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

Dayanand Saini, Damion J. Knudsen, James A. Sorensen, Charles D. Gorecki, Edward N. Steadman, and John A. Harju
Energy & Environmental Research Center, University of North Dakota, Grand Forks, North Dakota

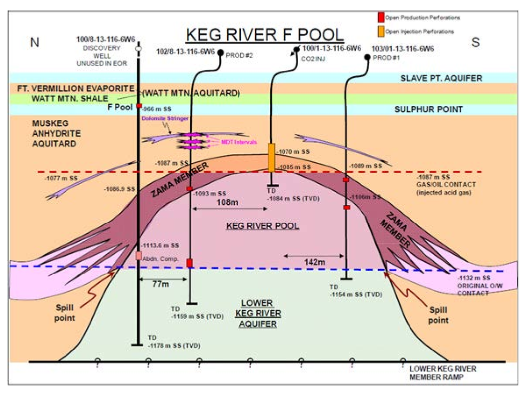
Abstract

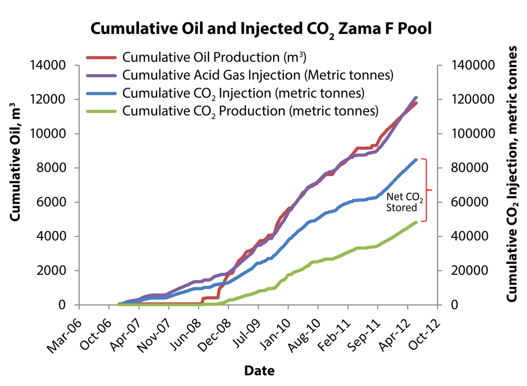
The Plains CO_2 Reduction (PCOR) Partnership is working with Apache Canada Ltd. (Apache) to validate the stored amount of CO_2 during ongoing enhanced oil recovery (EOR) operation at the F pool of the Zama oil field situated in northwestern Alberta, Canada. Apache is capturing CO_2 and H_2S from a nearby gas-processing plant and injecting this stream into the F pool for simultaneous EOR and CO_2 storage. Acid gas injection was initiated in December 2006 and is continuing to date. The present compositional flow simulation study aims to evaluate ways for maximizing incremental oil recovery and CO_2 storage capacity in this depleted and closed pinnacle reef structure.

Two different versions (Version 1 and Version 2) of a constructed static geologic model were used for performing dynamic simulations. In the first simulation scenario that used, the Version 1 static model, additional storage capacity gain by pressure management through water extraction (no oil production) from the water zone below the oil–water contact (OWC) was investigated. The results clearly indicate the viability of formation water extraction for increasing storage capacity in a closed geologic structure. The second iteration of the constructed static geologic model (Version 2) was chosen for simulating cases of continuing the current EOR scheme with and without a bottom water extraction well. A fivefold (0.30 million metric tonnes [MMt] to 1.22 MMt) increase in CO_2 storage capacity was observed with a bottom water extraction well compared to the case with no bottom water extraction well. This scheme also results in an incremental EOR recovery of 22.1% in the next 20 years, which is 5% more compared to the case of the existing EOR scheme (no bottom water extraction well).

With over 700 pinnacle reef structures (oil-bearing or water-bearing) in the Zama subbasin, a careful selection of pinnacle structures similar to the F pool may provide significant storage capacity gain through water extraction from the underlying water zone (aquifer) while achieving a significant increase in oil recovery.

