The Coal-Seq Project: Key Results from Field, Laboratory, and Modeling Studies

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Abstract

In October 2000, a multi-year government-industry R&D collaboration known as the Coal-Seq project was launched in the United States. Participants in the project include the U.S. Department of Energy as the project sponsor, Advanced Resources International, Burlington Resources, and BP America. The project objectives are to evaluate the feasibility of CO_2 sequestration in deep, unmineable coalseams using enhanced coalbed methane (ECBM) recovery technology. The Coal-Seq project is achieving its objectives via reservoir simulation studies of existing ECBM pilot projects in the San Juan basin, laboratory modeling studies of coal behavior, technical and economic sensitivity studies, and assessments of the potential and economic performance for ECBM recovery and CO_2 sequestration in deep, unmineable coals.

Since its inception, and now in its final year, many important findings have emerged from the project, some of the more notable being:

- CO_2 injection into coal can significantly improve methane recovery. At the Allison Unit CO_2-ECBM pilot in the San Juan basin, methane recovery was improved from 77% to 95% of original gas in place within the central pilot area.

- Coal permeability and CO_2 injectivity was substantially reduced with CO_2 injection (by up to an order of magnitude near the wells, and extending to an estimated 1,000 ft from the wellbores). This has a detrimental effect to ECBM/sequestration economics.

- While existing reservoir simulation models yield essentially similar results, the theoretical models they are based upon for multi-component sorption, diffusion and phase behavior may not accurately replicate actual reservoir behavior. Specifically, coal swelling cannot be adequately modeled in a dynamic fashion.

- N_2-ECBM appears more economically favorable than CO_2-ECBM. However, from a carbon sequestration perspective, a gas comprising of mostly CO_2 appears the most favorable.

- A technical/economic sensitivity has shed light on the most favorable coal conditions for sequestration. These include deep, high-rank coals with low permeability and that have not been previously developed for conventional coalbed methane production. However, this assumes technology is developed to overcome reduced injectivity due to matrix swelling.

- An assessment of CO_2-ECBM/sequestration potential in the U.S. suggests a potential resource of 150 Tcf of gas and a sequestration capacity of 90 Gt of CO_2 exists.

Introduction

In October 2000, a multi-year government-industry R&D collaboration known as the Coal-Seq project was launched in the United States. Participants in the project include the U.S. Department of Energy (DOE) as the project sponsor, Advanced Resources International (ARI), Burlington Resources, and BP America. The project objectives are to evaluate the feasibility of CO_2 sequestration in deep, unmineable coalseams using enhanced coalbed methane (ECBM) recovery technology. The Coal-Seq project is achieving its objectives via reservoir simulation studies of existing ECBM pilot projects in the San Juan basin, laboratory/modeling studies of coal behavior, technical and economic sensitivity studies, and assessments of the potential and economic performance for ECBM recovery and CO_2 sequestration in deep, unmineable coals. This paper presents the work performed and key findings from this important R&D project.

Project Activities and Major Findings

Allison Unit CO_2-ECBM Pilot

The Allison Unit CO_2 ECBM pilot in the San Juan Basin, operated by Burlington Resources, is the largest and longest running project of its kind, with four injector wells, 16 producers, and 6-years of injection history during which 370,000 tons of CO_2 was injected. A detailed reservoir study of the pilot, which included performing a full-field characterization, simulation history-matching, and performance forecasting, indicated that CO_2 injection improved methane recovery in the affected area from 77% to 95% of the original gas in place[1] (Figure 1). An economic analysis of the pilot indicated that it would have provided a positive net present value at gas prices above $2.60/Mcf, not including the impact of Section 29 tax credits. Thus the outlook for value-adding carbon sequestration in coal is promising with today's energy prices.

