFILES

Column A

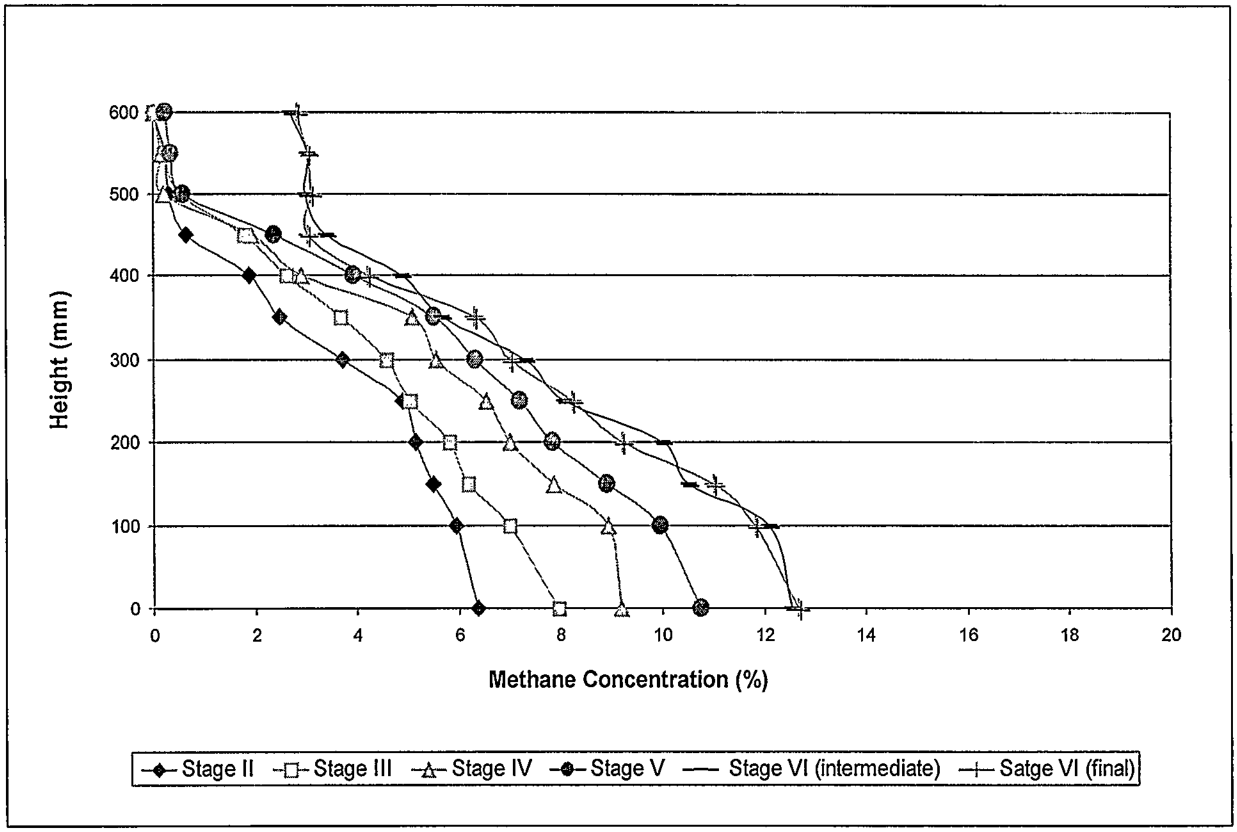

Figure C-33: Overall gas concentration depth profile – Column A

Column B

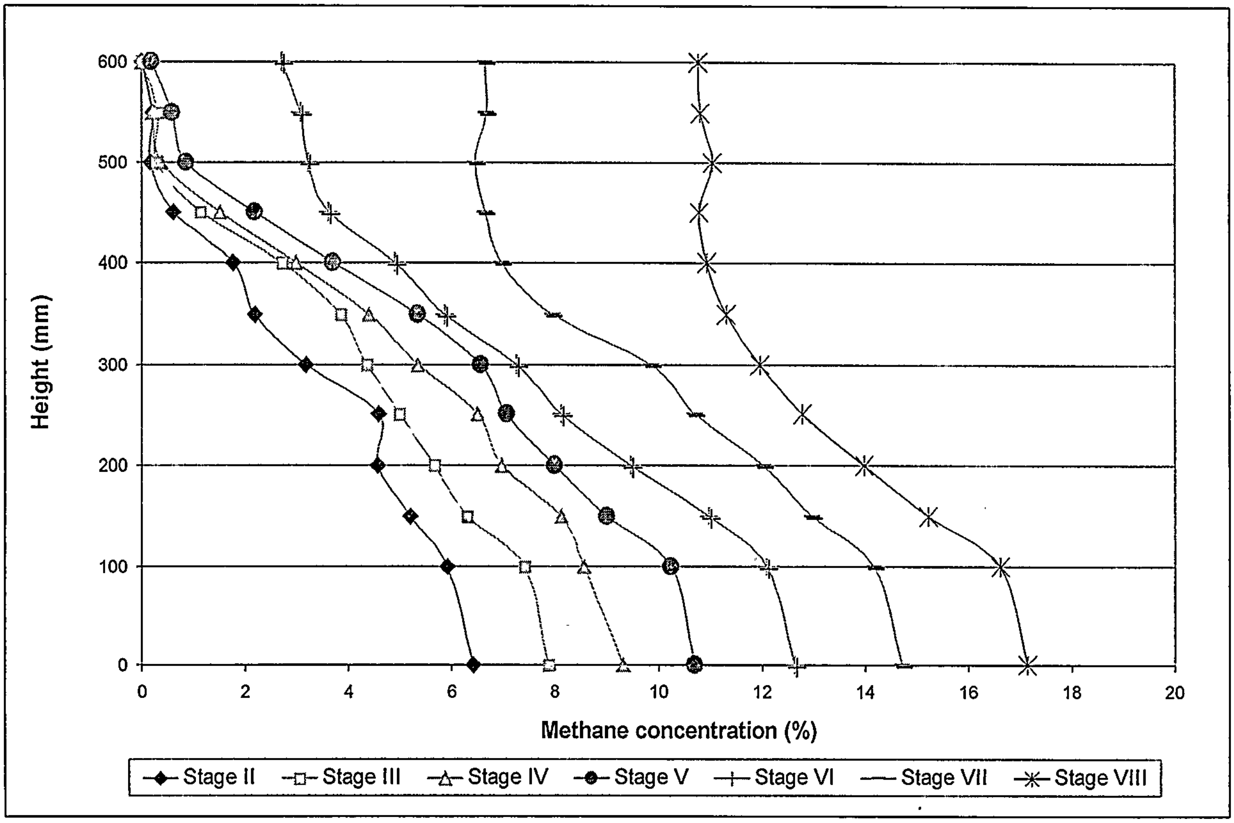

Figure C-34: Overall gas concentration depth profile – Column B

Column C

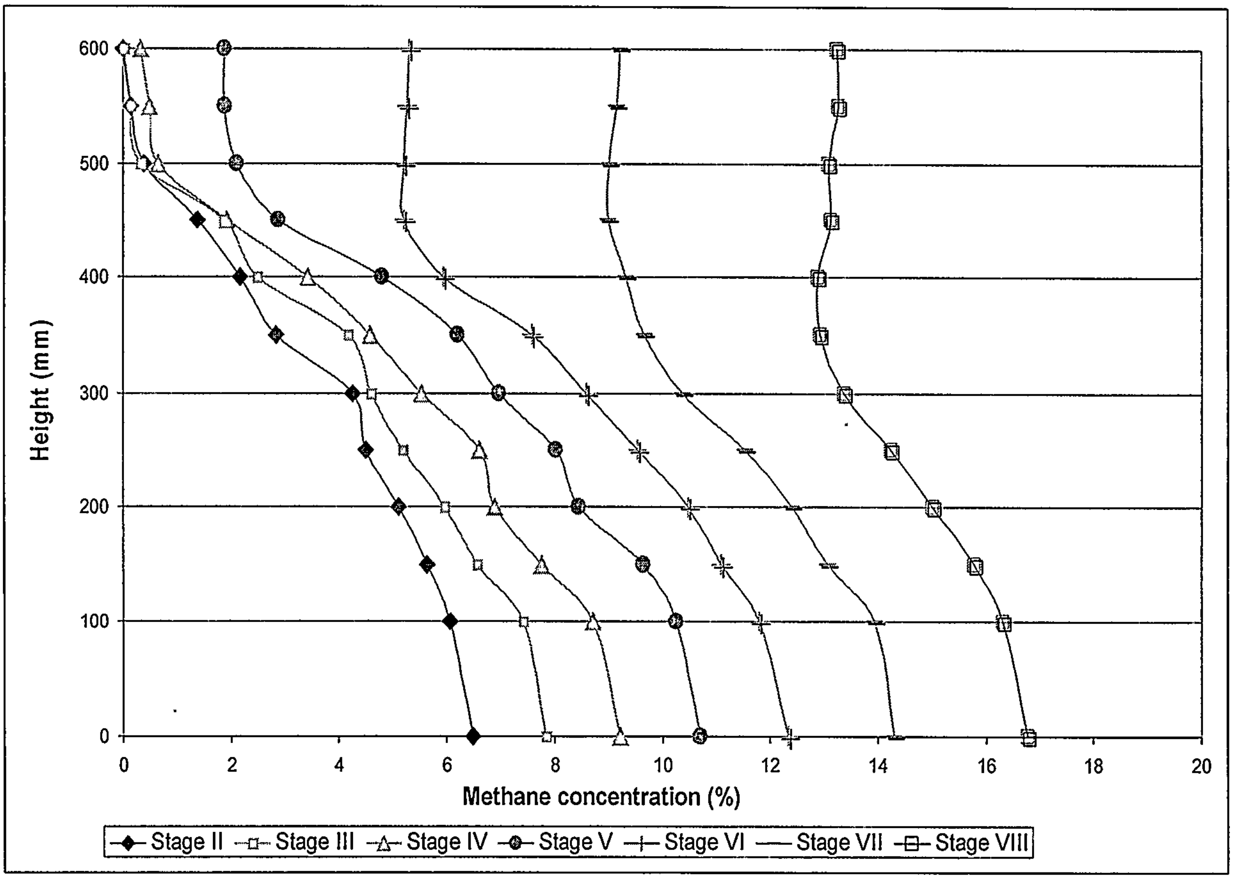

Figure C-35: Overall gas concentration depth profile – Column C

Column D

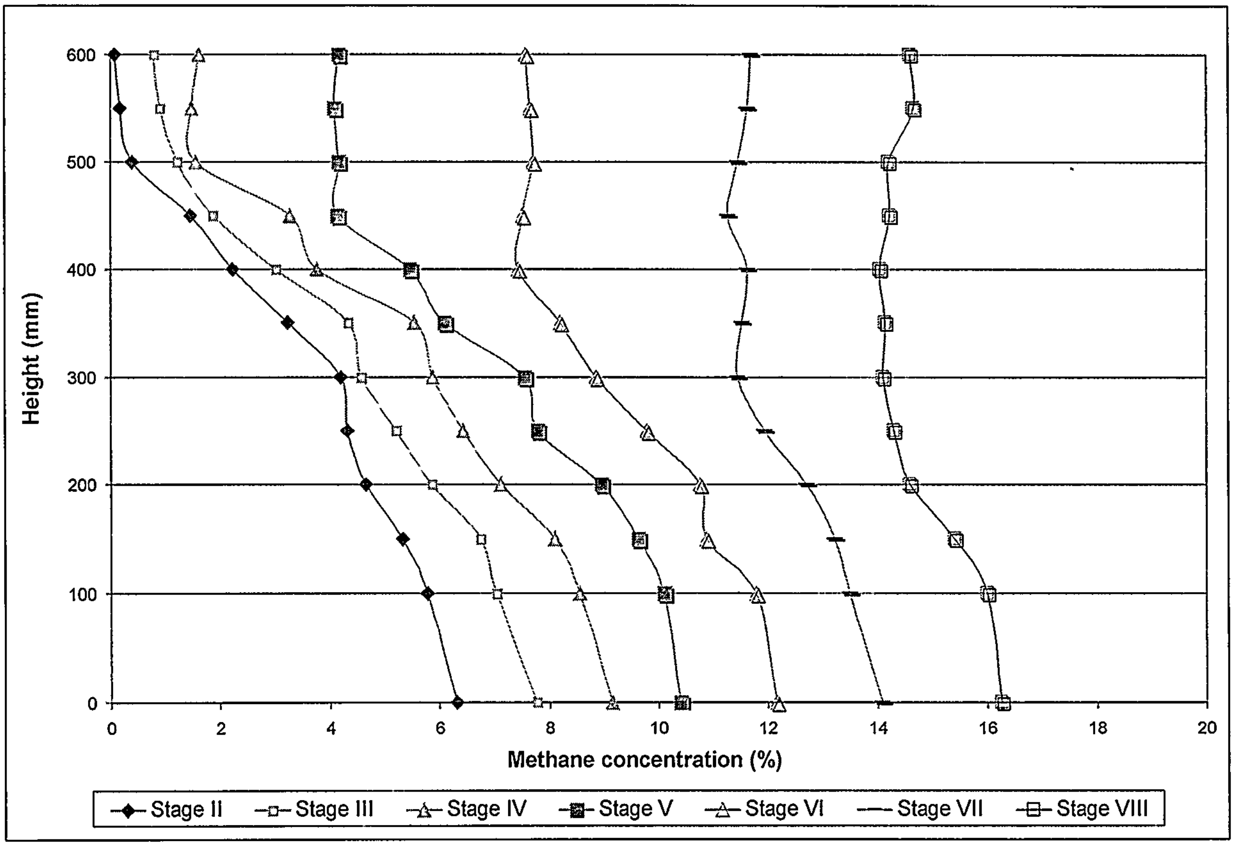

Figure C-36: Overall gas concentration depth profile – Column D

Column E

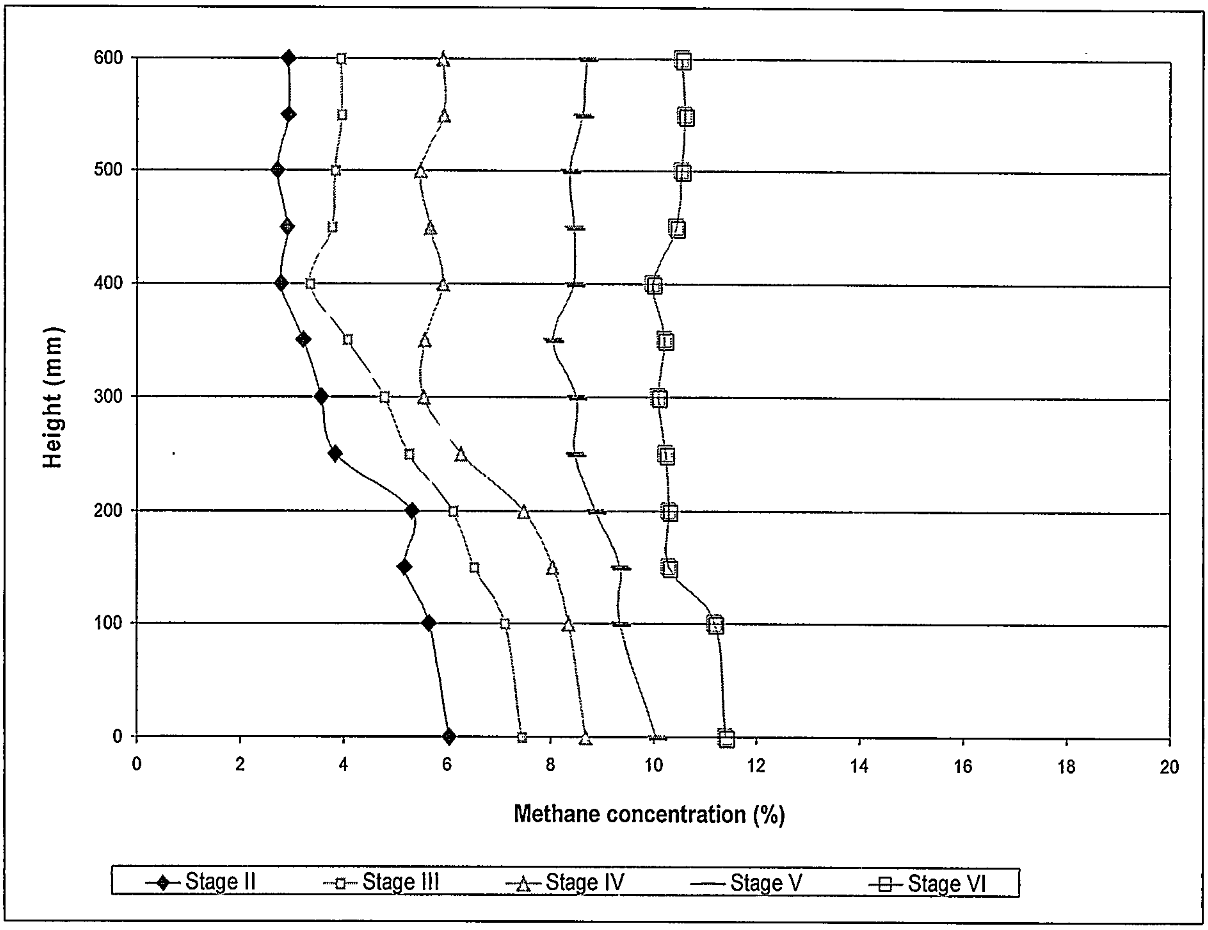

Figure C-37: Overall gas concentration depth profile – Column E

APPENDIX D: BATCH EXPERIMENT DATA AND CALCULATIONS

COLUMN A – 600 mm layer

Elapsed Time	Oxygen	Nitrogen	Carbon Dioxide	Methane
hrs	%	%	%	%
