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DocumentHeading

Field Test of CO_2 Injection and Storage in Lignite Coal Seam in North Dakota

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Abstract

The paper describes a CO_2 sequestration pilot test being conducted in northwestern North Dakota in a lignite coal seam. Laboratory and field tests conducted to date indicate that the lignite provides a viable target for CO_2 sequestration while, as could be expected, potential for methane production from lignite is questionable. It is suggested that in the future evaluation of gamma-ray logs and vertical pressure profiles can improve performance of enhanced coalbed methane production from lignites.

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Keywords: CO_2 sequestration; lignite; North Dakota; coal seams

1. Introduction

The US Department of Energy (DOE) has established a number of programs in response to demand to mitigate climate change and growing consumption of fossil fuel. The goal of the programs is to verify feasibility of carbon dioxide (CO_2) sequestration and development of unconventional resources in various regions of the US. The Plains CO_2 Reduction (PCOR) Partnership is one of seven partnerships created in the framework of DOE Regional Carbon Sequestration Partnerships (RCSP) Program. The PCOR Partnership is led by the Energy and Environmental Research Center (EERC) in the University of North Dakota. The PCOR Partnership's goal is to identify and test carbon capture and storage opportunities in the central interior of North America. Several means for geological

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storage of CO_2 are available in the region, including depleted oil and gas reservoirs, deep saline formations, CO_2-flood enhanced oil recovery (EOR) operations, coal seams, and enhanced coalbed methane (ECBM) recovery. The enhanced resource recovery methods of CO_2 storage also provide an economic benefit as a result of producing additional oil or methane. The PCOR Partnership region has extensive reserves for both EOR and ECBM recovery. A substantial part of the coal reserves are deep lignite seams concentrated mainly in the North Dakota portion of the Williston Basin. If proved to be suitable from both economic and safety points of view, lignite can be developed as additional resource for CO_2 storage and natural gas production.

The field validation test in Burke County, North Dakota, provides a unique opportunity to better understand the technical and economic feasibility of CO_2 injection, storage, and ECBM production in lignite. This study has investigated the mechanisms of gas storage in lignite and included thorough laboratory and field-based background data analysis, collection of baseline data, and monitoring, mitigation, and verification (MMV) activities. It is anticipated that the results generated in the duration of the project completion will be applicable to lignite coals worldwide.

2. Background

Coal seams are known to have the ability to store significant amounts of gases by absorbing them. This storage mechanism occurs naturally and is well documented, suggesting that a gas, particularly CO_2, can be reliably stored in coal seams. The opportunity looks even more attractive because of the possibility of simultaneous methane production. However, coals in different parts of the world and the United States significantly differ by their properties. North Dakota has abundant lignite coal reserves. There are multiple known seams that cannot be mined because of their depths and insufficient thicknesses. The PCOR Partnership field validation test in Burke County, North Dakota, is designed to define CO_2 sequestration capacity and CH_4 production potential of one of these seams. In particular, the following aspects have been studied:

- Methane content and CO_2 storage capacity and applicability of the existing experimental methods to the evaluation of those properties in lignite;
- Factors controlling the success of CO_2 sequestration/CH_4 production operations in lignite;
- Features of fluid transport in lignite;
- Stability of CO_2 stored within a lignite seam.

The first three of these aspects are discussed in this paper while the latter one is the subject of on-going study and results will be reported later.

3. Lignite in Burke County, North Dakota

Most of the coal (lignite) in North Dakota is found within the sediments of the Fort Union Group (Tertiary/Paleocene). Fort Union Group sediments were deposited as a clastic wedge thinning from eastern Montana into North Dakota (1). In general, the entire Fort Union Group can be described as consisting of alternating interbeds of sandstone, siltstone, clays and lignite, with some limestone. The lignite beds (seams), as with most other Fort Union sediments, were deposited in a complex fluvio-lacustrine environmental system. Lignite seams vary in thickness and distribution and range from a foot to a few feet in thickness. The thickest lignite seams in North Dakota are in the 50 ft range (1).

