APPLICATION OF METHANOTROPHIC BIOFILTERS (MBFS) IN TREATING METHANE (CH_4) EMISSIONS FROM OIL AND GAS INDUSTRY

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ABSTRACT

Microbial oxidation of methane (CH_4) may serve as an inexpensive technique for reducing fugitive methane emissions from the oil and gas industry. Laboratory experiments have shown the potential to apply methanotrophic biofilters to treat low-volume CH_4 releases. Field experiments are being undertaken to gain the required quantitative and qualitative understanding of these processes. A pilot-scale biofilter was constructed at a gas metering station owned by TransCanada. The surface flux, temperature, moisture content, and gas concentrations are monitored. In this paper, some of the preliminary results obtained from the operation of a field biofilter are presented. The atmospheric temperature effect on oxidation is well described by the observed results.

Furthermore, properly developed, calibrated and field validated mathematical models would provide predictive capabilities at a fraction of the cost of expensive laboratory or field programs. Suitable mathematical models could aid in the design of CH_4 oxidative systems by reducing the number of laboratory and field experiments required to generate sufficient data. To fulfill this need, a three-dimensional reactive-transport model that considers CH_4 gas transport, oxidation, heat transfer, moisture dynamics, and atmospheric processes is being developed. Once fully developed, the model can be used to design biofilters under a variety of field situations. The model calibration and verification will be undertaken using the data generated from laboratory experiments and field biofilters.

1.0 INTRODUCTION

Methane emissions from the transport of natural gas result from venting, fugitive losses and unburnt methane from combustion processes. Methane venting occurs in large volumes and cannot be addressed by biofiltration, other technologies are employed to mitigate this source. Unburnt methane can be only be mitigated by improving combustion efficiency. Fugitive losses fall into two categories, equipment leaks and engineered emissions. Equipment leaks are managed by implementing an effective leak detection and repair program. Engineered emissions, arising from equipment designed to release natural gas as part of their operation, are too small a volume releases to be mitigated using sophisticated technology such as incineration. However, potential exists to use a relatively simple technology known as methane biofiltration to effectively reduce methane escape into the atmosphere.

Biofiltration is a well-known and cost-effective technology for removing environmental pollutants from contaminated gas steams (Yang and Minuth., 2002). Considerable research efforts have focused on the use of biofiltration to eliminate or to treat air streams contaminated with BTEX vapors (Tahraoui and Denis Rho, 1998), volatile organic compounds (Yoon and Park, 2002), ethanol vapor (Arulneyam and Swaminathan, 2000), Toluene and Benzene (Li et al., 2002, Andreoni et al. 1997), hydrogen sulfide and ammonia (Chung et al., 2001, Chitwood and Devinny, 1997). However, the application of biofiltration in the treatment of CH_4 is relatively new. Methane biofilters use methanotrophs living in porous media to oxidize CH_4 to CO_2.

There are two major processes involved in the migration of gases through the biofilter media and then into the atmosphere. They are diffusion due to concentration gradients, and advection due to pressure gradients. The migration of gases through the filter media is determined by the factors such as properties of filter media, configuration of biofilters, reactions, temperature, moisture, and environmental factors such as wind and rain. Precipitation directly affects the moisture distribution of the filter media. Furthermore, CO_2 produced during methanotrophic activity can be dissolved in rainwater and moved out from the system as leachate. This changes the composition of gas mixture, and hence affects gas flow. Furthermore, it will decrease pH of the system. Methanotrophs favor temperatures within the range, 10^{o}C to 35^{o}C. The increase in outside temperature in the summer causes higher biological oxidation of methane and increases the biofilter temperature due to higher heat generation.

2.0 PRELIMINARY STUDIES

A series of laboratory experiments were carried out to investigate the methane oxidation capacity of different composts in passively arerated biofilter columns and to investigate efficiency of actively aerated biofilter columns (Stein et al, 2001). Figure 1 and figure 2 show some of the results of these experiments. The experience gathered from preliminary studies was used to design the pilot-scale field biofilter at Wildcat Hills meter station owned by TransCanada, Canada.

