Optimization, Scale-up, and Design of Coal-Dependent Methanogenesis in Preparation for *In Situ* Field Demonstration

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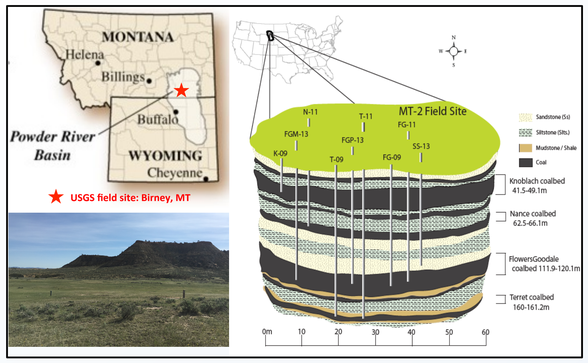
Center for Biofilm Engineering

a National Science Foundation Engineering Research Center in the MSU College of Engineering

Introduction

Study site: Powder River Basin (PRB) coal, Montana

- Largest coal deposit in USA (40% of coal reserves)
- Most coal not accessible to current extraction techniques



Industrial Relevance

Microbially-enhanced coal bed methane (MECBM)

- Stimulation of indigenous microbes with algae biomass
- Coal bioconversion into biogenic methane gas

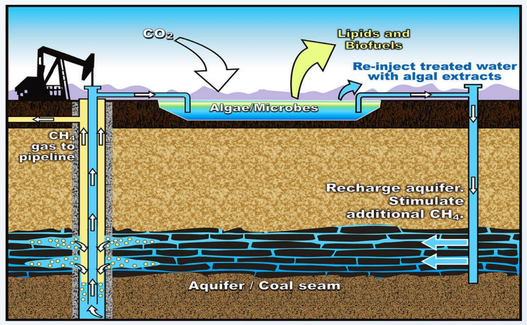


Figure 1 . Stimulation of coal bioconversion via methanogenesis using microalgae biomass grown in CBM production water pond.

OBJECTIVE - From batch culture tubes to field tests: can we scale-up MECBM under high pressure and slow flow?

Method development

Design of a small-scale high-pressure reactor system

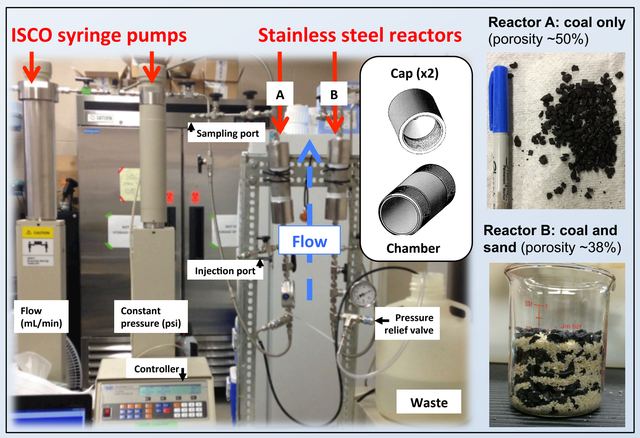
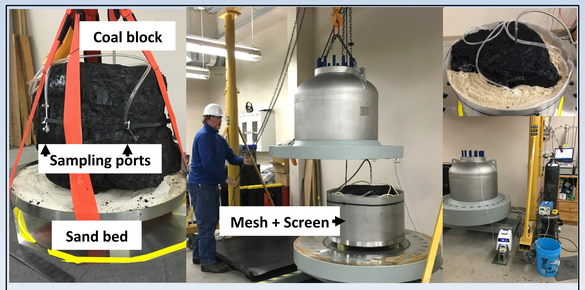


Figure 2 . Picture and description of the small-scale high-pressure column reactor system designed in this study.

