Calculation of CO$_2$ Storage Capacity for Arbuckle Group in Southern Kansas: Implications for a Seismically Active Region

Yevhen Holubnyak, Eugene Williams, Lynn Watney, Tandis Bidgoli, Jason Rush, Mina FazelAlavi, and Paul Gerlach

13th International Conference on Greenhouse Gas Control Technologies
Lausanne, Switzerland
November 18, 2016
Outline

• Modeling CO$_2$ storage capacity for South-Central Kansas Arbuckle aquifer
• Current state of seismicity and waste water disposal in Southern Kansas
• How risk of seismicity affects storage capacity
Regional Assessment of deep saline Arbuckle aquifer

Area of Interest
Plan for Capacity Estimations Study

• Determine formations of interest and outline the area of review
• Select promising sites of interest with known structure (total of 10)
• Gather data
  – Available through existing database at KGS and other sources
  – Drill and core wells, process 3D seismic, well test analysis, process logs, etc.
• Create geologic models for 10 sites and an entire region
• Perform dynamic simulations
Top Arbuckle Structure Map showing Study areas
Core from Lower Arbuckle Injection Interval

5089-92 ft

5080-83

5053-56

4995-97.7 ft
Thin Sections – Baffle Zone (Mid Arb.)

Flow units in the lower Arbuckle injection zone

Pairs of photomicrographs
Plane light and crossed nichols

R. Barker, S. Datta, KSU
Well KGS 1-32

weightfrac
0.00 w/w 1.00

Dry Weight Siderite QE
Dry Weight Parahexahedrite QE
Dry Weight Anhydrite QE
Dry Weight Dolomite QE
Dry Weight Calcite QE
Dry Weight K-Feldspar QE
Dry Weight Quartz QE
Dry Weight Chlorite QE
Dry Weight Kaolinite QE
Dry Weight Illite QE
Well
KGS 1-28
Br⁻/Cl⁻ and SO₄²⁻/Cl⁻

Identification of Baffles and Lack of Vertical Communication

• Br⁻ and Cl⁻ are conservative during water/rock interactions

• Very useful in detecting brine sources and mixing

• Values for brine of Lower Arbuckle vary substantially from Upper Arbuckle

• Lower Arbuckle brines cluster together

• Upper Arbuckle values more spaced out, suggests smaller baffles
Arbitrary seismic impedance profile – Wellington Field

distinct caprock, mid-Arbuckle tight, lower Arbuckle injection zone

Impedance = \( \rho \times \varnothing \)

- Top Oread
- Thick Lansing Group Shales
- Top Kansas City Ls.
- Top Mississippian
- Lower Pierson
- Top Arbuckle
- Top Precambrian

Baffle or potential barrier to vertical flow
(high impedance)

Low impedance injection interval

Hedke – DOE/CO2
Rock Mechanical Properties vs. Depth

- **Young's Modulus (x10^6 psi)**
- **Poison's Ratio**
- **Compressive Strength (psi)**

**Depth, ft**

- Upper Mississippian
- Lower Mississippian
- Cap-Rock
- Top Arbuckle
- Tight Arbuckle
- Injection zone
Step Rate Test Analysis
Pressure-Time plot

Estimated $K_h = 3750 \text{ md}$
Estimated FPP > 2800 psi

Field Data
Modeled Fit
Computed Kh & Kv in Arbuckle Group for Digital Type Wells ( )

- Correlation of flow units based on K_h & k_v
- Between Cutter and Wellington Fields (350 km apart)
- Testing log-derived permeability with Class I buildup test data

Simulation sites for commercial storage evaluation

350 km
Structural cross section showing regional Arbuckle flow units, southern Kansas

Index map, Kansas

Horizontal Permeability, md

Williams, Gerlach, Fazelalavi, Doveton, KS CO₂
Relative Permeability and Capillary Pressure

Co2-Brine Relative Permeability for Different RQI

Drainage

Imbibition
Conceptual & Geologic Architecture
- stratigraphic interpretation
- outcrop and field analogs

Well Logs and Core
- surface locations
- lithofacies/geologic data
- porosity/permeability

Seismic
- surfaces/stratigraphy/fluids
- porosity/facies attributes
- 4-D seismic monitoring

Engineering Data
- DST/RFT data
- pressure transient/tracer
- historical Q,P,C data

Forward Modeling
- stacking patterns
- geometric data for facies
- spatial information for porosity/permeability

modified from Deutsch, 2002
Rock Type Based on RQI

Permeability (K90)

Permeability (Vertical)

Rock Type Based on RQI

\[ RQI = 0.0314 \sqrt{\frac{Perm}{Porosity}} \]
Dynamic Simulation Model

Ground surface elevation is 1257 ft.
Kelly bushing elevation is 1270 ft.

Top Reservoir
Baffle Zone
Perforated Zone
Injection Interval

KGS 1-28

No-flow boundary (caprock)
No-flow boundary (base)

Arabian Group

Scale: 1:8681
Z/Y: 3.00:1
Axis Units: ft
Simulated commercial storage capacity in the Arbuckle saline aquifer for 10 sites