0.00	19.37	74.11	0.31	5.52
1.55	19.14	74.11	0.66	5.34
5.55	18.49	74.88	0.80	4.94
7.38	18.48	74.75	0.99	4.73
27.05	15.88	77.81	2.97	2.68
58.13	12.31	81.61	5.06	0.07
63.05	12.37	81.83	5.22	0.00

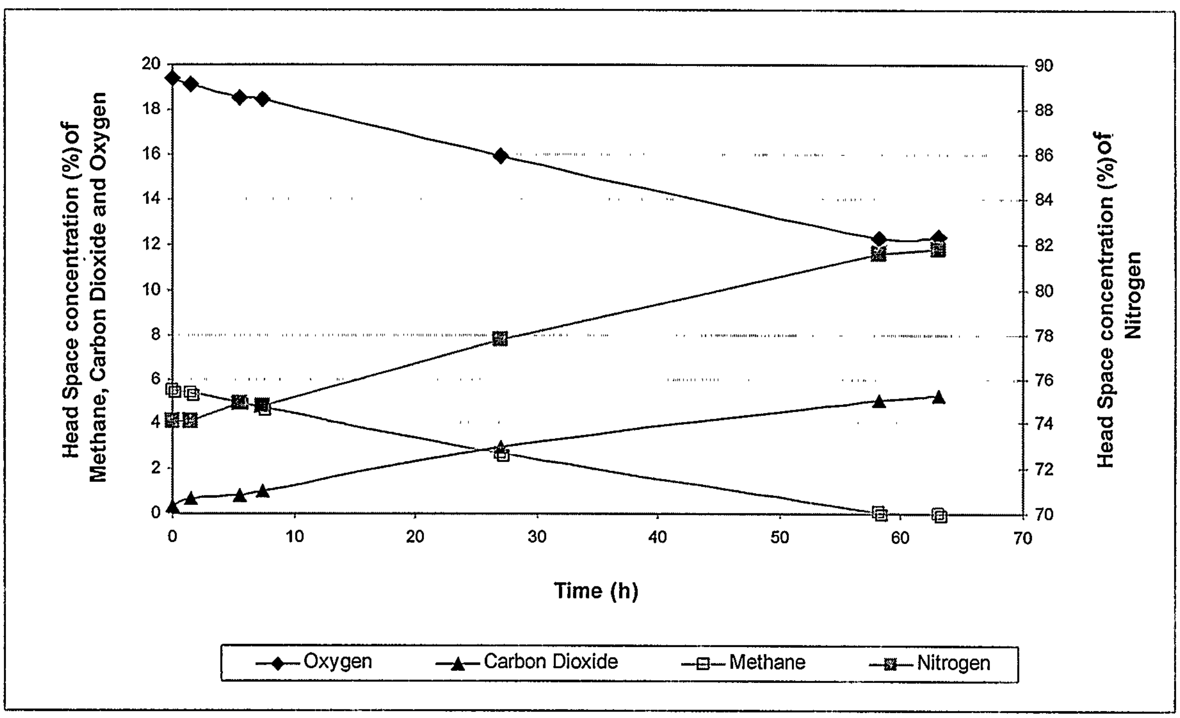

Figure D-1: Methane drawdown curve for biofilter column A at column height 600mm

COLUMN A – 500 mm layer

Elapsed Time hrs	Oxygen %	Nitrogen %	Carbon Dioxide %	Methane %
0.00	19.24	74.12	0.29	5.50
1.12	18.86	74.27	0.62	5.24
1.72	18.60	74.79	0.71	5.13
6.90	17.46	76.24	1.49	4.05
11.05	16.65	77.01	2.31	3.29
26.80	12.75	81.41	4.96	0.42
69.80	12.08	81.87	5.22	0.00

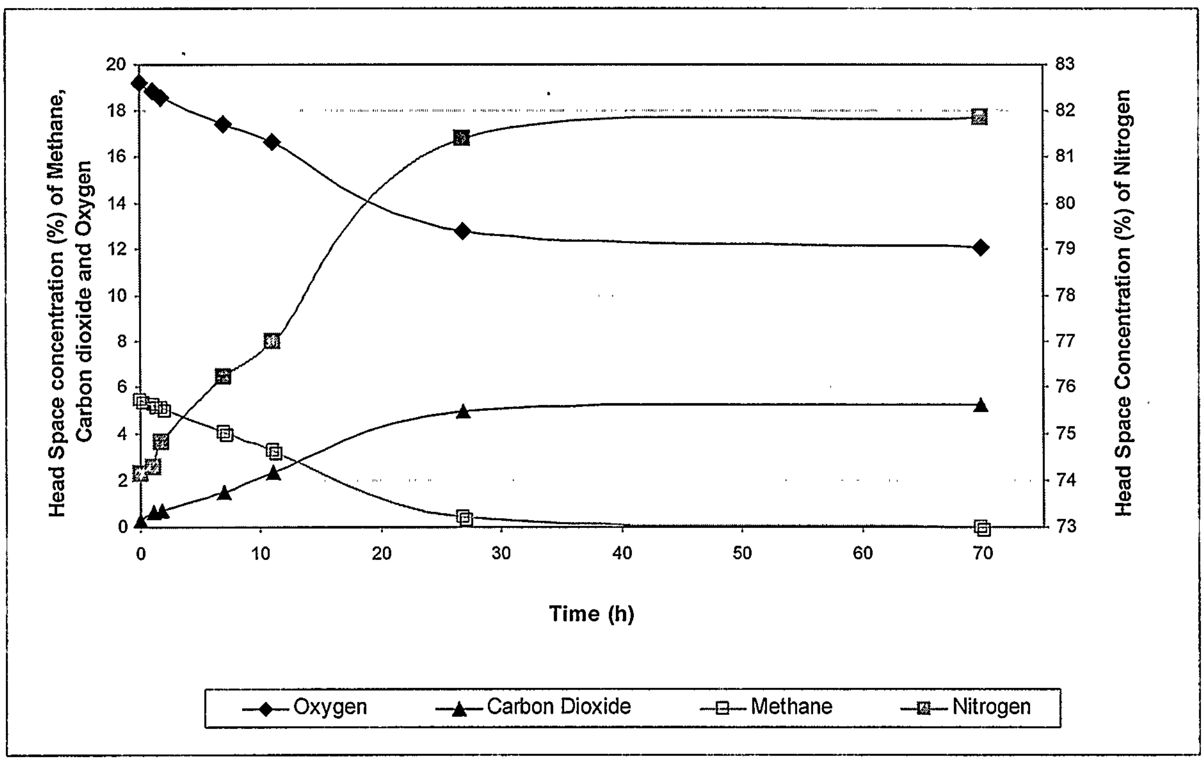

Figure D-2: Methane drawdown curve for biofilter column A at column height 500 mm

