[PS]CO_2 Plume Tracking and Monitoring at Wellington Field CO_2 EOR Pilot*

Yevhen Holubnyak[1], Lynn Watney[1], Christa Jackson[1], Brent Campbell[1], John Victorine[1], and Dana Wreath[1]

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Abstract

Approximately 20,000 metric tons of CO_2 were injected in the upper part of the Mississippian dolostone reservoir to verify CO_2 EOR viability in carbonate reservoirs and evaluate a potential of transitioning to geologic CO_2 storage through EOR. Total of 1,101 truckloads, average of 120 tonnes per day were delivered over the course of injection that lasted from January 9 to June 21, 2016.

Geochemical water analysis of organic and inorganic components was performed in order to understand if this method could be used as an early CO_2 detection system, as a plume location and containment method, and in order to understand a degree of impact of CO_2 on mineral composition, detect changes in water and rock geochemistry as a result of injection. Along with geochemical survey, pressure and production data was recorded at wells and tank batteries.

Based on reservoir simulations, wells surrounding CO_2 injector were grouped in three areas: two inner circles with the radii of 182 m and 460 m. Wells within this radius were sampled weekly during the course of CO_2 injection, since January 9, 2016. Wells within third radius of 1 km around KGS 2-32 were sampled after initial break-through at the wells of the first inner circle; however, sampling interval for these wells was chosen according to flood performance and was not strictly set from the beginning of the injection. In total, analysis of 17 wells surrounding injector well was performed. Additional geochemical sampling was performed by contracting Baker and Hughes Oilfield Services that conducted monthly sampling since the start of injection and continues currently (May 1, 2018).

Total dissolved solids and pH measurements were analyzed in the field, and alkalinity analysis was performed in the lab shortly after sample arrival. These results were used as an early detection for CO_2 arrival at well locations. On average, wells started to produce CO_2 approximately 2-3 weeks after initial increase in alkalinity. However, some wells did observe alkalinity increase without free gas production. Collected data (cation, anion, and organic components) is being currently analyzed and finalized results, and findings will be published at a later date.

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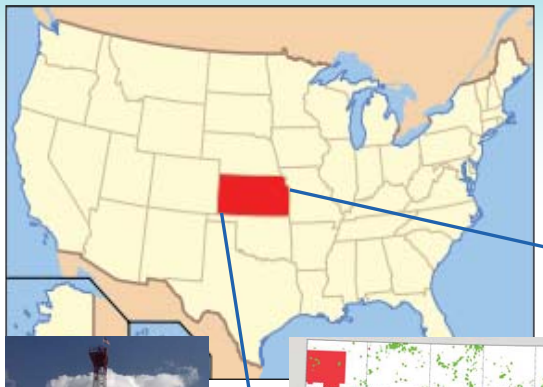

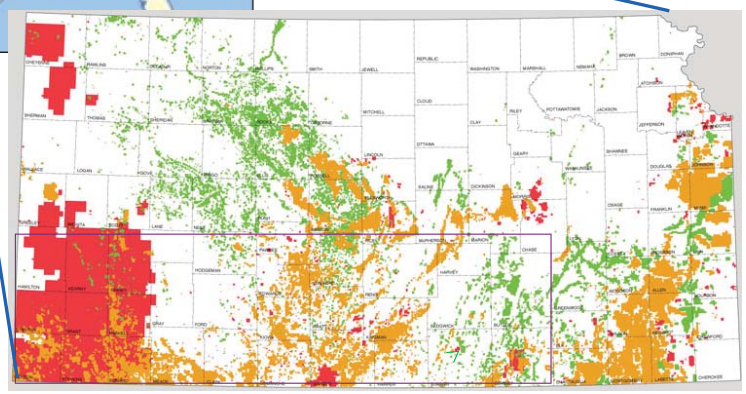

ABSTRACT

Approximately 20,000 metric tons of CO_2 were injected in the upper part of the Mississippian dolostone reservoir to verify CO_2 EOR viability in carbonate reservoirs and evaluate a potential of transitioning to geologic CO_2 storage through EOR. Total of 1,101 truckloads, average of 120 tonnes per day were delivered over the course of injection that lasted from January 9 to June 21, 2016.

