The Mississippian Thick Cypress Sandstone: A Nonconventional CO\textsubscript{2}-EOR Target in the Illinois Basin*

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Abstract

The Mississippian Cypress Sandstone is the most prolific oil reservoir in the Illinois Basin (ILB). A fairway of thick Cypress Sandstone that can exceed 46 m was deposited in an incised valley system in the ILB. In some places, these thick sandstones contain oil reservoirs in the top with the potential for an underlying residual oil zone (ROZ). These reservoirs typically have low primary recovery due to excessive water coning and are an under produced resource in the ILB. Nonconventional carbon dioxide (CO\textsubscript{2}) enhanced oil recovery (EOR) in such reservoirs provides economic incentive to mitigate CO\textsubscript{2} emissions by storing rather than recycling CO\textsubscript{2} compared to conventional CO\textsubscript{2}-EOR programs. This research focuses on quantifying the thick Cypress Sandstone CO\textsubscript{2}-EOR and storage resource in the ILB. Reservoir characterization using core and analogous outcrop data and analysis of open-hole geophysical logs of varying types and ages to identify the presence of ROZs are underway. If ROZs are present, the mechanism for their emplacement and the geologic characteristics of the formation must be understood so the distribution of ROZs can be predicted. Regional geologic characterization indicates that the thick Cypress Sandstone occurs as multistory fluvial sandstone bodies that become estuarine upward and were deposited in an accommodation limited setting. Marine incursions punctuate the fluvial sandstones with implications for reservoir quality, as marine beds create laterally continuous baffles to vertical fluid flow. Areas with the highest potential for CO\textsubscript{2}-EOR and storage occur where multiple sandstone bodies amalgamate and limit the thickness of the intervening marine strata while facilitating enhanced stratigraphic trapping due to differential compaction over the thick sandstones. Open-hole log analyses are being assessed to determine whether ROZs are present with early results showing oil saturation trends within the thick Cypress Sandstone indicative of ROZs. These methods are being refined to provide more confidence of the presence ROZs, with efforts being taken to collect cased-hole pulsed neutron logs and new core to validate open-hole log analyses. Methods developed here could be applied broadly, as analogous thick sandstones with oil reservoirs and potential ROZs are common in other Carboniferous strata in the ILB and likely in similar settings. Such regional resource assessments may provide industry with information needed to initiate CO\textsubscript{2}-EOR in the ILB.

References Cited

Melzer, L.S., 2006, Stranded Oil in the Residual Oil Zone. DOE contract report.

Determine potential for net carbon negative oil (NCNO) production via CO2-EOR and geologic storage

• Objectives of this four-year study include
  - Characterizing geology of CO2-EOR target formation
  - Identifying ROZs by looking for direct (oil saturation, relatively fresh water, different oil composition) indicators
  - Developing a CO2-EOR/storage strategy for the regional resource based on detailed case studies

Regional geologic characterization indicates that the thick Cypress Sandstone occurs as mostly tabular sandstones that become euxinic upward and were deposited in an accommodation limited setting. Marine incursions punctuate the thick Cypress sandstones with implications for reservoir quality, as marine beds create laterally continuous baffles to vertical fluid flow. Areas with the highest potential for CO2-EOR and storage occur where multiple sandstone bodies amalgamate and limit the thickness of the intervening marine strata while facilitating enhanced stratigraphic trapping due to differential compaction over the thick sandstones. Open-hole log analyses are being assessed to determine whether ROZs are present with early results showing oil saturation trends within the thick Cypress Sandstone indicative of ROZs. These methods are being refined to provide more confidence in the presence of ROZs, with efforts being taken to collect cased-hole pulsed neutron logs and new core to validate open-hole log analyses.

Methods developed here could be applied broadly, as analogous thick sandstones with oil reservoirs and potential ROZs are common in other Carboniferous strata in the ILB and likely in similar settings. Such regional resource assessments may provide industry with information needed to initiate CO2-EOR in the ILB.

Abstract

Geologic Setting and History of Noble Field

Noble Field Location
• Discovered in 1937
• Part of Clay City Consolidated Field
• Relatively few areas of the Basin where thick Cypress Sandstone is a prolific producer; Noble Field is the best example

Above is a graph of cumulative (blue line) and annual (orange line) production data for all formations and all leases in Noble Field over the entire history of the field. The Cypress Sandstone accounts for approximately 50% of the total cumulative production. Field has produced >45 MMBO~24 MMBO (~50%) from thick Cypress Sandstone

Structure map (Left) contoured on the base of the Barlow Limestone shows the NE-SW trending Clay City anticline on which Noble Field is situated.

Background and Study Area

Cypress Sandstone
• Multiple facies in the Illinois Basin (Below)
• Production commonly from sandstone lenses

Above - Generalized stratigraphic column of Noble Field showing the Cypress Sandstone

Above - Thin conventional reservoirs with potential residual oil zones (ROZs)
• Naturally waterflooded over geologic time
• EOR with high net CO2 utilization
• Saline storage potential of 3.5 to 40.2 Tcf (~0.2 to 2.3 Gt) of CO2 in the Illinois Basin (DOE/MGSC, 2012)

Above - Generalized stratigraphic column of Noble Field showing the Cypress Sandstone

To better understand and assess the regional resource, a detailed case study was conducted concentrating on:
• Geologic Characterization
• Petrophysics
• Geocellular modeling

Leveraging this multidisciplinary approach will allow for a better understanding of the petroleum system and will aid in assessing the regional resource.