COLUMN A – 400 mm layer

Elapsed Time hrs	Oxygen %	Nitrogen %	Carbon Dioxide %	Methane %
0.00	19.27	73.91	0.28	5.57
1.08	18.90	74.76	0.74	5.19
2.73	17.99	75.58	1.28	4.59
3.32	17.96	75.50	1.38	4.35
7.00	16.02	77.47	2.49	3.02
13.08	13.68	80.02	4.14	1.31
23.25	12.36	81.75	5.23	0.00

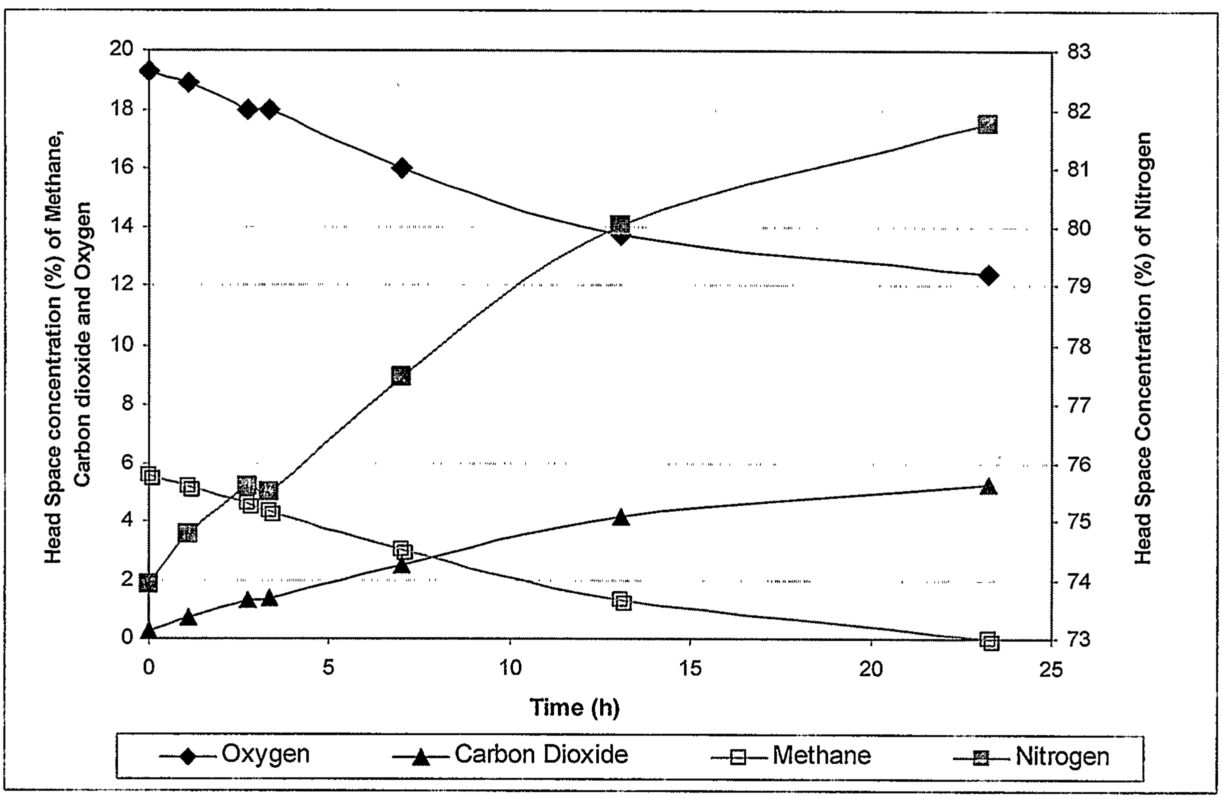

Figure D-3: Methane drawdown curve for biofilter column A at column height 400mm

COLUMN A – 300 mm layer

Elapsed Time	Oxygen	Nitrogen	Carbon Dioxide	Methane
hrs	%	%	%	%
0.00	19.48	73.98	0.40	5.64
1.63	18.43	74.86	0.87	4.99
2.52	18.19	75.30	1.08	4.64
3.93	17.69	76.07	1.69	4.07
6.85	16.02	77.37	2.67	3.00
11.93	14.20	79.86	4.04	1.31
22.68	12.17	81.96	5.31	0.00

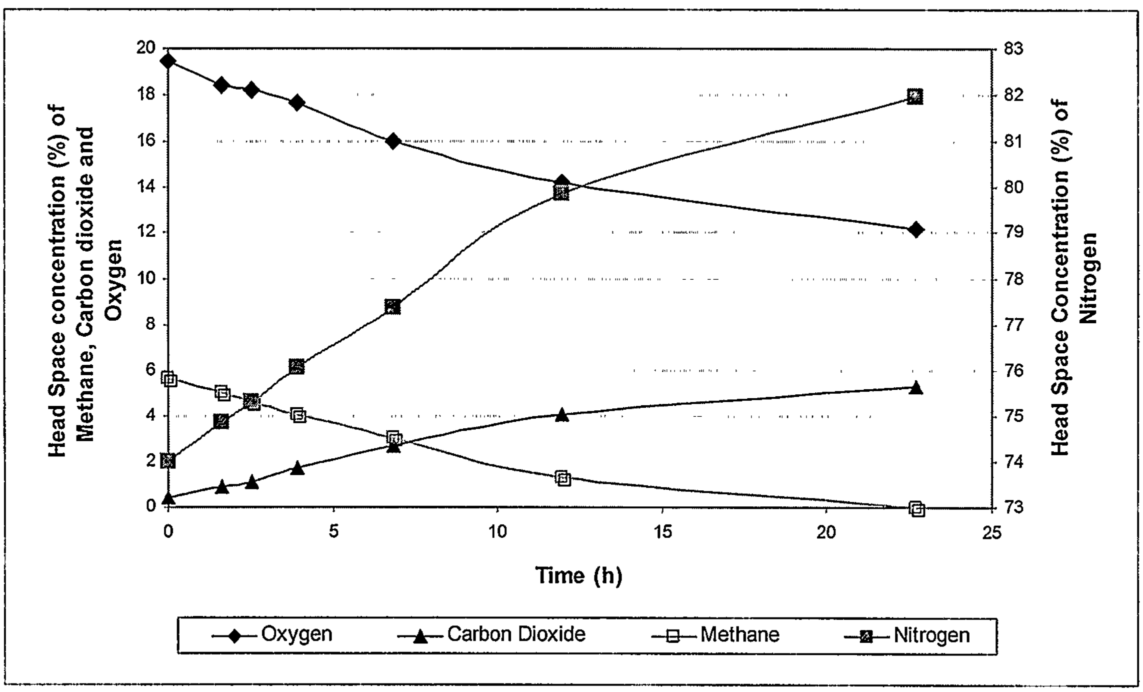

Figure D-4: Methane drawdown curve for biofilter column A at column height 300mm

COLUMN A – 200 mm layer

Elapsed Time hrs	Oxygen %	Nitrogen %	Carbon Dioxide %	Methane %
0.00	19.22	74.00	0.51	5.15
0.87	18.10	74.79	1.26	4.85
2.77	17.48	75.51	1.61	4.15
3.62	17.46	76.22	1.94	3.88
5.50	16.07	77.12	2.65	3.20
11.45	14.64	79.37	3.79	1.63
36.28	12.18	81.86	5.42	0.00

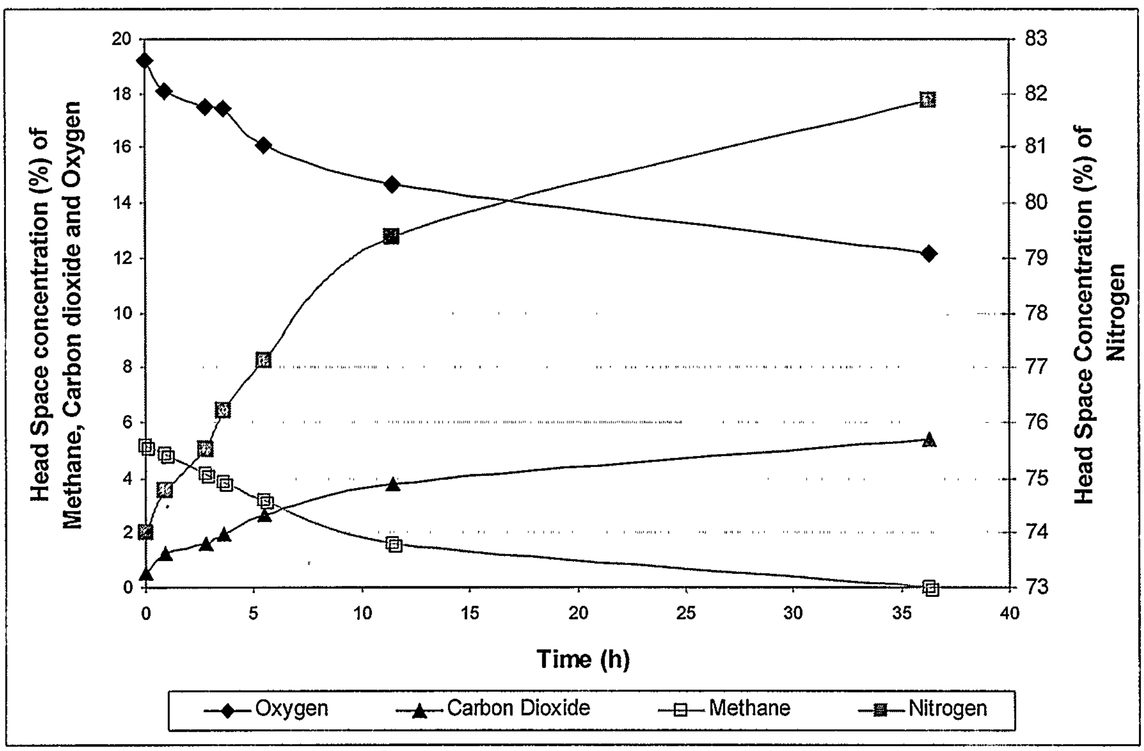

Figure D-5: Methane drawdown curve for biofilter column A at column height 200mm

COLUMN A – 100 mm layer

Elapsed Time hrs	Oxygen %	Nitrogen %	Carbon Dioxide %	Methane %
0.00	19.39	73.87	0.43	5.25
0.62	18.97	74.61	0.67	5.16
0.78	18.52	74.80	0.84	5.13
5.28	17.55	75.50	1.37	4.21
11.95	16.22	77.70	2.47	2.96
25.70	12.84	81.29	4.78	0.45
65.87	12.10	81.93	5.28	0.00

