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A Methanotroph-embedded Biotarp for Use as Alternative Daily Cover

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ABSTRACT

Although highly engineered bio-based systems exist to reduce methane emissions from closed landfill cells, no such system exists for open, active landfill cells. Data suggest that significant amounts of methane can be produced soon after waste placement, and large amounts of methane may enter the atmosphere before final capping and gas collection system installation. We have been investigating the methane oxidation capacity of immobilized methanotrophic bacteria in potential "biotarp" materials that could be used as alternative daily cover (ADC) to control emissions from open landfill cells. A population of methanotrophic bacteria enriched from landfill cover soil was immobilized by adsorption onto various combinations of commercial materials. Batch studies were conducted under a 10% methane-in-air headspace to measure the relative performance of the bacteria on different material supports. The results showed that methanotrophs adsorbed well to certain synthetic geotextiles that had high density and water absorbency, and the combination yielded high methane uptake rates. Methane oxidation rates by the adsorbed cells were assessed at varying temperatures, under 12-hour starvation cycles, and after agitation in water to simulate hard rainfall. Subsequently a continuous flow bioreactor designed to simulate field gas flux rates was used to examine biotarp prototypes. Methanotroph-embedded biotarp samples tested in continuous flow landfill gas simulation chambers (methane flux was 22.5 g/m^2/day) retained good methane oxidation activity when tested in batch after three weeks of incubation. Field trials of the methane oxidation capacity of immobilized methanotrophs are underway using flux chambers atop recently placed waste at a local landfill. Field trials suggest that flux reductions ranging from 30-100% are achieved when the geotextile is placed atop areas of flux ranging from 2-300 g/m^2/d.

INTRODUCTION

Landfills

- Account for 37% of annual US methane emissions
- Show evidence of biotic methane production beginning soon after waste placement
- Emit methane fluxes as high as several hundred g/m^2/d on open, active landfill cells
- Have final landfill capping systems to efficiently prevent fugitive methane emissions
- Have minimal methane mitigation on open, active cells

Methanotrophs

- Gram negative, aerobic bacteria
- Oxidize methane to carbon dioxide and water
- Found in many different environments, including landfill cover soil
- Also capable of co-metabolizing other hydrocarbon compounds

Methanotroph Embedded Biotarp

- A methanotroph embedded alternative daily cover
- Applied on open landfill cells at night to prevent wind blown litter and animal scavenging as well as to mitigate early methane emissions
- Removed at the beginning of the working day and stored until reapplied at the end of the day

Objectives

- To find an appropriate support on which to adsorb cells for incorporation into a biotarp
- To evaluate activity of adsorbed cells under potential environmental stresses
- To evaluate methane oxidation of a biotarp prototype in a simulated landfill bioreactor
- To evaluate methane oxidation of a biotarp prototype under field conditions

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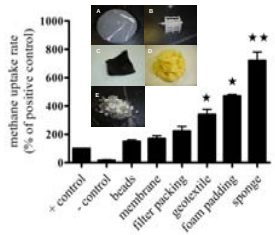

Fig. 1. Adsorption of a mixed population of methanotrophic cells to various types of supports. Error bars represent the standard deviation of two replicates. ★ indicates p<0.05 and ★★ indicates p<0.01 .

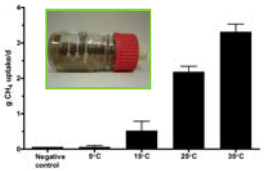

Fig. 2 . Methane uptake rate by methanotrophic cells absorbed to a synthetic geotextile at various temperatures. Error bars represent the standard deviation of three replicates.

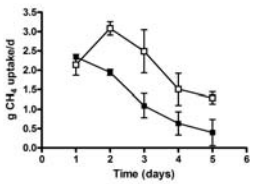

Fig. 3 . Methane uptake rates by methanotrophic cells absorbed to a synthetic geotextile with a constant methane atmosphere (□) or methane deprived for 12 hours every 24 hours (■). Error bars represent the standard deviation of two replicates.

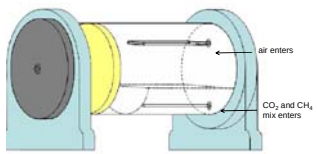

Fig. 4. Schematic of a continuous flow bioreactor to simulate the flow of landfill gases.

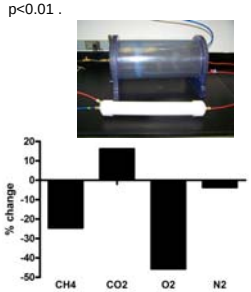

Fig. 5 . Overall percent change in each major gas analyzed in the continuous flow bioreactor. Negative values indicate consumption and positive values indicate production.

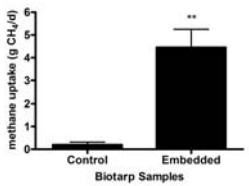

Fig. 6. Methane uptake of biotarp subsamples removed to batch after incubation in the bioreactor. Error bars represent the standard deviation of three replicates. ★★ indicates p<0.01

Fig. 7. Flux chamber inserted into the landfill surface to allow changes in emitted landfill gas to be monitored.

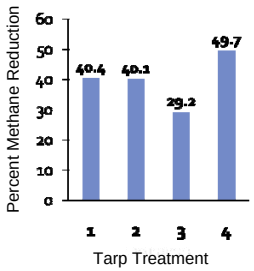

Fig. 8. Geometric mean of percent flux reduction by
(1)NMS-only tarps (n=14);
(2) NMS+shale tarps (n=21);
(3) NMS+bacteria tarps (n=9); and
(4) NMS+shale+bacteria tarps (n=19).

