A Simulation Study of Simultaneous Acid Gas EOR and CO_2 Storage at Apache's Zama F Pool

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Abstract

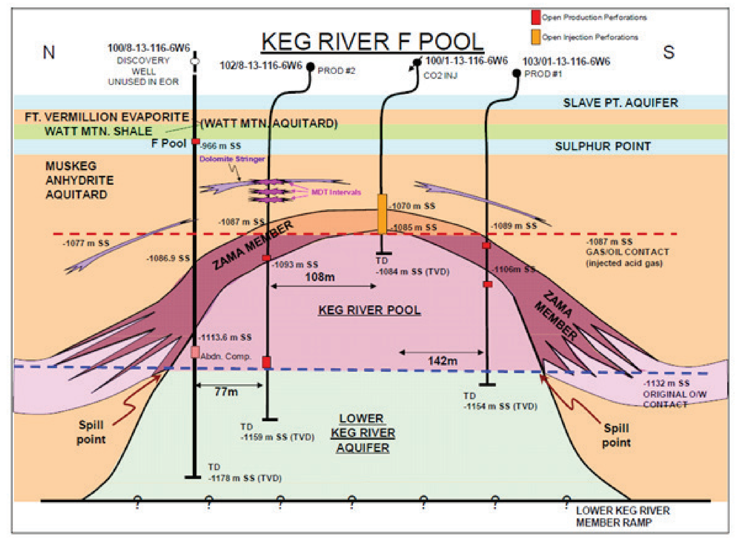
The Plains CO_2 Reduction (PCOR) Partnership, led by the Energy & Environmental Research Center, is working with Apache Canada Ltd. to validate the stored volumes of CO_2 in the F pool of the Zama oil field in northwestern Alberta, Canada. Since December 2006, acid gas (70% carbon dioxide [CO_2] + 30% hydrogen sulfide [H_2S]), captured at a nearby gas-processing plant, has been injected for simultaneous enhanced oil recovery (EOR) and CO_2 storage purposes.

To aid in the monitoring, verification, and accounting program, a detailed static geologic model of this heterogeneous pinnacle reef carbonate reservoir was constructed. A combination of object modeling and multiple-point statistics (MPS) workflow was used for spatial distribution of different properties extracted from available borehole image logs and other well log data.

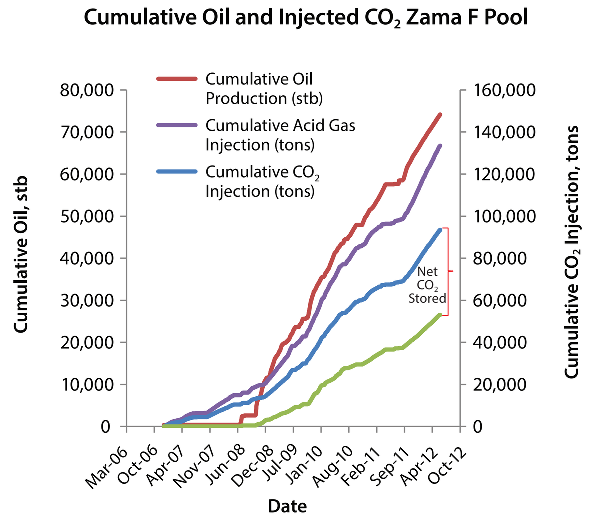
One of the equiprobable static realizations was chosen for performing history matching for model validation. The history-matching results were then used for further conditioning of a static geologic model that includes better representation of underlying aquifer and internal reservoir microfacies. The history-matching results indicate a residual oil saturation ranging from 40% to 60% in regions with good permeability. These areas will be targeted while evaluating the future incremental oil recovery potential for this reservoir.

The reef structure below the oil–water contact (OWC) was also modeled to explore the possibility of additional storage capacity gain in the underlying aquifer. With over 700 pinnacle reef structures in the Zama subbasin, a careful selection of pinnacle structures similar to the F Pool may provide significant storage capacity gain through water extraction.