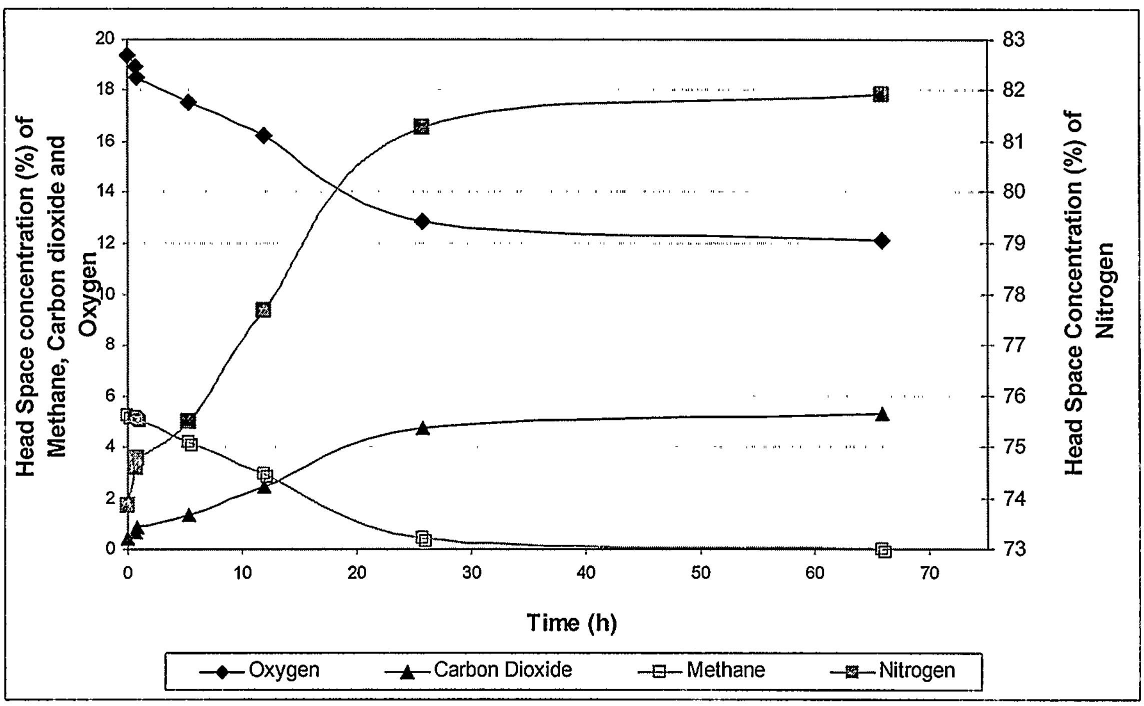

Figure D-6: Methane drawdown curve for biofilter column A at column height 100mm

COLUMN A – Bottom layer

Elapsed Time	Oxygen	Nitrogen	Carbon Dioxide	Methane
hrs	%	%	%	%
0.00	19.36	73.73	0.39	5.58
1.15	19.22	74.13	0.40	5.57
2.20	19.60	73.48	0.37	5.67
8.17	19.14	74.01	0.42	5.65
24.13	19.32	73.34	0.40	5.60
72.22	19.44	73.56	0.36	5.65
240.15	19.47	73.69	0.40	5.67

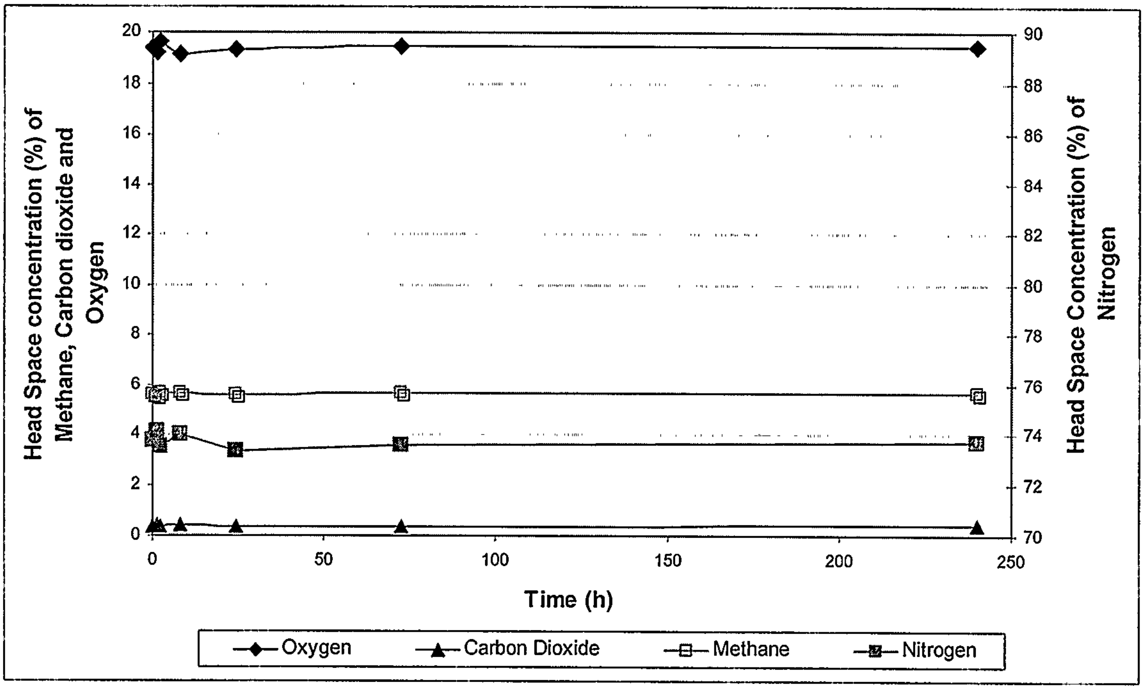

Figure D-7: Methane drawdown curve for biofilter column A at column height 0 mm

COLUMN B – 600mm layer

Elapsed Time hrs	Oxygen %	Nitrogen %	Carbon Dioxide %	Methane %
0.00	19.28	74.08	0.38	5.55
1.35	19.26	74.17	0.33	5.43
1.60	19.23	74.11	0.64	5.40
7.25	18.75	74.82	0.82	4.92
23.32	16.72	76.46	2.01	3.54
71.58	12.36	81.81	5.09	0.09
107.33	12.02	82.09	5.23	0.00

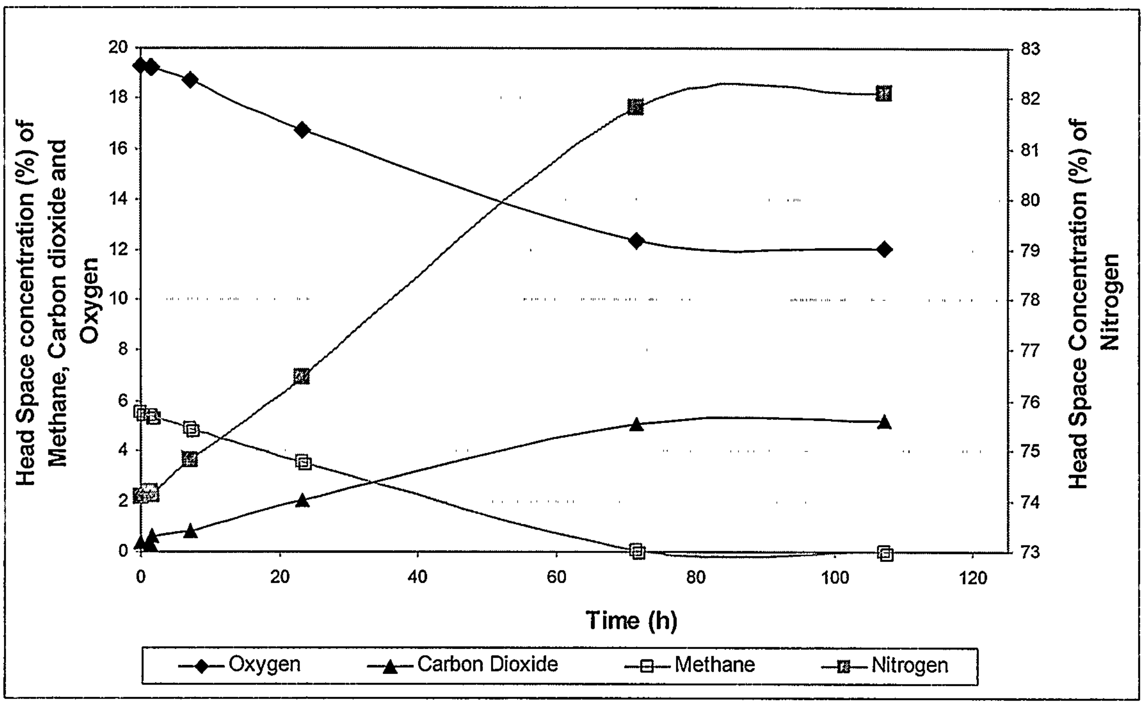

Figure D-8: Methane drawdown curve for biofilter column B at column height 600mm

COLUMN B – 500mm layer

Elapsed Time	Oxygen	Nitrogen	Carbon Dioxide	Methane
hrs	%	%	%	%
0.00	19.45	74.03	0.27	5.65
1.78	18.65	74.59	0.66	5.26
2.98	18.81	74.59	0.71	4.97
6.17	17.96	75.69	1.36	4.31
13.83	16.26	77.38	2.50	2.89
30.00	13.03	80.79	4.76	0.40
63.58	12.29	82.01	5.42	0.00

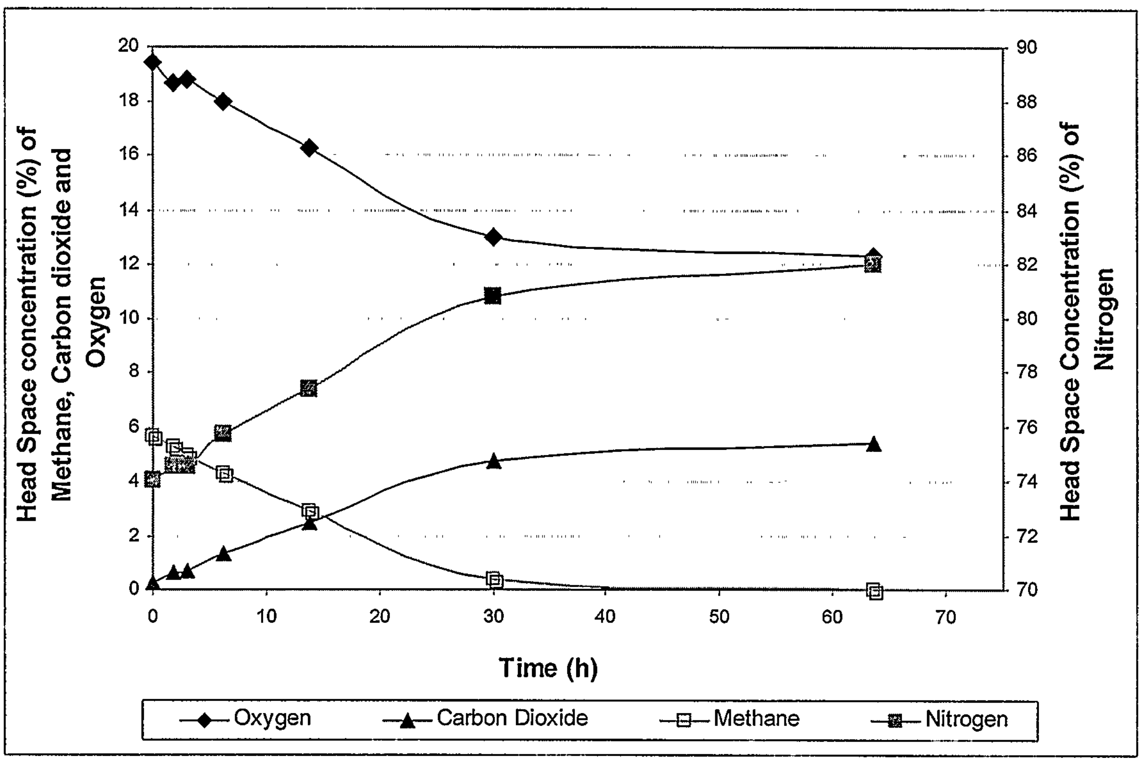

Figure D-9: Methane drawdown curve for biofilter column A at column height 500mm

COLUMN B – 400mm layer

Elapsed Time	Oxygen	Nitrogen	Carbon Dioxide	Methane
hrs	%	%	%	%
0.00	19.16	73.77	0.45	5.55
1.12	18.86	74.16	0.40	5.31
2.25	18.98	74.55	0.77	5.06
7.93	17.23	76.21	1.64	3.91
12.30	16.04	77.32	2.47	3.09
26.58	12.78	81.11	4.77	0.50
62.92	12.28	81.85	5.37	0.00