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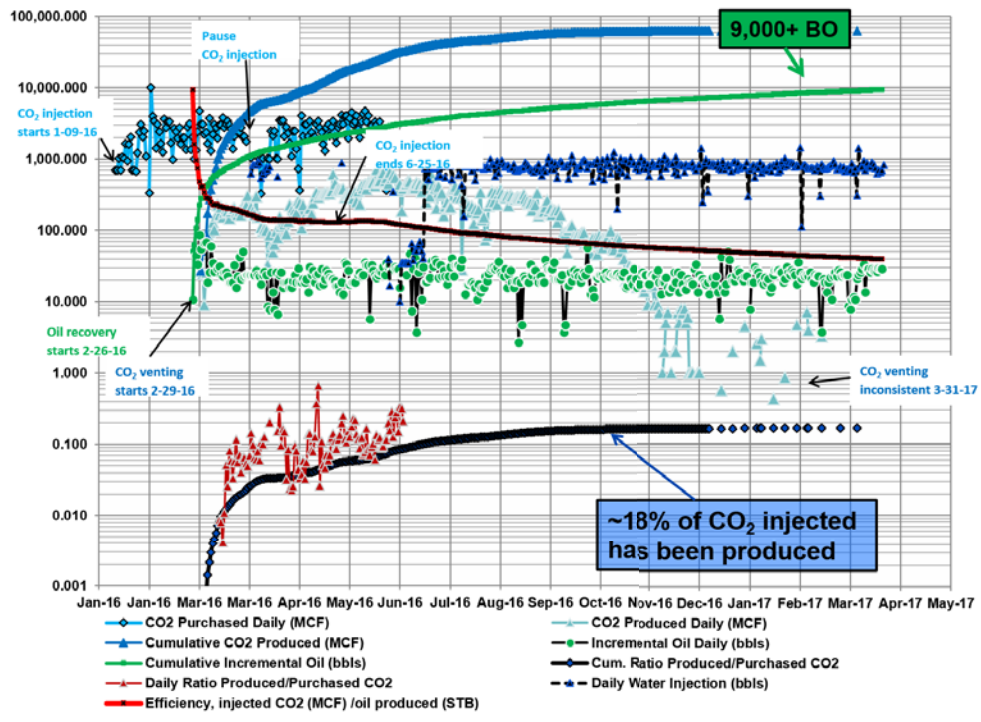
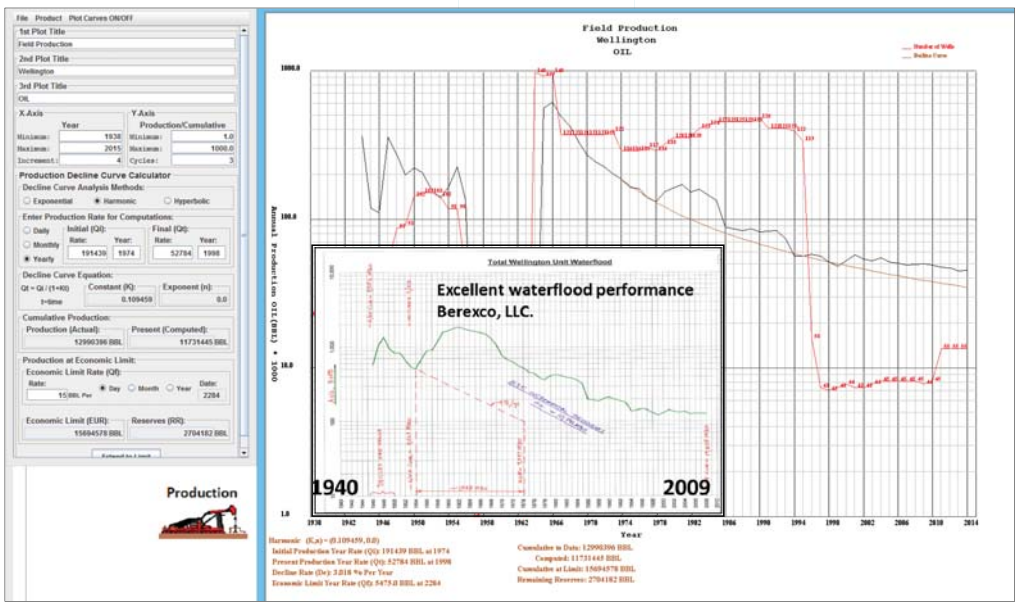
EOR SPECIFIC FIELD PRODUCTION DATA