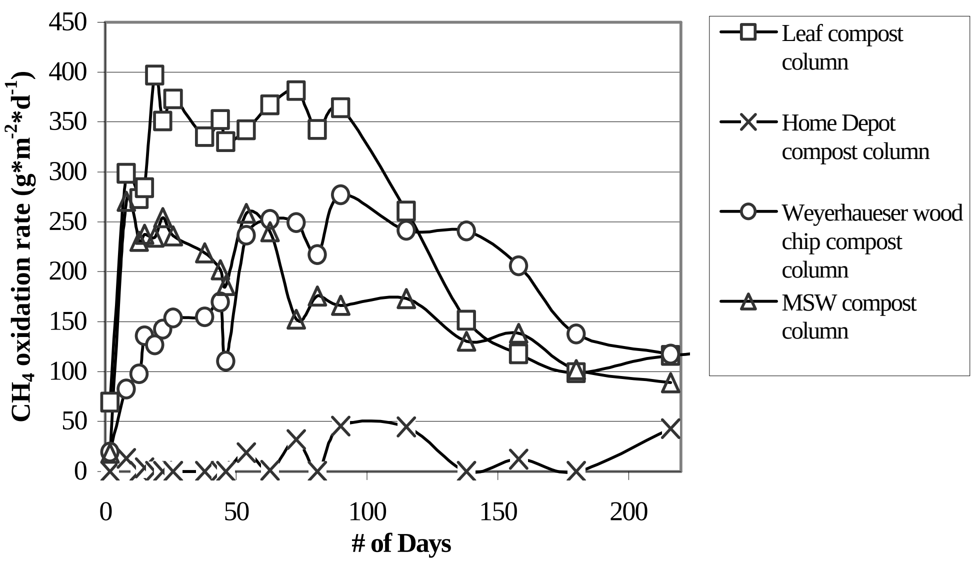

Figure 1: Performance of different compost types in passive biofilter columns

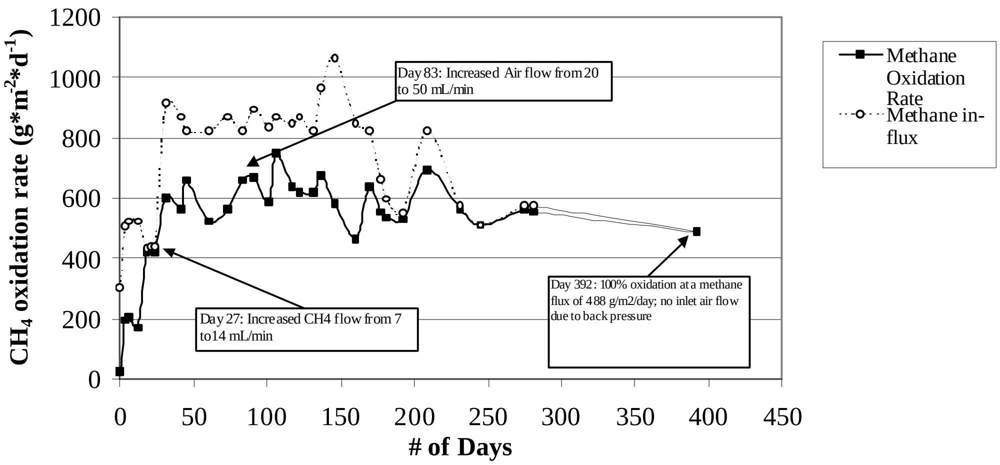

Figure 2: Performance of actively aerated biofilter columns

3.0 WILDCAT HILLS PILOT SCALE BIOFILTER

The Wildcat Hills Biofilter was installed in Summer 2002 as part of the Assessment of Application of Methanobiofillter (MBF) Technology to Control Engineered Emissions from Gas Transmission Facilities project. It is located within the confines of TransCanada's Wildcat Hills meter station. This station is located about 11 kilometres west of Cochrane, Alberta, Canada.

The biofilter has the dimensions of 2.4m x 2.4m x 0.37m. Figure 3 shows the biofilter and its gas distribution pipe network. The biofilter contains a leaf compost medium selected for this purpose based on experimental studies undertaken with several types of compost. In laboratory studies, the leaf compost outperformed typical organic soil by a factor of 2. Figure 4 shows the schematic diagram of the system that is used to divert methane gas (CH_4 gas) into the biofilter. The CH_4 inflow rate is 3.5 m^3/day and inflow has an impulsive characteristics and it comes in every 30 seconds.