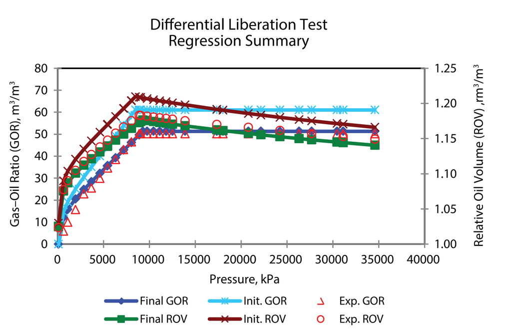
Simultaneous CO_2 EOR and Storage

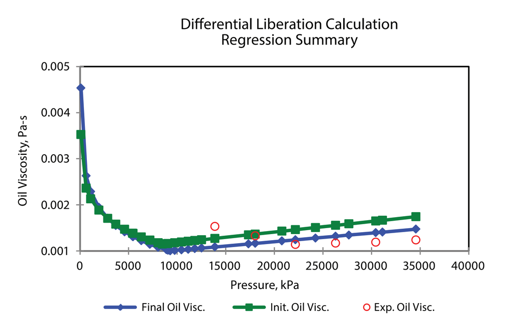




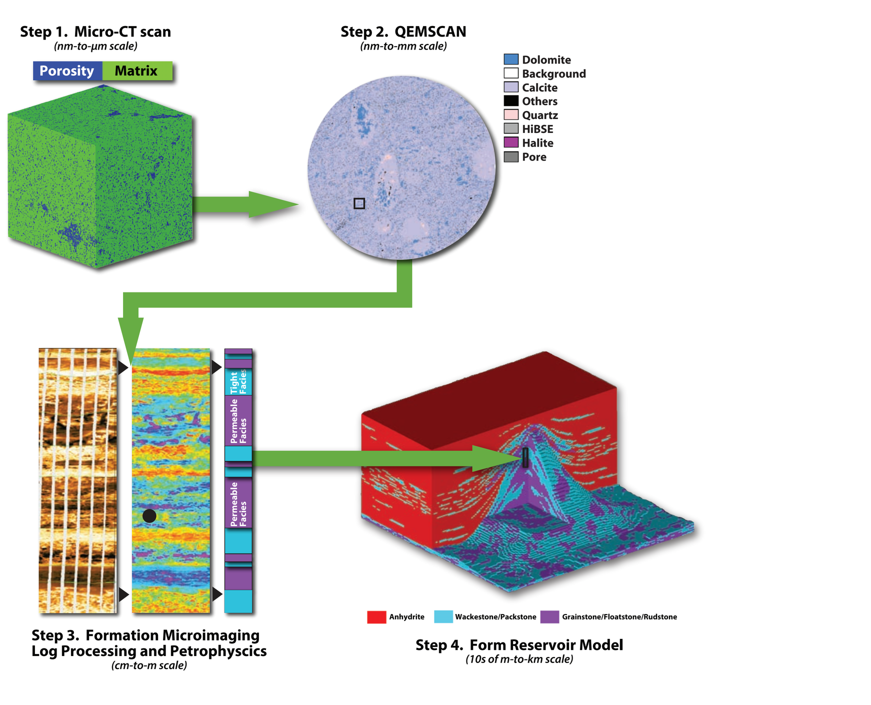
PVT (pressure, volume, and temperature) Modeling

- An 11-component Peng–Robinson equation of state (EOS) PVT model was developed to use in the 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