Simultaneous CO_2 EOR and Storage

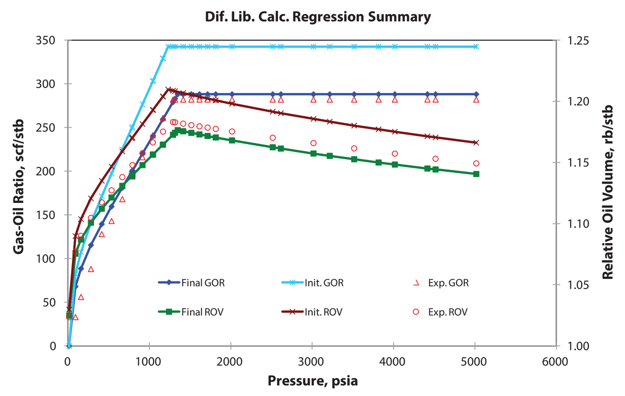


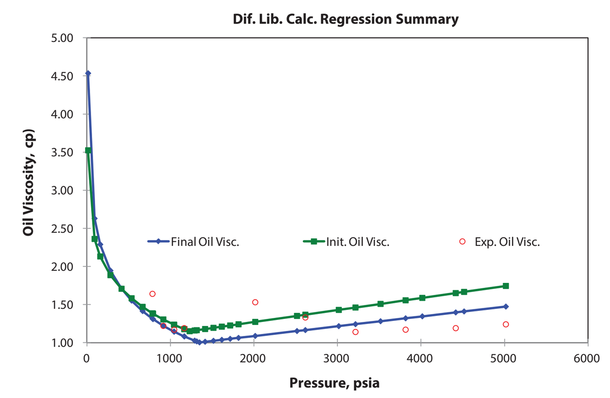
(Burke, 2009)



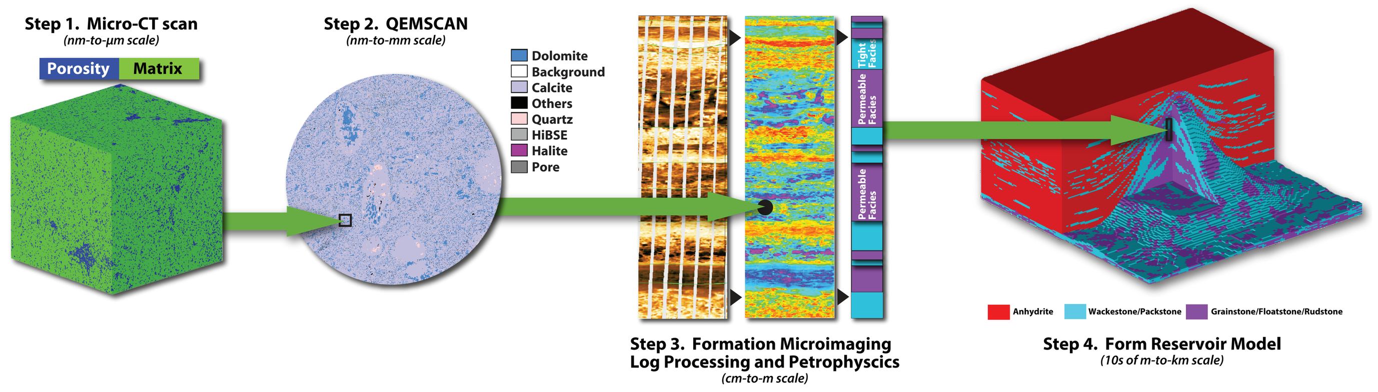
PVT (pressure, volume, and temperature) Modeling

- An 11-component Peng–Robinson equation of state (EOS) PVT model was developed to use in compositional simulation.
- Simulated minimum miscibility pressures (MMPs) were 4.1% higher and 5.5% lower than the measured values for pure CO_2 and acid gas (80% CO_2 + 20% H_2S) mixture, respectively.