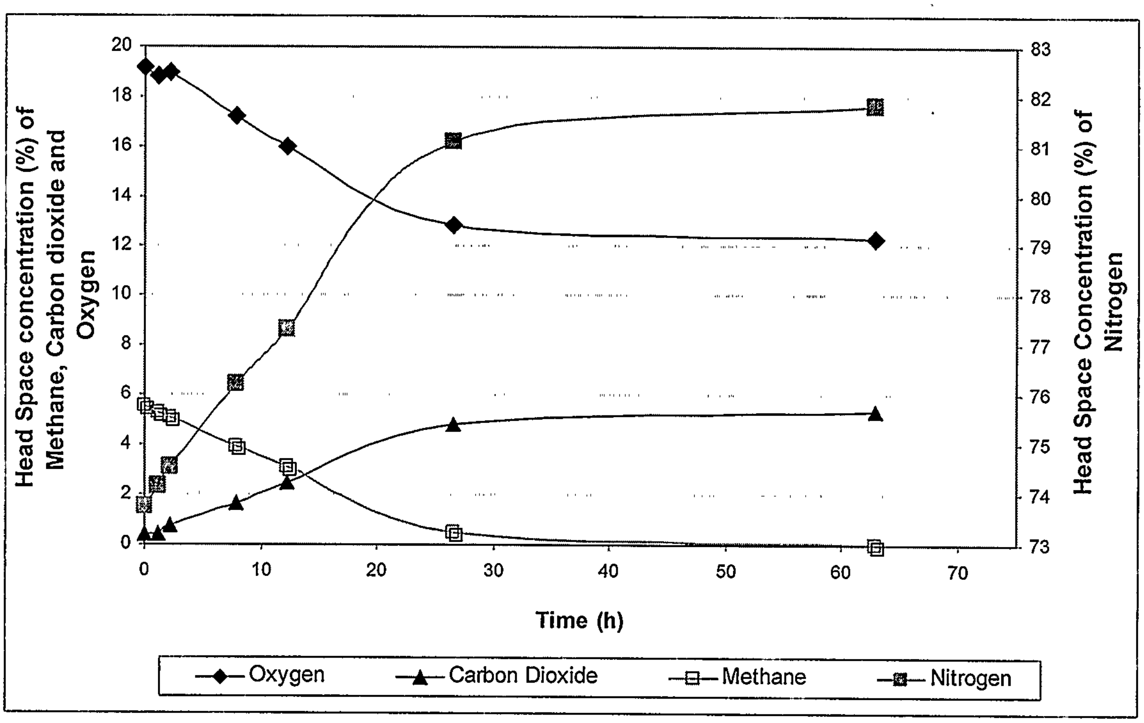

Figure D-10: Methane drawdown curve for biofilter column B at column height 400mm

COLUMN B – 300mm layer

Elapsed Time hrs	Oxygen %	Nitrogen %	Carbon Dioxide %	Methane %
0.00	19.24	74.17	0.43	5.49
1.05	18.63	74.61	0.69	5.09
1.30	18.86	74.60	0.82	4.99
3.72	17.54	75.78	1.55	4.16
6.10	16.38	77.20	2.26	3.30
11.97	14.56	79.46	3.78	1.70
25.88	12.01	81.93	5.36	0.00

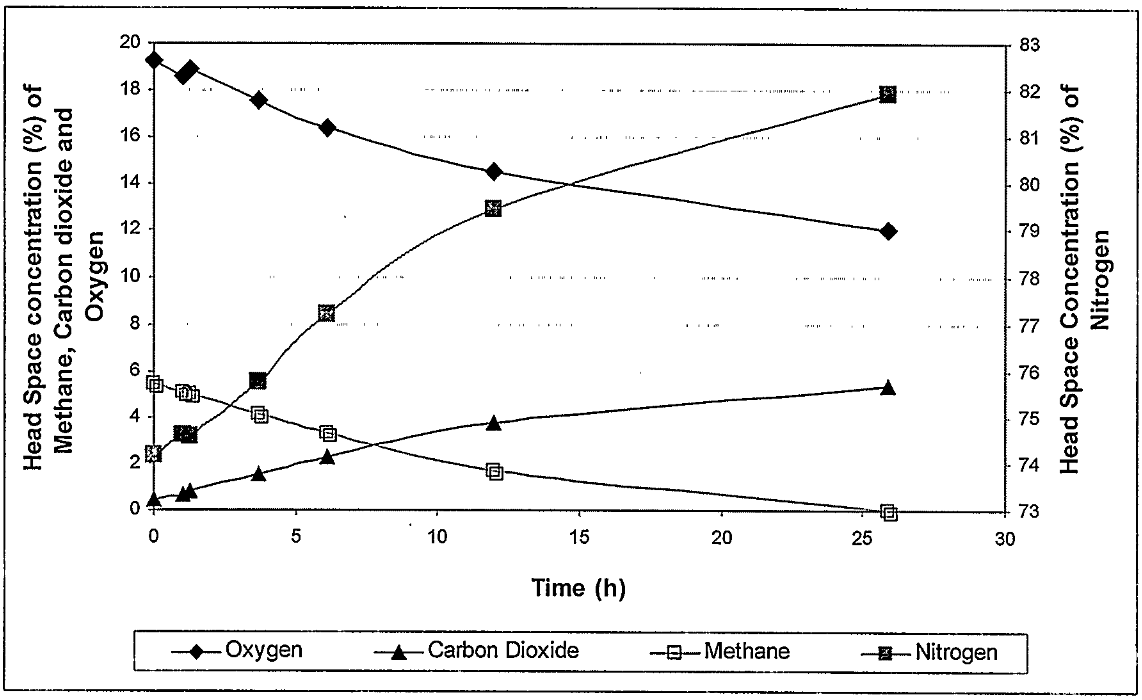

Figure D-11: Methane drawdown curve for biofilter column B at column height 300mm

COLUMN B – 200mm layer

Elapsed Time	Oxygen	Nitrogen	Carbon Dioxide	Methane
hrs	%	%	%	%
0.00	19.54	74.20	0.36	5.32
0.88	18.78	74.45	0.68	4.97
1.53	17.99	75.17	1.23	4.76
3.08	17.64	75.63	1.53	4.16
5.95	16.16	77.26	2.41	3.20
12.17	14.69	79.26	3.64	1.57
34.83	12.34	81.72	5.28	0.00

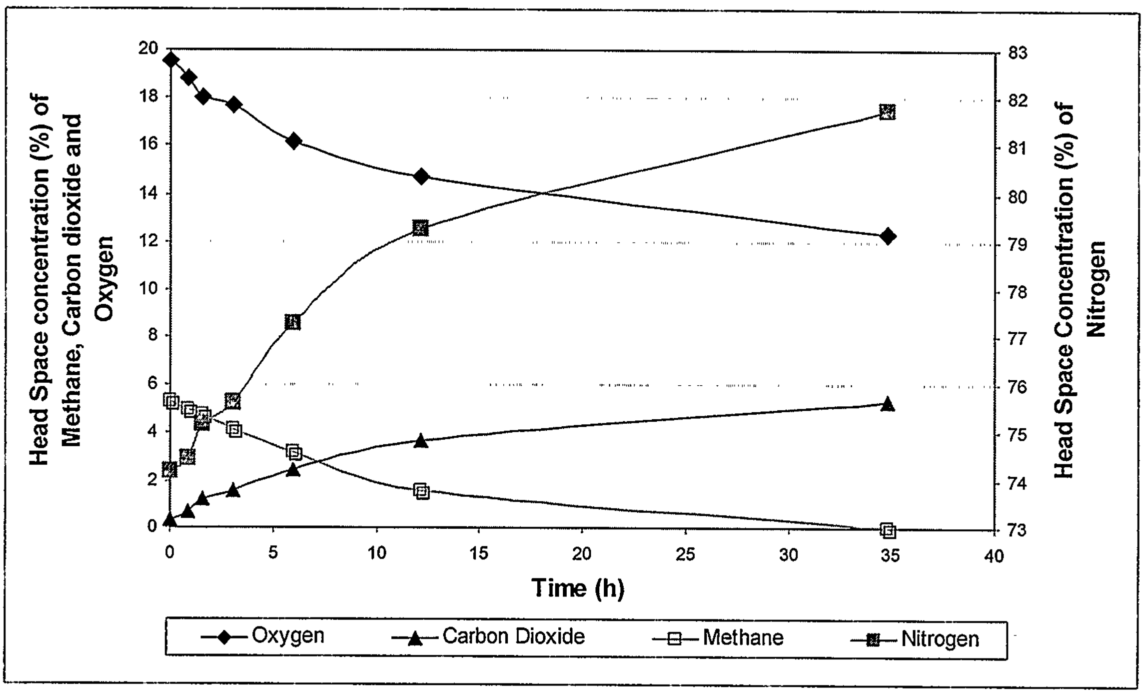

Figure D-12: Methane drawdown curve for biofilter column B at column height 200mm

COLUMN B – 100mm layer

Elapsed Time	Oxygen	Nitrogen	Carbon Dioxide	Methane
hrs	%	%	%	%
0.00	19.17	73.95	0.42	5.49
1.07	18.96	74.33	0.49	5.33
2.30	18.85	74.68	0.71	5.13
6.13	17.87	75.25	1.09	4.50
13.05	16.86	76.83	2.21	3.43
38.30	12.79	81.08	4.65	0.46
64.22	12.00	82.13	5.37	0.00

