Coal Characterization in CBM/ECBM Processes Using X-ray CT Analysis

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Summary

This paper presents the results of coal characterization during primary CBM and CO_2-ECBM experiments using x-ray CT techniques. The coal density and density distribution varied with the gas type and gas pressure are investigated. A coal core sample from Alberta Manville formation with the rank of SubB was used in this work. Core flood experiments in coal have been conducted in inert gas (helium) flow, methane production, methane displacement by CO_2 and inert gas flow after CO_2 desorption. The x-ray CT experiment was carried out parallel to the core flood experiment to provide x-ray images of coal core saturated with different gases at different system pressures. The x-ray techniques were used for visualization and mapping of larger fractures and mineral streaks, as well as identification of flow paths. The coal density and density distribution changed with the gas type and gas pressure were obtained.

The results show that net overburden pressure, gas adsorption capacity, and the production history are all key factors affecting coal core structure, leading coal density and density distribution variations. Hence, the core flow path, which contributes to the coal permeability, changes with those factors during CBM and Enhanced Coalbed Methane (ECBM) processes. The shrinkage and swelling of coal matrix due to adsorbing gases were also measured during production. The results from this study provide laboratory coal characterization techniques using x-ray imaging analysis.

Introduction

Coalbed methane (CBM), an unconventional natural gas resource, has the potential of contributing a significant portion of Canadian natural gas production in the foreseen future. The primary CBM production mechanism is to recover the methane gas by reservoir pressure depletion, which usually has less than 50% of the recovery rate. To further improve the gas recovery rate, CO_2 enhanced recovery is proposed in recent years and has been discussed by several researchers (Seidle, 2000 and Wong et al., 2000). If successful, its implications include CO_2 sequestration in deep unmineable coalbed formations. Coal characterization is viewed as one of the key components to successfully develop CBM and ECBM processes. Coal seams are heterogeneous in terms of lithotypes and morphologies. As an organic rock, coal structure is easily deformed by the net stress imposed on it.

The network of natural fractures and cleats in a coal determines to a large extent the mechanical properties of the coal. The stress and time dependent deformation of the coal porous structure is expected to change the behavior of the most important properties of the coal, such as porosity and permeability, which in turn change the reservoir production predictions. Coal physical properties such as density and compressibility are also dynamically changed with the coal structure deformation.

Computerized tomography (CT) provides a non-destructive method that visualizes the internal structure of an object. It allows continuous observation of the sample during the experiment and has proven to be a valuable tool in petroleum exploration and development research (Wellington, and Vinegar, 1987 and Akin and Kovscek, 2003). However, its application to coal deformation studies has been limited to a small number of studies (Karacan and Okandan, 2001 and Karacan and Mitchell, 2003). X-ray CT techniques are proposed as tools to characterize coal and demonstrate the use x-ray CT to investigate the coal density, and density distribution varied with the gas type and gas pressure during the CBM primary and enhanced gas recovery processes.

Experiments

Core-flood and X-ray CT experiments have been carried out to investigate coal density. The coal sample, from the Manville Group in Alberta has the characteristics listed in Table 1. The coal core had an average cross-sectional area of about 3580 mm^2 and was 85.5 mm long.

Table 1. Proximate analysis and coal rank classification						
Coal type	Depth (m)	Moisture(*) (%)	Ash(*) (%)	Vol. Matter (%)	Vitrinite reflectance (%)	Rank
Deal Bruce	853	9	14.1	36	0.47	Sub-B
* Equilibrium moisture basis.						

Table 1: Proximate analysis and coal rank classification

The core flood experiments were conducted by the core-flood rig in Figure1, consisting of helium, methane, CO_2 flow, gas adsorption and desorption, and the displacement of methane by CO_2. First, helium as a non-adsorbing gas was flowed through core at different combinations of overburden and pore pressure at a temperature of 23^oC. Then the core was saturated with methane at a given system pressure. After adsorption was reached, methane flowed through the core at the given system pressure. Then the system pressure was reduced to produce methane. After CBM production by pressure depletion, CO_2 was injected to displace methane. At the equilibrium CO_2 saturation conditions, CO_2 flowed through core at several system pressures. At the end of ECBM, the core was blown down and the CO_2 was allowed to desorb. Helium was flowed through core again to determine the permanent changes on the core.

The x-ray CT experiments were carried out parallel to the core flood experiments to provide x-ray images of coal core during helium flow, methane saturation and flow, CO_2 adsorption and desorption stages. The CT scanner used in all the CT experiment is the 3rd generation GE9800 with proper calibration. In total, there were 17 CT experiments conducted at the room temperature. Consistent scanning parameters were used for all the CT experiment to produce comparable CT images. The raw data is CT images each containing 512 × 512 pixels. Each pixel stands for 0.2 mm ×0.2 mm ×1.5 mm volume element. Each pixel readings as CT number, ranging from -1024 to

+3071, is an average CT number within that volume and is a function of mean density and effective atomic number. CT numbers are transferred to coal density by density calibration.

Density Logging

Figure 2 shows the coal bulk density log for helium flow. The group 1 curves are for helium flow before CBM primary production, and group 2 for helium flow after ECBM processes. The result shows that coal core is a highly heterogeneous material. Its density varies dramatically at different locations. The lowest density corresponds to the largest fracture region, while the highest density reflects the mineral streaks. The range of the density is typical for coal. Coal bulk density is strongly dependent upon rank (Gan, et al., 1972; Levine et al., 1993), pore volume and structure (Levine et al., 1993), and coal composition. From the graph, coal bulk density is directly increases with the incremental of the net overburden pressure imposed upon core. The pressure effect is very consistent for all the pressure settings. However, the differences between the group 1 curves are much smaller than those of group 1 curves. This means that there were the CBM primary and ECBM processes incurred permanent changes on coal structure.