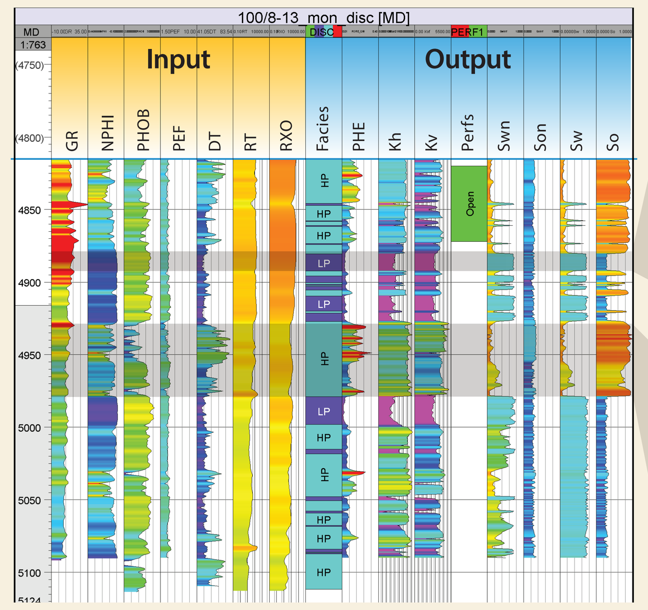


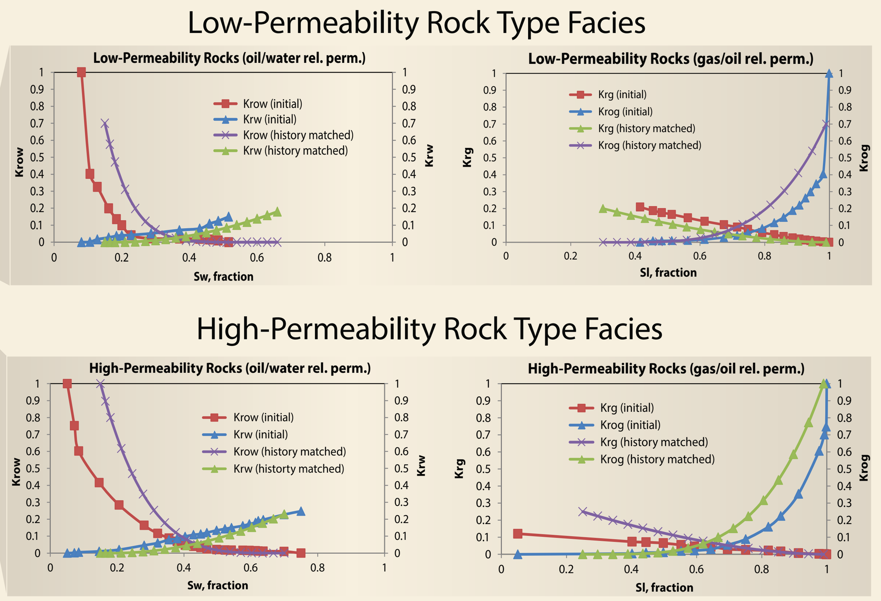


Static Modeling Workflow



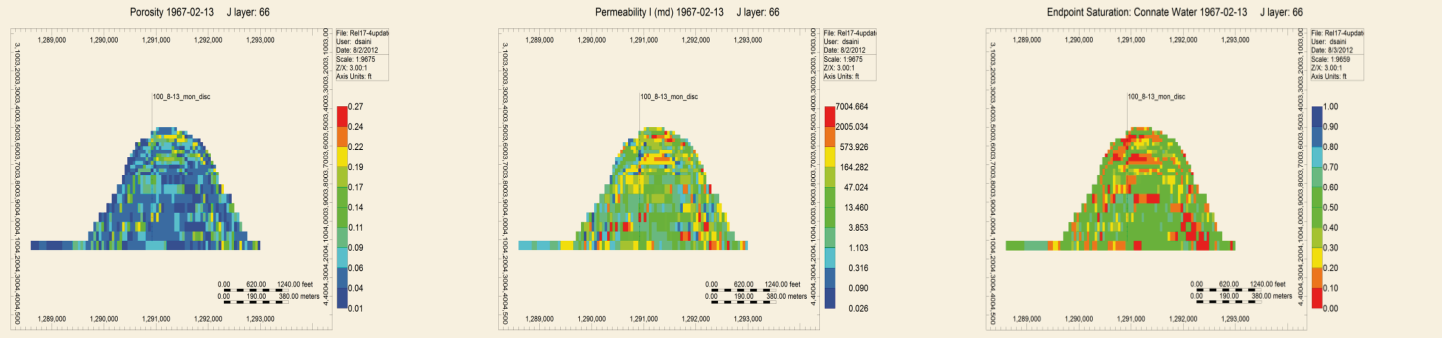
Petrophysics



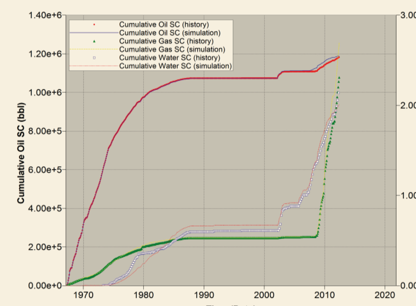


History Matching

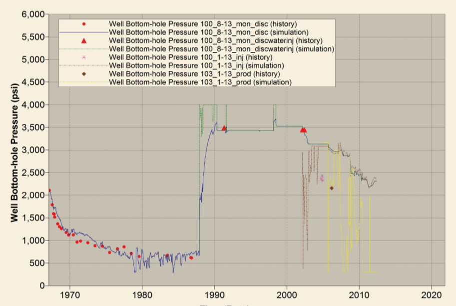
- History matching was performed with P10 OOIP (original oil in place) (4.3 MMstb) static model realization.
- A combination of object modeling and MPS workflow was used for spatial distribution of reef and nonreef facies in the static model.
- The adjusted parameters include vertical permeability, well productivity indices, and volume modifier for reef structure below the OWC, along with a numerical aquifer at the bottom of the structure.



