[PS]Reservoir Modeling for CO_2 EOR in Mississippian Carbonate Reservoir at Wellington Field in South-Central Kansas*

Yevhen Holubnyak[1], Willard Watney[2], Jason Rush[2], Mina Fazelalavi[2], Dana Wreath[3], and Tandis S. Bidgoli[2]

Search and Discovery Article #80621 (2017)**
Posted November 20, 2017

*Adapted from poster presentation given at AAPG 2017 Mid-Continent Section Meeting, Oklahoma City, Oklahoma, September 30 – October 3, 2017

[1]Kansas Geological Survey, University of Kansas, Lawrence, KS (eugene@kgs.ku.edu)
[2]Kansas Geological Survey, University of Kansas, Lawrence, KS
[3]Berexco LLC, Wichita, KS

Abstract

Since early 1930s over 2.4 trillion cubic feet (TCF) of gas and more than 290 million barrels of oil (MMBO) have been produced in southcentral Kansas from Mississippian carbonate reservoirs. Many Mississippian reservoirs are currently undergoing final stages of secondary recovery and are suitable for enhanced oil recovery (EOR) with CO_2 with estimated recoverable potential of 250-350 million barrels of oil. Wellington Field in South-Central Kansas has produced 20 MMBO since 1937 and is ready for a tertiary oil recovery phase with CO_2. A Department of Energy sponsored pilot-scale CO_2 EOR project is led by Kansas Geological Survey, Energy Research Section team and its industry partner and operator of the field, Berexco LLC. Approximately 23,000 metric tons of CO_2 will be injected in the upper part of the Mississippian reservoir to verify CO_2 EOR viability in carbonate reservoirs and evaluate a potential of transitioning to geologic CO_2 storage through EOR.

Baseline geologic characterization, geologic model development, studies of oil composition and properties, miscibility pressure estimations, geochemical characterization, reservoir modelling were performed. However, field deployment was delayed due to problems with CO_2 supply until early 2015. In March of 2015 the injection well (class II) KGS 2-32 was drilled, cored, and logged through an entire anticipated injection interval. Whole core samples were obtained and tested for porosity and permeability, relative permeability, and capillary pressure. The Drill Stem Test (DST) was also conducted to estimate injection interval permeability and pore-pressure. After the injection well KGS 2-32 was acidized, Step Rate (SRT) and Interference (IT) tests were conducted and analyzed for permeability, well pattern communication, and fracture closing pressure.

These additional characterization efforts and previous studies of the oil composition and properties, miscibility pressure estimations, and comprehensive 3D geological model for the entire Wellington Field led to updates and enhancements in the strategy for the CO_2 flood and the economic forecast for CO_2 EOR performance. The geological model estimates that the Wellington Field still holds at least 5 million barrels of

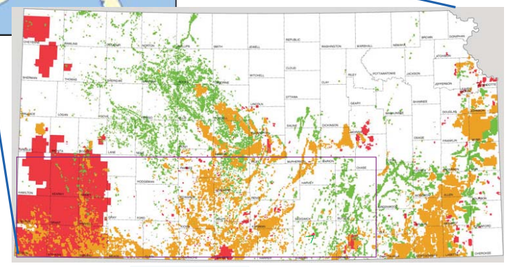
oil that could be potentially recovered. The reservoir simulation of the CO_2 miscible flood projects that additional 10-15% of primary and secondary oil production could be recovered, which amounts to nearly 8,500 bbls of additional oil production for the given part of the oilfield. It is also forecasted that nearly 73% of all injected CO_2 will be permanently stored during this EOR operation by the means of structural, residual, solubility, and mineral trapping.

Total of 1,101 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 30 bbls/day and a total of incremental more than 7,00 bbls of oil were produced as a result of CO_2 injection.