Acknowledgments

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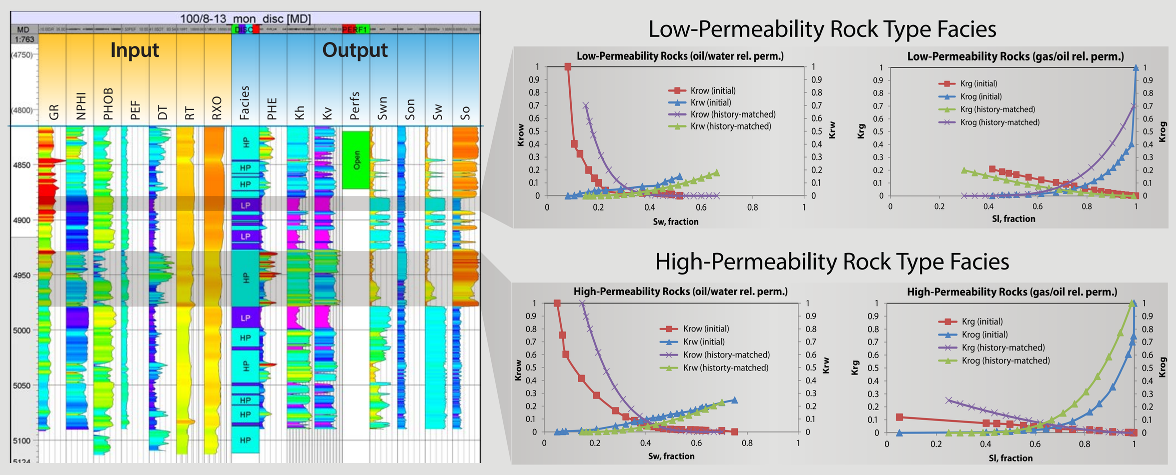
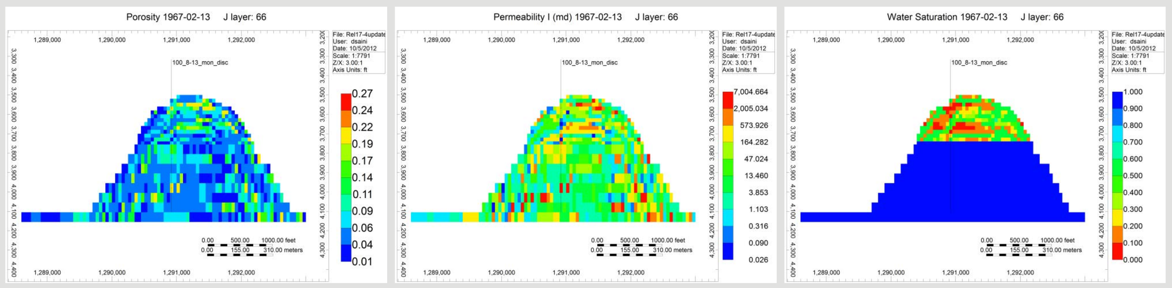
Petrophysics

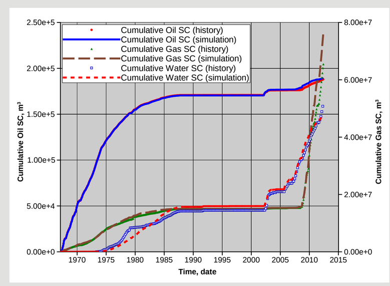


History Matching (Version 2 model)

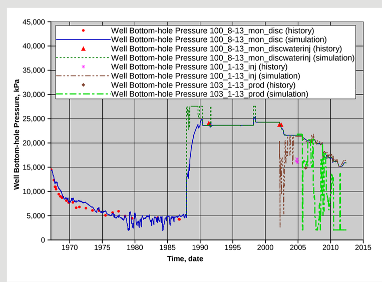
- History matching was performed with P10 OOIP (original oil in place) static model realization.
- A combination of object modeling and MPS workflow was used for spatial distribution of reef and nonreef facies in the static model.
- The adjusted parameters include vertical permeability, well productivity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



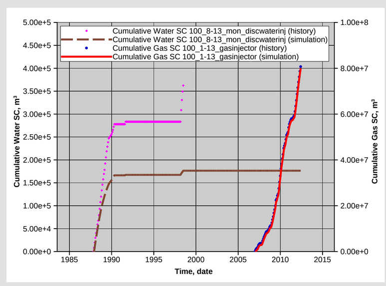
The Sequential Gaussian simulation algorithm was use to populate reservoir properties in the model.