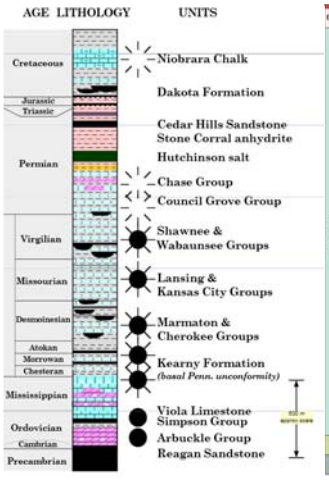
FIELD PRODUCTION HISTORY

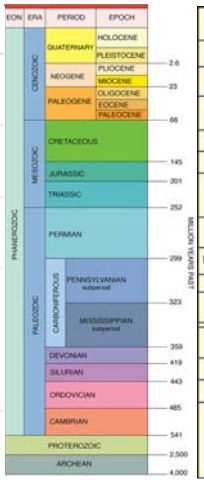


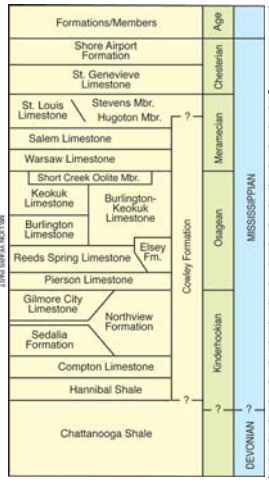
GEOLOGIC SETTING

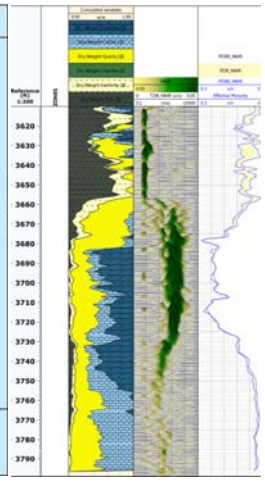
Rocks deposited during the Mississippian Subperiod, spanning about 359 million to 323 million years ago, are found in the subsurface throughout most of Kansas. Mississippian rocks get progressively deeper from east to west and are oil-bearing in several parts of central and western Kansas, where they have been buried several thousand feet deep. The Mississippian formation, based on lithology, can be divided from top to bottom, into 3 lithofacies sequences: Chat conglomerate, Dolomitic sequence and carbonate interval at the bottom.

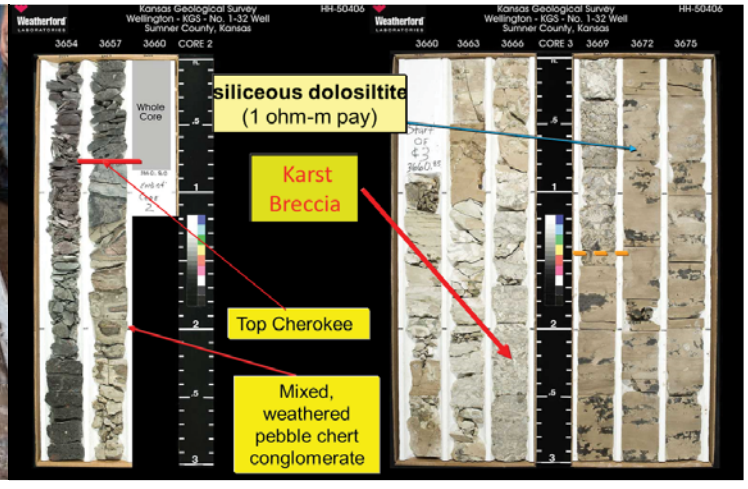
The Mississippian reservoir at Wellington Field has been analyzed using a host of data, including continuous core, an exhaustive suite of modern wireline logs, and multi-component 3D seismic data.