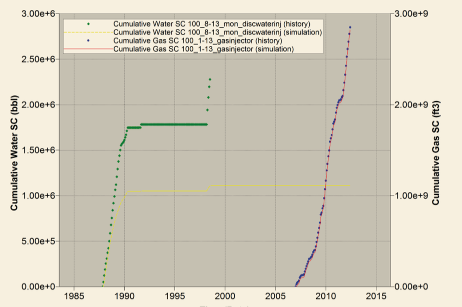
The Sequential Gaussian simulation algorithm was use to populate reservoir properties in the model.



History Match Results for Cumulative Oil, Water, and Gas Volumes



Actual and Simulated Well Bottom Hole Pressures (BHPs)

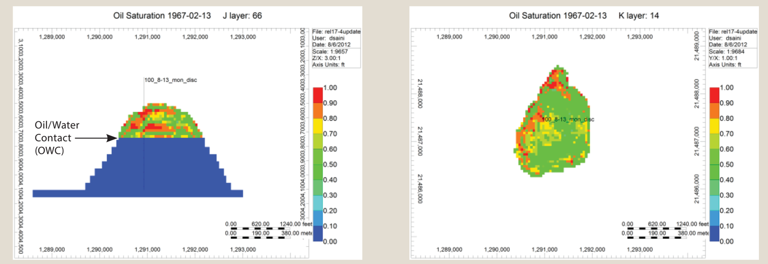


History Match Results for Cumulative Volumes of Injected Acid Gas and Water

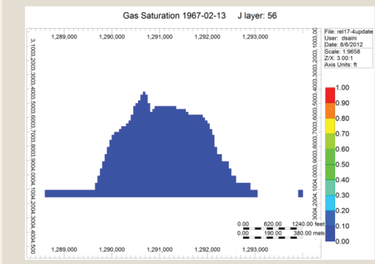
Predictive Simulation Results

Existing EOR Configuration (one gas injection and two production wells)

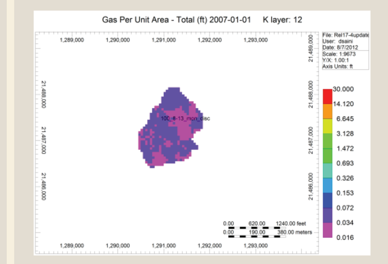
Two scenarios with minimum well BHP (bottom hole pressure) constraint of 300 and 2100 psi at production wells.



