Identification of Favorable Reservoir Properties for CO_2 Sequestration and Enhanced Coabed Methane Production in the Illinois Basin

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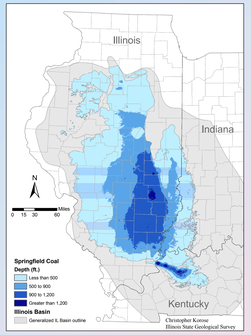
ABSTRACT

This parametric study examines the effects of varying coal seam properties of coalbed methane (CBM) reservoirs using a CBM reservoir simulator. The Illinois Basin was partitioned into three characteristic depth intervals (500-900 ft, 900-1200 ft, >1200 ft), to which parameter distributions were determined in each respective depth division. The distributions of coal properties were developed for the Illinois Basin from extensive databases compiled over decades by the Illinois, Indiana, and Kentucky State Geological Surveys. The coal properties examined in the parametric study included compressibility, depth, gas concentration, Langmuir volumes and pressures for CH_4, permeability, initial pressure, temperature, thickness, porosity, cleat spacing, and relative permeability.

Through CBM reservoir simulation of enhanced CBM (ECBM), recovery and CO_2 storage factors were estimated at various conditions that include the CO_2 fraction in production gas streams and breakthrough of CO_2 at gas producing wells. The results of reservoir simulations using the distributions of petrophysical and reservoir properties are applicable on a basin-wide scale as indicators of performance for CBM and ECBM production and CO_2 storage. Results from this parametric study will be used to screen and prioritize laboratory experiments, locations for CO_2 sequestration, and ECBM developments.

As production data becomes available, history matching field data from the Hon #9 CBM test well in northeastern White County, Illinois with the CBM simulator provides the opportunity to compare field data to simulator results from the statistical distribution of parameters.

Parametric Study Depth Divisions Applied to the Spatial Distribution of a Coal Seam



Depth divisions were selected on the following criteria:

<500 ft: CBM target in only selected localities (not considered here). No sequestration at these shallow depths.

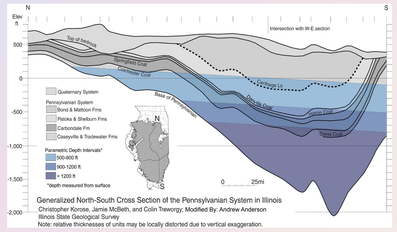
500-900 ft: CBM and ECBM target for target seams with thicknesses between 1.5* and 3.5** ft. No sequestration at this time.

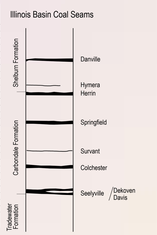
900-1200 ft: Sequestration target. No sequestration in mineable coals exceeding 3.5 ft.

> 1200: Sequestration target in seams greater than 1.5* ft. (Assumes coals to be unmineable at these depths.)

*1.5 ft: minimum thickness for identification, perforations, and producing a coal seam.
**3.5 ft: minimum mineable thickness by coal equipment.

Superposition of Depth Intervals on a N-S X-section of the Illinois Basin





*coal seams are denoted by black solid lines. Seams are contained in large gray stratigraphic units

General stratigraphic position of the major coals in the Illinois Basin studied by the MGSC. Coals are shown in order of geologic age (youngest seam at top). Formal nomenclature is from Jacobson et al. 1985.