Reservoir Modeling for CO_2 EOR in Mississippian Carbonate Reservoir at Wellington Field in South-Central Kansas

Yevhen Holubnyak, Willard Watney, Jason Rush, Mina Fazelalavi, Dana Wreath, and Tandis S. Bidgoli

BEREXCO | KU Kansas Geological Survey, The University of Kansas | U.S. Department of Energy, National Energy Technology Laboratory



ABSTRACT

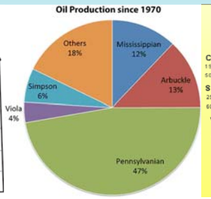
Since early 1930s over 2.4 trillion cubic feet (TCF) of gas and more than 290 million barrels of oil (MMBO) have been produced in south-central Kansas from Mississippian carbonate reservoirs. Many Mississippian reservoirs are currently undergoing final stages of secondary recovery and are suitable for enhanced oil recovery (EOR) with CO_2 with estimated recoverable potential of 250-350 million barrels of oil. Wellington field in South-Central Kansas has produced 20 MMBO since 1937 and is ready for a tertiary oil recovery phase with CO_2. A Department of Energy sponsored pilot-scale CO_2 EOR project is led by Kansas Geological Survey, Energy Research Section team and its industry partner and operator of the field, Berexco LLC.

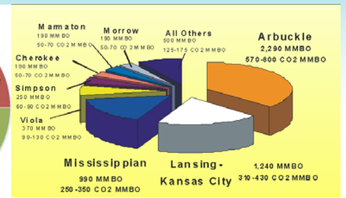
Baseline geologic characterization, geologic model development, studies of oil composition and properties, miscibility pressure estimations, geochemical characterization, reservoir modelling were performed. However, field deployment was delayed due to problems with CO_2 supply until early 2015. In March of 2015 the injection well (class II) KGS 2-32 was drilled, cored, and logged through an entire anticipated injection interval. Whole core samples were obtained and tested for porosity and permeability, relative permeability, and capillary pressure. The Drill Stem Test (DST) was also conducted to estimate injection interval permeability and pore-pressure. After the injection well KGS 2-32 was acidized, Step Rate (SRT) and Interference (IT) tests were conducted and analysed for permeability, well pattern communication, and fracture closing pressure.

These additional characterization efforts and previous studies of the oil composition and properties, miscibility pressure estimations, and comprehensive 3D geological model for the entire Wellington field led to updates and enhancements in the strategy for the CO_2 flood and the economic forecast for CO_2 EOR performance. The geological model estimates that the Wellington Field still holds at least 5 million barrels of oil that could be potentially recovered. The reservoir simulation of the CO_2 miscible flood projects that additional 10-15% of primary and secondary oil production could be recovered, which amounts to nearly 55,000 bbls of additional oil production for the given part of the oilfield. It is also forecasted that nearly 50% of all injected CO_2 will be permanently stored during this EOR operation by the means of structural, residual, solubility, and mineral trapping.

Total of 1,101 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 30 bbls/day and a total of incremental more than 7,00 bbls of oil were produced as a result of CO_2 injection.

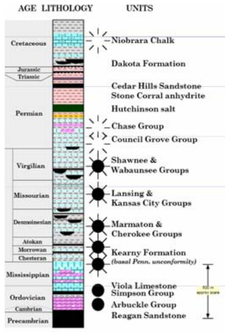
KANSAS OIL AND GAS PRODUCTION

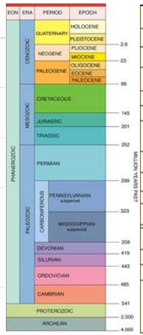


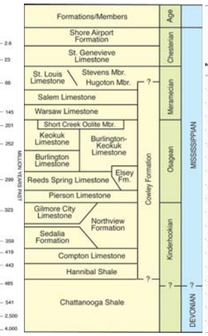


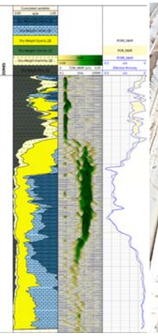
GEOLOGIC SETTING

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.

