geoconvention
Calgary • Canada • May 15-17 2023

# Improving methane oxidation in energy well leakage by biofilters: an exploratory lab study

*Dinu S. Attalage[1,2], Malana Loxam[1], Cathryn Ryan[1],*

*[1] Department of Geoscience, University of Calgary, 2500 University Drive, NW, Calgary, Alberta T2N 1N4 Canada*

*Dinu.attalage1@ucalgary.ca*

## Summary

The integrity of energy wells has become of concern due to environmental and economic issues identified at inactive and abandoned well sites [1]. Fugitive gases that leak out of wellbores are divided in to two categories i) surface casing vent flow (SCVF; primarily methane ($CH_4$) gas that escapes through casing strings via the well head/ surface casing vent flow) and ii) gas migration (GM; migration of primarily $CH_4$ in the subsurface outside the casing string [2,3]. Engineered systems like biofilters can optimize the oxidation of $CH_4$ by methanotrophic bacteria mitigate fugitive $CH_4$ emissions from the oil and gas industry, livestock farming, and landfills [4,5]. Biofilters are porous packed media beds that oxidize $CH_4$ to $CO_2$, which is a 28-34 times less potent greenhouse gas [5–7]. The selection of a suitable biofilter packing bed material is key in $CH_4$ design [6]. Organic porous media such as compost and topsoil are rich in nutrients and are desirable for microbial growth [8] but can be structurally unstable and susceptible to compaction, resulting in channeling which negatively impacts the overall performance [9]. These negative impacts can be avoided by mixing in inert media (e.g., perlite, lava rocks or tobermerlite), which also to help mitigate filter bed clogging due to excessive biomass development. Therefore, the objective of this research is to examine the $CH_4$ oxidation capacity of biofilter media that partially consist of inert material such perlite, in addition to biologically active material such as compost and topsoil. Our laboratory study showed that the maximum rate of $CH_4$ oxidation ($V_{MAX}$) were observed when the perlite volume ratios were low, and at high (>$20^{o}$C) or low ($5^{o}$C) temperatures. Mitigating methane in GM and SCVF around energy wells will require careful design.

## Methodology

Mixing ratios of compost, topsoil and perlite, and temperature were varied to assess the relative rate of methane oxidation in batches, and maximum methane oxidation rate ($V_{max}$) and half saturation coefficient ($K_m$) were estimated. Batch incubation experiments were conducted using compost+topsoil: perlite volume ratios ranging from 100: 0 to 38.75: 61.25. Moisture contents ranged from 20% to 80% of water holding capacity, and temperatures of $5^{0}$C, $20^{0}$C and $35^{0}$C were used in microcosm samples that were incubated for atleast 21 days.

Samples weighing ~ 20 g were incubated in 250-mL airtight amber serum bottles with a headspace $CH_4$ concentration of 9%. The $CH_4$ concentrations were then measured at several time intervals until zero using gas chromatography [10]. Design of experiments such as Doehlert design is a multivariant mathematical-statistical technique that investigates the behaviour of a system by a combining different levels of one or more variables impacting the system. A combination of 21 batch microcosm tests were conducted as guided by the Doehlert Design model (Table 1) and methods such as Lineweaver Burk Plot, Eadie and Hofstee Plot, and Hanes Plot were used to determine which combination had the highest maximum methane oxidation ($V_{MAX}$) rate [10]. The non-linear form (reaction rate vs substrate concentration) of the Michealis-

Menten reaction kinetic equation is transformed into various linear forms to calculate the kinetic parameters (VMAX and Km) accurately and the three most popular linear plots for the Michealis-Menten equation are Lineweaver-Burk, Eadie and Hofstee, and Hanes plots [10]. Design of experiments such as Doehlert design is a multivariant mathematical-statistical technique that investigates the behavior of a system by a combining different level of one or more variables impacting the system[11]. Among the different designs of experiments, Doehlert design is well known for its flexibility when selecting levels for different variables and cost reduction due to requirement of lesser number of experiments [12].

