Enhanced Methane Production: Turning Culm and Gob into Fuel

cb bioenergy

University of Utah

October 2011

Why Bother with Waste Coal?

Mining of coal and other hydrocarbon sources (e.g., tar sands and shales) results in mountainous waste heaps, which contain both mineral waste and lower grade coal materials, a useful fuel source. In the U.S. alone, the amount of accumulated culm and gob (waste products of anthracite and bituminous coal mining, respectively) is estimated at about two billion tons. Annually, about 50 million tonnes of waste coal are generated and pile up on mine sites as unprofitable mountains or valley fills that have the potential for contributing to generation of metal contaminated waters. Successful conversion of even a fraction of this waste material into useful fuel could prove advantageous to the mining industry and the environment.

Promising Results

Coal and waste coal samples used in this study were provided from the same mining operation and types of mined materials to permit a more direct comparison of the obtained results. The coal sample had total moisture content of 4.28% and 6.15% ash content as received. Over 76% carbon (dry) and a heat value of about 14,000 BTU/lb classify it as bituminous coal. On the other hand, the waste rock product, as received, contained over 50% of ash, only 28% carbon (dry), and had a calorific value of less than 4,400 BTU/lb.

Methanogenic microbial consortia from various environments were collected and characterized. These environments included coal (C), waste coal (WC), oil seeps (OS), natural gas wells (GW), lake sediments (LS), wetland sediments (WS), river sediments (RS), and anaerobic digester sludge (DS).

Glass serum bottles were used as bioreactors for methane and CO_2 generation. Over 650 samples, containing solid hydrocarbons, microbial consortia from various environments, and saline or nutrient solution amendments, were created. Three levels of nutrient amendments were selected: 0%, 10%, and 50%. Control samples were created by adding sterile normal saline solution to the respective pulverized samples without the addition of microbes. The samples were analyzed after a 30-day reaction period at about 23° C.

Headspace methane and carbon dioxide concentrations in the samples were analyzed with gas chromatography. Carbon dioxide generation is important; it is one of the direct methane precursors and can increase the overall methanogenic potential in the samples tested.

Control samples are represented on the following graphs by yellow and green lines for methane and CO_2, respectively. Any gases detected from control samples were a result of desorption from coal under atmospheric conditions and/or generation by the native microbial population present in the respective coal materials.

Generation of methane and CO_2 with no nutrient amendment indicates microbial breakdown of coal materials and subsequent utilization of the intermediate compounds to generate these gases. The highest concentration of methane produced from the tested waste coal sample was about 260 ppm, while carbon dioxide exceeded 14,000 ppm (Figure 1). Moreover, concentrations of both methane and carbon dioxide obtained from samples with no nutrient amendments were higher than in control samples, containing only normal saline solution and lower concentrations of native microbial populations. This strongly indicates that introduction of non-native species and/or higher concentrations of native species into solid hydrocarbon materials could potentially enhance the rates of gas production. Extrapolating, results show a production of methane directly from waste coal sources at about 0.22 to 0.3 SCF/ton. This represents a two- to five-fold increase over control samples.

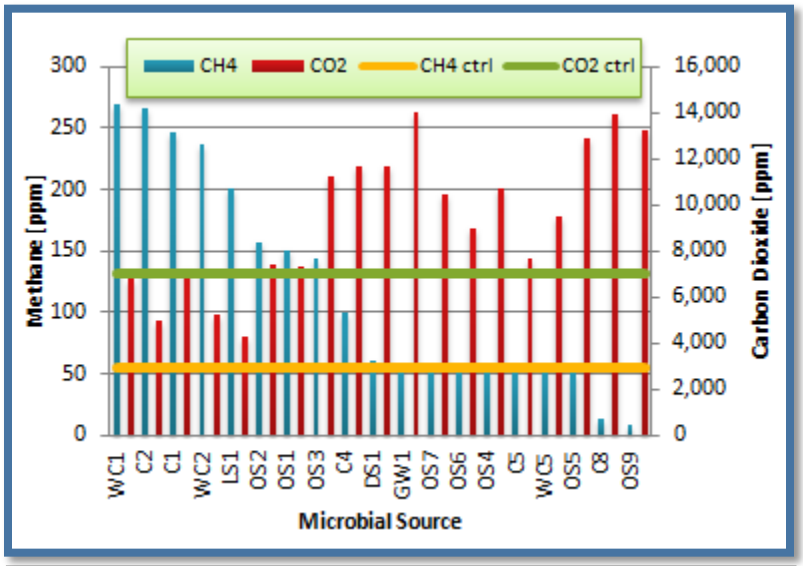

Figure 1. *Methane and carbon dioxide generated from waste coal samples inoculated with various microbial consortia (represented by the x-axis) after 30 days incubation period with no nutrient amendment.*

Initial nutrient addition might be necessary to stimulate the methanogenic population. Amendment with 10% nutrient solution did not result in much higher methane production from waste coal, with one exception generating nearly 400 ppm (figure not shown). However, CO_2 concentrations were significantly increased, ranging from 5,000 to 33,000 ppm, corresponding to 1-7 fold increase. The increase of nutrients to 50% resulted in a significant increase in generated gases from waste coal material, where up to 120,000 ppm of methane (480-2,000 fold increase) and 60,000 ppm carbon dioxide (4-15 fold increase) were produced (Figure 2).