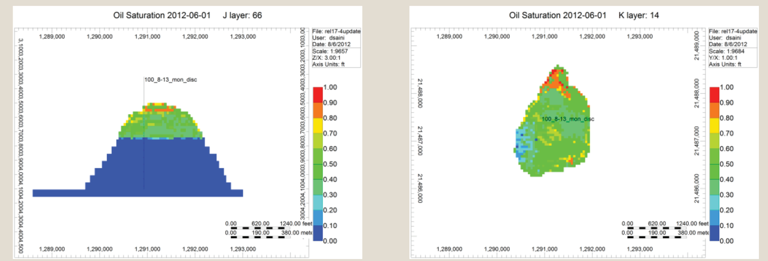
Initial Oil Saturation



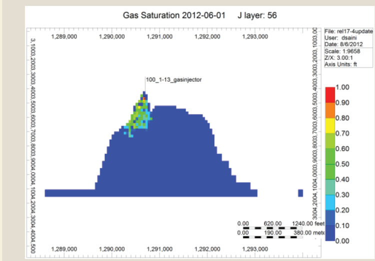
Initial Gas Saturation



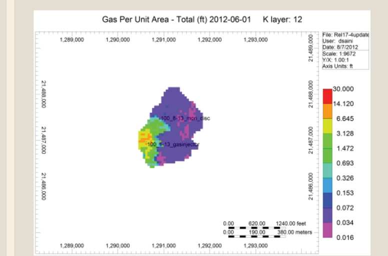
Total Gas per Unit Area (ft) at the Start of Gas Injection (Dec-2006)



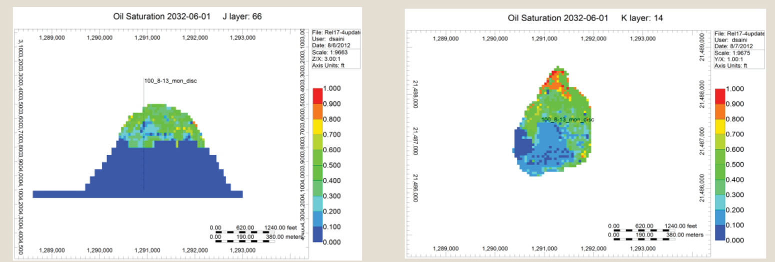
Oil Saturation at the End of History Match Period (2012-06-01)



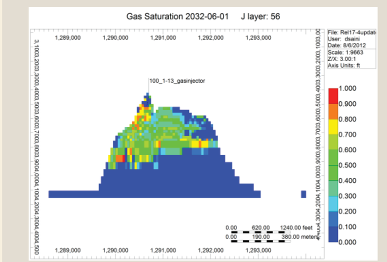
Gas Saturation at the End of History Match Period (2012-06-01)



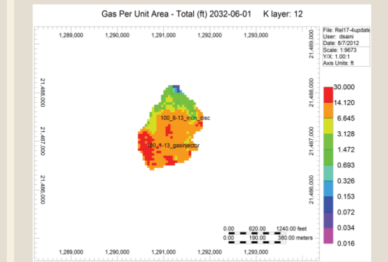
Total Gas Per Unit Area (ft) at the End of History Match Period (2012-06-01)



Oil Saturation (2032-06-01)[1]



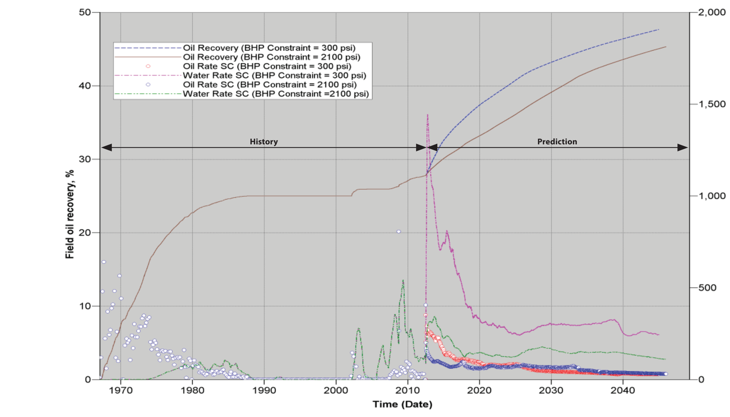
Gas Saturation (2032-06-01)[1]