<table>
<thead>
<tr>
<th>Area</th>
<th>Estimated Storage Capacity (P50), million tonnes</th>
<th>Area, km²</th>
<th>Gross Thickness, m</th>
<th>Net Reservoir Thickness, m</th>
<th>Porosity, %</th>
<th>Average Permeability, md</th>
<th>Depth, m</th>
<th>Limiting Injection Pressure, bar</th>
<th>Reservoir Pressure, bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>79</td>
<td>1.4</td>
<td>300</td>
<td>66</td>
<td>5</td>
<td>25</td>
<td>1184</td>
<td>187</td>
<td>144</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>5.2</td>
<td>223</td>
<td>49</td>
<td>4</td>
<td>15</td>
<td>1508</td>
<td>223</td>
<td>175</td>
</tr>
<tr>
<td>3</td>
<td>49</td>
<td>6.1</td>
<td>258</td>
<td>57</td>
<td>6</td>
<td>15</td>
<td>1388</td>
<td>210</td>
<td>162</td>
</tr>
<tr>
<td>4</td>
<td>121</td>
<td>6.6</td>
<td>240</td>
<td>53</td>
<td>6</td>
<td>15</td>
<td>1170</td>
<td>179</td>
<td>138</td>
</tr>
<tr>
<td>5</td>
<td>55</td>
<td>1.4</td>
<td>300</td>
<td>66</td>
<td>5</td>
<td>19</td>
<td>1581</td>
<td>240</td>
<td>185</td>
</tr>
<tr>
<td>6</td>
<td>98</td>
<td>2.4</td>
<td>205</td>
<td>45</td>
<td>6</td>
<td>23</td>
<td>1310</td>
<td>194</td>
<td>150</td>
</tr>
<tr>
<td>7</td>
<td>71</td>
<td>1.2</td>
<td>209</td>
<td>46</td>
<td>3</td>
<td>31</td>
<td>1266</td>
<td>189</td>
<td>145</td>
</tr>
<tr>
<td>8</td>
<td>104</td>
<td>2.6</td>
<td>240</td>
<td>53</td>
<td>6</td>
<td>20</td>
<td>1089</td>
<td>169</td>
<td>130</td>
</tr>
<tr>
<td>9</td>
<td>98</td>
<td>5.8</td>
<td>230</td>
<td>51</td>
<td>6</td>
<td>18</td>
<td>1377</td>
<td>206</td>
<td>158</td>
</tr>
<tr>
<td>10</td>
<td>104</td>
<td>5.4</td>
<td>208</td>
<td>46</td>
<td>6</td>
<td>25</td>
<td>1224</td>
<td>183</td>
<td>141</td>
</tr>
<tr>
<td>Regional Model</td>
<td>4000</td>
<td>821</td>
<td>243</td>
<td>54</td>
<td>5</td>
<td>21</td>
<td>1288</td>
<td>195</td>
<td>150</td>
</tr>
</tbody>
</table>
CO₂ Spatial Distributions: 10 sites vs Max Capacity
Predicted Delta Pressure Distributions: 10 sites vs Max Capacity
Brine injection in Oklahoma in 2014 was ~2 billion barrels
Earthquakes are larger and more numerous in Oklahoma.
Seismic and Waste Disposal Trends in Southern Kansas

Slight reduction in seismic activity following state restriction order on injection volumes and other factors

Equivalent of 9M CO₂ tones/year for one county
Kansas Earthquakes as Reported by NEIC

- First report on July 26, 2015 of new USGS temporary array “ismpkans” in Harper & Sumner counties

Saltwater disposal wells in earthquake zones

Vance radar just after 4.7 earthquake
Common Analogs?

- What is the capacity?
- Empty Volume = 37M ft³ = 6.6M bbls
- If $\phi = 5-7\%$
- Volume$_\phi$ = ~450K bbls
- If efficiency = 50%$
- Volume_e = ~225K bbls$
- High volume wells used to deliver up to 30K bbls/day
- Therefore
  
  It would take up to 7-15 days to fill up this volume (without considering existing water)

  It would take 111-222 “ES units” to accommodate 50M bbls injected in 2014

  Translates into 3.9-7.8M ft²

  Harper Co. Area = 22.4B ft²

  “Plunging” system?

Empire State Building

V=37M ft³

NS 187 ft

Arbuckle Porosity Model

Arbuckle Permeability Model
Basement geology from sample rock types in the area of the induced seismicity

→ thick arkosic sediment fill indicative of the Midcontinent Rift System (MRS)
Downhole Pressure Monitoring

- ~ 30 psi increase since 2011
- 16 psi pressure spikes

Estimated Kh = 3,750 md
Estimated FPP > 2,800 psi

Field Data
Modeled Fit
Summary

• Does the risk of induced seismicity affect storage capacity?
  – Yes, absolutely
• Is the risk of induced seismicity a CCS killer?
  – IMHO, No; however...
• Arbuckle/basement interface?
• More characterization
• Monitoring strategies
  – Seismicity monitoring
  – Engineering solutions (pressure monitoring, well testing, etc.)
• Injection management strategies
Acknowledgements & Disclaimer

**Acknowledgements**

- The work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Grant DE-FE0002056 and DE-FE0006821, W.L. Watney and Jason Rush, Joint PIs. Project is managed and administered by the Kansas Geological Survey/KUCR at the University of Kansas and funded by DOE/NETL and cost-sharing partners.

**Disclaimer**

- This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
Acknowledgements

• Bittersweet Energy – Tom Hansen with Paul Gerlach and Larry Nicholson; Dennis Hedke, Martin Dubois and SW Kansas CO$_2$-EOR industry consortium, John Youle, George Tsoflias and students at KU, Gene Williams, and KGS staff supporting the acquisition of data, stratigraphic correlation, regional mapping, and interpretations for the DOE-CO$_2$ project
• Dana Wreath, Berexco, LLC for access and participation in drilling and testing at Wellington and Cutter fields and small scale field test at Wellington
• Rick Miller and Shelby Petrie, Wellington seismometer array, high resolution seismic
• Justin Rubinstein, USGS
• Induced Seismicity Task Force -- Rex Buchanan and Rolfe Mandel