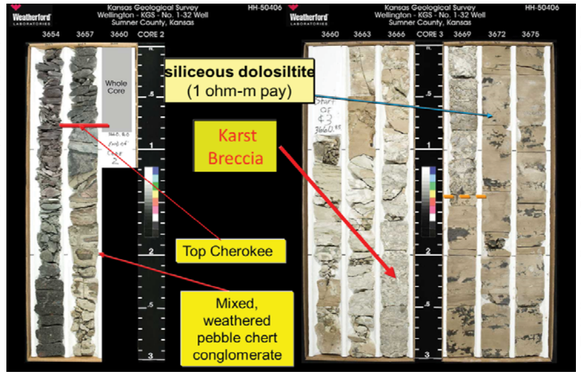








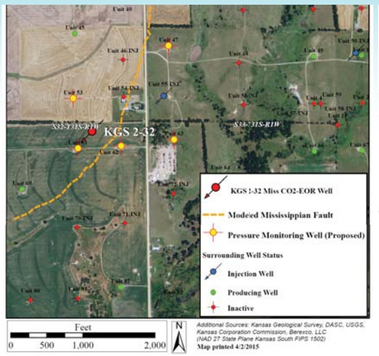
The Mississippian reservoir at Wellington Field has been analysed using a host of data, including continuous core, an exhaustive suite of modern wireline logs, and multi-component 3D seismic data. These data demonstrate that the reservoir has an average thickness of 42 ft. and is moderately fractured at a range of scales, typical of carbonates in general. The reservoir exhibits an upward increasing porosity trend through the mid-section of the field, with effective porosity ranging from 5-27%. Permeability from whole core in Wellington #1-32 ranges from 0.13 to 60 md.

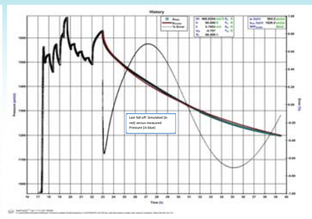


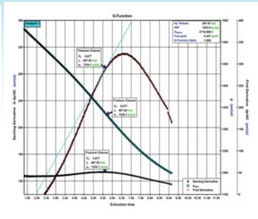
The data set for the log analysis consists of 16 wells with complete suites of porosity and resistivity logs drilled from 1956 to 2011. Also, there were are 5 older wells with older completion dates from 1936 to 1948. These wells had one porosity log, usually Neutron logs with no scale, and no resistivity logs. The Neutron logs of the 5 older wells were normalized with the Neutron logs of the new well (1-32), which was drilled and logged specifically for the purposes of the project, and then converted to the equivalent formation porosity. The 16 newer wells were quality controlled and analysed by Techlog in terms of porosity, water, oil saturation and minerals. 2 of these 16 wells (1-32 and 1-28) had NMR log. The NMR logs were analysed by Techlog to derive Coates permeability and capillary pressure curves.

KGS, Berexco LLC, and other team members: (1) drilled, cored, and logged new injection well KGS 2-32. Core and well logs were analysed and interpreted. Flow units defined in previous phase of work were confirmed and geologic models were updated.

