Abstract

Residual Oil Zones (ROZs) are volumes of rock in which oil accumulated and was later naturally displaced by encroaching water, leaving residual oil saturation in the range of 20% to 40%. Carbon dioxide enhanced oil recovery (CO₂-EOR) is used to recover oil from known thick carbonate ROZs in the Permian Basin. In other basins, ROZs are not recognized or are ill-defined. Due to the technical and economic limitations of recovering oil at residual saturation to water, there have been few attempts at ROZ production. Therefore, a challenge in ROZ resource assessment is identifying ROZs and quantifying the oil in place. In addition to the economic benefit of oil production via CO₂-EOR, ROZs have the potential for associated CO₂ storage. In the Illinois Basin, an ROZ play has been identified in the Mississippian Cypress Sandstone. The results of the resource assessment of the Cypress ROZ play is presented.

The Cypress Sandstone includes a fairway of thick (up to 175 ft (53 m)) multistory fluvial sandstones that are laterally continuous and vertically amalgamated with high porosity and permeability. Regional correlation and mapping using log data from 4,500 wells provided the basis for a net-sandstone isopach map. Conventional core analysis and porosity log data from ~2,000 wells were combined with the isopach map to generate an isoporosity map. Based on these maps, the thick Cypress fairway covers ~1.9 million acres and contains ~1 billion m³ (1 billion m³) of pore volume.

To identify the oil saturation distribution in the fairway, the Illinois State Geological Survey oil field database was searched for ROZ indicators (e.g. oil shows, core saturation). The Cypress ROZ play was delineated by 18,000 wells with ROZ indicators. To quantify the oil in place, 200 well logs were analyzed, providing thickness and saturation data to constrain the locations of ROZs prospects within the play. Using the median residual oil saturation from well log analysis of 23%, an estimated 1.7 billion barrels of oil in place is contained within the prospects, of which up to 168 million barrels is estimated to be recoverable using a continuous CO₂ flood EOR factor of 9.9% assuming miscible conditions. Associated CO₂ storage in the ROZs, not accounting for main pay zones or underlying brine aquifers, is estimated to be 7.6 billion tonnes,
assuming 45 tonnes/1000 barrels. This resource assessment demonstrates the potential of the Cypress ROZ play for CO$_2$-EOR and associated storage.
Residual Oil Zones (ROZs) are volumes of rock in which oil accumulated and was later naturally displaced by encroaching water, leaving residual oil saturation in the range of 20 to 40%. Carbon dioxide enhanced oil recovery (CO$_2$-EOR) is used to recover oil from known thick carbonate ROZs in the Permian Basin. In other basins, ROZs are not recognized or are ill-defined. Due to the technical and economic limitations of recovering oil at residual saturation to water, there have been few attempts at ROZ production. Therefore, a challenge in ROZ resource assessment is identifying ROZs and quantifying the oil-in-place. In addition to the economic benefit of oil production via CO$_2$-EOR, ROZs have the potential for associated CO$_2$ storage. In the Illinois Basin, an ROZ play has been identified in the Mississippian Cypress Sandstone. The results of the resource assessment of the Cypress ROZ play will be presented.

The Cypress Sandstone includes a fairway of thick (up to 175 ft [53 m]) multistory fluvial sandstones that are laterally continuous and vertically amalgamated with high porosity and permeability. Regional correlation and mapping using log data from 4,500 wells provided the basis for a net-sandstone isopach map. Conventional core analysis and porosity log data from ~2,000 wells were combined with porosity log data from ~2,000 wells to constrain the location of ROZs prospects within the play. Using the median residual oil saturation from well log analysis of 23%, an estimated 1.8 billion barrels of oil in place is considered within the prospects, of which up to 1.6 billion barrels are estimated to be recoverable using an 80-acre blanket WAG CO$_2$ flood EOR factor of 11.4%, assuming miscible conditions. Associated CO$_2$ storage in the ROZs, not accounting for main pay zones or underlying brine aquifers, is estimated to be 3.5 to 40.2 Tcf (0.2 to 2.3 Gt) of CO$_2$ in the Illinois Basin (DOE/NETL, 2012).

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CO₂ Storage and EOR Resource Assessment of the Cypress Sandstone Residual Oil Zone Play in the Illinois Basin

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Methodology: ROZ Identification and Mapping

Understanding petroleum migration into (e.g., Lowen et al., 2000) and reservoir characteristics of the Cypress Sandstone in the Illinois Basin (e.g., Webb et al., 2016) provide the framework for identifying potential ROZs.