The following criteria are currently used by the state of North Dakota to assess economic feasibility of coal mining [1]:

- A minimum cumulative coal thickness of ten feet–typically occurring in one or two beds;
- A minimum individual-bed thickness of 2.5 feet;

- A maximum stripping ratio of 10 feet of overburden for every foot of coal;
- A minimum of 20 feet of overburden to minimize the effects of weathering;
- Coal depth is less than 170 feet.

At a depth of over 1000 feet, the lignite seam targeted by the PCOR Partnership is considered to be unmineable.

The site for the PCOR Partnership pilot-scale CO_2 sequestration / ECBM project is located in Section 36, Township 159 North, Range 90 West in southeastern Burke County, North Dakota (Figure 1). In the Burke County project area, the coal seam that is the focus of this study is approximately 10 ft thick. Lateral continuities of lignite seams vary greatly; in general, thicker seams are more continuous than thinner beds. According to well log data obtained from the North Dakota Department of Mineral Resources [2], the coal seam of interest can be traced within a 4-mile radius of the project site. The targeted coal seam is a part of the lower Fort Union Formation at an approximate depth of 1100 ft. The composite stratigraphic column of the section is shown in Figure 2. The test is designed in a five-spot configuration allowing for an effective data collection and monitoring program. The five wells were drilled in August, 2007. Development of the wells was conducted over the summer of 2008 in an effort to maximize communication between the wells and the target lignite seam. The study of the lignite and its properties has been conducted in two scales: laboratory and field scale. The following subsections describe the tests.

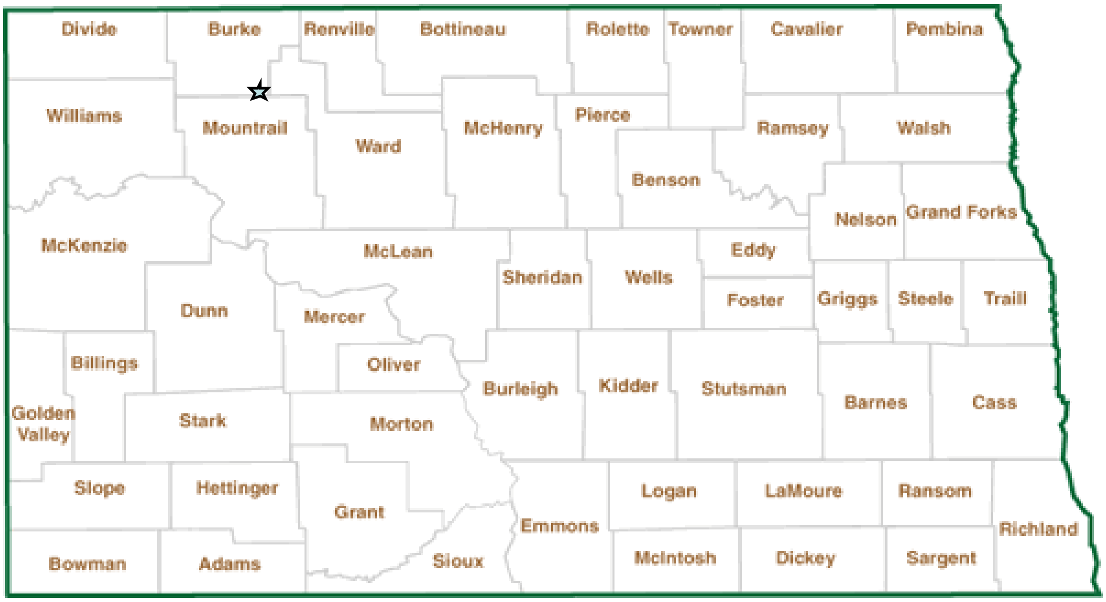


Figure 1. Location of the lignite ECBM site.