Coal Permeability Reduction with CO_2 Injection

During CO_2 injection at the Allison Unit, a reduction in injectivity of about 60% was initially observed (Figure 2)[2]. This was the first documented field evidence confirming the phenomena of coal swelling and permeability reduction with CO_2 injection, as long predicted by industry experts. Studies of this behavior, including well testing, indicated that the coal permeability near the well was reduced by up to two orders-of-magnitude, but that the effects gradually became less severe further from the well, and affected the coal a maximum distance of about 1,000 feet from the well. This profile of permeability decline is consistent with a 60% reduction in injectivity. What was unexpected was the rebound in injectivity following the initial decline. Further analysis concluded that this was caused by a continued decrease in overall reservoir pressure with time (methane production volumes from the reservoir were considerably greater than CO_2 injection volumes into it), which enabled the adsorbed CO_2 near the well to desorb and migrate further into the reservoir, causing matrix shrinkage and a permeability increase, similar to that observed during primary methane depletion. An assessment of the performance of the pilot had injection rates been much higher (i.e., no reduced permeability or an effective strategy to mitigate it) was performed and suggested a significant improvement in economics would have resulted. Thus finding a solution to this problem should be a priority R&D topic for the future.

Modeling Reservoir Mechanics

Through the course of simulating the results of the Allison Unit and another, N_2-ECBM pilot in the San Juan Basin (the Tiffany Unit, operated by BP America)[3], it was discovered that certain injection and production pressure behavior related to matrix shrinkage/swelling could not be satisfactorily replicated. Benchmarking of the simulator used for the study, ARI's COMET3, against other industry simulators on standardized sequestration/ECBM problems, as well as running the Allison/Tiffany models using another simulator, resulted in essentially similar results, and suggests a fundamental disconnect exists between the physics used in the simulators and actual reservoir behavior. Further study indicated that the theories used in the simulators are not accurate for modeling multi-component sorption, bi-directional diffusion, and CH_4-CO_2-N_2 gas properties. These findings are based upon actual laboratory studies. Upgrading this capability should be a priority research topic for carbon sequestration in coals, for the lack of reliable predictive models will present a considerable barrier to technology adoption.

Benefits of Nitrogen

Based on the results of the Tiffany Unit N_2-ECBM reservoir modeling study, the potential benefits of retaining some N_2 in a flue gas stream for sequestration purposes were indicated – N_2 is a very effective ECBM injectant, providing a much more rapid ECBM response than CO_2. While the breakeven gas price for Tiffany was slightly less than that for Allison (~$2.40/Mcf), not including the benefits of Section 29 tax credits, the upside with today's gas prices was much greater. Thus one can easily envision how the inclusion of some N_2 in a flue gas stream for sequestration would improve overall sequestration economics.

Sensitivity Study

To examine the impact of flue gas composition, as well as other reservoir and operating parameter, on technical and economic performance of ECBM/sequestration projects, a screening model was developed[4]. A sensitivity study was then performed using it to evaluate the impact of various parameters on project performance[5]. That study indicated that deeper, higher rank and lower permeability coals, that have not been previously developed for conventional coalbed methane production previously (i.e., a large gas resource can be recovered to offset sequestration costs), are the best economic environments for CO_2 sequestration. However, this assumes that technology is developed to overcome or otherwise mitigate the detrimental effects of coal swelling and injectivity reduction. It was also noted that in most cases, near-pure CO_2 provides the best economic results. This is due to additional capital costs related to N_2 separation and recycling, and lesser net sequestration volumes (due to lesser CO_2 injection volumes as well as additional carbon emissions associated with nitrogen generation and handling). However, in the lowest permeability and highest rank coal environments, the inclusion of more N_2 appears very promising.

CO_2-Sequestration/Capacity Assessment

A national assessment of the U.S. sequestration capacity in coals, as well as associated incremental ECBM recovery was performed[6]. That assessment, which evaluated 17 basins/regions in the U.S., estimated that the CO_2 sequestration capacity is about 90 Gt. Between 25 and 30 Gt of CO_2 can be sequestered at a profit, and 80 – 85 Gt can be sequestered at costs of less than $5/ton. The ECBM recovery potential associated with this sequestration is estimated to be over 150 Tcf. Several Rocky Mountain basins, including the San Juan, Raton, Powder River and Uinta appear to hold the most favorable conditions for sequestration economics. The Gulf Coast and the Central Appalachian basin also appear to hold promise as economic sequestration targets, depending upon gas prices. In general, and similar to the results of the sensitivity study, the "greenfield" areas (those areas that are not expected to produce primary coalbed methane commercially) appear more favorable for sequestration economics than the "brownfield" areas. This is because there is more in-place methane to recover in these settings.