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



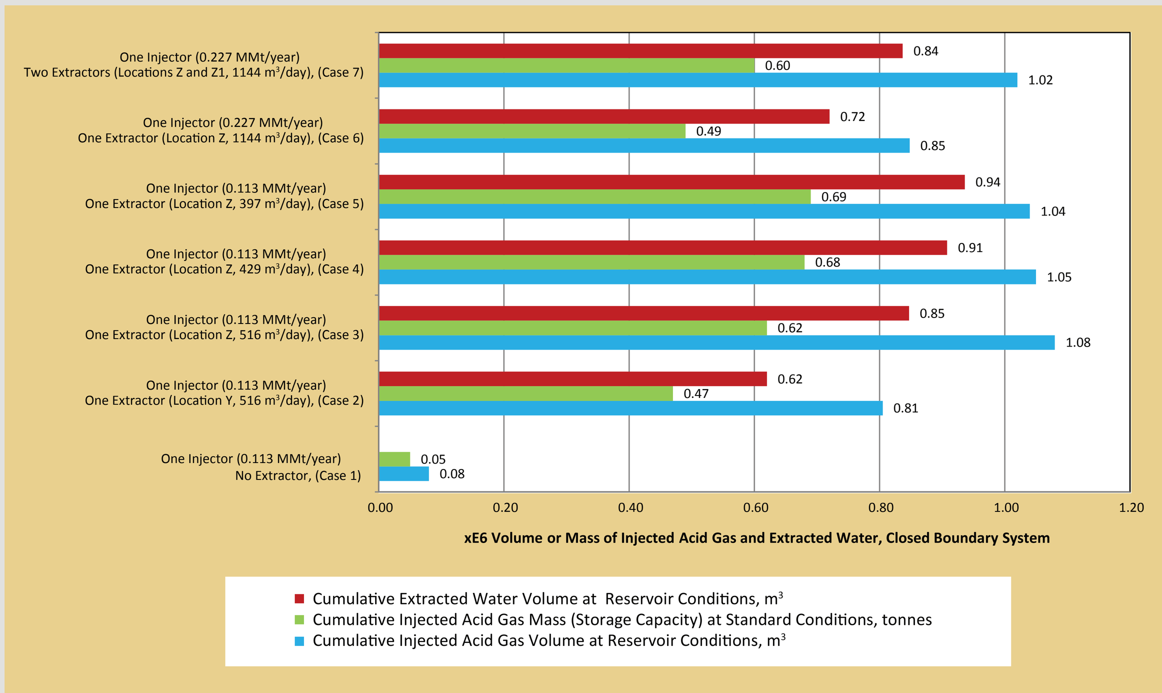
Actual and Simulated Well Bottomhole Pressures (8HPs)



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

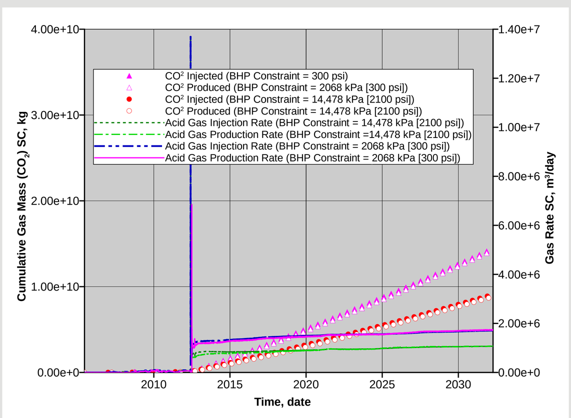
Predictive Simulation Results

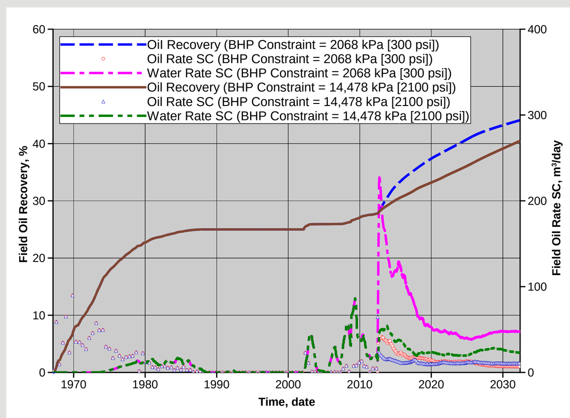
Formation Water Extraction Assisted by Acid Gas Injection (no oil production), Version 1 model