Table 1. Variations of experimental factors and level used in incubation studies

| Experiment No | X1-MC (% WHC) | X2-Compost: Topsoil volume ratio | X3:Perlite to organic (topsoil+compost) volume ratio | X4: Temperature$^0$C |
|---|---|---|---|---|
| **1** | 80 | 50/50 | 35/65 | 20 |
| **2** | 65 | 100/0 | 35/65 | 20 |
| **3** | 35 | 0/100 | 35/65 | 20 |
| **4** | 65 | 0/100 | 35/65 | 20 |
| **5** | 35 | 100/0 | 35/65 | 20 |
| **6** | 65 | 66.7/33.3 | 70/30 | 20 |
| **7** | 35 | 66.7/33.3 | 70/30 | 20 |
| **8** | 50 | 16.7/83.3 | 70/30 | 20 |
| **9** | 65 | 33.3/66.7 | 0/100 | 20 |
| **10** | 35 | 33.3/66.7 | 0/100 | 20 |
| **11** | 50 | 83.3/16.7 | 0/100 | 20 |
| **12** | 65 | 66.7/33.3 | 43.75/56.25 | 35 |
| **13** | 35 | 33.3/66.7 | 26.25/73.75 | 5 |
| **14** | 65 | 33.3/66.7 | 26.25/73.75 | 5 |
| **15** | 50 | 83.3/16.7 | 26.25/73.75 | 5 |
| **16** | 50 | 50/50 | 61.25/38.75 | 5 |
| **17** | 35 | 66.7/33.3 | 43.75/56.25 | 35 |
| **18** | 50 | 16.7/83.3 | 43.75/56.25 | 35 |
| **19** | 50 | 50/50 | 8.75/91.25 | 35 |
| **20** | 20 | 50/50 | 35/65 | 20 |
| **21** | 50 | 50/50 | 35/65 | 20 |

## Results and Conclusions

Out of the 21 media combinations tested, the media with 33.3% compost to 66.7% topsoil (and 0% perlite) blend exhibited the highest methane oxidation rate with a $V_{MAX}$ value of 29.8 $CH_4$-μmol $g^{-1}$ $h^{-1}$. In the blends where perlite was present, the highest methane oxidation rate with a Vmax value of 10.6 $CH_4$-μmol $g^{-1}$ $h^{-1}$ was observed when the perlite volume ratio in the tested media was 8.75% as shown in Figure 1 below. A drop in methane oxidation rates was observed when the moisture content was either too high or too low and highest oxidation rates were observed when the moisture content was 35% of the water holding capacity of the media being tested. Low rates of methane oxidation at low (5°C) or high temperatures (>20°C) decreased methane reflect the fact that most methanotrophs are classified as mesophiles [6,13], might be mitigated by construction of a biofilter immediately around the well casing that is insulated from the outside air.