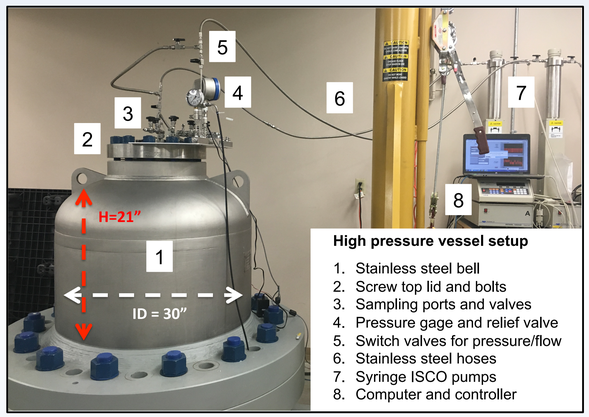
Mesoscale high-pressure reactor

Vessel contents: bulk and liquid phases from the field



- Vessel filled with 200 L CBM water (filtered through 0.45 um)
- Fluid pumped into the reactor and de-oxygenated on coal

Final setup of the high-pressure system (80 psi)

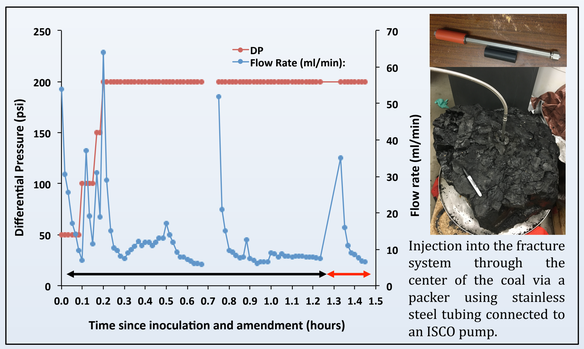


High pressure vessel setup

1. Stainless steel bell
2. Screw top lid and bolts
3. Sampling ports and valves
4. Pressure gage and relief valve
5. Switch valves for pressure/flow
6. Stainless steel hoses
7. Syringe ISCO pumps
8. Computer and controller

Figure 3. Picture and description of the mesoscale high-pressure reactor system used to scale-up microbial coal bioconverison into methane gas.

Flow rate during inoculation and ^{13}C algae amendment



Injection into the fracture system through the center of the coal via a packer using stainless steel tubing connected to an ISCO pump.

Figure 4. The flow rate was observed to decrease over time as the inoculation occurred and amendment was injected into the coal (black arrow) and when 120 ml of CBM water (red arrow) was pushed into the system to rinse the pump and tubing.

Sampling of the vessel over time

Method	Sample	Analysis
General parameters	Unfiltered fluid, untreated	**pH, DO, sulfate**
Gas chromatography and Mass Spectrometry	Dissolved gases	**CH_4, CO_2 and respective ^{13}C isotopic composition**
Cell fixation	Unfiltered fluid, formaldehyde	**Scanning electron microscopy**
DNA extraction	Liquid and bulk phases	**Sequencing, qPCR (mcrA, 16S)**
HPLC	Filtered fluid	**Organics (acetate)**
ICP-MS	Filtered fluid in % HNO_3	**Dissolved total metals**

Methane production

Performance of the small-scale column reactors

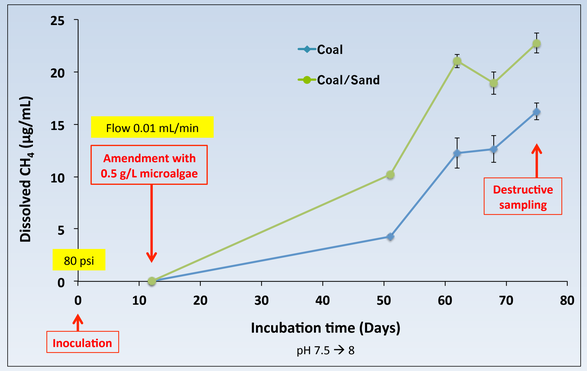


Figure 5. Methane accumulation over time in the small-scale reactors under high pressure and slow flow.