Figure 3: Field biofilter and its gas distribution pipe network

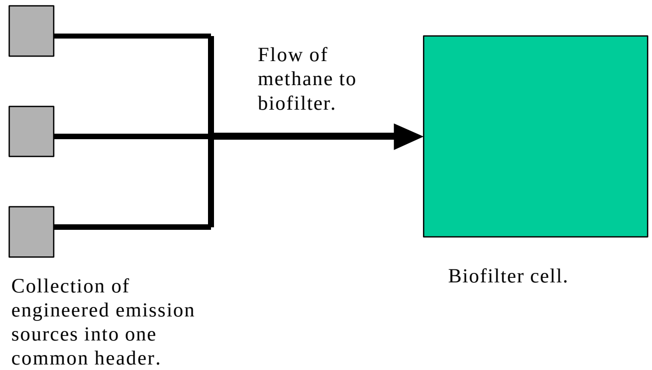

Figure 4: CH_4 inflow to the biofilter

3.1 PARAMETERS MONITORED

At the biofilter, surface flux, temperature, and gas concentrations are being monitored. The surface flux is measured at 16 grid points on three different levels, hence giving a total of 48 data points. The grid size used is 0.6 m x 0.6 m. The levels are at 5 cm, 20 cm, and 35 cm from the biofilter top surface. The biofilter is open to the atmosphere. The moisture content and kinetics of biological activities are measured in the laboratory using standards methods.

Concentrations of CH_4, CO_2, O_2 and N_2 are determined by taking 2 ml samples from each sampling location. The gas concentrations are determined using gas chromatography (portable HP Micro-Gas Chromatography with thermal conductivity detectors). In Gas chromatography, CH_4, CO_2 and air are separated using Porplot_Q column (4 m x 0.32 mm ID, 10 μm df) and O_2 and N_2 were separated using MS-5A molecular sieve (10m x 0.32 mm ID, 30 μm df). The GC columns are maintained at 100^oC, injection time 100ms, sampling time 10 sec. All peaks were quantified with HP EZ-Chrome integration software on a personal computer. Thermocouples are used to measure the temperature at all of the sampling locations.

The surface emission of CO_2 and CH_4 gas at the biofilter is measured using the closed flux chamber technique. This technique allows estimation of the biofilter's total CH_4 emission rate (Q_{out}) and hence the percentage oxidation that is occurring within the biofilter medium. The following equation is used to calculate the methane flux into the flux chamber:

$$CH_4 Flux = \frac{dC_{CH4}}{dt} \times \frac{V}{A}$$

Where: dC/dt = the change in the percentage of CH_4 in the chamber with time. This value is calculated by linear regression of the CH_4 concentration in headspace samples.
V = chamber volume
A = chamber area.

Other parameters monitored are atmospheric temperature, moisture content and kinetics.

3.2 PRELIMINARY RESULTS FROM FIELD EXPERIMENTS

Some of the results obtained from field experiments that were carried out from the summer 2002 to summer 2003 are presented in this section. The atmospheric temperature effect on oxidation is evident in the observed results. Percentage methane oxidation at the biofilter is an important parameter to evaluate the performance of the biofilter and it is calculated using the following formula:

$$Oxidation(\%) = \frac{(Q_{CH4})_{in} \times (C_{CH4})_{in} - (Q)_{out} \times (C_{CH4})_{out}}{(Q_{CH4})_{in} \times (C_{CH4})_{in}} \times 100\%$$

Where,

$(Q_{CH4})_{in}$ = Methane flow rate from column base
$(Q)_{out}$ = Flow rate at exit point
$(C_{CH4})_{out}$ = Outflow methane concentration
$(C_{CH4})_{in}$ = Inflow methane concentration

However, this equation can be simplified to the following form:

$$Oxidation(\%) = \frac{(Q_{CH4})_{in} - (Q_{CH4})_{out}}{(Q_{CH4})_{in}} \times 100\%$$

The percentage CH_4 oxidation results obtained during the period of September 4th 2002 to August 15th 2003 is shown in Figure 5. It also shows the effect of atmospheric temperature on oxidation.