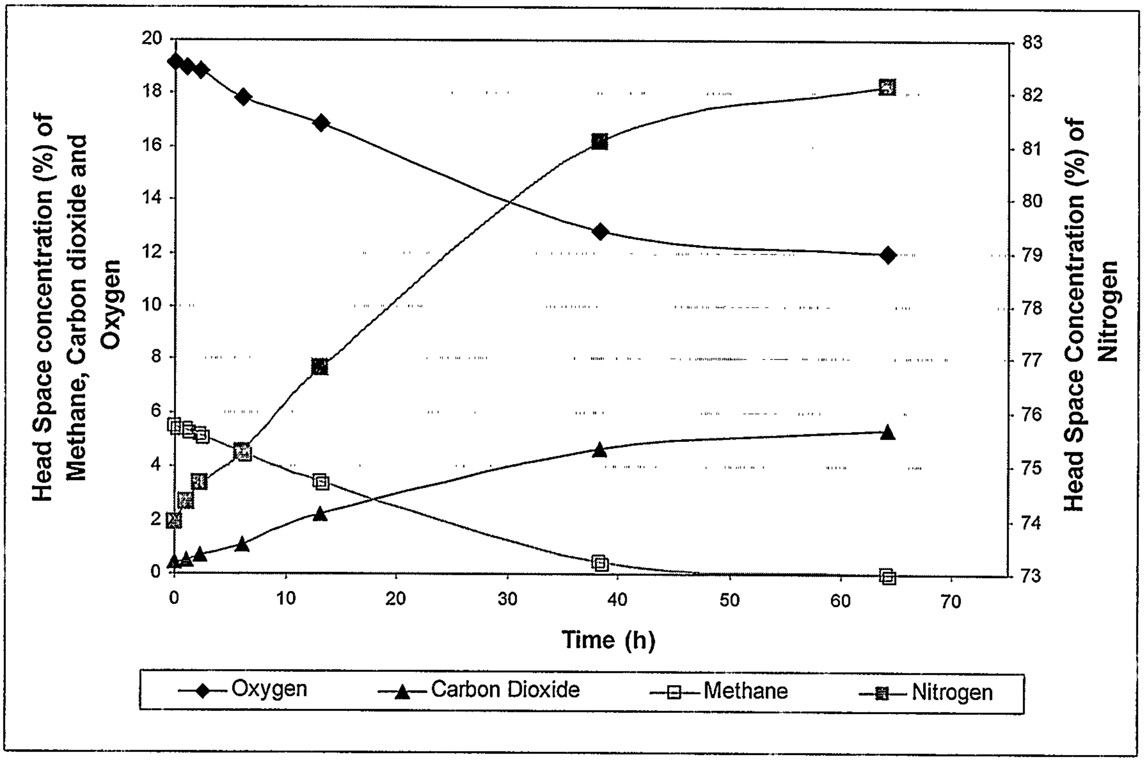

Figure D-13: Methane drawdown curve for biofilter column B at column height 100mm

COLUMN B – Bottom layer

Elapsed Time hrs	Oxygen %	Nitrogen %	Carbon Dioxide %	Methane %
0.00	19.46	73.21	0.38	6.12
1.15	18.82	73.00	0.38	6.08
2.20	19.42	73.31	0.40	6.14
8.17	18.88	73.34	0.37	6.16
24.13	19.26	73.06	0.40	6.14
72.22	19.13	73.88	0.41	6.14
240.15	18.90	73.51	0.39	6.16

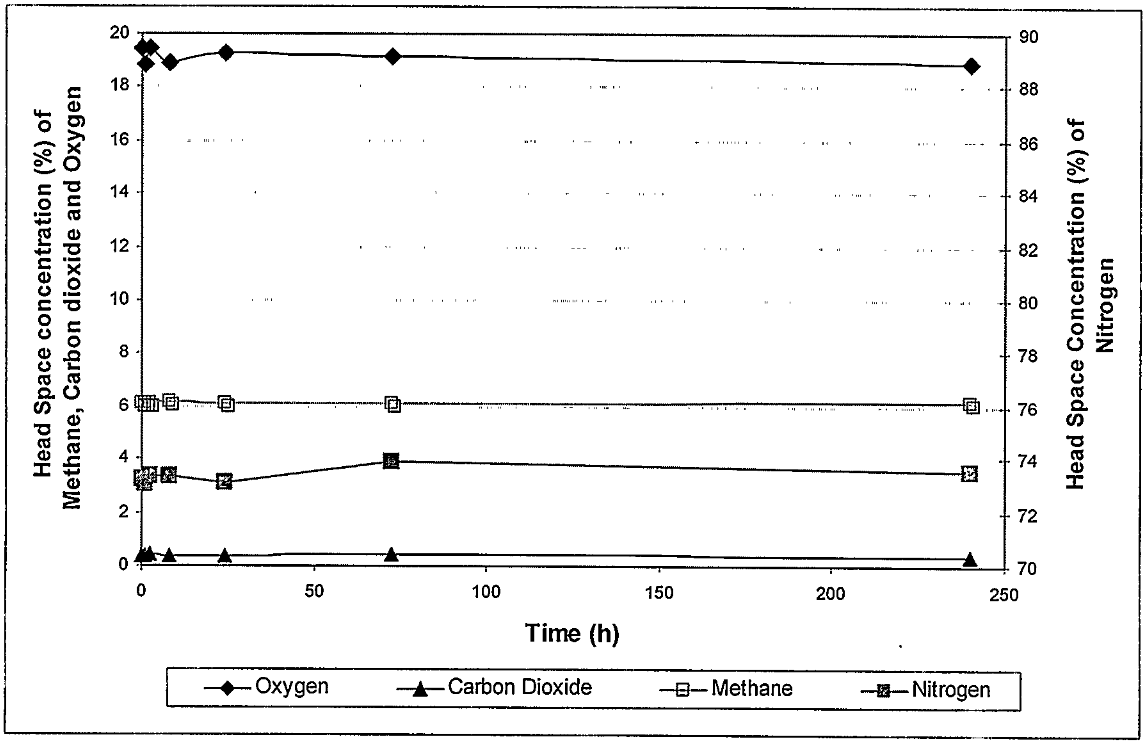

Figure D-14: Methane drawdown curve for biofilter column B at column height 0 mm

COLUMN C – 600mm layer

Elapsed Time	Oxygen	Nitrogen	Carbon Dioxide	Methane
hrs	%	%	%	%
0.00	19.25	74.06	0.35	5.65
1.58	19.39	74.24	0.31	5.53
3.10	19.37	74.28	0.44	5.41
9.85	18.71	74.96	0.83	4.86
24.58	16.84	76.70	2.09	3.69
74.58	12.60	81.62	5.06	0.07
117.58	11.91	81.75	5.34	0.00

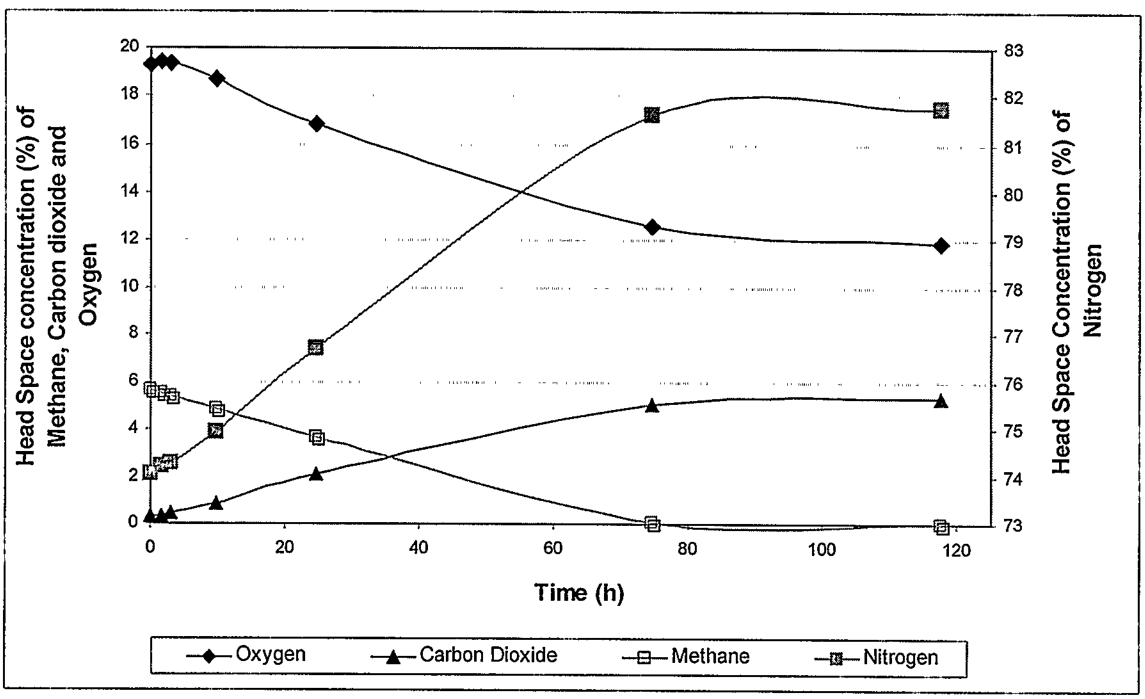

Figure D-15: Methane drawdown curve for biofilter column C at column height 600mm

COLUMN C – 500mm layer

Elapsed Time	Oxygen	Nitrogen	Carbon Dioxide	Methane
hrs	%	%	%	%
0.00	19.55	74.09	0.18	5.53
0.47	19.14	74.21	0.46	5.44
2.15	18.96	74.38	0.69	5.12
5.72	18.29	75.53	1.19	4.52
12.47	16.57	76.99	2.13	3.36
29.80	12.89	81.11	4.67	0.49
71.88	12.23	82.10	5.15	0.00

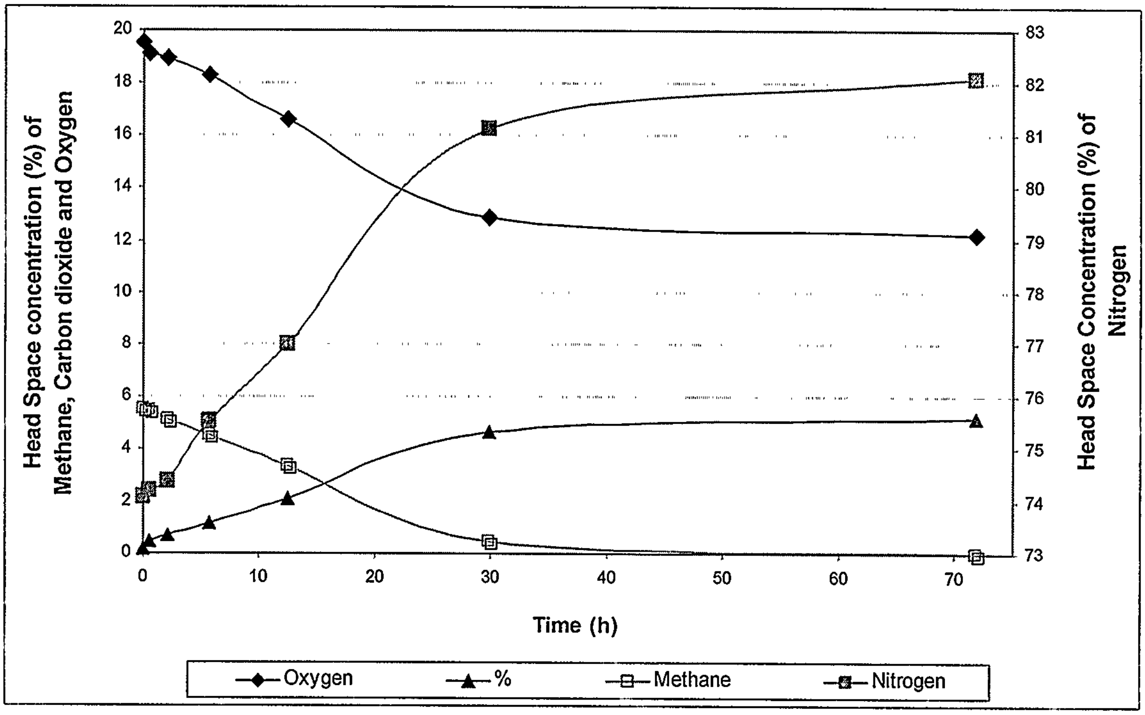

Figure D-16: Methane drawdown curve for biofilter column C at column height 500mm