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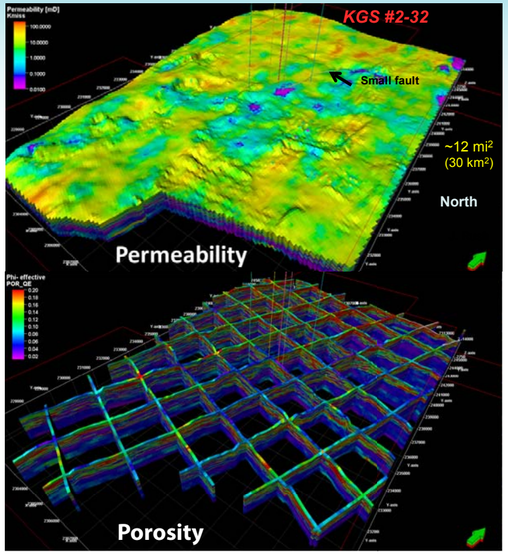
GEO-MODEL



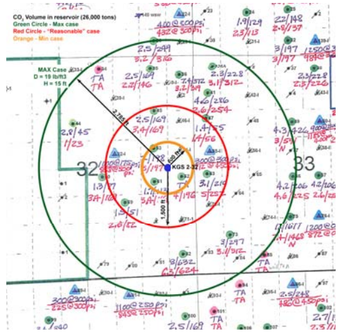
Schluberger Petrel's volume attribute processing (i.e., genetic inversion) was used to derive a porosity attribute from the Pre-Stack Depth Migration (PSDM) volume to generate the porosity model . The seismic volume was created by re-sampling (using the original exact amplitude values) the PSDM 50 feet above the Mississippian and 500 feet below the Mississippian sequence (i.e., approximate Mid. Arbuckle Group). The cropped PSDM volume and conditioned porosity logs were used as learning inputs during neural network processing. A correlation threshold of 0.85 was selected and 10,000 iterations were run to provide the best correlation. The resulting porosity attribute was then re-sampled, or upscaled (by averaging), into their corresponding 3-D property grid cell.

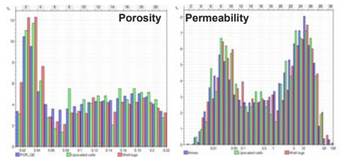
The porosity model was constructed using Sequential Guassian Simulation (SGS). The porosity logs were upscaled using arithmetic averaging. The raw upscaled porosity histogram was used during SGS. The final porosity model was then smoothed. The following parameters were used as inputs: 1) Variogram type: spherical with nugget: 0.001; 2) Anisotropy range and orientation: lateral range (isotropic): 5000 ft, vertical range: 1-ft, distribution: actual histogram range (0.06–0.11) from upscaled logs; 3) Co-Kriging with secondary 3-D variable: inverted porosity attribute grid and correlation coefficient: 0.75.