WELL TESTS: INTERFERENCE, DST, and STEP RATE

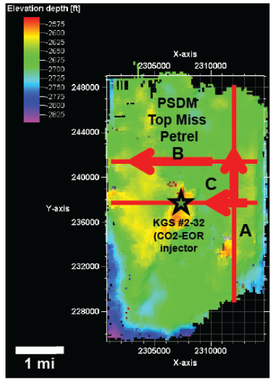


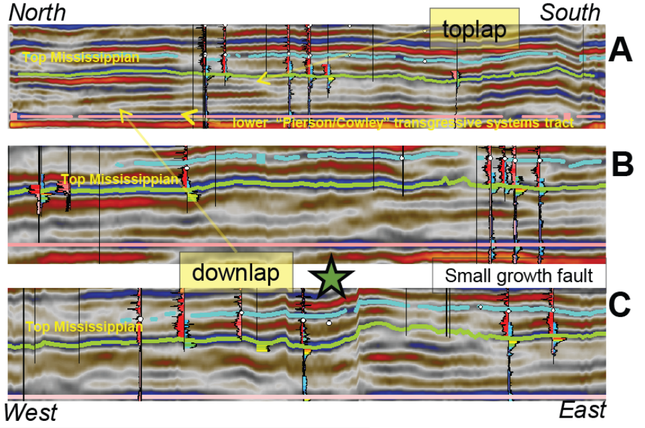


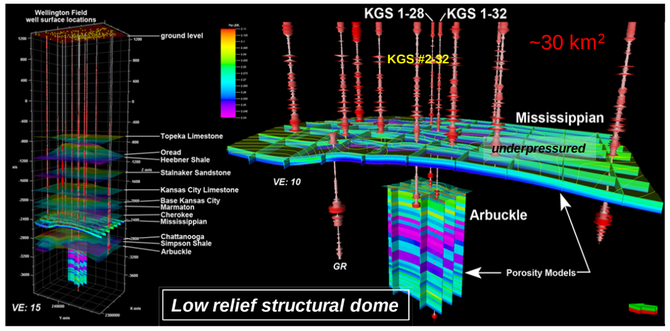


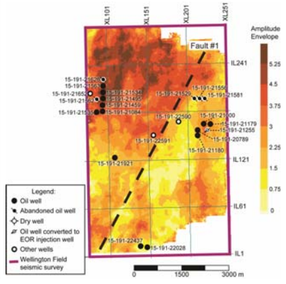
A number of well tests were performed on newly drilled KGS 2-32 well. DST test was completed immediately after drilling commencement and after completion and additional well treatment SRT and interference well tests were performed and analysed. Log derived permeabilities were correlated with well test derived values. Fracture gradient, operational pressures, and well communication for pilot injection area were confirmed. Measured reservoir pressure at 5 well locations within pilot area ranged from 50 bar to 70 bar, a departure from initial 114 bar reservoir pressure.

SEISMIC STRATIGRAPHY USING PSDM







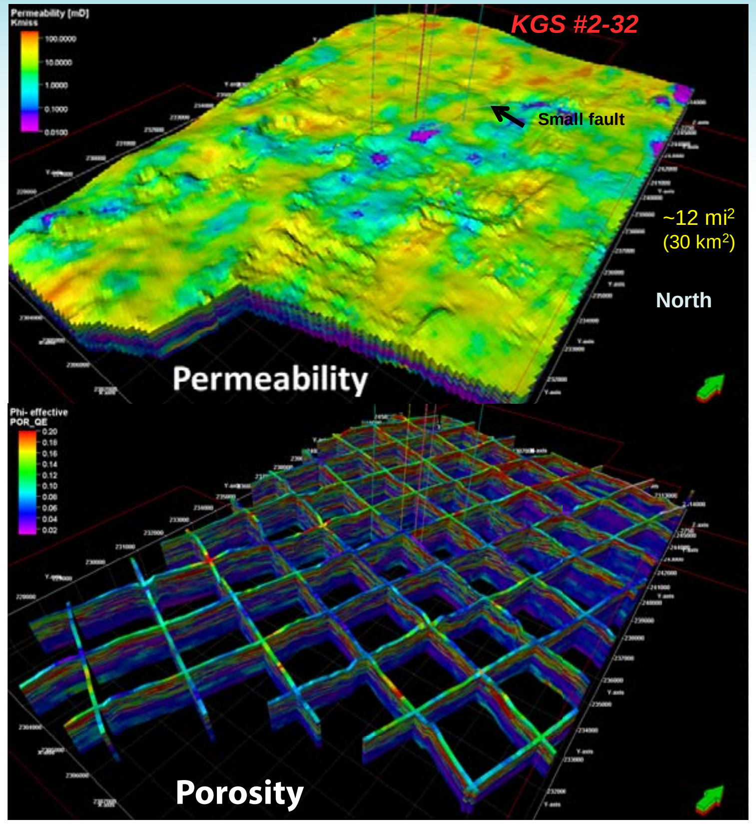


Reservoir Modeling for CO_2 EOR in Mississippian Carbonate Reservoir at Wellington Field in South-Central Kansas

Yevhen Holubnyak, Willard Watney, Jason Rush, Mina Fazelalavi, Dana Wreath, and Tandis S. Bidgoli

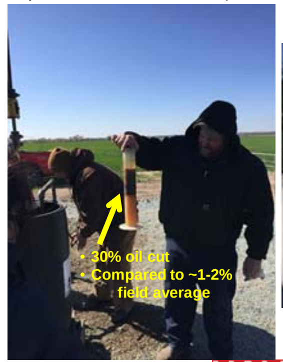
BEREXCO · KU Kansas Geological Survey, The University of Kansas · U.S. Department of Energy · National Energy Technology Laboratory

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 formation (i.e., approximate Mid. Arbukle formation). 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.

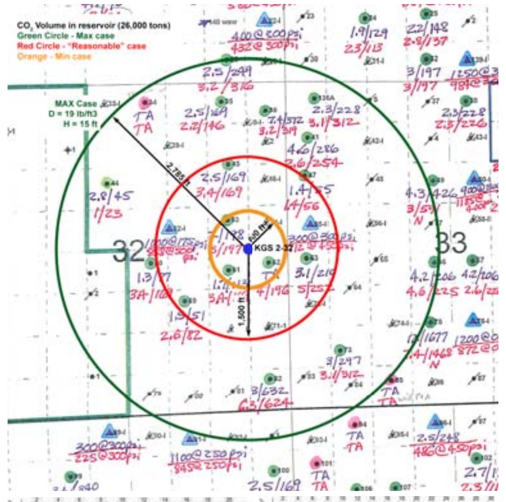
The porosity model was constructed using Sequential Guassian Simulation (SGS). The porosity logs were upscaled using arithmetic averaging. The raw upscaled porosity histogram was used during SGS. The final porosity model was then smoothed. The following parameters were used as inputs: 1) Variogram type: 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.