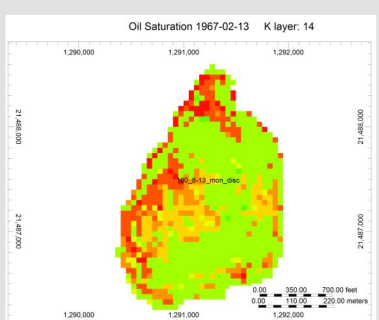


Existing EOR Configuration (one gas injection and two production wells)

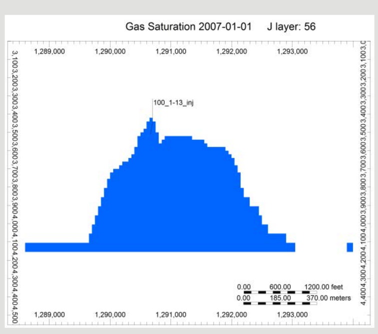
Two scenarios with minimum well BHP (bottomhole pressure) constraint of 2068 kPa (300 psi) and 14,478 kPa (2100 psi) at production wells



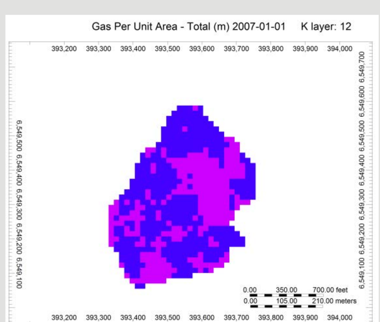




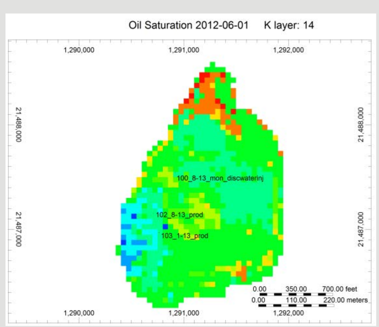
Initial Oil Saturation



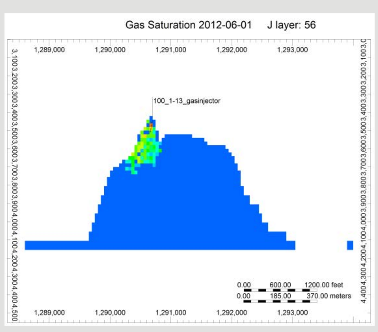
Gas Saturation at the Start of Gas Injection (Dec. 2006)



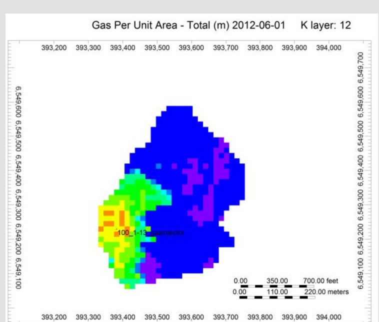
Total Gas per Unit Area (m) at the Start of Gas Injection (Dec. 2006)



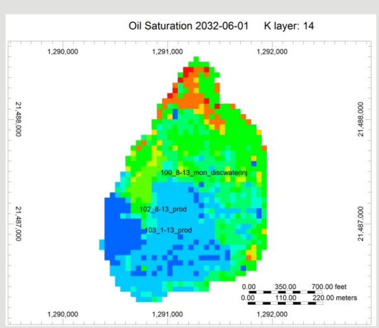
Oil Saturation at the End of History Match Period (2012-06-01)