SCADA System installed on wells

VOLUMETRICS

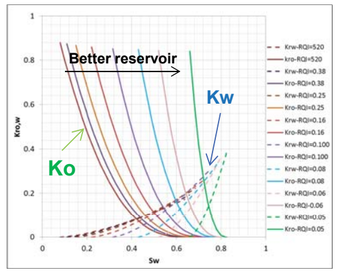
	Bulk volume(ft3)	Pore volume(ft3)	Pore volume(bbl)	Pore volume, %	Oil in place 1 (STB)	Oil Sat. 1 %	Oil in place 2 (STB)	Oil Sat. 2 %
Field C-O	2,387,595,862	42,984,996	241,342,841	10.1%	16,937,907	39.4%	7,154,649	16.6%
Field Zone A	24,434,120,000	508,651,707	2,855,867,395	11.7%	187,245,212	36.8%	94,580,661	18.7%
Field Total	26,821,715,862	551,636,703	3,097,210,237	11.5%	204,183,118	37.0%	102,135,310	18.5%
3000 ft R C-O	343,455,825	5,318,080	29,862,206	8.7%	1,766,160	33.2%	650,836	12.2%
3000 ft R Zone A	3,563,482,652	70,558,476	396,156,443	11.1%	24,565,224	34.8%	11,408,585	16.2%
3000 ft R Total	3,906,938,477	75,877,582	426,018,649	10.9%	26,331,384	34.7%	12,059,421	15.9%
1500 ft R C-O	110,679,911	1,697,509	9,530,804	8.0%	563,104	33.2%	196,769	11.6%
1500 ft R Zone A	883,255,413	18,000,976	101,067,588	11.4%	6,779,178	37.7%	3,265,144	18.1%
1500 ft R Total	993,935,324	19,698,485	110,598,392	11.1%	7,342,282	37.3%	3,461,913	17.6%



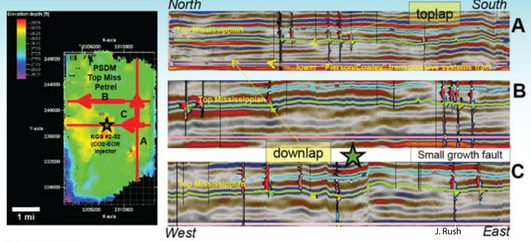


RELATIVE PERMEABILITY AND CAPILARY PRESSURE

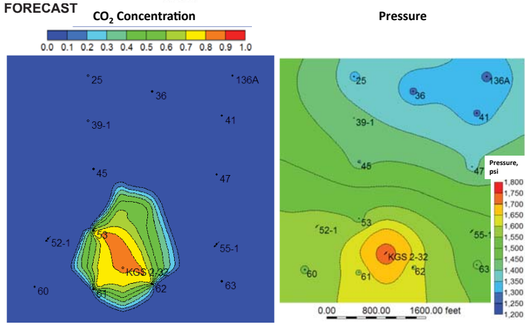
Rock tables with capillary pressure hysteresis were implemented. The relative permeability is assumed to be gravity stable (straight line pseudo function), with the end point saturations dependent on the rock quality index.



SEISMIC STRATIGRAPHY USING PSDM



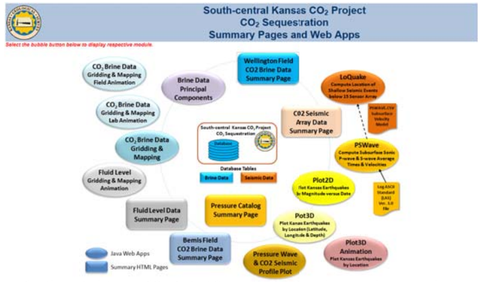
FORECAST



The main goal for this task of numerical simulations was to determine the outline of the CO_2 front for optimal monitoring of the EOR performance, efficiency, and CO_2 movement in through existing structural elements.

