Brine Disposal Reservoirs in the Appalachian Basin: Injection Performance and Geological Properties

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Outline

1. Project Overview/Background
2. Geological/Class 2 Operational Data Collection
3. Reservoir Analysis
4. Injection Performance Analysis
5. Local-scale Analysis of injection zones
6. Local-scale injection simulations
7. Conclusions/Future Work
Project Overview

- Project funded by RPSEA/DOE-NETL under their 2011 Unconventional Onshore Program (contract 11122-73)
- Period of Performance: 2 years from 4/1/2013 to 3/31/2015
- Project team: Battelle, KY, OH, PA, WV Geological Surveys NSI Tech.
- Material reflects team contributions!
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Project Overview

• Objective- Provide an understanding of the geology and operational history for Class 2 brine disposal in the Appalachian Basin to support safe, reliable, and environmentally responsible brine disposal in the region.

Geological Analysis

Operational Data

Geotechnical Tests

Injection Test/Data Analysis

Reservoir Simulations
Background - Demand for Brine Disposal

- Growth in shale gas = increased demand for Class II brine disposal.
- Geologic/regulatory constraints in other states leading to commercial-scale facilities in western Appalachian basin, especially in eastern Ohio.
- The geologic and reservoir parameters of injection zones poorly understood - planned assessment is required to meet long-term demand.
- Concerns about potentially low injectivity, fracture pressure constraints, and induced seismicity.
Background – Study Area

- Study area includes Eastern Kentucky, Ohio, Pennsylvania, and West Virginia.
Background – Class 2 UIC Wells

- Note: Class 2 UIC includes both brine disposal wells and EOR wells. This project addresses brine disposal wells only.

UIC Class II Well Locations

Legend:
- Other Class II Well
- Active Class II Well

Active well locations from data collected August 2013. All other locations from 2008 data. All locations approximate.
Background - Brine Disposal Sources

- Source areas are most intense along Marcellus trend.
- Few disposal wells near the most intense well density.
Background – Geology

- Diverse range of injection zones are present in the Appalachian Basin.
- Injection spread from Mississippian age sandstones to Cambrian Basal sands.
Background – Geology

- Injection zones reflect regional geology with younger zones more prevalent into the basin in WV, PA, and KY.
Class 2 Operational Data

- Class 2 UIC brine disposal monthly operational data was obtained from UIC programs for 2008-2012:

<table>
<thead>
<tr>
<th>State</th>
<th>Class II Status</th>
<th>Regulatory Agency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kentucky</td>
<td>Regional Implementation</td>
<td>USEPA Region 4 UIC Program</td>
</tr>
<tr>
<td>Ohio</td>
<td>State Primacy</td>
<td>Ohio Dept. of Natural Resources Division of Oil &amp; Gas</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>Regional Implementation</td>
<td>USEPA Region 3 UIC Program</td>
</tr>
<tr>
<td>West Virginia</td>
<td>State Primacy</td>
<td>West Virginia Dept. of Env. Protection Office of Oil &amp; Gas</td>
</tr>
</tbody>
</table>

- Data was tabulated from permit reports and evaluated with statistics, graphs, and maps based injection formations, depths, locations.

- We looked at 2008-2012 time period and 2012.

- As of ~August 2013, records showed approximately 324 Class II brine disposal wells with active permits in the study area.

<table>
<thead>
<tr>
<th>Class II Injection Wells</th>
<th>E. KY</th>
<th>OH</th>
<th>PA</th>
<th>WV</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Brine Disposal Wells</td>
<td>30</td>
<td>211</td>
<td>7</td>
<td>76</td>
<td>324</td>
</tr>
<tr>
<td>Inactive/Abandoned Brine Disposal Wells</td>
<td>15</td>
<td>461</td>
<td>14</td>
<td>44</td>
<td>534</td>
</tr>
<tr>
<td>EOR Wellsa</td>
<td>~1,200</td>
<td>~1,700</td>
<td>~1,800</td>
<td>~650</td>
<td>~5,400</td>
</tr>
</tbody>
</table>

a. Source: USEPA Class II survey data
Class 2 Operational Data

- Survey data show brine disposal volumes doubled from 2008-2012.
Class 2 Operational Data