Conclusions

Some of the main conclusions drawn from the project to-date include:

- CO_2 injection into coal can significantly improve methane recovery. At the Allison Unit CO_2-ECBM pilot in the San Juan basin, methane recovery was improved from 77% to 95% of original gas in place within the central pilot area.

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References

1. Reeves, S. R., Taillefert, A., Pekot, L., and Clarkson, C.; "The Allison Unit CO_2-ECBM Pilot: A Reservoir Modeling Study", for period January 1, 2000 – June 30, 2002, Topical Report submitted to U.S. Department of Energy, February, 2003.

2. Pekot, L. J., Reeves, S. R., "Modeling Coal Matrix Shrinkage and Differential Swelling with CO_2 Injection for Enhanced Coalbed Methane Recovery and Carbon Sequestration Applications", for period April 1, 2001 – March 31, 2002, Topical Report submitted to U. S. Department of Energy, November, 2002.

3. Reeves, S. R., Oudinot, A. Y., Erickson, D.; "The Tiffany Unit N_2 – ECBM Pilot: A Reservoir Modeling Study", for period January 1, 2000 – March 31, 2004, submitted to the Department of Energy, June, 2004.

4. Davis, D. W., Oudinot, A. Y., Sultana, A., and Reeves, S. R.; "Coal-Seq V2.1: A Screening Model for ECBM Recovery and CO_2 Sequestration in Coal", for period October 1, 2003 – April 15, 2004, submitted to the U. S. Department of Energy, April, 2004.

5. Reeves, S. R., Davis, D. W., and Oudinot, A. Y.; "A Technical and Economic Sensitivity Study of Enhanced Coalbed Methane Recovery and Carbon Sequestration in Coal", for period January 1, 2004 – March 31, 2004, submitted to the U. S. Department of Energy, April, 2004.

6. Reeves, S. R.; "Assessment of CO_2 Sequestration and ECBM Potential of U. S. Coalbeds", for period October 1, 2002 – March 31, 2003, submitted to the U. S. Department of Energy, February, 2003.