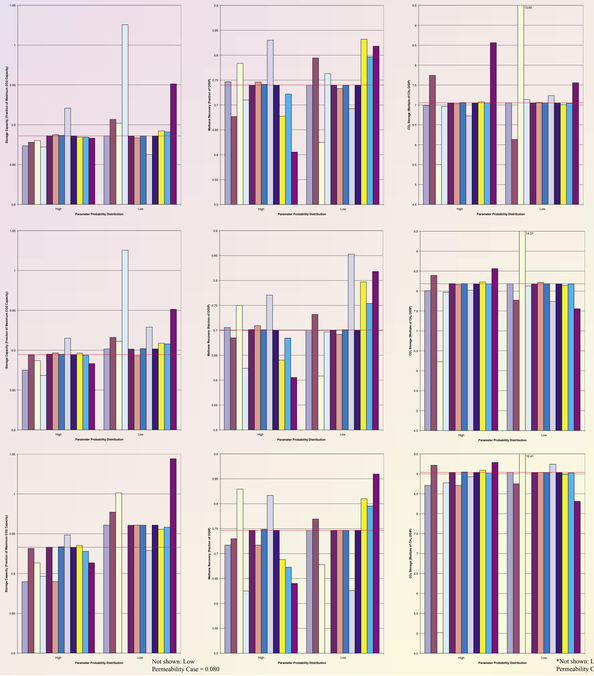
Parametric Study: ECBM and CO_2 Sequestration Capacity

Performance Indicators: Storage Factor (G_s + PV) | Recovery Factor | Storage Factor (OGIP)

Depth Interval 500 - 900 ft

Depth Interval 900-1200 ft

Depth Interval >1200 ft



Performance Indicators shown are calculated at 50% CO_2 cut in the production gas stream and represent a continous CO_2 injection scenario.

Recovery Factor: fraction of Original Gas (methane) In-Place (OGIP) produced from the reservoir.

$$RF = \frac{G_{p(CH_4)}}{OGIP_{(CH_4)}}$$

Storage Factor (OGIP): volume of CO_2 sequestered expressed as a multiple of methane OGIP.

$$SF_2 = \frac{G_{inj(CO_2)} - G_{p(CO_2)}}{OGIP_{(CH_4)}}$$

Storage Factor (G_s + PV): volume of CO_2 sequestered. This is expressed as a fraction of CO_2 stored to the total storage capacity of the matrix. If the matrix is saturated and free phase CO_2 present in the cleats then this term will be greater than 1.

$$SF = \frac{G_{inj(CO_2)} - G_{p(CO_2)}}{Ah(1-\phi)G_{s(CO_2)}}$$

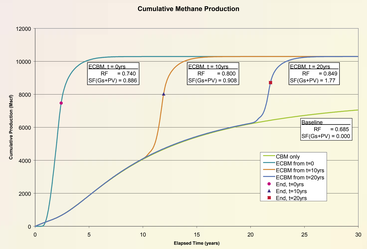
Example Desorption Isotherms

Summary Table of Performance Indicators

		Greatest Changer		
Depth Interval	Effect	RF	SF(OGIP)	SF(Gs+PV)
500-900 ft	Positive Negative	VL Rel Perm	Rel Perm Depth	Perm Porosity
900-1200 ft	Positive Negative	Porosity Rel Perm	Rel Perm Rel Perm	Perm Perm
>1200 ft	Positive Negative	Rel Perm Perm	Rel Perm Perm	Rel Perm Perm

* SF(OGIP) is dominated by changing the Initial Gas concentration (G_{con}). G_{con} is not included in the summary table. More CO_2 is not sequestered by coal volume, but a large result is observed from the ratio of the sequestered volume to OGIP for highly undersaturated coals (with respect to method).

Effect of Injection Time on Performance Indicators



By delaying initiation of ECBM a greater total RF and SF is achieved.

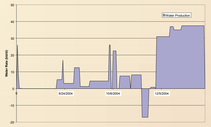
The cumulative production plots show the effect of ECBM initiation time on recovery and storage factors. Injection is continuous once initiated. The parameters used in each scenario are from the 900-1200 ft base case (i.e. typical values).

The points labeled 'End, t=' indicate when CO_2 cut in the production stream is 50 percent.

