Evaluation of Sequestration Options for Deep Saline Formations and Oil and Gas Fields in Eastern Ohio

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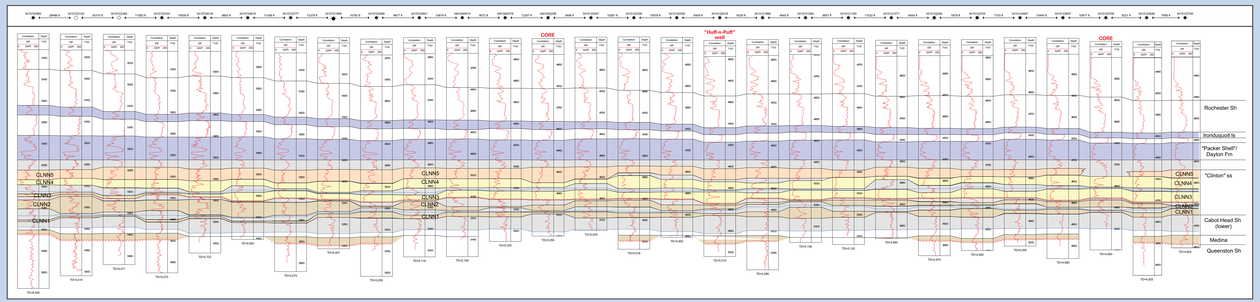
Reservoir Characterization of the Silurian "Clinton" Sandstone in the East Canton Oil Field, Ohio

SUMMARY

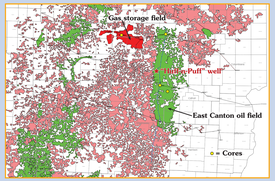
The Ohio Geological Survey conducted a detailed reservoir characterization of the Silurian "Clinton" sandstone in the East Canton oil field to evaluate the potential for CO_2-EOR (enhanced oil recovery). This investigation, in cooperation with private industry, included an 80-ton CO_2 cyclic test ("Huff-n-Puff") in Stark County. The East Canton oil field has produced approximately 95 million barrels of oil through primary recovery since 1947 from approximately 3,100 wells within 175,000 acres. With an estimated 1.5 billion barrels of original oil-in-place, there remains significant "stranded" oil in this nearly depleted but economically promising oil field. There have been limited secondary recovery efforts in this mature field because of the tight, heterogeneous nature of this reservoir.

Regional stratigraphic cross sections were generated across and surrounding the East Canton oil field and correlated to full-diameter cores and published reports to establish the regional "Clinton" sequence stratigraphy and depositional setting. The stratigraphic framework developed by these cross sections established regionally consistent formation/interval boundaries that were used for construction of regional structure and isopach maps. Detailed reservoir maps of up to five sandstone units and surrounding impermeable shale units within the "Clinton" interval were mapped and related to production in a 16-square-mile area around the CO_2 cyclic test. The geologic model was used as input into a reservoir simulation to estimate behavior of reservoir fluids from CO_2 injection.

REGIONAL CORRELATIONS TO ESTABLISH THE STRATIGRAPHIC FRAMEWORK

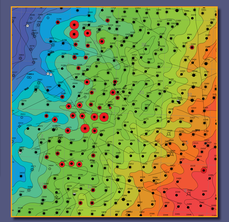


Regional stratigraphic cross section trending north–south (see blue line in the map at lower left) through the East Canton oil field, illustrating the "Clinton" interval and the five individual sandstone units. Datum is the base of the "Packer Shell"/Dayton Formation.

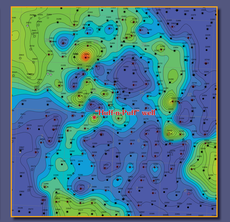


Map of northeast Ohio showing all of the "Clinton" oil and gas fields, "Clinton" cores, and the regional cross section lines.