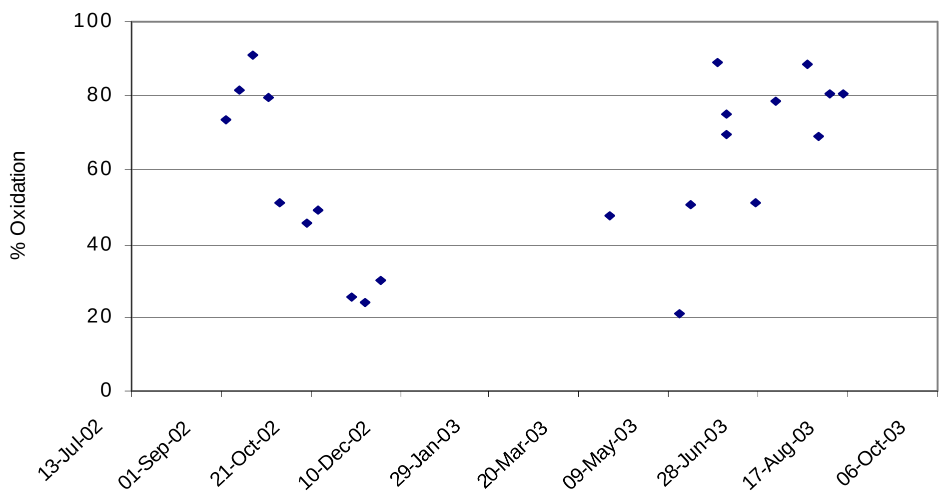

Figure 5: Variation in percentage oxidation during biofilter operation

As oxidation can be impacted by diurnal variations in temperature, and other related factors, the biofilter was monitored for a period of 12 hours to elucidate these effects. During the observation, the weather conditions fluctuated throughout the day. In early morning the temperature was 14^{o}C, humidity was 46% and with cloudy and slight wind conditions. At 12 noon, the temperature rose to 18^{o}C. Early afternoon (around 3:00 pm) saw a short (5 to 10 minute) but heavy rainfall event. As a result, the ambient temperature decreased from a high of 22^{o}C to 17^{o}C, and the relative humidity increased to 54%, and with high winds. Another heavy rainfall event occurred late afternoon (from 5:00 - 5:30 pm) and the ambient temperature decreased further to 14^{o}C, and humidity increased to 79% and with bright sky with no wind (at 6.00 pm). The same environmental conditions were observed at 9:00 pm. The average oxidation was calculated from the flux measurements and Figure 6 shows the results. The results show that the diurnal variation in average oxidation is not that significant.

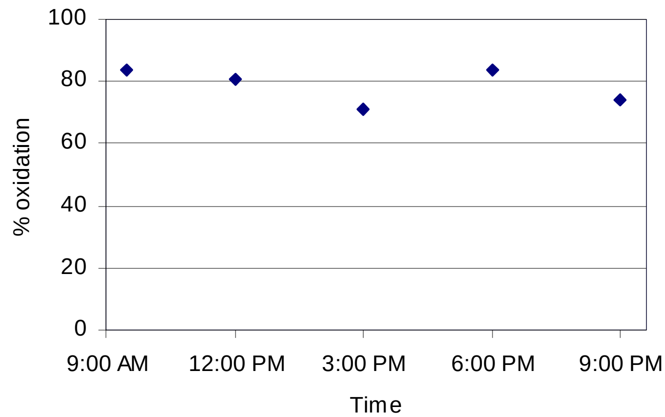

Figure 6: Diurnal variation of methane oxidation in the pilot scale biofilter

Other than the gas concentrations, temperatures at all of the sampling locations at the three different depths were measured. A significant increase in the temperature of the system is observed due to the heat generation during biological activities. The measured temperature data will be used later in the detailed analysis. The analysis would allow designing biofilters that can be efficiently operated at lower atmospheric temperatures. Figure 7 shows a typical data set of gas concentration profiles and temperature profiles at some selected points.

From ambient temperature and surface flux data, a relationship between atmospheric temperature and biofilter performance was developed. Figure 8 shows the predicted oxidation using average monthly temperatures in Calgary and the regression equation that was found from field results. Although, predictions are approximate the predicted oxidation pattern helps to understand the importance of heat tracing during cold weather.