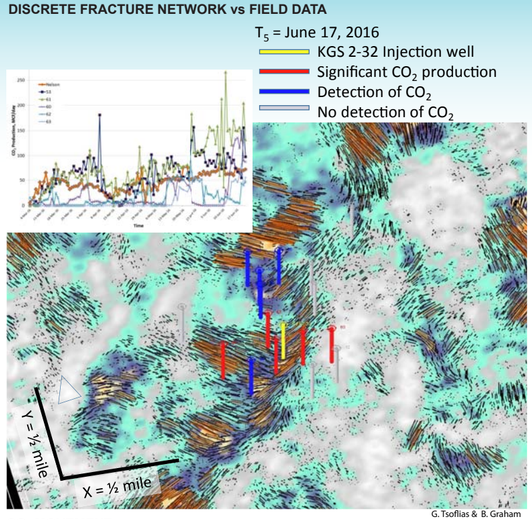
The Petrel-based geomodel mesh discussed above consists of 130 x 114 horizontal grid and 32 vertical layers for a total of 451,887 cells. The model domain encompasses a 1.56 miles^2 area and the formations from the base to the top of Mississippian sequence. This grid with populated reservoir parameters (permeability, porosity, and water saturation) was imported to CMG Builder where other reservoir properties discussed above were applied. Boundary conditions were determined as Carter-Tracy aquifer with allowed leakage. Historical matching of the field performance was performed with CMOST software from CMG.

ONLINE DATABASE

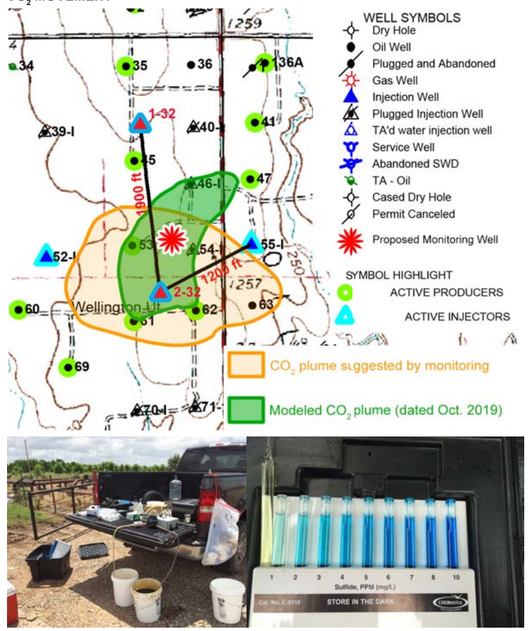


Phase II South-central Kansas CO_2 Project Summary Pages and Java Web Apps webpage contains URL links to Java Web Apps (oval icon buttons) and Summary HTML pages (rectangle icon buttons) to view data collected over the last 2 years in monitoring the CO_2 -EOR in the Mississippian sequence of the Wellington KGS 2-32 well. The data collected for the CO_2 -EOR effort is the geochemistry, oil production / CO_2 emissions / CO_2 & brine injection data, earthquake events around the Wellington Field in real time and pressure/temperature monitoring in the Wellington KGS 1-28 Arbuckle Group ~5020 feet depth.

DISCRETE FRACTURE NETWORK vs FIELD DATA



CO_2 MOVEMENT



MONITORING

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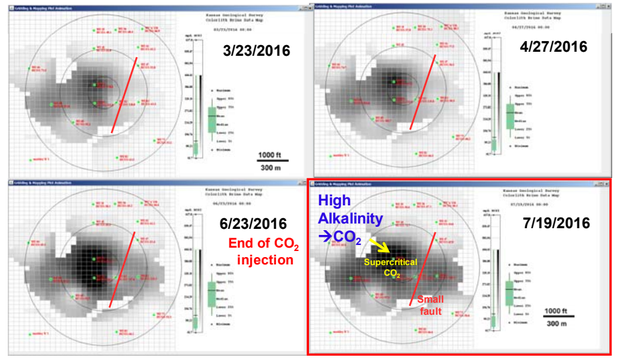

FIELD OPERATIONS

CO_2 EOR effectiveness and CO_2 retention and storage efficiencies in application to Mississippian carbonate reservoirs in Kansas were successfully tested with this small-scale field project. Total of 1101 truckloads, 19,803 metric tons, average of 120 tonnes per day were delivered over the course of injection that lasted from January 9 to June 21, 2016. Current incremental average oil production rate is 34 bbls/day and a total of incremental 6300 bbls of oil were produced as a result of CO_2 injection. Only 12% of injected CO_2 was produced back currently.

ACKNOWLEDGMENTS

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