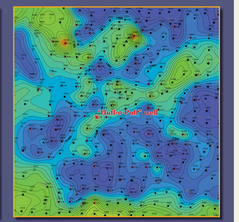
RESERVOIR CHARACTERISTICS AND MAPPING OF THE "CLINTON" SANDSTONE



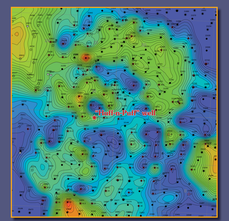
Structure map on the base of the "Packer Shell"/ Dayton Formation with interpreted lineaments from structure contours, LiDAR, and DEM. Also shown is a bubble map of cumulative production (red circles).



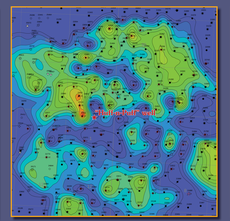
Net sandstone map of the "Clinton" unit 3 using a RHOB cutoff of 2.55 gm/cc.



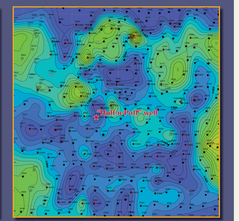
Average porosity map of the "Clinton" unit 3 using a RHOB cutoff of 2.55 gm/cc.



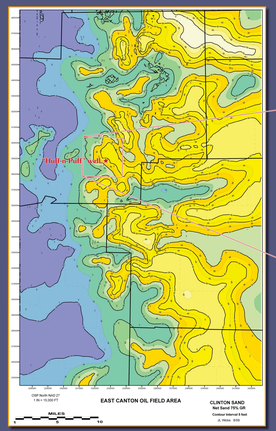
Net sandstone map of the entire "Clinton" interval using a RHOB cutoff of 2.55 gm/cc.



Net sandstone map of the "Clinton" unit 4 using a RHOB cutoff of 2.55 gm/cc.



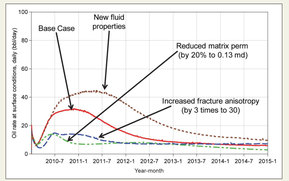
Average porosity map of the "Clinton" unit 4 using a RHOB cutoff of 2.55 gm/cc.



Location map of the area of interest showing all the "Clinton" penetrations and the cross section lines. Also shown is the CO_2 cyclic test ("Huff-n-Puff").

Regional net sandstone map of the "Clinton" interval based on a gamma ray curve cutoff of 75%. Also shown are the 16-section area of interest and the "Huff-n-Puff" test.

SIMULATION AND SENSITIVITY TESTS

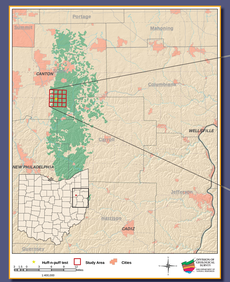


Forecast of oil production rate for the East Canton oil field pilot area central producer for the five-year simulation period showing the Base Case and three sensitivity study cases. Modified from Riley and others (2011).

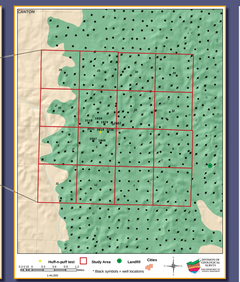
SOME OUTPUT FROM SENSITIVITY TESTS (reservoir parameters and pilot design were varied)

- Rock and fluid properties have a significant effect on oil production. In particular for the rock, lower matrix permeability or a larger fracture anisotropy ratio could lead to a significant increase or reduction in oil production rate.
- Lowest oil production is realized from the pilot area when matrix permeability is reduced to 20 percent of the Base Case (0.13 md compared to 0.65 md).
- Significant reduction in forecasted production occurs when the permeability anisotropy ratio in the fractures is increased from the Base Case of 10 up to 30. If a value of 30 is used, greater preferential movement of CO_2 occurs along the fractures, and consequently less oil is displaced towards the central producer.
- If reservoir fluid properties differ from assumed, oil production could be significantly higher.
- Shutting in offset producing wells did not improve capture of displaced oil by the central producer.
- Shutting in the water injectors did not reduce oil production significantly. The potential for creating a water shield should be further evaluated.