The density loggings during the CBM primary and ECBM processes are plotted in Figure 3. The effect of the gas type on the coal density is much pronounced because coal density has a dramatic increase by CO_2 injection. The effect of the gas type on coal density reflects the degree of coal swelling due to gas adsorption.

Density Variation

Figure 4 represents how coal average density changes during the core-flood experiment. First, the coal average density increases with the net stress due the increased overburden pressure. It decreases as the net stress reduces by increasing the pore pressure. Here the observed hysteresis indicates permanent changes in coal structure. Coal has larger density compared to the observed trend when increasing overburden pressure at the same net stress. This hysterisis is consistent with the coal permeability change reported in a previous publication (Guo, et al., 2007). Introducing methane in coal increases coal average density. After methane production, coal density is boosted by CO_2 adsorption. The coal density change due to the adsorbing gas flow is correlates well to the coal permeability change (Guo, et al., 2007). Coal permeability is provided by the coal fracture network. The swelling of the coal matrix due to adsorption of gas on coal squeezes the coal fracture, which is the gas flow path. Therefore the coal permeability decreases during methane and CO_2 flow. Hence both coal density and permeability are affected by the same factors and follow the similar trend. Coal density under CO_2 saturation is not a single function of net stress. This implies that pore pressure also affect coal density.

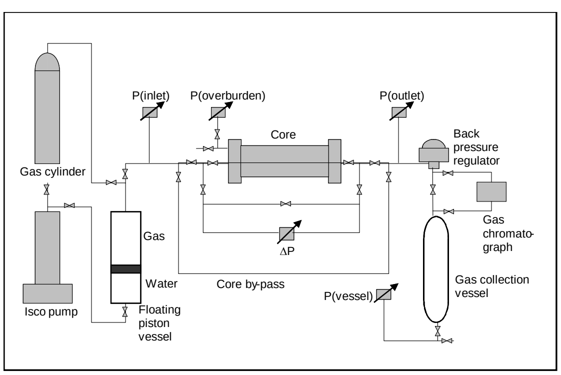

Figure 1: Schematic of the core-flood rig

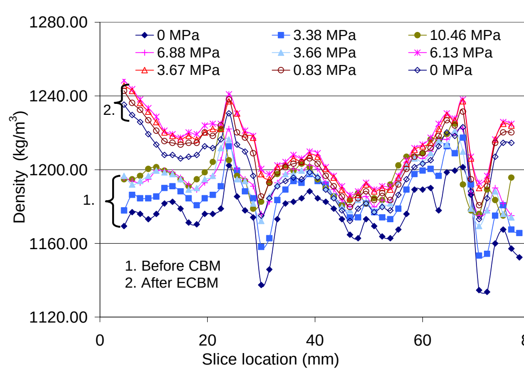

Figure 2: Density log for helium flow at different net overburden pressure

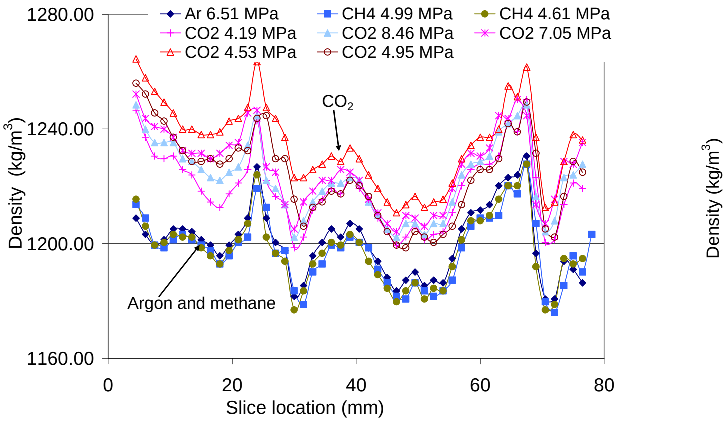

Figure 3: Density log with CO_2 at different net overburden pressure

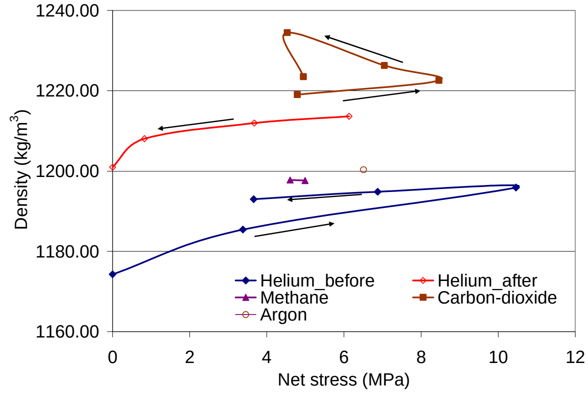

Figure 4: Coal average bulk density change

Conclusions

From the above results, we can see that net overburden pressure, gas adsorption capacity, and production history are all key factors affecting coal core structure, leading coal density and density distribution variations. Hence, the core flow path, which contributes to the coal permeability, changes with those factors during CBM and ECBM processes. The swelling of coal matrix due to adsorbing gases has greater effect on coal density than imposing pressure. This study shows that x-ray CT technique is a useful tool in coal characterization during CBM/ECBM processes.

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