			Coal	Coal/Sand
Input (carbon)	Bulk coal	(g)	111.4	80.55
	Carbon from amendment	**(mg)**	**25**	**25**
Output (methane)	Cumulated CH_4 production	(mg)	16.09	31.96
	Desorption 5h30min	(mg)	0.009	0.000
	Initial vacuum	(mg)	1.35	0.98
	Overnight vacuum	(mg)	0.92	0.49
	Total CH_4 production	**(mg)**	**18.36**	**33.42**
		(µg/g coal)	164.80	414.91

Dissolved methane in the vessel over time

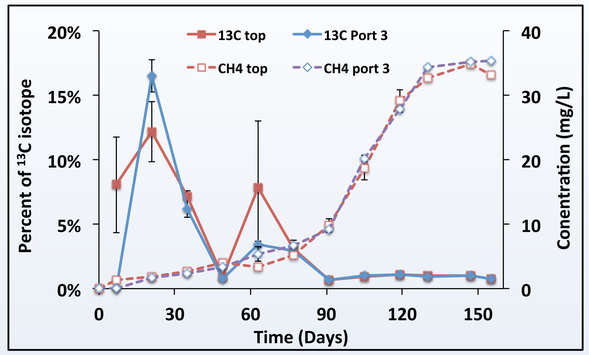
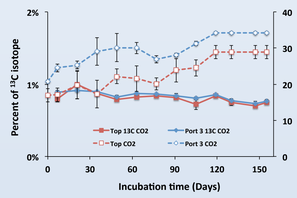


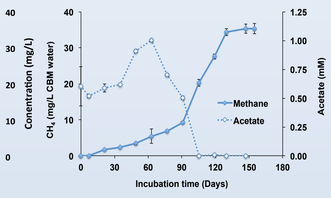
Figure 6. Methane accumulation over time in the mesoscale reactor under high pressure and slow flow (top of vessel and samping port #3).

Fluid geochemistry

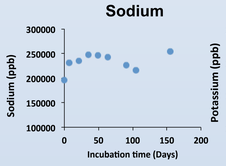
Dissolved carbon dioxide (GC-MS)



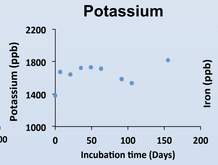
Dissolved acetate and methane (HPLC)



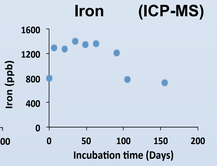
Sodium



Potassium



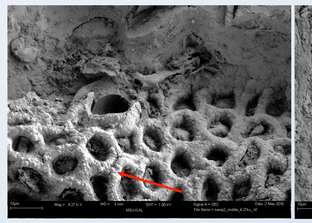
Iron (ICP-MS)



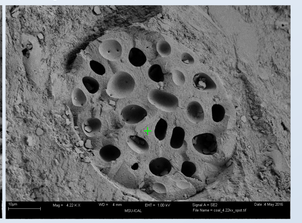
Scanning Electron Microscopy

Coal in the small-scale column reactors

Biofilm on "honeycomb" structure **(Pressure 80 psi)**

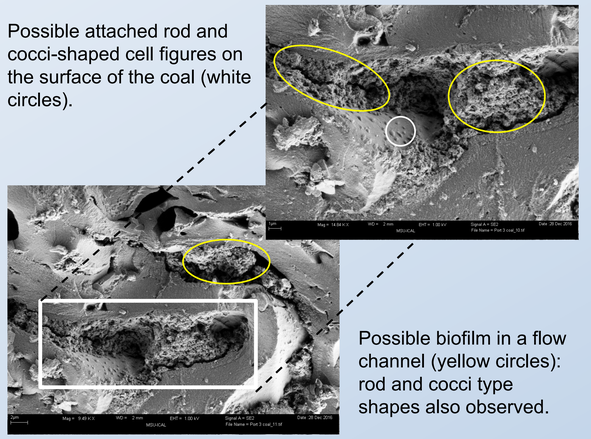


Control "honeycomb" structure **(No pressure)**



Coal in the mesoscale high pressure reactor (80 psi)

Possible attached rod and cocci-shaped cell figures on the surface of the coal (white circles).



Possible biofilm in a flow channel (yellow circles): rod and cocci type shapes also observed.

Conclusions

- Successful growth of methanogenic consortia under high pressure and low flow in small to large scale bioreactors
- Demonstrated coal bioconversion after algae amendment
- Demonstrated biostimulation during the first month
- Confirming the scale-up of methanogenesis process inside the fracture system of a coal block
- Moving towards field validation of microbial coal bioconversion strategies

Future Work

- Ongoing sequencing and data analysis
- Field validation of the MECBM technology
  - Define a specific experimentation area
  - *In situ* injection tests of the algae amendment (density, viscosity, settling rate, concentration)
  - Scale-up the costs, volumes and methane yields