COLUMN C – 400mm layer

Elapsed Time hrs	Oxygen %	Nitrogen %	Carbon Dioxide %	Methane %
0.00	19.54	74.28	0.18	5.65
0.75	19.36	74.20	0.35	5.51
3.07	18.83	74.62	0.59	5.15
6.50	18.11	75.20	0.92	4.64
15.57	16.58	77.09	2.08	3.36
33.07	13.35	80.52	4.30	0.84
66.48	12.10	82.21	5.19	0.00

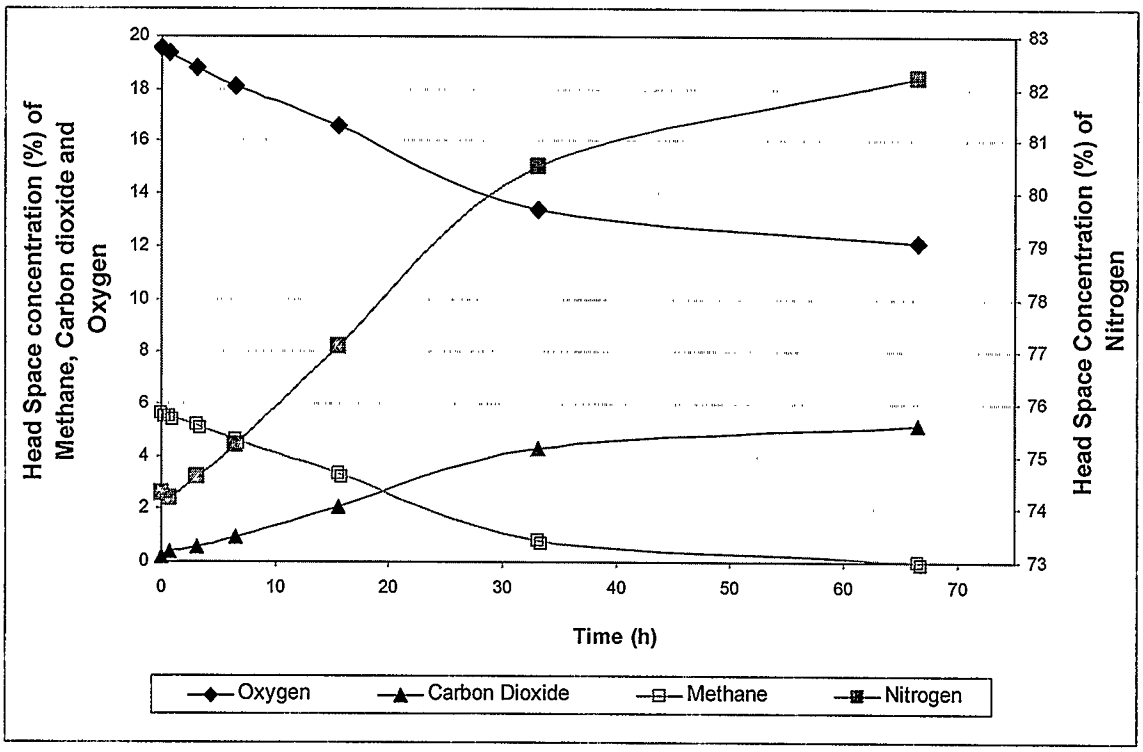

Figure D-17: Methane drawdown curve for biofilter column C at column height 400mm

COLUMN C – 300mm layer

Elapsed Time hrs	Oxygen %	Nitrogen %	Carbon Dioxide %	Methane %
0.00	19.19	74.02	0.29	5.54
1.48	18.76	74.60	0.76	5.07
2.80	18.17	75.28	1.10	4.65
3.27	17.97	75.63	1.10	4.52
6.83	16.76	76.75	2.15	3.45
19.48	13.79	80.08	4.18	1.07
51.42	12.30	81.74	5.12	0.00

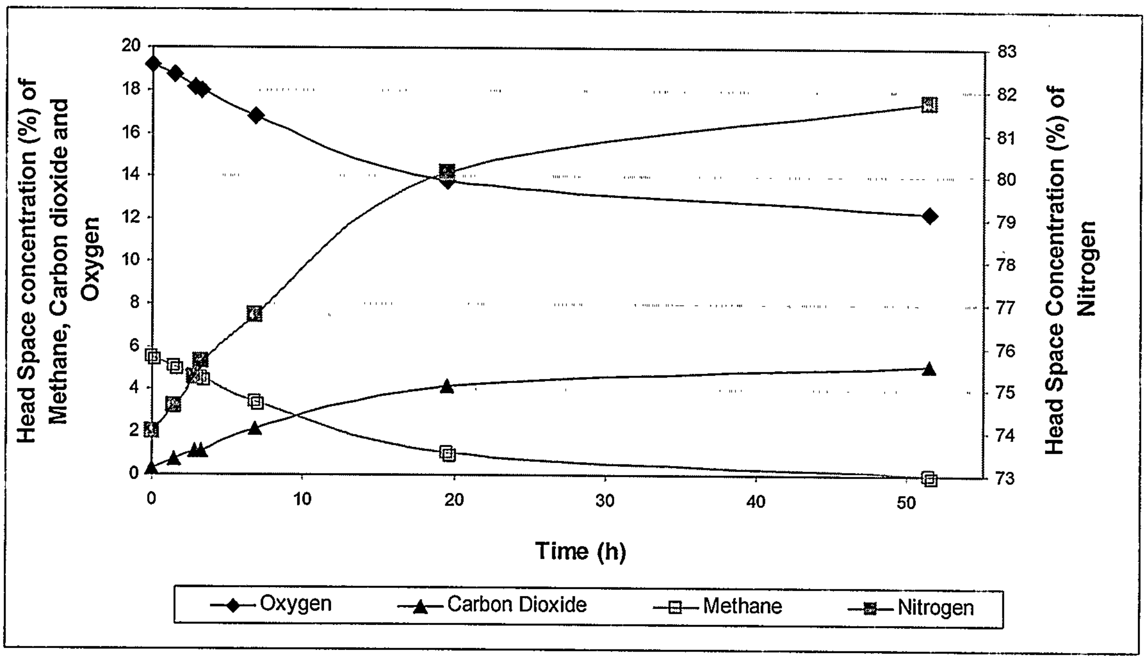

Figure D-18: Methane drawdown curve for biofilter column C at column height 300mm

COLUMN C – 200mm layer

Elapsed Time hrs	Oxygen %	Nitrogen %	Carbon Dioxide %	Methane %
0.00	19.43	74.08	0.21	5.46
1.05	18.72	74.89	0.73	5.09
2.15	18.38	75.47	0.96	4.69
2.90	17.64	75.85	1.15	4.44
5.32	16.97	76.69	1.91	3.57
13.57	13.97	80.48	3.94	1.20
31.15	12.30	82.17	5.20	0.00

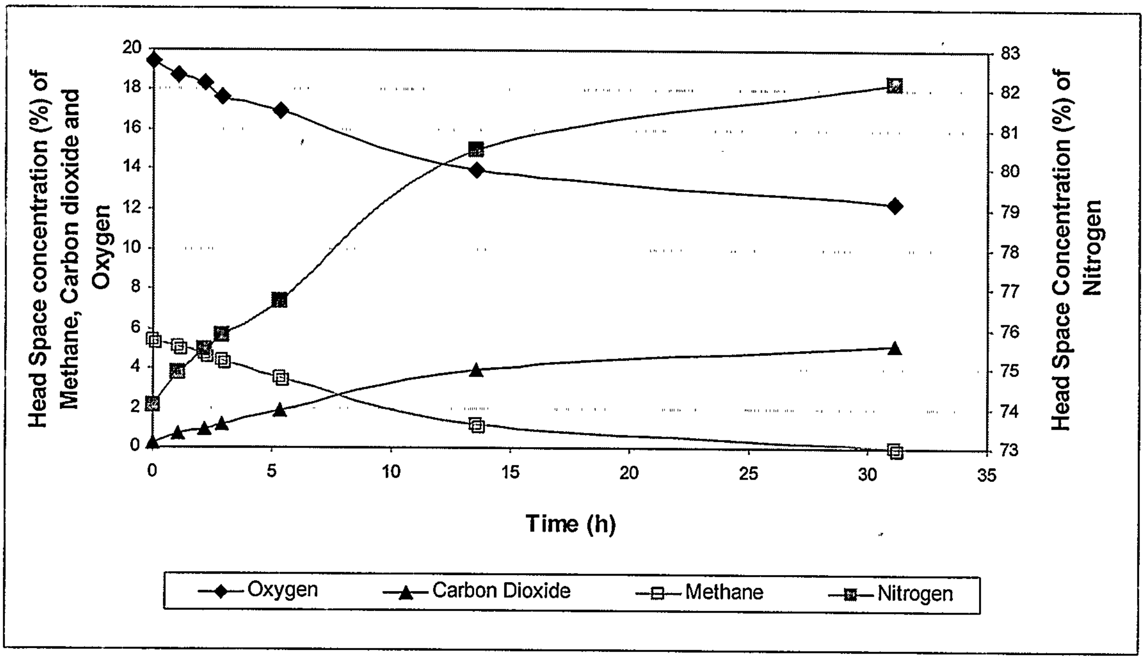

Figure D-19: Methane drawdown curve for biofilter column C at column height 200mm

COLUMN C – 100mm layer

Elapsed Time hrs	Oxygen %	Nitrogen %	Carbon Dioxide %	Methane %
0.00	19.41	74.19	0.18	5.56
1.70	19.24	74.41	0.44	5.32
3.57	18.70	74.61	0.54	5.05
5.25	18.45	75.10	0.79	4.84
11.40	17.47	76.22	1.55	4.03
43.83	12.99	81.07	4.72	0.47
67.00	12.11	82.11	5.08	0.00

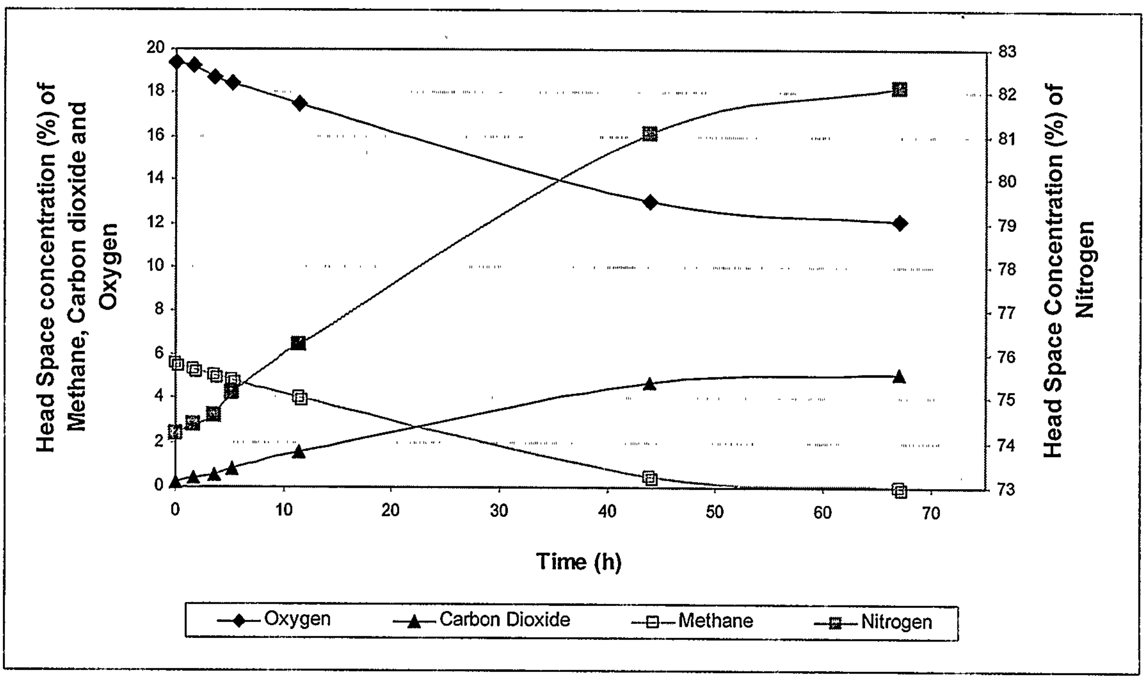

Figure D-20: Methane drawdown curve for biofilter column C at column height 100mm