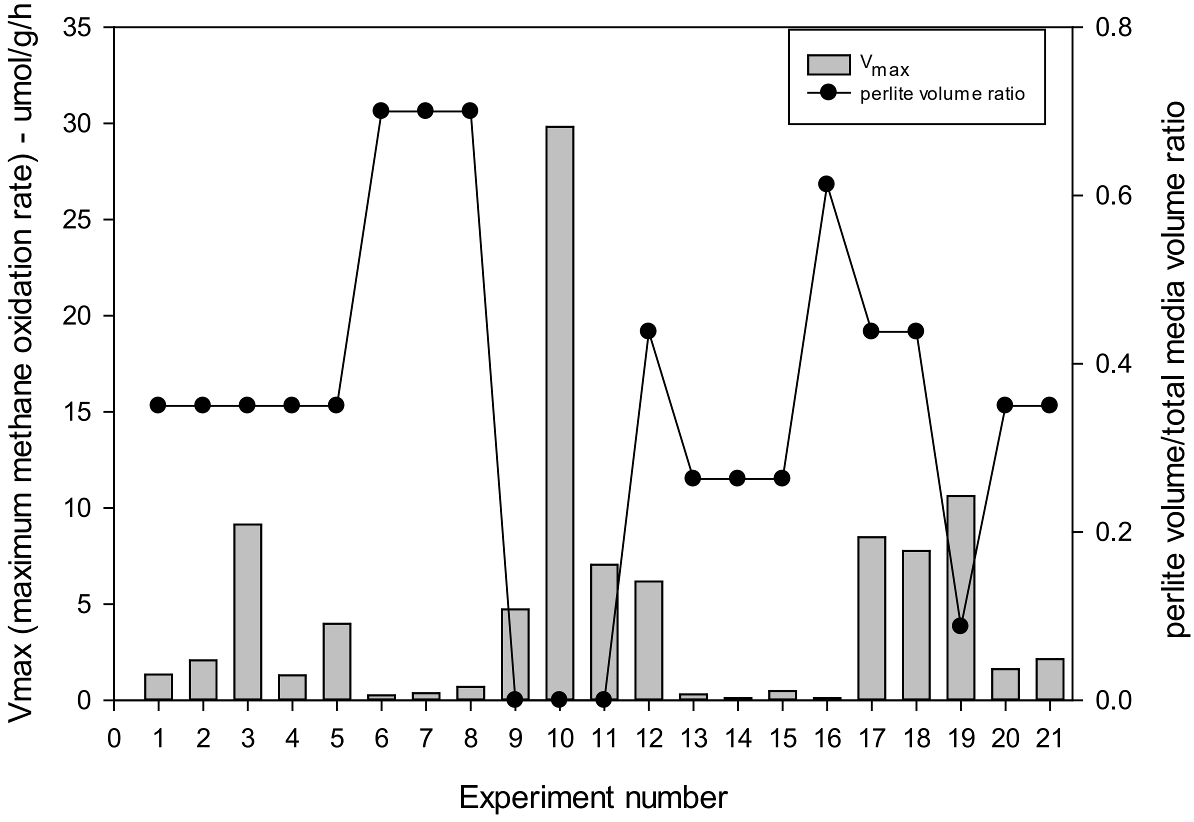

Figure 1. Vmax values of the 21 experimental combinations

## Acknowledgements

The authors wish to acknowledge the funding received from the Global Research Initiative in Sustainable Low Carbon Unconventional Resources (GRI) at the University of Calgary to undertake this research.

**References**

1. Schiffner, D.; Kecinski, M.; Mohapatra, S. An Updated Look at Petroleum Well Leaks, Ineffective Policies and the Social Cost of Methane in Canada's Largest Oil-Producing Province. *Clim Change* **2021**, *164*, doi:10.1007/s10584-021-03044-w.
2. Abboud, J.M.; Watson, T.L.; Ryan, M.C. Fugitive Methane Gas Migration around Alberta's Petroleum Wells. *Greenhouse Gases: Science and Technology* **2021**, *11*, 37–51, doi:10.1002/ghg.2029.
3. Fleming, N.A.; Morais, T.A.; Mayer, K.U.; Ryan, M.C. Spatiotemporal Variability of Fugitive Gas Migration Emissions around a Petroleum Well. *Atmos Pollut Res* **2021**, *12*, doi:10.1016/j.apr.2021.101094.
4. Mancebo, U.; Hettiaratchi, J.P.A. Rapid Assessment of Methanotrophic Capacity of Compost-Based Materials Considering the Effects of Air-Filled Porosity, Water Content and Dissolved Organic Carbon. *Bioresour Technol* **2015**, *177*, 125–133, doi:10.1016/j.biortech.2014.11.058.
5. Gunasekera, S.S.; Hettiaratchi, J.P.; Bartholameuz, E.M.; Farrokhzadeh, H.; Irvine, E. A Comparative Evaluation of the Performance of Full-Scale High-Rate Methane Biofilter (HMBF) Systems and Flow-through Laboratory Columns. *Environmental Science and Pollution Research* **2018**, *25*, 35845–35854, doi:10.1007/s11356-018-3100-1.
6. La, H.; Hettiaratchi, J.P.A.; Achari, G.; Dunfield, P.F. Biofiltration of Methane. *Bioresour Technol* 2018, *268*, 759–772.
7. Timma, L.; Dace, E.; Knudsen, M.T. Temporal Aspects in Emission Accounting—Case Study of Agriculture Sector. *Energies (Basel)* **2020**, *13*, 800, doi:10.3390/en13040800.
8. Wilshusen, J.H.; Hettiaratchi, J.P.A.; Stein, V.B. Long-Term Behavior of Passively Aerated Compost Methanotrophic Biofilter Columns. *Waste Management* **2004**, *24*, 643–653, doi:10.1016/j.wasman.2003.12.006.
9. Huete, A.; de los Cobos-Vasconcelos, D.; Gómez-Borraz, T.; Morgan-Sagastume, J.M.; Noyola, A. Control of Dissolved CH4 in a Municipal UASB Reactor Effluent by Means of a Desorption – Biofiltration Arrangement. *J Environ Manage* **2018**, *216*, 383–391, doi:10.1016/j.jenvman.2017.06.061.
10. Pokhrel, D. Compost Based Biocap Performance (Ph.D Thesis), 2006.

11. Cerqueira, U.M.F.M.; Bezerra, M.A.; Ferreira, S.L.C.; de Jesus Araújo, R.; da Silva, B.N.; Novaes, C.G. Doehlert Design in the Optimization of Procedures Aiming Food Analysis – A Review. *Food Chem* **2021**, *364*, 130429, doi:10.1016/j.foodchem.2021.130429.

12. Araujo, P.; Janagap, S. Doehlert Uniform Shell Designs and Chromatography. *Journal of Chromatography B* **2012**, *910*, 14–21, doi:10.1016/j.jchromb.2012.05.019.

13. Stein, V.B.; Hettiaratchi, J.P.A. Methane Oxidation in Three Alberta Soils: Influence of Soil Parameters and Methane Flux Rates. *Environmental Technology (United Kingdom)* **2001**, *22*, 101–111, doi:10.1080/09593332208618315.