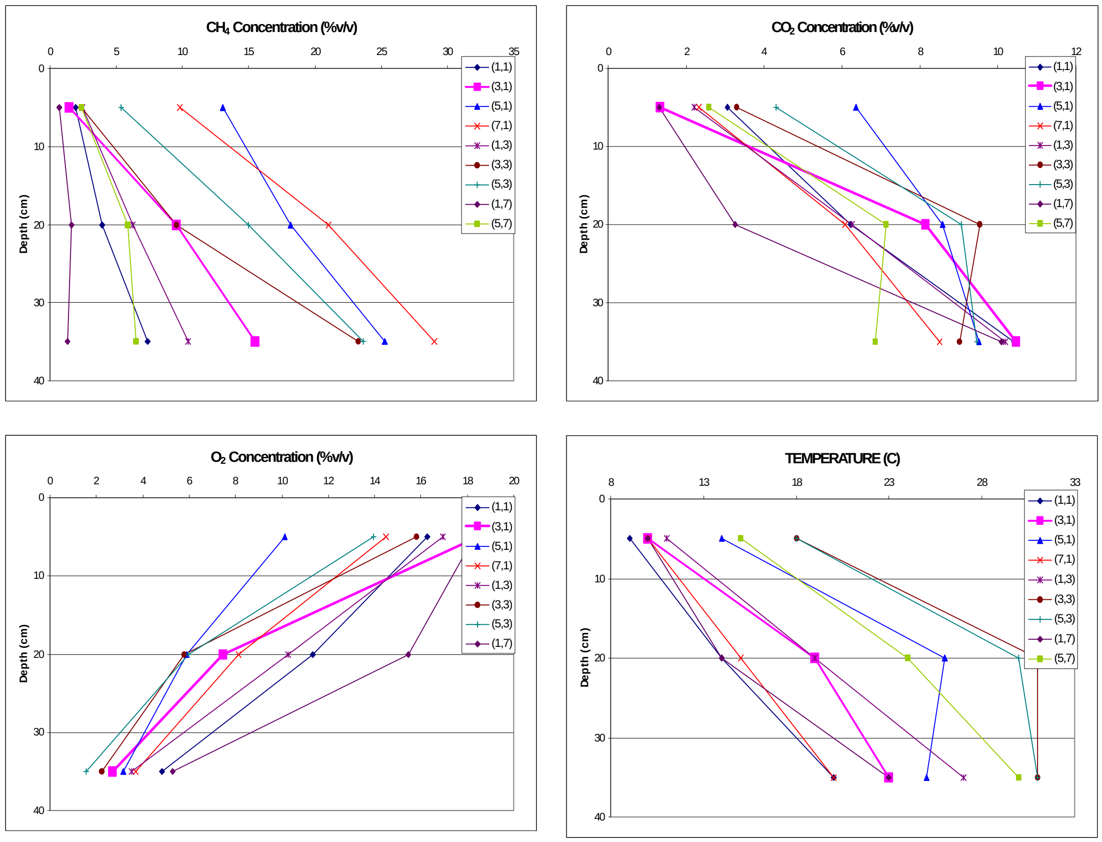

Figure 7: Concentration and temperature depth profiles at selected locations

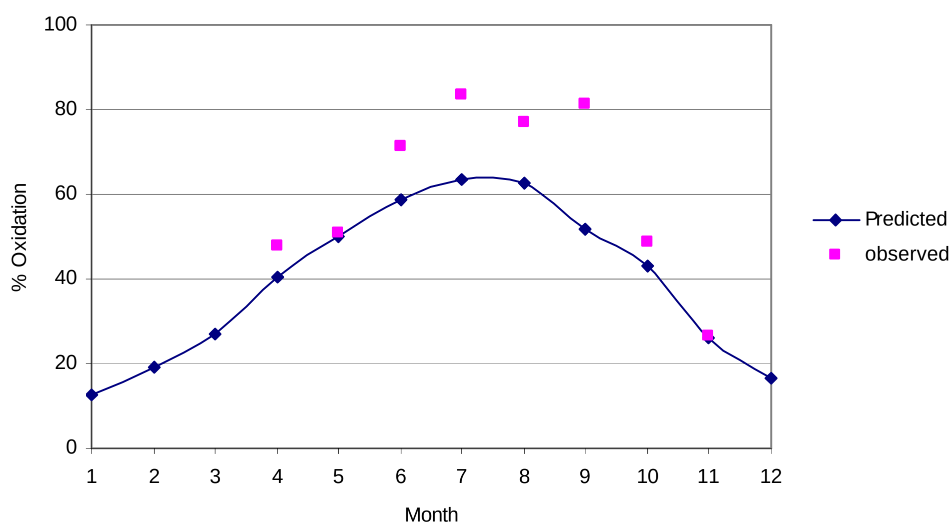

Figure 8: Predicted annual biofilter performance without heat tracing

4.0 CONCLUSIONS

Results from a pilot-scale field methnotrophic biofilter are presented. Results show the influence of seasonally variable ambient temperature on biofilter performance. Results also show that the biofilter does not exhibit variability according to diurnal variations in ambient conditions. Therefore, a single measurement on a given day could accurately predict the performance of the biofilter. The data collected so far, indicates that the biofilter is performing according to expectations. However, the data also clearly demonstrate to safeguard the biofilter against seasonal variations in temperature.

5.0 REFERENCES

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