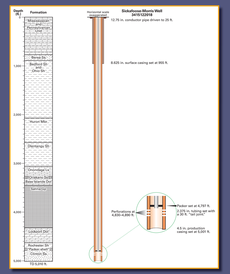
CO_2 Cyclic Test ("Huff-n-Puff") in the East Canton Oil Field, Ohio



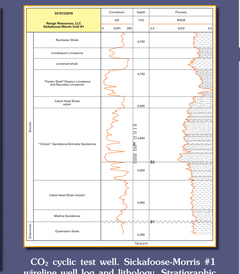
Map showing location of East Canton oil field and Sickafoose-Morris #1 well (permit number 2018). Detailed-study area is outlined in red.



Map showing location of the Sickafoose-Morris #1 well (permit number 2018) and surrounding wells. Observation wells that were tested for gas analyses are labeled with permit numbers.



Sickafoose-Morris #1 well completion diagram with perforations and test set-up.

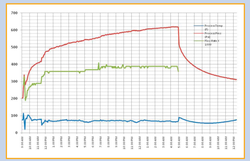


CO_2 cyclic test well. Sickafoose-Morris #1 wireline well log and lithology. Stratigraphic nomenclature is from the Ohio Division of Geological Survey (2004) and Ryder (2004).

RESULTS OF CO_2 CYCLIC TEST

- Clearly demonstrated the capacity of the "Clinton" sandstone in East Canton oil field to accept significant volumes of injected CO_2. Approximately 81 tons (1.39 MMCFG) of CO_2 were injected into the test well during a 20-hour period.
- CO_2 was injected at a maximum surface injection pressure of 617 psi (1,300 psi bottom-hole pressure), which is below MMP of 1,450 psi. Results demonstrate that even under immiscible conditions, CO_2 diffuses into the oil in the pore space, enhancing oil mobility. Injection of larger volumes of CO_2 at or above MMP is clearly feasible; moving to a pilot flood phase is appropriate and higher-efficiency recoveries are anticipated.
- After the test well was returned to production, it produced 174 bbl of oil during a 60-day period (September 22 to November 21, 2008). This is an estimated 58% increase in oil production over pre-injection estimates.
- Majority of the injected CO_2 entered the matrix porosity where it diffused into the oil. Evidence includes: (A) the volume of injected CO_2 greatly exceeded capacity of the hydro-frac, (B) gradual injection and pressure rate build-up during the test, (C) the gradual flashout of the CO_2, and (D) a large amount of CO_2 off-gassed from wellhead oil samples 3½ months after injection.
- Multiple lines of evidence indicated the injected CO_2 did not channel off but stayed within matrix porosity near the test well, including: (A) absence of CO_2 found in gas samples from offset wells, (B) the persistent but gradual decrease of CO_2 in fluid samples taken from the injection well after production was restarted, and (C) a standard calculation of radius of influence. Holtz (2008) calculated the radius of influence to be approximately 68 ft.
- Most of the CO_2 probably was pushed into and then diffused within the higher-permeability "Clinton" sandstone zones that communicate with the hydro-frac system near the borehole.

CO_2 INJECTION RATE

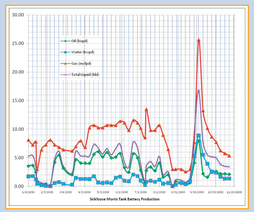


Graph of the Sickafoose-Morris #1 well CO_2 injection operation conducted August 19–20, 2008 showing process temperature, pressure, and flow rate versus time.

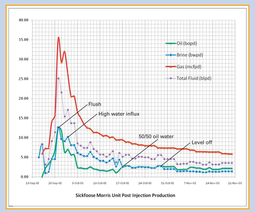
Pressure (psi)	Effective Injection Radius (ft)	CO_2 Volume Subsurface (cf)
1300	34	5986
700	68	24236
300	114	67425

Estimated radius and volume of CO_2 within the formation through the range of pressures encountered by the cyclic test (Holtz, 2008).