COLUMN C – Bottom layer

Elapsed Time hrs	Oxygen %	Nitrogen %	Carbon Dioxide %	Methane %
0.00	18.99	73.53	0.24	5.64
1.15	18.96	74.18	0.37	5.67
2.20	18.75	73.47	0.38	5.65
8.17	18.83	73.86	0.38	5.62
24.13	19.06	73.36	0.26	5.68
72.22	19.09	74.14	0.37	5.59
240.15	19.07	73.95	0.44	5.64

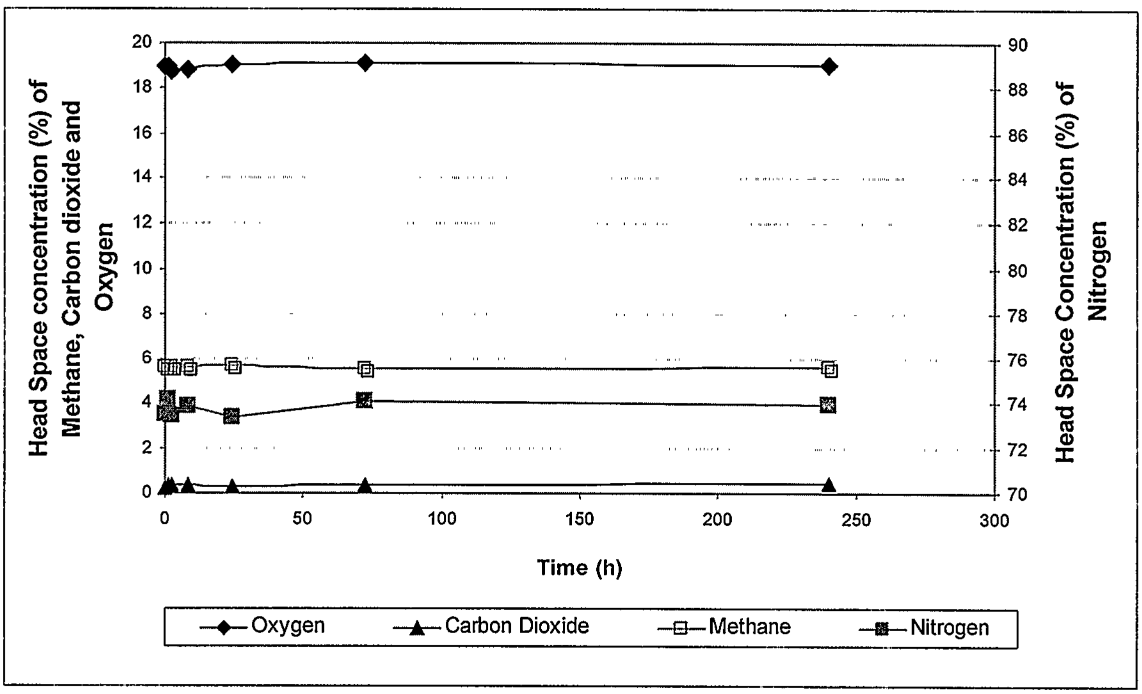

Figure D-21: Methane drawdown curve for biofilter column C at column height 0 mm

APPENDIX E: MOISTURE CONTENT AND ORGANIC CARBON CONTENT DATA AND CALCULATIONS

COLUMN A

Sample 1:

Column Height (mm)	Port	Wo (g)	Ws (g)	Wd(g)@ 100C	Wd(g)@ 550C	Moisture Content (%)	Organic Carbon Content (%)
600	Top	26.179	30.454	27.498	27.398	30.84	7.56
500	9	27.438	30.955	28.418	26.898	27.87	9.48
400	7	24.595	30.550	27.996	24.663	57.12	25.93
300	5	26.097	31.449	29.349	26.447	60.76	19.84
200	3	24.416	30.422	27.767	25.580	55.79	14.27
100	1	26.816	30.160	27.599	25.387	23.41	6.05
0	Bottom	27.066	30.062	27.184	25.673	3.93	5.79

Sample 2:

Column Height (mm)	Port	Wo (g)	Ws (g)	Wd(g)@ 100C	Wd(g)@ 550C	Moisture Content (%)	Organic Carbon Content (%)
600	Top	26.277	30.616	27.555	27.452	29.47	8.05
500	9	25.675	30.054	26.973	26.898	29.65	9.45
400	7	27.808	30.995	29.590	24.663	55.90	25.18
300	5	25.749	31.853	29.367	26.447	59.28	21.22
200	3	27.790	31.682	29.942	25.580	55.31	14.03
100	1	26.548	30.680	27.440	25.387	21.60	5.85
0	Bottom	26.734	31.612	26.892	25.673	3.24	3.92

Sample 3:

Column Height (mm)	Port	Wo (g)	Ws (g)	Wd(g)@ 100C	Wd(g)@ 550C	Moisture Content (%)	Organic Carbon Content (%)
600	Top	26.609	30.766	27.835	27.728	29.48	8.75
500	9	26.772	31.908	28.232	26.898	28.43	9.71
400	7	27.917	31.728	30.079	24.663	56.72	26.46
300	5	25.332	30.359	28.323	26.447	59.51	20.02
200	3	24.632	31.776	28.562	25.580	55.01	15.27
100	1	25.480	31.782	26.894	25.387	22.43	6.79
0	Bottom	25.795	30.585	25.919	25.673	2.58	4.93

COLUMN B

Sample 1:

Column Height (mm)	Port	Wo (g)	Ws (g)	Wd(g)@ 100C	Wd(g)@ 550C	Moisture Content (%)	Organic Carbon Content (%)
600	Top	27.882	30.656	28.592	28.532	25.59	8.44
500	9	27.288	31.748	28.412	26.898	25.19	7.91
400	7	27.745	30.527	28.546	24.663	28.80	22.88
300	5	25.182	30.131	27.608	26.447	49.01	20.62
200	3	26.414	30.464	28.613	25.580	54.31	10.59
100	1	25.414	31.237	26.489	25.387	18.45	6.25
0	Bottom	27.338	31.238	27.464	25.673	3.23	4.65

Sample 2:

Column Height (mm))	Port	Wo (g)	Ws (g)	Wd(g)@ 100C	Wd(g)@ 550C	Moisture Content (%)	Organic Carbon Content (%)
600	Top	24.153	30.921	25.961	25.818	26.72	7.92
500	9	26.041	30.282	27.102	26.898	25.01	7.99
400	7	27.878	30.330	28.608	24.663	29.80	23.69
300	5	26.271	31.079	28.639	26.447	49.25	19.55
200	3	27.348	30.842	29.263	25.580	54.83	9.91
100	1	25.178	30.818	26.257	25.387	19.13	6.56
0	Bottom	25.053	30.631	25.248	25.673	3.48	4.77

Sample 3:

Column Height (mm))	Port	Wo (g)	Ws (g)	Wd(g)@ 100C	Wd(g)@ 550C	Moisture Content (%)	Organic Carbon Content (%)
600	Top	27.721	30.058	28.303	28.265	24.91	6.59
500	9	26.773	30.079	27.572	26.898	24.17	9.66
400	7	27.030	31.570	28.421	24.663	30.65	24.12
300	5	24.728	30.556	27.501	26.447	47.58	18.78
200	3	25.160	30.181	27.911	25.580	54.78	11.07
100	1	26.984	30.065	27.614	25.387	20.47	4.75
0	Bottom	24.431	30.756	24.599	25.673	2.65	5.10

COLUMN C

Sample 1:

Column Height (mm))	Port	Wo (g)	Ws (g)	Wd(g)@ 100C	Wd(g)@ 550C	Moisture Content (%)	Organic Carbon Content (%)
600	Top	27.551	30.541	28.186	28.143	21.22	6.76
500	9	27.075	30.240	27.705	26.898	19.91	7.25
400	7	27.154	31.899	28.259	24.663	23.30	19.32
300	5	24.993	31.676	27.828	26.447	42.41	17.18
200	3	26.265	31.619	28.624	25.580	44.07	8.09
100	1	25.683	31.846	26.541	25.387	13.93	4.13
0	Bottom	26.594	31.035	26.722	25.673	2.88	5.33

Sample 2:

Column Height (mm))	Port	Wo (g)	Ws (g)	Wd(g)@ 100C	Wd(g)@ 550C	Moisture Content (%)	Organic Carbon Content (%)
600	Top	27.878	30.342	28.401	28.369	21.21	6.14
500	9	26.565	30.665	27.423	26.898	20.94	8.22
400	7	26.764	31.178	27.748	24.663	22.30	18.25
300	5	25.329	31.585	27.936	26.447	41.68	16.71
200	3	25.413	30.312	27.579	25.580	44.22	8.70
100	1	25.093	31.316	25.908	25.387	13.10	5.29
0	Bottom	24.568	31.476	24.734	25.673	2.40	4.29

Sample 3:

Column Height (mm))	Port	Wo (g)	Ws (g)	Wd(g)@ 100C	Wd(g)@ 550C	Moisture Content (%)	Organic Carbon Content (%)
600	Top	25.681	30.543	26.703	26.635	21.02	6.66
500	9	27.343	30.209	27.940	26.898	20.84	6.59
400	7	26.728	30.010	27.453	24.663	22.10	19.84
300	5	25.005	30.353	27.303	26.447	42.96	18.69
200	3	26.502	31.603	28.817	25.580	45.39	8.44
100	1	26.851	30.561	27.355	25.387	13.59	5.47
0	Bottom	27.804	30.853	27.934	25.673	4.26	4.86

AVERAGE MOISTURE AND ORGANIC CARBON CONTENT CALCULATIONS (based on sample data)

Column A:

Column Height (mm))	Port	Average Moisture Content (%)	Average Organic Carbon Content (%)
600	Top	29.93	8.12
500	9	28.65	9.55
400	7	56.58	25.85
300	5	59.85	20.36
200	3	55.37	14.52
100	1	22.48	6.23
0	Bottom	3.25	4.88

Column B:

Column Height (mm))	Port	Average Moisture Content (%)	Average Organic Carbon Content (%)
600	Top	25.74	7.65
500	9	24.79	8.52
400	7	29.75	23.56
300	5	48.61	19.65
200	3	54.64	10.52
100	1	19.35	5.85
0	Bottom	3.12	4.84

Column C:

Column Height (mm))	Port	Average Moisture Content (%)	Average Organic Carbon Content (%)
600	Top	21.15	6.52
500	9	20.56	7.35
400	7	22.57	19.13
300	5	42.35	17.52
200	3	44.56	8.41
100	1	13.54	4.96
0	Bottom	3.18	4.83