- Production or perforations
- Oil shows
- Core oil saturation
- Drill stem tests

Followed Treinham and Melzer’s (2016) “cookbook” approach to document and reinterpret existing data to identify oil indicators used to explore for ROZs:

- Identification of oil indicators, especially in areas with no associated production and within the thick sandstone fairway, guided the selection of wells for further analysis.

Results: ROZ Fairway and Prospects

- Applied well log analysis to quantitatively determine the thickness and saturation values of residual oil.
- Map showing results of well log analysis. Wells with both MPZ and ROZ are shown in green dots, wells with only ROZ are shown with yellow dots, and wells with no indications of oil saturation are shown with red dots.
- Map developed based on:
  - Probability distribution function of median residual oil saturation for 194 wells across the Basin that contained a ROZ. Median (23%) and standard deviations (16% and 3%) are shown with red links.
  - Isopach map to define porous and permeable (p/a) zones.
  - Isopach and structure maps guided spider map of potential oil migration pathways.
  - Occurrence of oil indicators from well data (~18,000 wells with oil indicators) and well log analysis.

Within the ROZ fairway, discrete ROZ prospects were defined (Above Right):
- Prospects were delineated by grouping wells with Cypress oil indicators with wells at which well log analysis indicated a ROZ.
- Structure and thickness maps were used to delineate the boundaries of each potential prospect, where appropriate; some prospects lack clearly defined structural closure.
- Regional isopach map was used for volumetric calculations within each defined prospect (Right).

Above - Map showing results of well log analysis. Wells with both MPZ and ROZ are shown in green dots, wells with only ROZ are shown with yellow dots, and wells with no indications of oil saturation are shown with red dots.

Above - The Cypress Sandstone ROZ fairway (shaded in brown) is defined as the area of the Basin that, based on regional mapping and data analysis, has potential to contain ROZ prospects. Map developed based on:
- Probability distribution function of median residual oil saturation for 194 wells across the Basin that contained a ROZ. Median (23%) and standard deviations (16% and 3%) are shown with red links.
- Isopach map to define porous and permeable (p/a) zones.
- Isopach and structure maps guided spider map of potential oil migration pathways.
- Occurrence of oil indicators from well data (~18,000 wells with oil indicators) and well log analysis.

Below - CO₂ EOR, Net Utilization, and Storage for ROZ prospects. An asterisk (*) next to the prospect name denotes prospects with ROZs that were shallower than the 2,100 ft depth cutoff where the immiscible factors were applied.
Future Work: Continued Research on Illinois Basin ROZs

ROZ validation and screening for other ROZ and stacked CO₂-EOR and associated storage opportunities

- Conduct additional well log analyses to improve confidence in:
  - Spatial distribution of Cypress ROZ fairway and prospects
  - ROZ thickness, porosity, and saturation
- Volumetric estimates of oil in place
- Apply CO₂-EOR and storage factors based on reservoir simulations and published results to determine economic viability of the ROZ play
- Drill a new well and collect fresh core through the Cypress in the Noble ROZ Prospect to validate thickness and saturation estimations
- Expand analyses to include other Illinois Basin formations with potential to host ROZs (Right)

Conclusions:
Cypress Sandstone Resource Assessment

- Preliminary estimate of oil in place for all ROZ prospects
  - Oil in place may or may not be technically recoverable
  - ROZ fairway likely contains oil beyond the boundaries of the prospects defined here

- Based on well log analysis, the median So within Cypress ROZs is 23%, with +/- one standard deviation of 16% and 30%
- MGSC (2005) estimated the total original oil in place for Cypress Sandstone main pay zones in the Illinois Basin to be 2.86 billion barrels
- Identified ROZ prospects may contribute an additional 49% to 91% to oil in place values for the Cypress Sandstone

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References

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- For project information, including reports and presentations, please visit: www.isgs.illinois.edu/research/erd/nco2eor

Contributors
The four year study of the Cypress Sandstone involved contributions from a number of ISGS staff:
- Project leadership – Nathan Webb, Scott Frailey, Nathan Grigsby
- Geologic Characterization – Nathan Webb, Kalin Howell, Mingyu Yu, Leo Giannetta, Jared Freiberg, 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, Fang Yang, Scott Frailey
- Feedback/Discussion – John Grube and Bev Seyler