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Geologic Characterization

Create a conceptual geologic model by characterizing depositional and diagenetic facies to better understand petrophysical properties of the rock

Petrophysics

Use logs to quantify oil saturation and determine oil saturation profiles

Geocellular Modeling

Numerical models that reflect geologic heterogeneity in petrophysical properties and can be populated with fluid saturation data. Models are calibrated to production data and used for reservoir simulation of CO2-EOR and storage scenarios
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Methods

- Petrophysical analysis can provide indirect indication of ROZs
- Need core and cased hole logs for validation

**Recovery of Source Oil**
- Some continuous shale breaks
- Persistent calcite, cemented zones
- Base of sandstone truncates underlying units
- Isopach shows interacting NN-SE and NE-SW trending sandstone bodies (Right)

**Depletion Environments**
- The Cypress Sandstone at Noble Field is likely part of a lowerland (LLS) incised valley environment
- Multistory sandstones built through parasequence-scale transgression/fotomy of depositional apaxes
- Amalgamated surficial to estuarine channels are punctuated by marine incursions as indicated by fossil fragments

**Geological Model (Below)**
- Noble Field is surrounded by-several thin amalgamated sandstones
- Core based volume of shale will be used to calibrate log-based estimates to improve petrophysical analysis
- The Cypress Sandstone at Noble Field is likely part of a lowerland (LLS) incised valley environment
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**Geophysical Logs**
- Can be used to calculate water saturation (Sw)
- Gradual transition in Sw between oil reservoir and brine aquifer may indicate ROZs (Example Log, Right)

**Contrast in back-scattered electron images** is determined by the atomic number (Z) of the phase

**Grain-coating chlorite rosettes**

**Densely packed detrital shale clast**

**Incorporating Microporosity**

- Microporosity in clay minerals creates a continuously conducting path of water-filled zones
- Extra source of conductance can cause a low resistivity log response, resulting in an overestimation of water saturation
- Core based volume of shale will be used to calibrate log based estimates to improve petrophysical analysis

**Effective porosity (e_p)** is the pore space that contributes to fluid flow

- Water in clay microporosity is immobile (does not flow) during production

- This can lead to significant overestimations of porosity, and therefore recoverable oil
- For accurate resource assessment, microporosity (e_p) must be excluded from total porosity (e_t)

**Comparison of Weight Percent and Volume Percent from Ve calculations from BSE images**

**Effect of Microporosity**
- Microporosity in clay minerals creates a continuously conducting path of water-filled zones
- Extra source of conductance can cause a low resistivity log response, resulting in an overestimation of water saturation

**Core based volume of shale** will be used to calibrate log based estimates to improve petrophysical analysis

**Areole - Saturation curves** show potential ROZs below the producing OCR

- Similar trends are produced between Archie and Ratio methods, but the Ratio method generally had a suppressed Sw curve

- Consistently lower Sw than the Archie Method
- Several wells had Sw values >100%
Findings and Implications

• Noble Field is a microcosm of the regional nonconventional CO₂-EOR resource of the thick Cypress Sandstone
  ◦ Abundant oil production and sound geologic interpretation provide confidence in modeling results and information for better understanding the regional resource
  ◦ Noble Field has thickest known oil column and >25% recovery efficiency, highlighting the potential for CO₂-EOR
  ◦ Indications of an ROZ has implications for the regional nonconventional CO₂-EOR target
  ◦ Oil/water contact is tilted towards the south
  ◦ Petrophysical analysis indicates possible ROZ
  ◦ Calcite cement below oil/water contact may represent paleo-oil/water contact
  ◦ Integrating geologic characterization, petrophysics, and geocellular modeling leads to a better overall interpretation

Future Work

• Fingerprint oil to its source to understand migration into the reservoir
  ◦ Understanding the mechanism for ROZ formation to predict where they occur
  ◦ Investigate calcite cemented zones and relationship to oil/water contact
  ◦ Indications of paleo-oil/water contact? Evidence for ROZ?
  ◦ Coring and cased hole logging to validate petrophysical results
  ◦ Simulate production history to determine the most effective CO₂-EOR and storage method
  ◦ Scenarios weighted towards oil production and storage
  ◦ Potential to produce net carbon negative oil (NCNO)
  ◦ Map thick Cypress Sandstone at regional scale
  ◦ Identify locations with oil reservoirs and possible ROZs analogous to Noble Field
  ◦ Estimate regional resource using results from Noble Field case study and reservoir simulation
  ◦ Better understanding of the geology of the thick Cypress Sandstone
  ◦ Refine algorithm for identifying ROZs

References


Contributors

• Co-Prs – Scott Frailey and Hannes Leetaru
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• Geocellular Modeling and Production History – Nate Grigsby
• Petrophysical Analysis – Josh Armeson and Scott Frailey
• Clay Microporosity and Mineralogy – Leo Giannetta and Shane Butler
• Sedimentary Descriptions – Kalin Howell and Zohreh Askari
• Petrography – Jaclyn Daum and Jared Freiburg
• Reservoir Simulation – Fang Yang and Roland Okwen
• Feedback/Discussion – John Grube and Bev Seyler
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• For project information, including reports and presentations, please visit: http://www.isgs.illinois.edu/research/oil-gas/doe