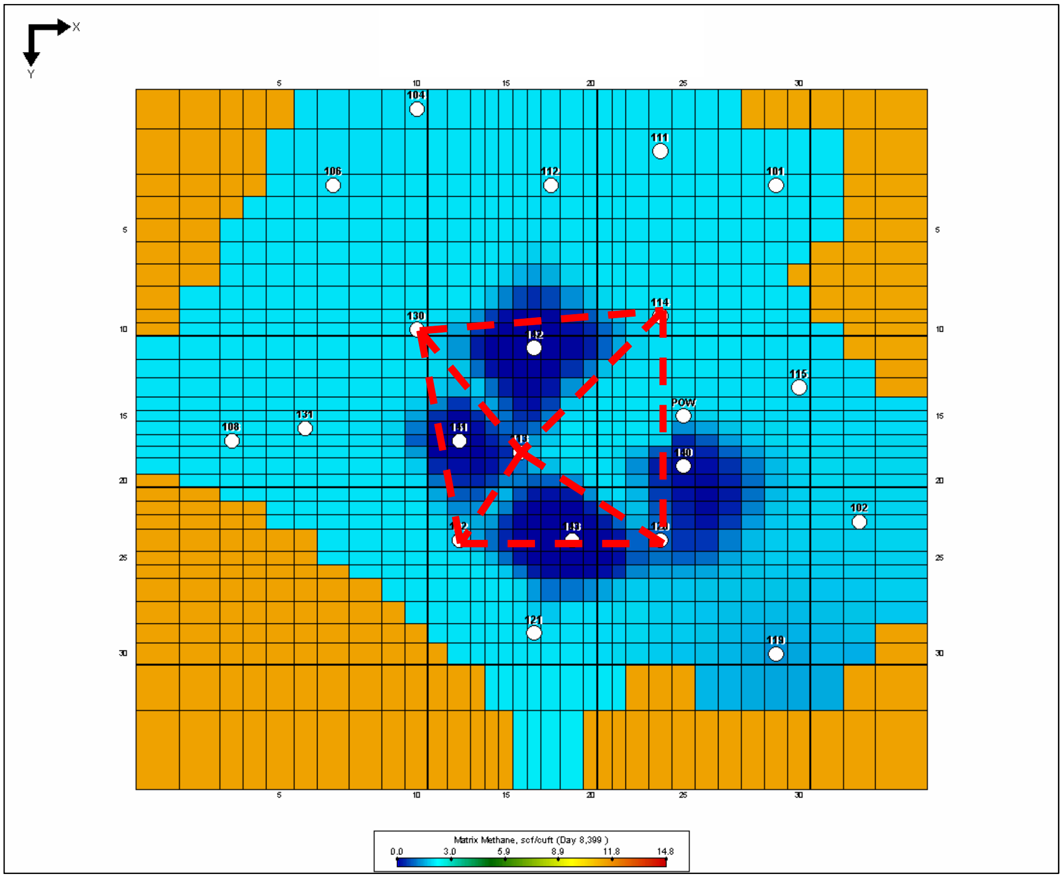

Figure 1: Coal Methane Content Following CO_2 Injection, Allison Unit

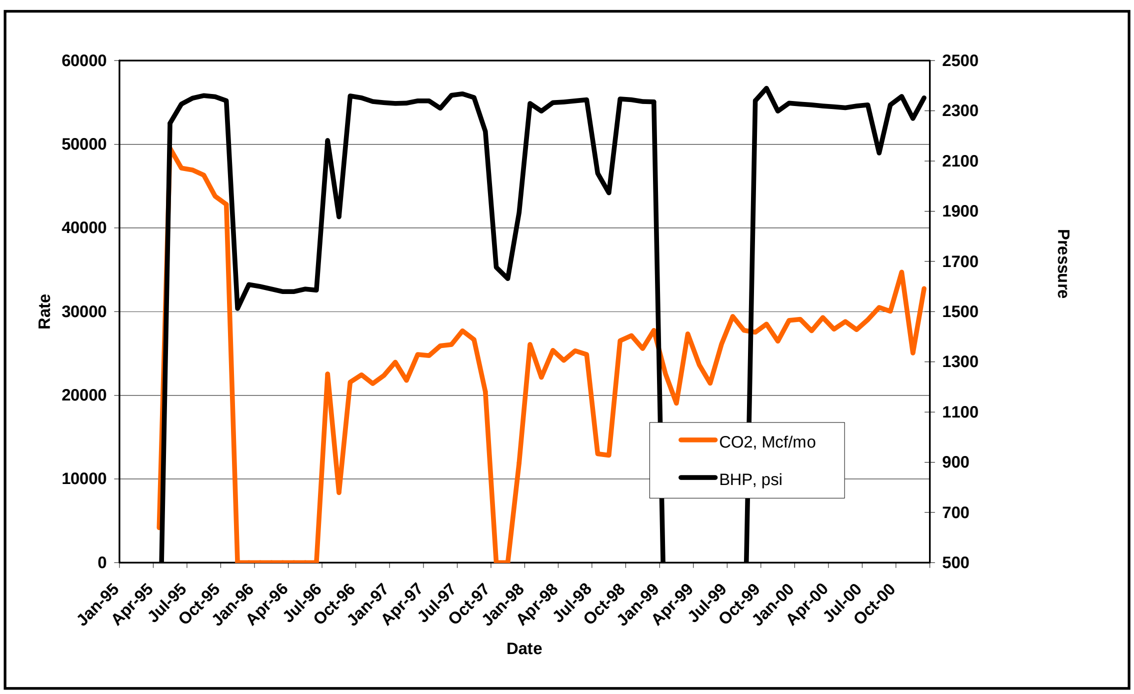

Figure 2: Injectivity Decline in a CO_2 Injector Well, Allison Unit