3.2. Laboratory tests

In addition to the standard suit of coal-specific laboratory experiments, coal sorptive, petrophysical, geomechanical and structural properties were investigated. Particularly, CO_2 and methane adsorption isotherms were obtained (Figure 3a,b) and the dependence of coal permeability on confining and pore pressures and on the presence of CO_2 was studied. Tests indicated that compared to other coals the tested lignite has somewhat lower sorptive capacity to methane: Langmuir volume was estimated at $V_{LCH_4} = 89.4 scf / ton = 2.9 scc / gm$ on raw basis while typical values for higher rank coal seams are in the range of 100-800 scf/ton [3]. However, the low sorptive capacity to methane is not a surprise as previous laboratory and field-based studies of North Dakota lignite yielded similar results [4]. The lignite has much higher sorptive capacity for CO_2, though: CO_2 Langmuir volume ($V_{LCO_2} = 898.9 scf/ton = 28.0 scc/gm$) is 10 times higher than CH_4 Langmuir volume.

A series of experiments with different gases and confining pressures indicated that permeability strongly depends on both stress state and presence of CO_2. Mechanical loading and unloading of the lignite confirmed its plastic behaviour, which, in combination with other possible laboratory artefacts, could affect the measurements. Despite the artefacts, the measurements support the conclusion of relatively high matrix permeability of the lignite (up to 1 md). The experiments also indicated that CO_2 is likely to cause significant swelling of the coal which can occur very fast: during one of the experiments an order of magnitude of permeability was lost in 10 minutes in response to CO_2 exposure.

3.1. Geophysical log data and field tests

A Schlumberger Sonic Scanner log was run in the central well in addition to the Platform Express logging suit. Although, due to poor consolidation of the rocks in this section, thorough geomechanical analysis was not possible, the interpretation of Sonic Scanner data provided some valuable information. Particularly, acoustic data indicates that a developed cleat system might not be present in the coal. This conclusion is in agreement with direct core observations and is important for the prediction of injection performance. Sonic data also indicates that the stress

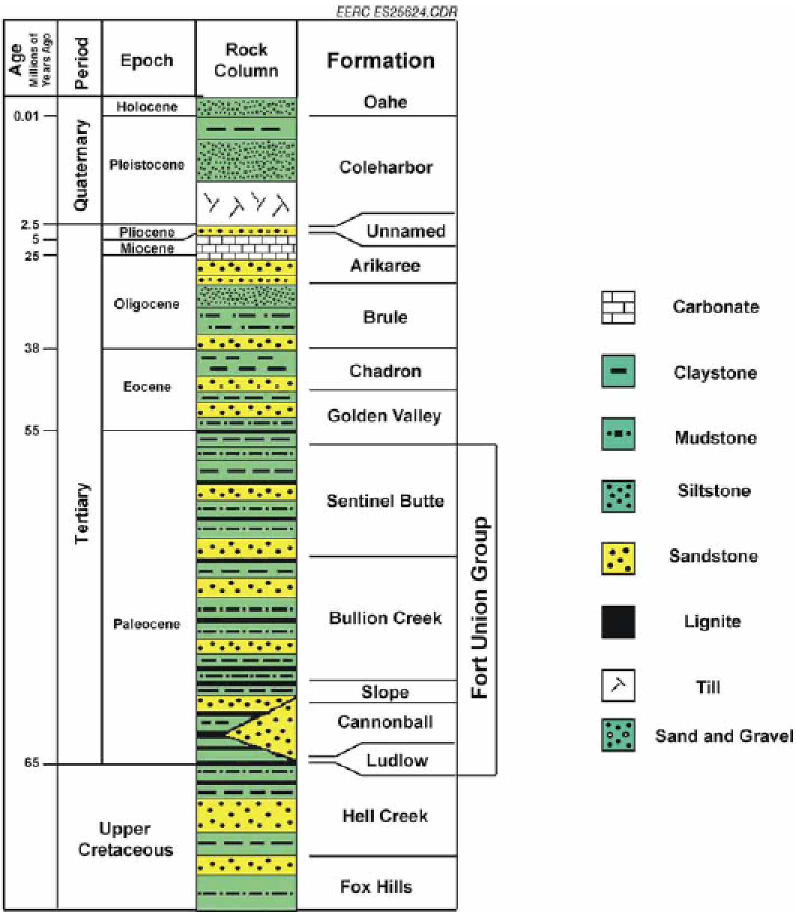
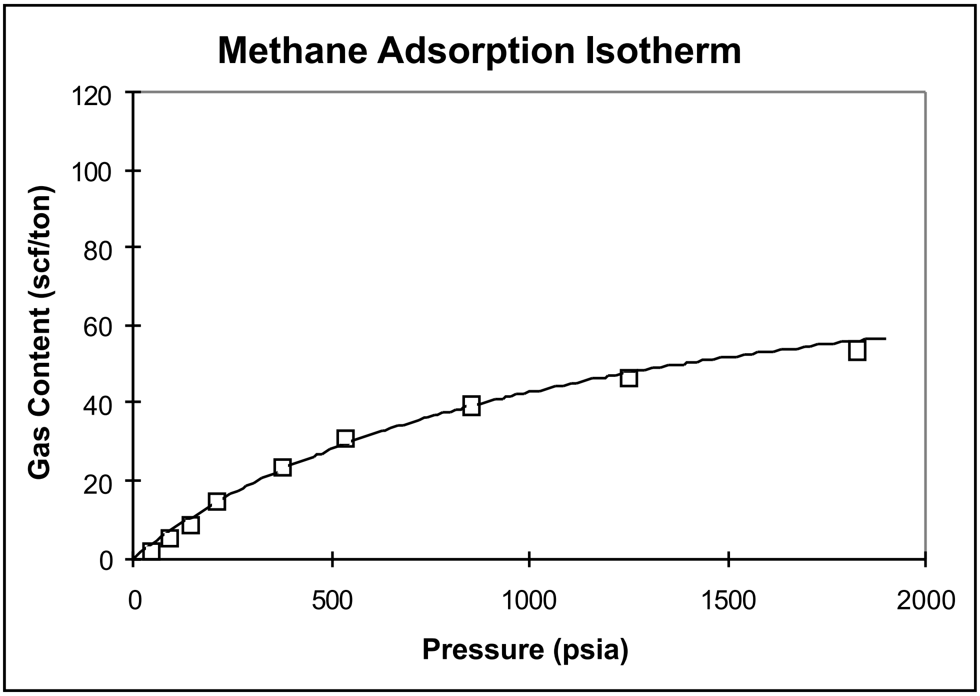


