A novel methodology of using well log analyses to identify brownfield and greenfield ROZs in the Illinois Basin

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Abstract

A methodology of analyzing well logs to identify residual oil zones (ROZs) was developed as part of a carbon dioxide enhanced oil recovery (CO₂-EOR) and storage resource assessment of the Cypress Sandstone in the Illinois Basin. The methodology uses a combination of Archie’s oil saturation, the moveable hydrocarbon index, bulk volume water, and apparent water resistivity to pick the top and base of the main pay zone (MPZ) (if present) and ROZ. The methodology was developed to identify and characterize brownfield and greenfield ROZs; however, the lack of data availability requires unique considerations for use in greenfield ROZs. The application of the methodology to the Cypress Sandstone across the Illinois Basin identified 25 brownfield ROZs within oil fields. The resistivity of the formation water (Rw), base of the ROZ, and Archie’s cementation exponent were statistically analyzed to assess their variability within each field and across the basin. Results of well log analyses of MPZs were checked against historical records (i.e. drill stem tests, oil shows, producing MPZ perforations, and core analysis reports) to validate that they contained mobile oil. Rw was derived from historical brine samples and used to calibrate Archie’s cementation exponent. Modifications were required to apply the methodology to greenfields. Well log parameters from data-rich brownfields were used in nearby wells (i.e. outside of the brownfield) to search for associated greenfield ROZs. Regional geologic characterization and interpreted fluid flow pathways were used to estimate rock (volume of shale, cementation exponent) and fluid (Rw) properties for analyses of wells suspected to be a greenfield. Regional maps of these rock and fluid properties were created to ensure that trends were geologically explainable and to support the use of well log parameters in the greenfield wells. The estimates of residual oil saturations from well log analyses of the greenfields were compared to those from the brownfields to ensure that the methodology modifications were effective. The results demonstrate that well log analyses can be used to detect and quantify low oil saturations found in siliciclastic ROZs when validated with historical data and highlights the challenges of identifying ROZs on the basin scale.

References Cited


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Research in the Paradox Basin concluded that ROZs exist within a "fairway" of porous and permeable rock (Pratt et al. 2012; Austin, 2015; Scurlock & Atkinson, 2016). Evidence that such a fairway may exist within the thick Cypress Sandstone in the Illinois Basin:

- Oil production from the thick reservoir is often patchy, with high water cuts in certain areas and low water cuts in others, indicating that the ROZ may be spatially variable.
- Detailed petrophysical characteristics used to develop better understanding of extent and spatial variability of thick Cypress Sandstone.
- Fields within fairway with Cypress production were primary targets.
- Wells with modern logs that fully penetrate thick Cypress were digitized and analyzed.
- Production and historical records (pilot steam tests, drilling reports, drill stem tests) were compiled and compared to well log analyses.

Narwhal West Oil Field

Field Background

- 50 production from the MPZ and top of thick Cypress sandstone. Drilling occurred in low to high brine.
- 36 wells within the 100% with porosity an average to porosity logs. Logs captured post-primary and secondary recovery.

- Unique opportunity to see information from modern wells to determine if wells with old logs can be used to subdivide ROZs.

- See how saturation changes in response to primary and secondary recovery.

- Better understand the difference between a "natural" ROZ and defined MPZ.

- A 90% new (based on neck) published in June 2015.

- K-sigma adjusted until Archie makes 90% of the true transmissibility.

Results

- R-values from the 100% were compared to those from the 50% to determine how Archie based on SP alone would vary with competency and character the ROZ.

- Archie calculated to analyze MPZ, which is expected to shift the PORC-gas and decrease oil saturation within the MPZ. The ORC and residual oil saturation were not expected to change over time.

- Three reported fields were studied:

- The ORC remained constant over time at ~20%.

- Residual oil saturation only remained constant over time at ~20%.

- PORC on the fields ~80% of the total relative to ~20% of the bulk.

- Oil saturation within the MPZ decreased from ~95% to ~4%.