- We generally focused on monthly injection rates, volumes, days active, and wellhead pressures as reported.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Count &gt;0</td>
<td>218</td>
<td>218</td>
<td>174</td>
</tr>
<tr>
<td>Max</td>
<td>766,596</td>
<td>120,976</td>
<td>2,384</td>
</tr>
<tr>
<td>Mean</td>
<td>80,620</td>
<td>7,061</td>
<td>628</td>
</tr>
<tr>
<td>Median</td>
<td>32,015</td>
<td>2,668</td>
<td>543</td>
</tr>
<tr>
<td>STD</td>
<td>122,317</td>
<td>12,293</td>
<td>480</td>
</tr>
</tbody>
</table>

- The status of Class II brine disposal wells is highly variable. Data should not be considered a definitive list of Class II wells. This information is maintained by state or regional EPA UIC programs and changes frequently.
Class 2 Operational Data

- Many existing Class II brine disposal wells from the 1980s were used initial disposal (most of these wells were related to ‘Clinton’ development in Ohio).

- More wells have recently been installed to meet demand for brine disposal.
Class 2 Operational Data

- This research focuses on 2008-2012 since that operational data was available at the time we collected data from UIC programs.

- Over 30 new Class II brine disposal well permits since 2012 in the Appalachian Basin, including 5 in Pennsylvania.
Class 2 Operational Data

- Summary of Class 2 Brine Disposal Total Injection Volume in 2012 by Deepest Injection Formation.
- Data may reflect well activity more than injection capacity/performance.
Class 2 Operational Data

- Summary of Class 2 Brine Disposal Total Injection Volume in 2012 by Deepest Injection Formation.
- Data may reflect well activity more than injection capacity/performance.

**2012 Average Injection Rate (bbl/month)**

- Penn-Miss (Big Injun, Weir, Maxton, etc)
- Upper Dev. (Berea, Dev SH, Bradford)
- Mid. Dev. Ondondaga, Huntersville
- Upper Sil. Lockport, Newburg, Comiferous
- Lwr Silurian Clinton-Medina
- Undiff. Knox
- Rose Run
- Copper Ridge, Trempealeau
- Mt. Simon, Basal SS

**2012 Average Wellhead Injection Pressure (psi)**

- Penn-Miss (Big Injun, Weir, Maxton, etc)
- Upper Dev. (Berea, Dev SH, Bradford)
- Mid. Dev. Ondondaga, Huntersville
- Upper Sil. Lockport, Newburg, Comiferous
- Lwr Silurian Clinton-Medina
- Undiff. Knox
- Rose Run
- Copper Ridge, Trempealeau
- Mt. Simon, Basal SS
Operational Data- Field Operations Monitoring

Objective

- Monitor wellhead pressure/flow for existing Class 2 Brine disposal wells to estimate reservoir properties for injection zones in the Appalachian Basin.

Methods

- Provide wellhead loggers to operators during routine operation/injection cycles.
- Complete pressure falloff/buildup analysis to estimate reservoir properties.
- Data also provided better understanding of operational cycles in relation to reservoir properties.
‘Clinton’-Medina

-Five Silurian ‘Clinton’-Medina wells monitored.

-4 Wells run continuously at high pressure and rate, showing no falloff.

-1 well had limited injection testing (~50 minutes step rate injection and well went on vacuum) made analysis uncertain. Best guess analysis = 17 mD across 160 ft.

