Probabilistic Risk Assessment of CO_2 Sequestration in the Farnsworth EOR Field

Feng Pan[1,2], Brian J. McPherson[1,2], Zhenxue Dai[3], Wei Jia[1,2], Si-Yong Lee[4]

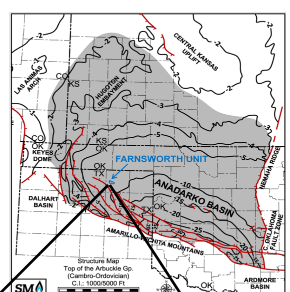
[1]Energy & Geoscience Institute, The University of Utah; [2]Department of Civil & Environmental Engineering, The University of Utah; [3]Earth and Environmental Sciences Division, Los Alamos National Laboratory; [4]Schlumberger Carbon Service

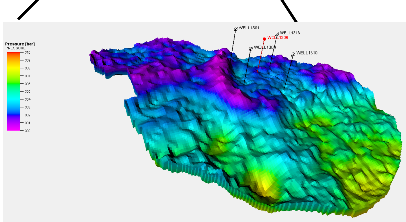
Problems and Objectives

- Injection of CO_2 for enhanced oil recovery (EOR) is a proven technique for improving production from reservoirs considered "depleted" following water-flooding. Thus, "CO_2-EOR" is perhaps the most feasible option for geologic CO_2 sequestration;
- For a commercial-scale CO_2-EOR field, potential risks associated with CO_2 injection include pressure buildup, formation damage, induced seismicity, and possible leakage to overlying drinking water aquifer;
- The objective of this study is to quantify risks and associated uncertainties of CO_2 storage and oil recovery, especially forecasted uncertainty propagated from parameter uncertainty at a commercial-scale CO_2-EOR field.

Farnsworth EOR Field

- The Farnsworth Unit (FWU) CO_2-EOR site operated by Chaparral Energy LLC was selected as a case study, which is an existing CO_2-EOR project under the auspices of Phase III of the Southwest Regional Partnership on Carbon Sequestration (SWP).
- Chaparral began CO_2 injection in December 2010. A total of 1 million metric tons of CO_2 is slated for injection into the Upper Morrow formation of FWU over 5 years.
- The Upper Morrow formation mainly consists of incised valley-fill sandstones that extend from Colorado to Texas;
- The Morrow formation of FWU has an average depth of 7,750 feet ranging from 7,550 to 7,950 ft with an average dip of less than one degree.

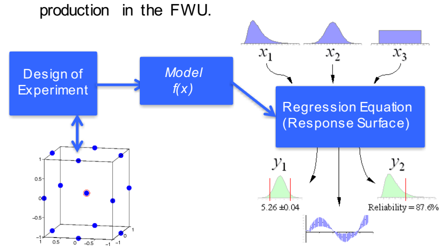




Location of Farnsworth Unit within the Anadarko Basin (top, modified from Mitchell, 2012) and Farnsworth EOR unit model domain (bottom).

Methodology

- A response surface methodology (RSM) integrated with Monte Carlo sampling was employed to quantify the uncertainties of CO_2 storage associated with oil production in the FWU.



Workflow chart of the response surface methodology.

Uncertain independent variables assigned in the design of numerical experiment.

	Independent variables (Xi)	Low (-1)	Mid (0)	High (+1)	Statistical distribution
X1	Permeability (mD)	0.33	11.07	374.97	Log-normal
X2	Anisotropy ratio (K_v/K_h)	0.1	0.55	1.0	Uniform
X3	WAG time ratio (CO_2 injection time/water injecation time)	1.0	1.5	2.0	Uniform
X4	Initial oil saturation	0.19	0.28	0.37	Uniform

Farnsworth 3-D Reservoir Model

- ✓ The 3-D reservoir model for the western half of FWU was constructed with a total of 202,120 cells (163*155*8) with the cell size of 100*100 ft in horizontal direction.
- ✓ One five-well pattern was placed in the western half of the model domain for the reservoir simulations.
- ✓ A total of 6 years was simulated with the 5-year water-alternating-CO_2 injection and 1-year monitoring and recovery.
- ✓ A total of 25 runs of 3-D reservoir simulations were conducted using the Eclipse E300 simulator, based on the numerical experimental design.

Response Surface Model

- A second-degree polynomial approximation is used for the response surface models to develop the relationship between a response (y) and associated independent variables (x_i):

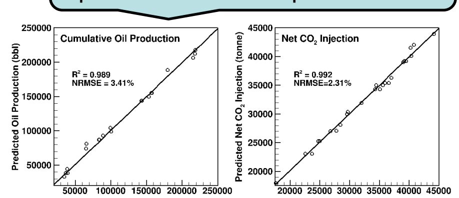
$$y = \beta_0 + \sum_{i=1}^{k}\beta_i X_i + \sum_{\substack{i=1,j=2\\ i<j}}^{k}\beta_{ij} X_i X_j + \sum_{i=1}^{k}\beta_{ii} X_i^2 + \varepsilon$$

- The least square method is used to estimate the β_i:

$$\hat{\beta} = (X'X)^{-1}X'y$$

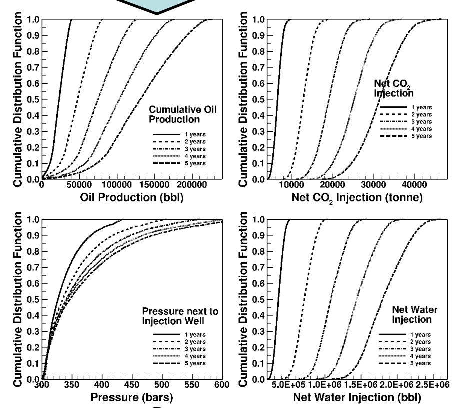
Risk Assessment Results

The results of goodness-of-fit measures (R^2 and NRMSE) indicates the high accuracy of the response surface models for prediction.



Simulated (using reservoir model, dot) and predicted (using response surface models, line) cumulative oil production and net CO_2 injection after 5 years of simulations.

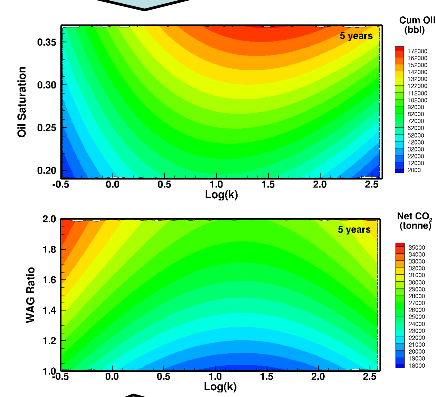
Uncertainties of output variables increase over time and the significant uncertainties are propagated from the parameter uncertainties.



Pressure next to the injection well shows increased mean predictions and uncertainties over 5 years.

The cumulative distribution functions (CDFs) of output variables.

When permeability ranges from 10 to 31.6 mD (close to the mean value), maximum oil production amount is achieved.



The effects of permeability on net CO_2 injection is opposite to that on cumulative oil production.

The response surface of output variables in relation to uncertain input parameters after 5 years of simulations.

Take-Away Lessons

- ✓ Uncertainty specific to oil production is relatively larger than the uncertainty of net CO_2 injection according to the RSM results.
- ✓ The developed RSM approach can be effectively applied to risk assessment of CO_2 storage, providing a probabilistic framework for commercial-scale CO_2-EOR fields.

Acknowledgments

U.S. DEPARTMENT OF ENERGY
NETL