Figure 2. *Methane and carbon dioxide generated from waste coal samples inoculated with various microbial consortia (represented by the x-axis) after 30 days incubation period with 50% nutrient amendment.*

Table 1 shows extrapolated gas generation potential from waste coal as compared to coal material. From the obtained results, it is calculated that 3.3 SCF of methane could be generated annually per ton of waste coal using no nutrient amendments. Under the same conditions, coal materials could generate only 0.7 SCF of methane more. Addition of 50% nutrient increases the annual methane generation potential to 1,600 SCF/ton of waste coal. To put this into perspective, commercial CBM gas production via dewatering and desorption may generate about 150 SCF CH_4/ton of coal over its lifespan. Furthermore, under all nutrient levels, carbon dioxide generation from waste coal was significantly higher than that from coal materials. It indicates that higher methane yields from waste coal materials are possible with a more complete conversion of CO_2.

Table 1. *Extrapolated values for maximum annual gas generation potential from waste coal as compared to coal material.*

	0% Nutrient		10% Nutrient		50% Nutrient	
	CH_4	CO_2	CH_4	CO_2	CH_4	CO_2
Waste coal [SCF/ton/year]	3.3	186	5.3	450	1,600	800
Coal [SCF/ton/year]	4.0	80	7.3	400	2,660	660

The highest concentrations of methane were obtained from samples inoculated with consortia cultured from coal (C) or waste coal (WC) environments. This was expected, since coal populations contain native methanogens that are adapted to this environment. Interestingly, the highest concentrations of carbon dioxide were produced from samples inoculated with consortia cultured from other environments. These included oil seep (OS), natural gas wells (GW), lake sediments (LS), digester sludge (DG), and river sediments (RS). This is an important finding, indicating that introduction of non-native species could increase the rate of hydrocarbon biodegradation, with CO_2 as an end product. It can be assumed that under proper environmental conditions, all generated carbon dioxide would ultimately be converted to methane.

The Bottom Line

Literature results report successful methane generation potentials of between 10^1 – $8x10^3$ SCF per ton of coal per year. Data obtained from waste coal and presented here falls in the same range. In many of the literature studies, in patented methods, and in some of results identified as such and presented in this document, the reported enhanced methane production is somewhat controversial. The controversy comes from the fact that the nutrients and other materials added to the test systems are themselves a major source of the methane increases observed. In other words, in many cases, the additional methane produced comes mostly from the conversion of added nutrients. Table 2 summarizes the best methane and carbon dioxide generation from coal and waste coal materials and compares them to the maximum theoretical nutrient conversion. Addition of nutrient solution stimulated the degradation of hydrocarbon material and a subsequent methanogenesis. Only a small fraction of methane (1-2%) and carbon dioxide (1-3%) generated from these samples was a direct result of nutrient conversion.

Table 2. *The best gas production results as compared to the maximum theoretical gas generation from nutrients.*

		Nutrient	Coal	Waste Coal
0% nutrient	**CH_4 [ppm]**	0	290	270
	CO_2 [ppm]	0	6,100	14,000
10% nutrient	**CH_4 [ppm]**	428	580	400
	CO_2 [ppm]	286	29,000	33,000
50% nutrient	**CH_4 [ppm]**	2,143	200,000	120,000
	CO_2 [ppm]	1,429	50,000	60,000

The results given in this paper represent a one-time measurement after a 30-day testing period. Consequently, it is not known whether the maximum conversion to methane or CO_2 was achieved or whether partial gas pressures in the reaction vessels limited the amount produced. Furthermore, only limited conclusions on conversion kinetics can be drawn from the results obtained.

Regardless of the nutrient amendment level, methane generated from waste coal materials was at the same order of magnitude as that produced from coal. Additionally, with no additional nutrients, carbon dioxide concentrations detected from waste coal samples were over twice as high as those produced from coal. Waste coal materials represented coal materials that had probably undergone partial surface degradation, both chemically and biologically, and were therefore potentially more susceptible to subsequent initial microbial degradation. No conclusion as to whether the observed rates of methane and/or CO_2 production in any of the samples can be maintained for an extended period can be drawn from this study. Nevertheless, these results suggest that culm, gob, and potentially other waste hydrocarbon materials can be converted to useful fuel. In at least some cases, methane could efficiently be produced using both above ground and in situ bioreactors.

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