PRODUCTION ANALYSIS



Sickafoose tank battery production from July 11, to September 19, 2008.



Graph of the Sickafoose-Morris #1 well production for the 60-day period following the CO_2 injection and 32-day "soak" period.

Date	Sickafoose Morris 2018		Sickafoose 2036		Brenner 2057		PER DAY TOTAL		5 WEEK AVERAGE	
	Gas (mcf)	Fluid (bbl)	Gas (mcf)	Fluid (bbl)	Gas (mcf)	Fluid (bbl)	Gas (mcf)	Fluid (bbl)	Gas (mcf)	Fluid (bbl)
7/18/08	3	1.42	3	1.42	3	1.46	9	4.3		
7/25/08	3	1.14	3	1.14	3	1.17	9	3.45		
8/1/08	4	1.72	4	1.72	4	1.77	12	5.21		
8/7/08	3	0.67	3	0.67	3	0.69	9	2.03		
8/13/08	3	0.86	3	0.86	3	0.88	9	2.6	9	3.52
8/22/08	shuts	shuts	shuts	shuts	shuts	shuts	shuts	shuts		
8/27/08	shuts	shuts	1.5	0.39	1.5	0.4	3	0.79		
9/5/08	shuts	shuts	1.5	0.67	1.5	0.67	3	1.34		
9/12/08	shuts	shuts	1.5	0.35	1.5	0.35	3	0.7		
9/19/08	shuts	shuts	1.5	0.71	1.5	0.72	3	1.43	3	1.07
									6.00	2.45

Estimated Sickafoose-Morris average daily production prior to test:

Estimate by fluid type: 1.84 bopd
at est 25% water cut: 0.61 bopd
6.00 mcfpd

*Production split equally among the 3 wells

The 2008 production from the Sickafoose tank battery commingling production from the Sickafoose-Morris #1 (permit number 2018), Sickafoose #1 (permit number 2036), and the Brenner #1 (permit number 2057) wells. The Sickafoose-Morris #1 was shut in after August 15, 2008, and turned on September 22, 2008. The Sickafoose #1 and Brenner #1 wells were shut in after September 22, 2008.

SUMMARY OF PRODUCTION AND "CLINTON" RESERVOIR CHARACTERISTICS FOR SICKAFOOSE-MORRIS #1

Completion Date	1969
Initial Production	115 BOPD
Cumulative Production	60,000 BO
Gross Sandstone	110 ft
Net Sandstone	52 ft (>6%)
Porosity Range	4–14%
Completion technique	F/W 5,100 bbl water + 75,000 lb sd proppant + 100 scf of N

References Cited

Holtz, Mark, 2008, Appendix G—Pressure CO2 huff n' puff, Sickafoose-Morris unit #1 well, in Wicks, J.L., Riley, R.A., Nuhfer, Steve, Perry, C.J., 2009, Results of the Sickafoose-Morris cyclic CO_2 test, East Canton oil field, Ohio, U.S. DOE Quarterly Report, prepared for DOE cooperative agreement No. DE-NT0005113, 18 p.

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Riley, R.A., Wicks, J.L., and Perry, C.J., 2011, Silurian "Clinton" sandstone reservoir characterization for evaluation of CO_2-EOR potential in the East Canton oil field, Ohio: Ohio Department of Natural Resources, Division of Geological Survey Open-File Report 2011-2, 35 p.

Ryder, R.T., 2004, Stratigraphic framework and depositional sequences in the Lower Silurian regional oil and gas accumulation, Appalachian basin—from Ashland County, Ohio, through Southwestern Pennsylvania, to Preston County, West Virginia: U.S. Geological Survey Miscellaneous Investigations Series Map I-2810, scale 1:1,000,000, 2 sheets, accompanying pamphlet 8 p.