Modeling of ECBM Pilot: History Match

Hon #9 Injection-Falloff Testing Results

Well Name/ Interval	Perforation Depth (ft)	Calculated Permeability (md)	Calculated Avg Reservoir Pressure (psi)	Test Radius of Investigation (ft)	Skin Factor
Test 1 (5' net)	1109-16	14.1	496 (0.45 psi/ft)	440	-0.3
Test 2 (2' net)	1068-69	5.2	516 (0.48 psi/ft)	120	-3.4
Test 3 (4' net)	996-1000	3.3	440 (0.44 psi/ft)	189	-4.9
Test 4 (6' net)	884-886	21.7	681 (0.77 psi/ft)	497	-1.8
Test 5 (5' net)	809-810	4.3	510 (0.63 psi/ft)	219	-4.9



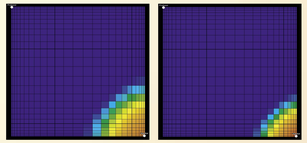
History matching of the Hon #9 ECBM pilot provides field data for model validation and a tool for predicting production rates, effectiveness of well stimulations, and the design of field tests.

The pressure transient tests in conjunction with coal seam and reservoir properties are used to match the water production rates seen in the adjacent figure to make an accurate history match.

Propagation of CO_2 Through ¼, 5-spot Parametric Study Model with Hybrid Grid; 2 Permeabiltiy Cases

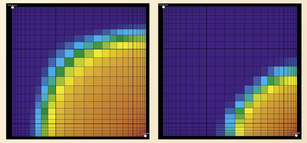
Permeability = 50 md | Permeabilty = 15 md

Elapsed Time 0.21 years



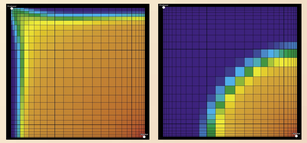
RF: 0 (DW), SF: 0.141, k: 50 md | RF: 0 (DW), SF: 0.052, k: 15 md

Elapsed Time: 0.82 years



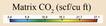
RF: 0.121, SF: 0.504, k: 50 md | RF: 0 (DW), SF: 0.188, k: 15 md

Elapsed Time: 1.51 years

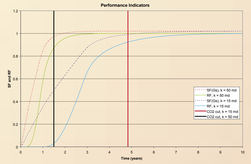


RF: 0.710, SF: 0.890, k: 50 md | RF: 0.029, SF: 0.330, k: 15 md

Matrix CO_2 (scf/cu ft)



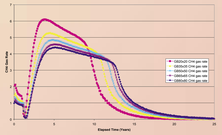
* DW = Dewatering (Period of water production that proceeds methane production when pressure exceeds the saturation pressure)



The CO_2 injection well is located in the lower right corner. The producing well is located in the upper left corner.

For the 50 md case, at 1.51 years CO_2 breaks through at the producer. This time is indicated on the above graph with a vertical black line. The blue to orange gradient shows the sweep efficiency (area contacted by CO_2) of the CO_2 displacing in-place methane. Thus, navy grid cells represent reservoir areas not contacted by CO_2 before breakthrough and in this example show a recovery factor (RF) of 0.71 for the 50 md case. The 15 md case has not had CO_2 breakthrough, which will occur at 4.83 years (not shown).

Gridblock Sensitivity



CONCLUSION

From analysis of the parametric study results the parameters with the greatest effect on the calculated performance indicators are permeability and relative permeability. The effect of initial gas concentration on SF(OGIP) is ignored as it is a reflection of the calculation method and not on the sequestered volume. Changing the initialization time of ECBM after primary depletion has an effect on total RF and SF. In a scenario with continuous injection, as modeled in this study, delaying the start of ECBM increases total methane recovery factor and CO_2 storage factor. The parameter distributions used in the parametric study are composed of the distribution of coal and reservoir properties in the Illinois Basin and thus the results of this study are widely applicable. The Hon #9 well provides an opportunity to validate the model with field data of a CBM well with multiple perforated coal seams, onsite measurement of coal and reservoir properties, and production history. Future modeling will focus on projecting production rates and designing effective well tests.

References:
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