Fuel 216 (2018) 274–283

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Modeling of microbial methane generation from coal and assessment of its impact on flow behavior

Suman Saurabh, Satya Harpalani*

College of Engineering, Southern Illinois University, Carbondale, IL 62901, USA

ARTICLE INFO

Keywords:
Biogenic methane
Logistic equation
Flow modeling
Coalbed methane

ABSTRACT

Enhanced microbial conversion of coal to methane has been a topic of research in the scientific community since its inception in the mid-nineties. Significant advances have since been made and the technique is now termed Microbially Enhanced Coalbed Methane (MECBM), with tremendous promise in the energy industry. However, analytical treatment of the bioconversion of coal using mathematical modeling is lacking. This paper is devoted to developing a fundamental outlook of the process of bioconversion of coal to methane using the concept of logistic population growth. The modeling exercise using laboratory results sheds light on the correlation between microbial growth rate, the ability of the environment to support the microbial population and environmental factors controlling the two. Furthermore, simulation of the impact of the technology on modifying the flow behavior of coal under *in situ* conditions is presented. The results demonstrate that the model can be used as a useful tool to evaluate the effect of *any* parameter, whether controllable for optimum gas production or an outcome of continued bioconversion, on actual gas production. The analysis of the results shows that the impact of environmental parameters, such as temperature, particle size and pH of the medium on bioconversion process can be optimized. Finally, it is shown that changes in flow behavior of coal are not very significant and can possibly even be negative.

1. Introduction

During the last few years, there has been a surge of interest in bioconversion of coal to methane in the scientific community worldwide. Since its inception in 1995 by Scott [1], now termed Microbially Enhanced Coalbed Methane(MECBM), significant effort has been devoted in this direction in Japan [2], Australia [3], Canada [4], China [5,6] and United States [7–11]. If the technical and economic feasibility of the process can be demonstrated for specific coal types, it has tremendous application in utilization of coal waste and post-mining residual coal, extraction of energy from unmineable coal and methane recharge of depleted coalbed methane (CBM) reservoirs.

Biogenic methane, known to occur naturally in coal environments, is classified as either primary biogenic methane or late stage biogenic methane [12]. Primary biogenic methane is created during the initial stages of coalification whereas the late stage biogenic methane is formed by microbial action due to groundwater re-charge or, meteoric re-charge of coal, activating the microbial community [13]. The emphasis of most research studies has been to optimize the microbial communities and nutrients, and environmental conditions to best stimulate the bioconversion of coal. Recent research studies have also concentrated on modifying the nutrient solutions used to culture the microorganism population in laboratory studies for bioconversion of coal. These nutrient solutions provide steady and improved growth of microorganism in the culture, which is primarily aimed to increase the production of methane from coal [9,14,15]. However, this paper is aimed *not* at proposing changes in the composition of nutrient solution for more sustainable and economic bioconversion of coal, rather at providing a fundamental analytical model to characterize the nature of biogenic methane production by application of logistic modeling. Furthermore, the paper strives to evaluate the impact of variations in environmental factors of the medium, like pH, temperature and coal particle size, on methane production resulting from the bioconversion process. These three factors were selected since they have been shown to affect the microbial growth in a few studies [9,15]. The paper also establishes the effect of bioconversion on the coal cleat structure, which is the single most important factor affecting coal permeability [16–19]. The basis for the paper is the application of logistic modeling for population growth of microorganism during bioconversion, developed using the results of the experimental work completed in the laboratory. Furthermore, regression-based analyses of the two model parameters are used to determine the impact of environmental factors mentioned

* Corresponding author.
E-mail address: satya@engr.siu.edu (S. Harpalani).

https://doi.org/10.1016/j.fuel.2017.12.015
Received 13 August 2017; Received in revised form 26 November 2017; Accepted 4 December 2017

Nomenclature

a	Cleat spacing
b	Cleat width
c	Rate of change in cleat width due to bioconversion
C	Methane concentration
k	Permeability
r	Growth parameter
K	Carrying capacity
t	Time
ρ_g	Methane density
ρ_c	Coal density
P	Population

above. Data reported by Green et al. [15] is used for this exercise.

A brief description of the experiments conducted in this study is included in Section 2. In addition, since data generated by Green et al. [15] is an essential component of this paper, a brief discussion of the study and results is presented below.