MATERIALS AND METHODS

Cultures and Conditions

- Isolated a mixed methanotroph population from landfill cover soil
- Maintained at room temperature in Whittenbury's Nitrate Mineral Salts (NMS) media in custom gas-tight bottles with a 10% methane in air headspace

Adsorption

- Six types of supports tested for their ability to maintain a robust population of methane oxidizers: natural sponge, a 0.95 cm x 2 cm x 4 cm sample of a highly wettable PP nonwoven geotextile; a 2.5 x 3 x 4 cm piece of synthetic foam padding with a 1.2 lb/ft^3 density; a small sub-section of injection molded polypropylene plastic tower packing material; a 90 mm diameter circle of polycarbonate membrane with a 0.22µm pore; and glass beads with a 200-300 mm diameter
- An overnight culture of mixed methanotrophs was added to a support material in a gas-tight bottle under a 10% methane:air headspace and incubated at room temperature.
- Methane uptake analyzed by gas chromatography after 24 hours

Temperature Stress

- An overnight culture of the mixed methanotrophs added to the geotextile in a gas-tight bottle under a 10% methane:air headspace and incubated at 5°C, 15°C, 25°C, and 35°C
- Methane uptake analyzed by gas chromatography after 24 hours

Methane Starvation

- Geotextile embedded with mixed methanotroph culture incubated at room temperature in a gas-tight bottle under a 10% methane:air
- Samples alternately exposed and deprived of methane in 12-hour cycles, while controls were continually exposed to methane

Continuous Flow Bioreactor Design

- 45cm long clear plexiglas pipe (ID 20cm) sealed at one end
- Aerated through ¼ " perforated stainless steel tubing (8cm x 20cm "U" shape)
- CO_2 and CH_4 premixed and delivered at bottom through ¼" perforated stainless steel tubing covered by gravel
- Flow regulators used to control and monitor inflow gases
- Gas sampled through a septum mounted in the outlet cover.
- Biotarp samples sandwiched between two plexiglas frames (16.8cm x 25.5cm ¼" with a central section removed)
- A 10cm dia. semi-circle sealed the bottom portion of the platform
- Volume-based flow meter fed readings at15 min intervals to computer for averaging

Examination of Biotarp Prototypes in Continuous Flow Chambers

- Biotarp prototypes were soaked for 10 minutes in 300 mL of a mixed methanotroph culture in NMS (all liquid absorbed)
- DI water-only control geotextile prepared in a similar manner
- Inlet and exit methane concentrations and flows monitored for mass balance analysis
- Samples were monitored for one week. Upon dismantling, 4cm x 4 cm biotarp subsamples were placed in gas-tight bottles in a 10% methane in air headspace to assess oxidation activity
- Circle of commercial furnace air filter fabric positioned in reactor cross-section to ensure mixing before exit gas sampling
- Threaded bolts and a gasket used to ensure a gas tight-seal

Field Testing and Flux Chambers

- Field site was the Allied Waste landfill in Cabarrus County, NC
- Flux chambers were used to measure gas emissions atop intermediate cover
- Chambers have metal bases secured in the soil.
- For measurements, a stainless steel lid, fitted with a gas-tight sampling port, was clamped to the collar, and the joint between the two was filled with water to form a gas-tight seal
- Biotarp prototypes were soaked in 1 L of NMS (controls) or NMS+mixed methanotroph culture
- Factors tested included biotarp thickness, addition of compost layer, addition of shale layer, and daily moisture/nutrient application
- Gas flux measured with and without biotarps or controls in place
- Samples withdrawn in 60 mL valved syringes and injected into evacuated gas-tight vials for transport to lab, GC measurements, and flux calculations.

RESULTS AND DISCUSSION

- Supports with high moisture-holding capacity (synthetic geotextile and natural sponge) yielded highest methane oxidation activity by adsorbed cells. (Fig. 1) Natural sponge was eliminated because of poor durability.
- Optimal temperature for methane oxidation by cells adsorbed to geotextile was 25°C and 35°C; uptake was negligible at 5°C (Fig. 2)
- Methane deprivation reduced but did not eliminate oxidation over time . Controls showed a less pronounced decline (Fig. 3) Storage of the biotarp during the working day may reduce the methane mitigation potential of the biotarp.
- Continuous flow chambers (Fig. 4) achieved a maximum 25% methane uptake when incubated with a 22 g/m^2/d flux (Fig. 5)
- Biotarp samples tested in batch after continuous flow incubation had a significantly higher methane oxidation rate than in the chambers(Fig. 6), suggesting retention time under continuous flow limited performance
- Field baseline fluxes were highly variable between sampling sites, ranging from 2700 to 27 g CH_4/m^2/d. Therefore geometric means of the six chamber sites are reported. They were 51.6, 128, 139, 27, 5.23, and 176 CH_4/m^2/d.
- Shale was the most effective amendment, but tarp emission reduction rates were quite variable. Geometric means of the percent removal by different tarp treatments are shown in Fig. 8.

CONCLUSIONS

- Methanotrophs can be adsorbed to a synthetic geotextile support, and the cells oxidize methane well when adsorbed.
- Low temperatures and methane deprivation reduce methane oxidation rates by adsorbed cells.
- Methanotrophs adsorbed to a layered geotextile biotarp prototype removed 25% of introduced methane in landfill simulations.
- In the field, bare soil methane fluxes were highly variable, and tarp flux reduction was also variable, likely due to weather changes.
- Addition of shale improved biotarp performance, perhaps because of better microbial adsorption and/or better water holding capacity.
- Future work will test a newly designed geotextile with superior water-holding capacity and investigate the potential for methanotroph inhibition by ammonia or other non-methane emissions.