Figure 2. Composite stratigraphic column (Upper Cretaceous to Quaternary) in North Dakota (modified from Murphy and Goven, 1998).

field in the coal is likely to be homogeneous with the maximum principal stress being the pressure of overburden with minimal influence of tectonic forces. This sets limitations on injection rates which should be maintained low enough to prevent vertical fracturing of the coal with subsequent out of zone fluid migration. The data also indicated that drilling of the well may have resulted in the creation of a significant damage zone (> 4ft) around the well bore. This conclusion is also in agreement with data from field operations. Indeed, in the initial stages of well development none of the wells drilled into the lignite seam produced sufficient amounts of fluid. Development of the wells was conducted by employing different stimulation techniques, including swabbing, sonic hammer, nitrogen minifrac, and acid treatment. To date acid treatment provided the best result in respect with the development of the wells. Nitrogen treatment and pressure transient analysis have resulted in a conclusion that the reservoir is sufficiently underpressured with recorded pressure of $p = 345 psi$ while the normal pressure gradient at the reservoir depth would yield pressure of about $p = 470 psi$. This may largely explain the damage to the zone around the wells. Specifically, the evidence indicates that the wells were drilled using a largely overbalanced drilling mud density (e.g. higher density than was required to maintain borehole stability). This meant that drilling fluid, and later cement, could penetrate deep into the formation. The underlying mechanism responsible for the underpressured condition of the reservoir is not quite understood though. Underpressure can be attributed [5] to the expansion of the reservoir rocks in response to uplift and erosion. Studies of the Williston Basin have indicated that evidence exists for the latter effects in many formations [6]. Isostatic rebound from the geologically recent removal of glacial ice from Burke County at the end of the Pleistocene Ice Age may also account for expansion due to uplift.