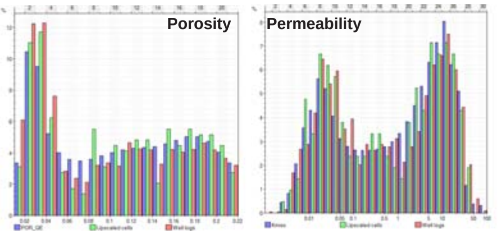


SCADA System installed on wells

VOLUMETRICS

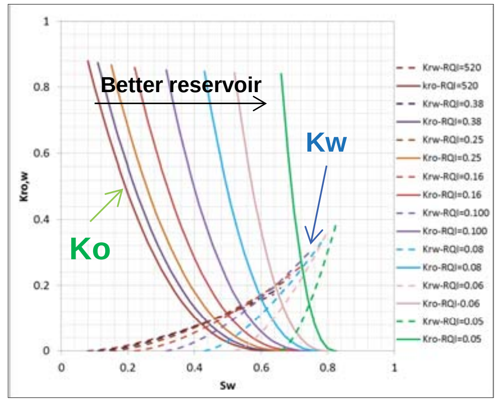
	Bulk volume[ft3]	Pore volume[RB]	Pore volume[ft3]	Pore volume, %	Oil in place 1 [STB]	Oil Sat. 1 %	Oil in place 2 [STB]	Oil Sat. 2 %
Field C-ch	2,387,595,862	42,984,996	241,342,842	10.1%	16,937,907	39.4%	7,154,649	16.6%
Field Zone A	24,434,120,000	508,651,707	2,855,867,395	11.7%	187,245,211	36.8%	94,980,667	18.7%
Field Total	26,821,715,862	551,636,703	3,097,210,237	11.5%	204,183,118	37.0%	102,135,316	18.5%
3000 ft R C-Ch	343,455,825	5,318,686	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	75,877,162	426,018,649	10.9%	26,331,384	34.7%	12,059,421	15.9%
1500 ft R C-Ch	110,679,911	1,697,509	9,530,806	8.6%	563,104	33.2%	196,769	11.6%
1500 ft R Zone A	883,255,413	18,000,976	101,067,980	11.4%	6,779,178	37.7%	3,265,143	18.1%
1500 ft R Total	993,935,324	19,698,485	110,598,786	11.1%	7,342,282	37.3%	3,461,912	17.6%



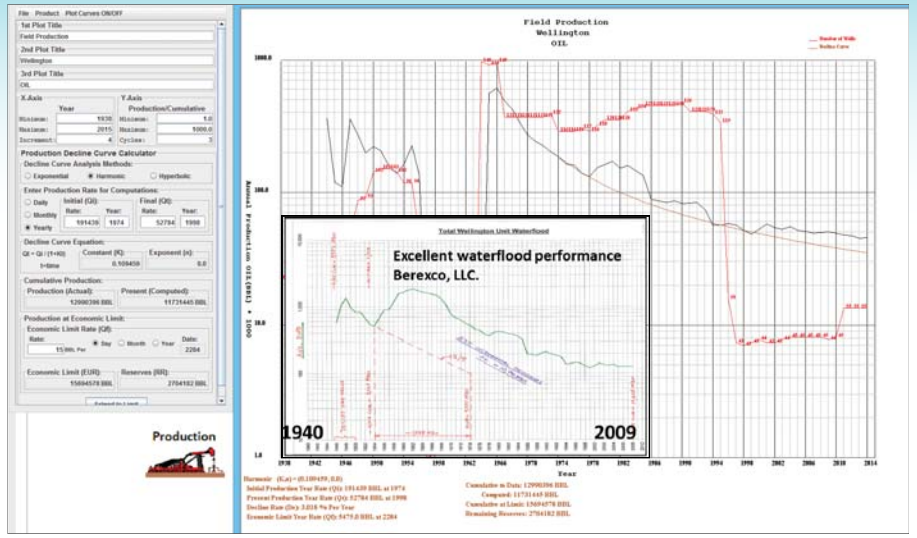


Rock tables with capillary pressure hysteresis were implemented. The relative permeability is assumed to be gravity stable (straight line pseudo function), with the end point saturations dependent on the rock quality index.