- Residual saturation models calculated using Archie's model on well data and then used to determine how ORC would change over time. The agreement between ORC calculations for each well and the calculated ORC was found to be high. This model is expected to improve accuracy in primary and secondary recovery.

- St. James Oil Field

- Production from several formations indicates a MPZ in the thick Cypress Sandstone in the southern portion of the field. Low to north oil shows some Cypress production.

- Log interpretation indicates a cluster of waterflooded and gasflooded wells in the center of the southern portion of the field, indicative of a depleted oil field.

- Production from the 100% of the field (the main gas and oil reservoirs) were used to determine values in the north wells outside the field boundaries.

- Structure of the porosity below and Cypress indicates gas and oil may interact between the production in the northeast. This is supported by well logs outside the field boundaries with interpreted gas and oil saturation.

- Wells just outside production shows no waterflooded water, which suggests that the ROZ extent and OOO calculated have underestimated resources. More research is needed to constrain true extent of associated gas-water.

- Northern Greenfield Example: Cumberland Greenfield

- Northern, thick Cypress fairway in evidence of a "greenfield fairway".

- Thick intervals of low oil saturation away from disestablished oil fields.

- Milliliters suggest that this oil is not mobile.

- Limited data, difficult to validate, difficult to constrain extent.

- Greenfield Survey: Field Well

- High and low SOZ on field and and field conditions on Greenfield Oil. This and field wells with PNL calculated for the entire interval which suggests mapping in a fluid model.

- Noble Oil Field

- Noble Oil Field served as the primary study area for this project. Oil production from the MPZ near the north edge. Thickest API mudrock reservoirs. Thick and light API mudrock reservoirs at top and near lower edge. The field has several distinct indications of an ROZ beneath the MPZ (field ORZ), high water cut, calcite cementation, etc.

- Geopetal characterization developed for the field and used to construct detailed geocellular models for use in numerical simulation to test hydrocarbon and injectivity scenarios.

Validation

- Packed water logs (PWLs) were run on wells in Noble Field in 2017.

- Assumed to be a more reliable water saturation profile.

- Independent measure of water saturation used to validate agreements between log derived, model derived, and observed water saturation within each Archie and ORC.

- Noble Failed Neutron Validation

- Analysis of logs from the November 2015 DPH survey on a field to determine how well the field ORZ (MPZ) and calculation for the effective ORZ (MPZ) calculated from the ORZ saturation in fluid model.

- Illinois Whole Well Survey data shown in.
Conclusions

- Evidence of ROZs within the thick Cypress Sandstone in 27 “pools” around the Illinois Basin
- Residual oil saturation was within the range expected for sandstones (20-30%)
- The results were statistically analyzed and validated with historical records and modern pulsed neutron logs
- Pools are generally brownfield ROZs within existing oil fields (due to data density)
- Also have evidence of “associated greenfield” wells at the periphery of oil fields and “greenfield fairway” wells far from established oil fields
- Evidence that old logs can be used to identify and characterize ROZs but examples are ideal conditions (known Rw, m, core, thick, clean homogenous sandstone) and have modern logs to support findings. More work is required to determine if porosity logs are necessary in other conditions
- Logs represent snapshot in time. Interpreted ROZs may be depleted MPZs

Current/Future Work: Continued Research on the Illinois Basin ROZs

- Expanded and refined resource assessment
- Using Trentham and Melzer’s (2016) “cookbook” to assess other formations ROZ potential for CO2-EOR and stacked storage capacity
- Field laboratories to validate Cypress ROZ and better understand controls on residual oil saturation