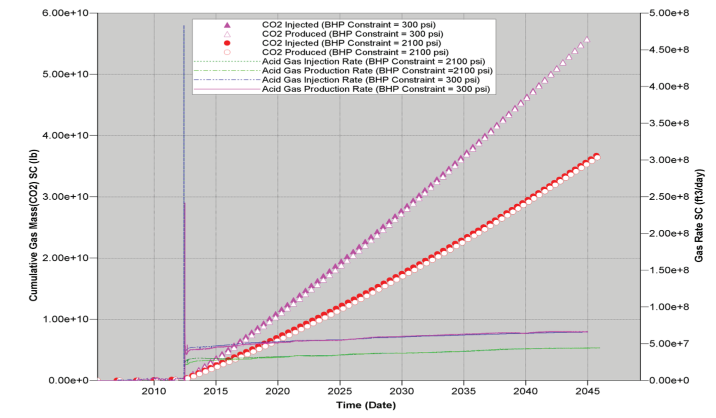
Total Gas per Unit Area (ft)[1]

[1]After 20 years of EOR operations, Minimum BHP constraint of 300 psi at production well.

Predictive Simulation Results (continued)



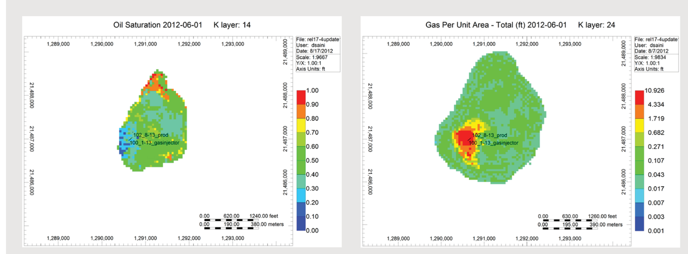
Predicted Oil Recovery, Field Oil, and Water Rates (existing EOR configuration)



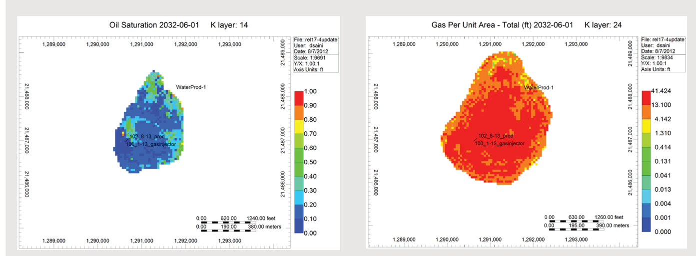
Amounts and Rates of Injected and Produced CO_2 (existing EOR configuration)

Additional CO_2 Storage Capacity Gain Through Water Extraction

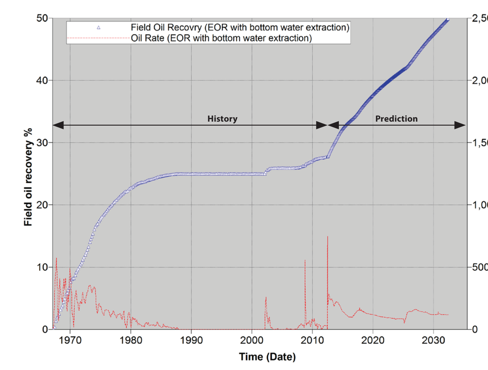
One water extraction well completed in bottom water zone with existing EOR configuration (one gas injection and two oil production wells).