Green et al. [15] conducted a MECBM study using Powder River basin coal. They tested coal samples with microbial community capable of supporting methane generation under laboratory conditions and reported positive results. In addition to coal, they used methanol and acetate as other sources of methane generation in their study. They filled the headspace over the solution used for bioconversion of coal with H_2 and CO_2 and reported that these gases had no impact on methane generation. They reported maximum methane generation rate at 22 °C to be 0.084 m^3/t coal/day. The production rate increased by 300% when the temperature was increased to 38 °C. Similarly, when they reduced the pH from 7.4 to 6.4, production rate increased by 680%. With reduction of particle size to approximately ten times, methane production increased by 200%. In addition, they reported that methane generation was boosted by addition of the solvent, N,N-dimethylformamide (DMF). Finally, they concluded that coalbed methane reserves can be enhanced by microbial stimulation of *in situ* coal, especially by increasing the coal solubility and dissolution rates. Details about the microbial solution preparation and experimental setup used in their study is given in their published work [15].

2. Experimental work

2.1. Experimental Sample

The coal used for the experimental work was obtained using chunks of coal, retrieved from Herrin seam in the central Illinois coal basin. The coal rank was bituminous. The coal pieces were ground and sieved to obtain -74 m size. The sample size used for microbial treatment was ten grams.

2.2. Experimental Setup

The experimental setup consisted of a leak-proof sample container, designed and fabricated to hold the nutrient solution and microbes. The container was fitted with a pressure transducer to enable monitoring the variation in the setup pressure with continued bioconversion. In addition, the headspace above the microbial solution was purged with helium to maintain a constant pore pressure of ~3 MPa (450 psi), representative of the *in situ* pore pressure at ~1000 feet. The experiments were carried out at a constant temperature of 32 °C, again representative of the *in situ* condition, using a water bath. The experimental setup used is shown in Fig. 1.

2.3. Medium

The medium consisted of the nutrient solution and microbial community. The nutrient solution used was that proposed by Zhang et al. [9] for the coal type and microbial community present. The MS (Murashige and Skoog) [20] recipe was prepared using one L of distilled and

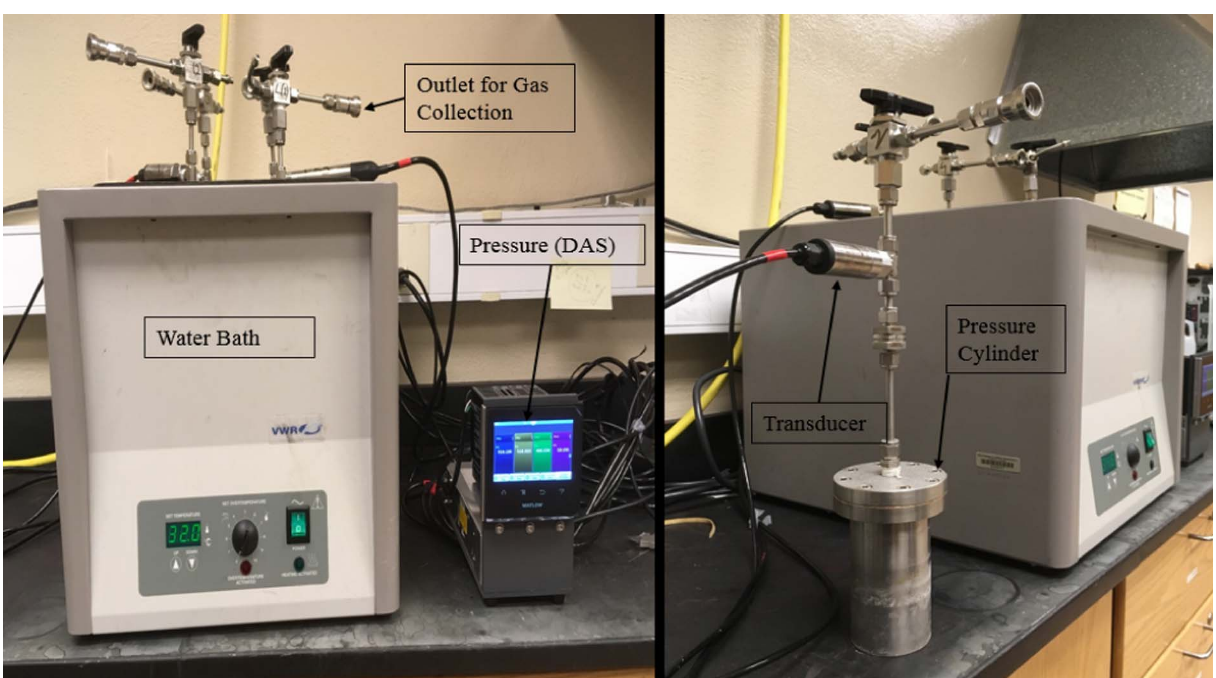

Fig. 1. Experimental setup used for bioconversion of coal.