References


Contributors

The four year study of the Cypress Sandstone involved contributions from a number of IGSS staff:
- Project Lead/Incubator -- Nathan Webb, Scott Frailey, Nathan Grigsby
- Geologic Characterization -- Nathan Webb, Kalin Howell, Mingyu Yu, Lio Giannetta, Jared Freiburg, Shane Butler, Yaghoob Lasemi, Zohreh Askari
- Geocellular Modeling and Production History -- Nathan Grigsby
- Well Log Analyses -- Nathan Grigsby and Scott Frailey
- Reservoir Simulation -- Roland Okwen, Scott Frailey, and Fang Yang
- Feedback/Discussion -- John Grube and Bajie Sleyer

www.isgs.illinois.edu/research/erd/nco2eor
Abstract

The application of the methodology to the Cypress Sandstone data availability requires unique considerations for use in greenfield ROZs. The methodology was developed to identify and characterize brownfield and greenfield ROZs; however, the lack of data availability requires unique considerations for use in greenfield ROZs. The application of the methodology to the Cypress Sandstone across the Illinois Basin identified 25 brownfield ROZs within oil fields. The resistivity of the formation water (Rw), base of the ROZ, and Archie’s cementation exponent were statistically analyzed to assess their variability within each field and across the basin. Results of well log analyses of MPZs were checked against historical records (i.e., drill stem tests, oil shows, producing MPZ perforations, and core analysis reports) to validate that they contained mobile oil. Rw was derived from historical brine samples and used to calibrate Archie’s cementation exponent.

Modifications were required to apply the methodology to greenfields. Well log parameters from data-rich brownfields were used in nearby wells (i.e., outside of the brownfields) to search for associated greenfield ROZs. Regional geologic characterization and interpreted fluid flow pathways were used to estimate rock volume (volume of shale, cementation exponent) and fluid (Rf) properties for analyses of wells suspected to be a greenfield. Regional maps of these rock and fluid properties were created to ensure that trends were geologically explainable and to support the use of well log parameters in the greenfields. The estimates of residual oil saturations from well log analyses of the greenfields were compared to those from the brownfields to ensure that the methodology modifications were effective. The results demonstrate that well log analyses can be used to detect and quantify low oil saturations found in siliciclastic ROZs when validated with historical data and highlights the challenge of identifying ROZs on the basin scale.

Equations

The methodology uses a combination of Archie’s oil saturation, the movable hydrocarbon index, bulk volume water, and apparent water resistivity to pick the top and base of a ROZ and quantify the oil within each interval (MPZ) if present and ROZ.

Archie Water Saturation (Sw)

\[
S_w = \left(\frac{R_w}{R_o a + R_f a_T}\right)^\frac{1}{n}
\]

Moveable Hydrocarbon Index (MHI)

\[
MHI = \frac{R_o}{R_w} = \frac{\frac{R_w}{a}}{\frac{R_w}{a + R_f a_T}}
\]

Apparent Water Resistivity (Rwa)

\[
R_{wa} = \frac{a m}{a + R_f a_T}
\]

Bulk Volume Water (BWV)

\[
BWV = S_w + \Phi
\]

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Motivation

ROZs are emerging as a historically overlooked oil resource that can be economically produced via CO2-EOR in the Permian Basin. It is believed that ROZs exist elsewhere, but research is required to identify and better characterize them.

The majority of oil wells drilled in the Illinois Basin have an associated suite of geophysical logs. This poster explores how this existing dataset can be used to identify and characterize historically overlooked siliciclastic ROZs in the Illinois Basin.

Considerations

Well log analyses have unavoidable uncertainty and ROZs inherently have low oil saturations. Therefore, it is vital to understand sources of uncertainty, minimize error, and use all available data to support results wherever possible.

ROZs are most easily identified in thick, clean, sandstone with water saturated base in established oil field. The high data density within a field can be used to constrain input parameters (Rw, m) and results (residual oil saturation, OWC) can be compared to retime uncertainty. Better geologic characterization can be developed to understand how geologic properties (such as the presence of detrital clay and/or clay mineral cements) may influence log interpretation.

Greenfield wells can be interpreted but the lack of data makes their interpretation less reliable. It is vital to validate results with “hard” data, historical records, oil production, core analysis reports, modern logs whenever possible.

ROZ definitions

A “Brownfield” ROZ is defined here as an interval of residual oil that exists beneath a MPZ, an “Associated Greenfield” ROZ exists at the periphery of an established oil field (but has no overlying MPZ), and a “Greenfield Fairway” ROZ exists away from the structure of a MPZ.