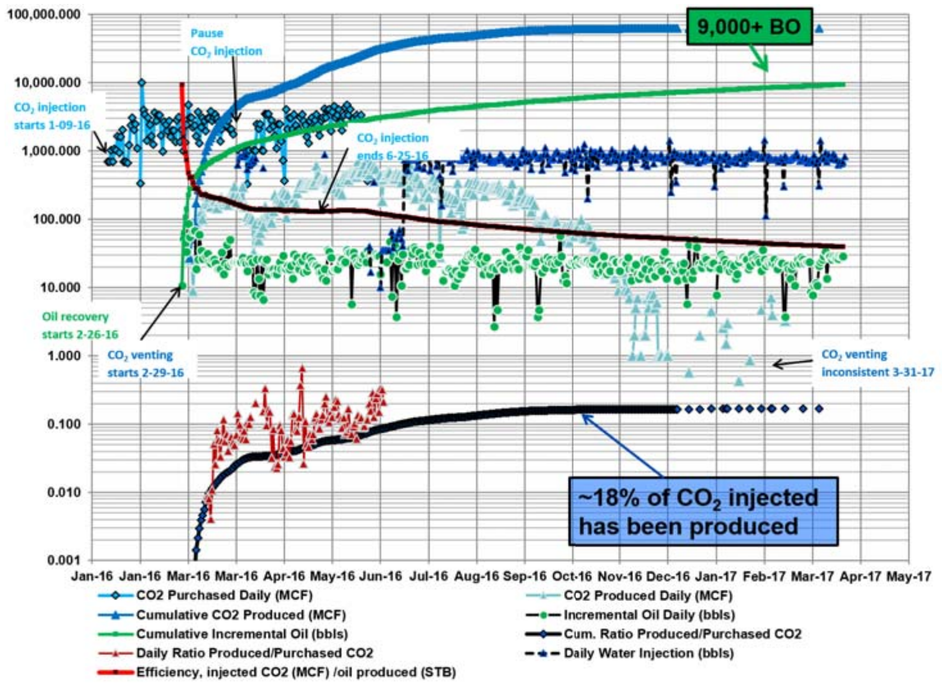
RELATIVE PERMEABILITY AND CAPILARY PRESSURE