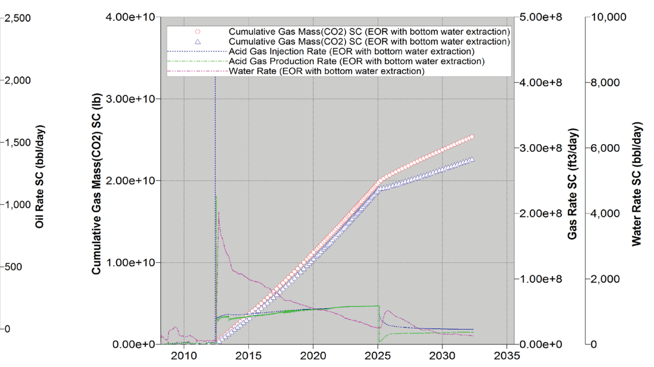
Oil Saturation and Total Gas per Unit Area (2012-06-01), EOR with Bottom Water Extraction



Oil Saturation and Total Gas per Unit Area (2032-06-01), EOR with Bottom Water Extraction



Predicted Oil Recovery, Field Oil, and Rate (existing EOR configuration with water extraction)



Amounts and Rates of Injected and Produced CO_2 (existing EOR configuration with water extraction)

Predictive Simultion Results (20 Years of EOR Operations)

Variable	Existing EOR Configuration		Existing EOR Configuration with Water Extraction From Water Zone Below OWC)
	Minimum BHP Constraint = 300 psi at Production Wells	Minimum BHP Constraint = 2100 psi at Production Wells	Minimum BHP Constraints of 300 psi and 2100 psi at Production Wells and Water Extaction Well, Respectively
Incremental Oil Recovery (%)	16.2	12.6	22.1
Injection/Production Duration, Years	20	20	20
Cumulative CO_2 Injeted, Million Tons	16.07	10.09	12.70
Cumulative CO_2 Produced, Million Tons	15.84	9.79	11.35
Net CO_2 Stored, Million Tons	0.24	0.30	1.35
Oil Produced, MMstb	0.70	0.55	0.95
Water Produced, MMstb	3.07	1.17	7.86

Summary

A detailed static geologic model was constructed using MPS algorithm and object-modeling workflow for performing compositional simulations (history matching and prediction) of simultaneous acid gas EOR and CO_2 storage in this complex oil-producing carbonate pinnacle reef structure.

Good agreement between historical data (cumulative production and gas injection volumes and pressure) and simulated results was obtained by reconditioning of both the static and dynamic models.

Predictive simulation results suggest that under the current EOR configuration, an ultimate recovery of 44% (16% incremental recovery) can be achieved in the next 20 years while storing 0.25 million tons of CO_2 in the reservoir.

A significant increase in the ultimate CO_2 storage capacity (from 0.25 million tons to 1.35 million tons, i.e., an increase of 540%) can be achieved in the next 20 years if a water extraction well away from existing oil producers and gas injection wells is used to extract water from the bottom aquifer. In controlled water extraction (minimum BHP constraints of 2100 psi at water injector and 300 psi at oil producers), incremental oil recovery of 21% was observed, which is 5% more compared to the case with no water extraction. These gains in oil recovery and CO_2 storage capacity may be attributed to attainment of better sweep by allowing injection gas movement to contact residual oil remaining in unswept regions of the reservoir.

With over 700 pinnacle reef structures in the Zama subbasin, similar studies will be conducted for several other oil-producing pinnacle reefs to evaluate their EOR and CO_2 storage capacity potential.

References

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3. Burke, L., 2009, PCOR Project Apache Zama F pool acid gas EOR & CO_2 storage: Report prepared by RPS Energy Canada for the Energy & Environmental Research Center, September.
4. Knudsen, D.J., Saini, D., Gorecki, C.D., Peck, W.D., Sorensen, J.A., Steadman, E.N., and Harju, J.A., 2012, Using multiple-point statistics for conditioning a Zama pinnacle reef facies model to production history: Poster presented at American Association of Petroleum Geologists Annual Conference and Exhibition, Long Beach, California, April.

Acknowlegments

The Authors thank the U.S. Department of Energy (DOE) for providing financial support for this study. Special thanks to Apache Canada Ltd. for providing the necessary data for geologic and reservoir modeling. Many thanks to Megan Grove and the EERC's Graphics and Editing staff for their help with poster preparation.

PCOR Partnership 2003 – Present