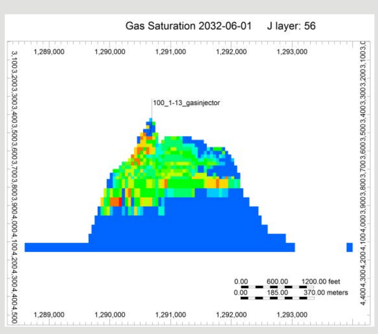
Gas Saturation at the End of History Match Period (2012-06-01)



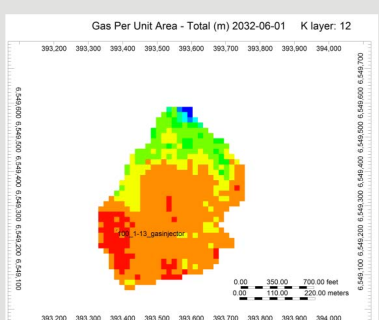
Total Gas per Unit Area (m) at the End of History Match Period (2012-06-01)



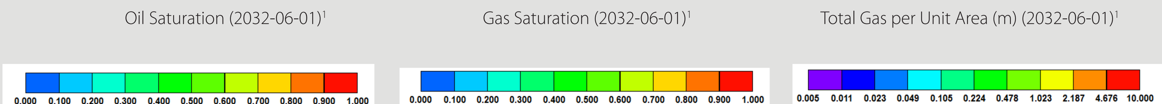
Oil Saturation (2032-06-01)[1]



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



Total Gas per Unit Area (m) (2032-06-01)[1]

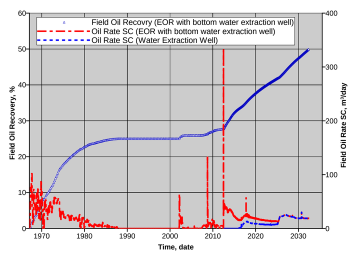


[1] After 20 years of EOR operations, minimum BHP constraint of 2068 kPa (300 psi) at production well.

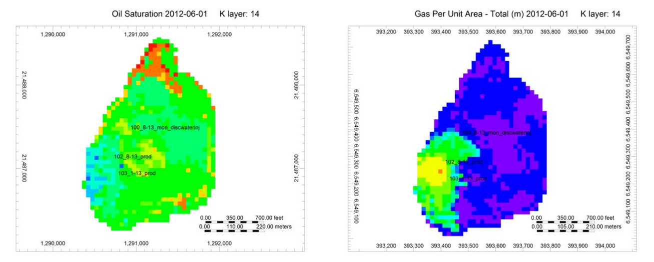
Predictive Simulation Results (continued)

Additional CO_2 Storage Capacity Gain Through Water Extraction

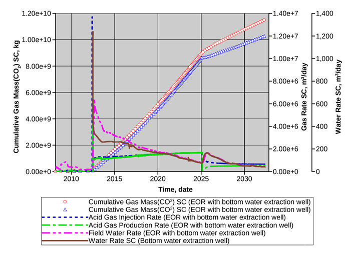
One water extraction well completed in bottom water zone with existing EOR configuration (one gas injection and two oil production wells).



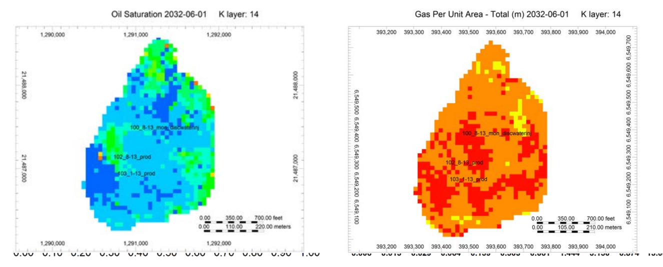
Predicted Oil Recovery, Field Oil, and Rate (existing EOR configuration with water extraction)