FIELD PRODUCTION HISTORY



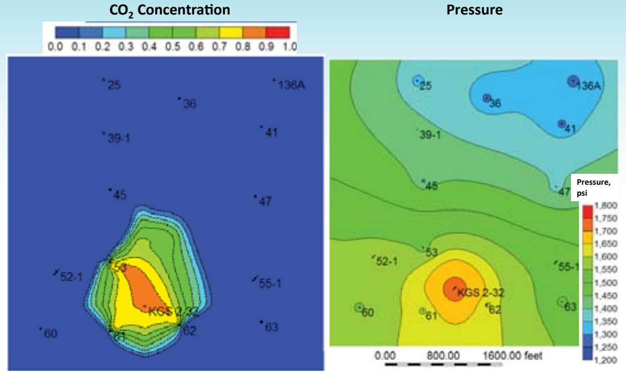
EOR SPECIFIC FIELD PRODUCTION DATA



DECLINE CURVE

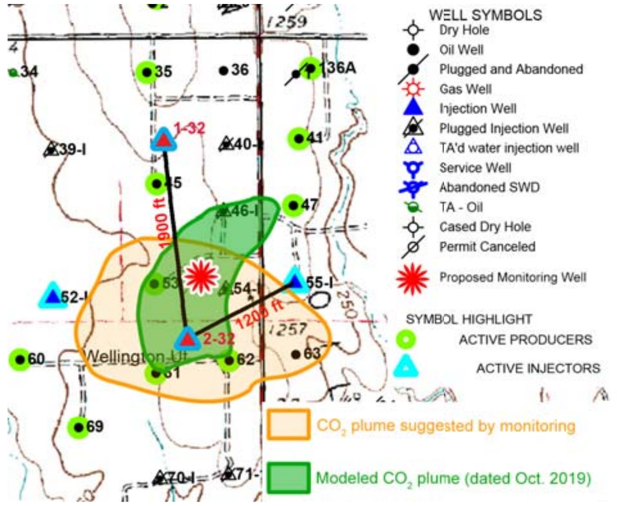
Harmony software calculated the cumulative oil production for each curve in the table below from the start of the forecast to April 2027. The difference between the two cumulative oil productions is the cumulative additional oil by CO_2 flood. The area between the curves equals to ~32 Mstb, which is the cumulative additional oil production by only CO_2 flood. Cumulative oil production by CO_2+waterflood from initial CO_2 response to April 2027 is ~69 Mstb.

FORECAST

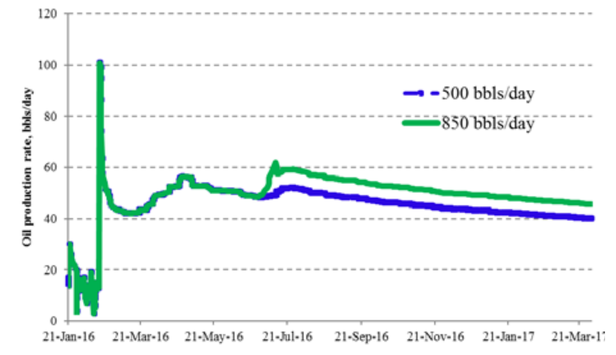


The main goal for this task of numerical simulations was to determine the outline of the CO_2 front for optimal monitoring of the EOR performance, efficiency, and CO_2 movement in through existing structural elements.

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 miles2 area and the formations from the base to the top of Mississippian formation. 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.



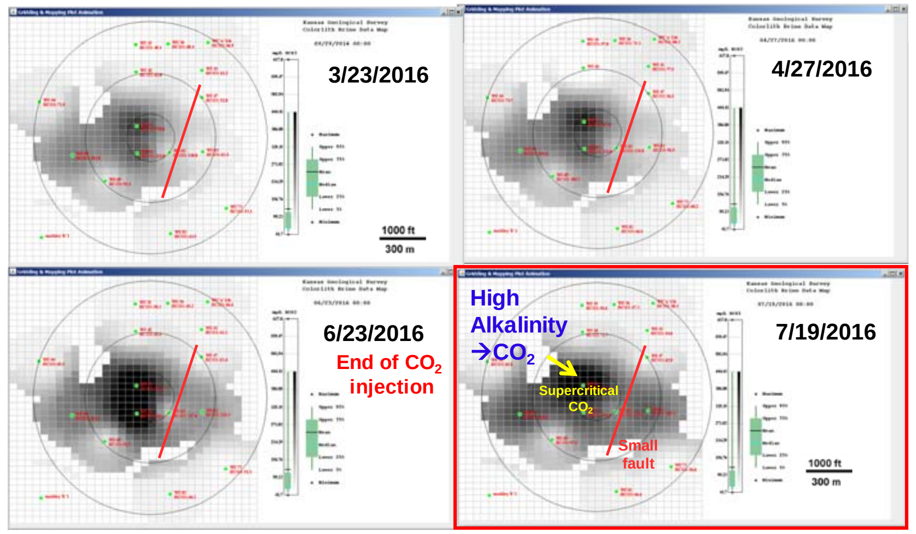
OIL PRODUCTION FORECAST FOR POST-CO_2 PHASE



MONITORING

Based on reservoir simulations, wells surrounding CO2 injector were grouped in three areas: two inner circles with the radiuses 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 since the start of injection and continues currently.

Total dissolved solids and pH measurements were analysed 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 data is being currently analysed and finalized results and findings will be published at a later date.



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 1,101 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 6,300 bbls of oil were produced as a result of CO_2 injection. Only 12% of injected CO_2 was produced back currently

ACKNOWLEDGMENTS

Kansas Geological Survey, Energy Section team, and University of Kansas Center for Research acknowledges continues support from Department of Energy, National Energy Technology Laboratory, Berexco LLC, and Computer Modeling Group.Kansas Geological Survey, Energy Section team, and University of Kansas Center for Research acknowledges continues support from Department of Energy, National Energy Technology Laboratory, Berexco LLC, and Computer Modeling Group.