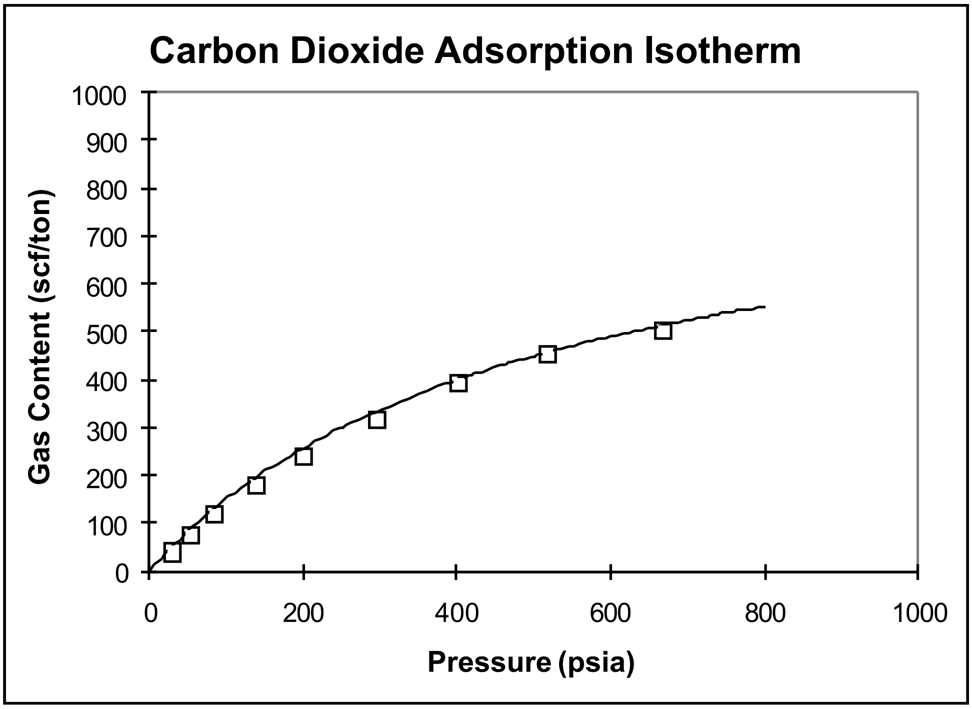


Figure 3 a) Methane and b) carbon dioxide adsorption isotherms (raw basis: $T = 61\,^0$F, Ash Content = 9%, Eq. Moisture Content = 32.17%)

4. Monitoring, Mitigation and Verification Program

MMV activities are designed to fit the overall purpose of the test, namely estimate natural gas content and ensure feasibility of CO_2 storage within lignite beds. It is planned that pressure, temperature and pH monitoring will be conducted in the monitoring wells providing continuous readings of the parameters both during the development of the wells and during and after the injection of CO_2. Besides that, time lapse crosswell seismic surveys will be conducted in order to monitor CO_2 plume extent. It also will help in understanding the structure of the lignite and verify that no geological faults are present in the studied area. Moreover microseismic monitoring with simultaneous tilt measurements is planned to complement plume monitoring and for early warning in case of fracturing of the formation in response to injection. A tracer study is intended for detecting possible leaks into the adjacent strata. Finally surface gas flux monitoring will be conducted primarily to assure public in the safety of the operations and to ensure that no leakage to the ground surface takes place.

5. Preliminary Conclusions and Path Forward

Laboratory and field work on the North Dakota lignite indicates that, as was expected, methane content and consequently methane production potential of the target lignite in Burke County is not significant. On the other hand the results of CO_2 sorption studies indicate the seams are likely to provide good targets for CO_2 storage. Another expected challenge in the field is the possible absence of a well developed cleat system, which would significantly influence fluid injection and transport in the lignite seam. This can be a common problem in lignite seams as cleat systems are known to develop with the maturity of coal. Thus, specific attention will be paid in future project activities to understand the in-situ transport properties of coal. This will be done by comparing the field-based data obtained by injection activities to the laboratory-derived parameters. Further research can be conducted in the direction of choosing techniques for the better characterization of coals on the stage of feasibility studies. For instance it has been suggested that existence of fractures, which weaken the mechanical integrity of the borehole wall, can occasionally give anomalous gamma ray signals. These signals are often being interpreted as the washing out of the borehole across the coal-bearing interval [7]. It also can be suggested that regional vertical pore pressure profiles be evaluated to ensure that the reservoir pressure is favourable for higher original gas in place.

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