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

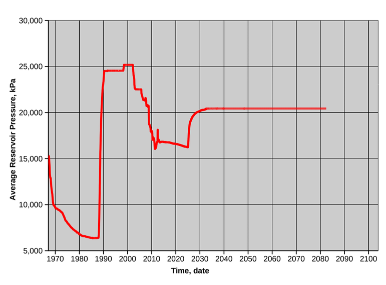


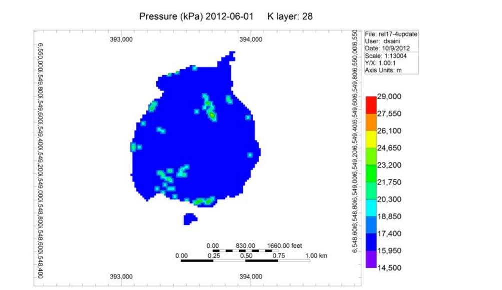
Amounts and Rates of Injected and Produced CO_2 (existing EOR configuration with water extraction)

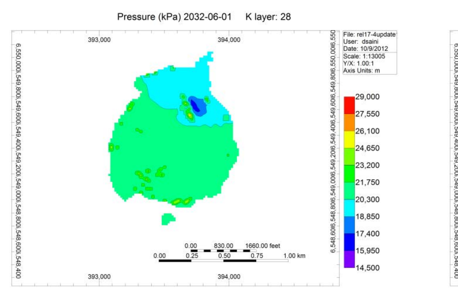


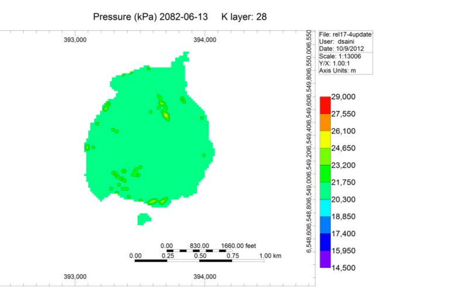
Oil Saturation and Total Gas per Unit Area (2032-06-01), EOR with Bottom Water Extraction

Variable	Continuing current EOR configuration		Current EOR configuration with bottom water extraction well (completed [perforation at the bottom of the structure] in the water zone below OWC)
	Minimum BHP constraint of 2068 kPa (300 psi) at production wells	Minimum BHP constraint of 14,478 kPa (2100 psi) at production wells	Minimum BHP constraints of 2068 kPa (300 psi) at production wells and 14,478 kPa (2100 psi) at water extraction well
Incremental oil recovery (%)	16.2	12.6	22.1
Injection/production duration, years	20	20	20
Cumulative CO_2 injected (70% of total acid gas injection), MMt	14.58	9.15	11.52
Cumulative CO_2 produced, MMt	14.37	8.85	10.30
Net CO_2 stored, MMt	0.21	0.30	1.22
Oil produced, m³ (MMstb)	1.98e4 (0.70)	1.55e4 (0.55)	2.69e4 (0.95)
Water produced, m³ (MMstb)	8.69e4 (3.07)	3.31e4 (1.17)	2.223e5 (7.86)









Reservoir Pressure Behavior During Acid Gas EOR and 50-year Postinjection Period

Summary

The results of detailed static and geologic modeling performed in this study suggest that water extraction from underlying water zone (aquifer) can effectively be used for additional gain in both oil recovery and CO_2 storage capacity in a closed system like the Zama F pool. The availability of additional pore space in the water zone below the OWC through controlled water extraction has resulted in a significant increase in F pool storage capacity. A combination of topdown gas injection EOR coupled with bottom water extraction appears to provide a new way to increase overall recovery efficiency and storage capacity in such reservoirs. In view of the high salinity of the formation water, produced water can be injected into another formation if a suitable completion strategy like downhole water sink (DWS) is used to complete water extraction wells. With over 700 pinnacle reef structures in the Zama subbasin, a careful selection of eight (EOR with bottom water extraction) to 16 (water extraction, no oil production) can provide a total CO_2 storage capacity in excess of 10 MMt. This can be achieved in a project span ranging from 4.5 years (water extraction, no oil production) to 20 years (EOR with bottom water extraction).

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PCOR Partnership 2003 – Present