Well 1
Well 2
Well 3
Well 4
Well 5

Well Test
Lockport - ‘Newburg’

- Injection cycles monitored on Newburg Class 2 injection well
- Well showed several pressure fall off cycles.
- Analysis suggests ~5 mD across 94 ft.
Knox (Rose Run-Copper Rdg)

- Injection cycles monitored on a Knox (Rose Run-Copper Ridge) injection well.
- Well showed several pressure fall off cycles.
- Analysis suggests 3 mD across 124 ft.
Local scale analysis of Injection Zones

• Local scale geological analysis of injection zones completed for 7 areas to define distribution of formations in relation to operational history.
Local scale analysis of Injection Zones

- Example: Weir sandstone in Eastern Kentucky.
- Tabular sandstone used for local disposal.
- Injection on downdip monocline with sealing fault.
Local scale analysis of Injection Zones

- Example: Lockport-Newburg in NE Ohio.
- Most injection in the Lockport targeted carbonate buildups.
- Reefal trends in the Lockport will aid in predicting zones with potentially high porosity.
Local scale analysis of Injection Zones

- Example: Upper Devonian Bradford in PA.
- Thin, discontinuous sands with limited injection potential.
Local scale analysis of Injection Zones

- Example: Big Injun Sandstone in central WV.
- Injection may be influenced by local structures.
Reservoir Performance Analysis

- Results of the geological analysis and operational data were evaluated for indicators of reservoir performance.
- More detailed ‘relative injectivity index’ analysis was completed for monthly operational data for indicators of reservoir performance.

![Average Monthly Injection vs Porosity-Ft](image)
Reservoir Performance Analysis

• ‘Relative injectivity index’ analysis provided more qualitative indicator of injection performance over time for 24 wells.
• (Injectivity Index = Injection Rate/Delta Pressure)

Example- Lockport–‘Newburg’ Injection Well (10+ years of operational data shows decrease in injectivity index)

Example- Mount Simon/Basal Sandstone Well (10+ years of operational data shows steady injectivity index)
Geocellular Model Development

- Geocellular models developed for key injection zones to provide basis for injection simulations.

Lockport-Newburg

Knox-Basal Sand

‘Clinton’-Medina

Weir Sandstone
Injection Simulations

Objective- Simulate brine injection process to assess pressure buildup and fluid migration effects.


Weir SS

Knox-Basal SS

‘Clinton’-Medina
**Weir Sandstone**

- Model based on Weir injection well in W. Appalachian basin.
- 78 BBL/day injection rate 10 yrs
- Anticline structure with sealing fault

![Simulated Salinity, 125,000 ppm injection fluid at 3650 days X 78 BBL/day](image1.png)

![Simulated Pressure (Max Delta P = 355 psi)](image2.png)

VE = 10X
Clinton-Medina

- Model based on composite data from 4 wells in central App.Bas.
- Formation salinity set at 150,000 mg/L, Injection rate = 1250 bbl/day for 10 years (based on nearby wells typical rates).

Simulated Salinity, 125,000 ppm injection fluid at 3650 days X 1250 BBL/day

Simulated Pressure (max delta P = >1500 psi)
Knox to Basal Cambrian Sandstone

- Permeability assigned based on NMR log est. permeability by layer.
- Well screened from Copper Ridge-Rome.
- Low density (125,000 ppm) and high density (250,000 ppm) injection simulated @ 450 bbl/day for 10 years.

Simulated Salinity, 250,000 ppm injection fluid at 3650 days X 450 BBL/day

Simulated Pressure Max Pressure Buildup = ~497 PSI
Lockport Dolomite “Newburg”

- 10 years injection @ 300 bbl/day.
- Formation salinity 278,000 ppm, injection 200,000 ppm.

- Simulated salinity profile through time.
- 10 years injection, 15 yrs post-injection.
Conclusion/Future Work

1. Existing brine disposal framework reflects historical oil & gas developments in the Northern Appalachian Basin. Since 2003, unconventional shale gas production has increased demand for Class 2 brine disposal, including more fluid related to well treatment/flowback along with produced water.

2. There are a wide variety of injection zones used for Class 2 brine disposal in the N. Appalachian Basin, and they vary in character, distribution, and injection potential.

3. Historical operational data provides useful information on safe operating ranges for brine injection wells (monthly injection rates, injection pressures) which will be useful for operators. However, sometimes data merely reflects well activity.
Conclusion/Future Work

5. Integrating geologic data with operational data proved challenging, and many wells only provided indicators of reservoir performance.

6. Field monitoring of injection operations was used for pressure-falloff analysis, which indicated moderate reservoir permeability which may be a limiting factor on injectivity.

7. Local scale analysis of injection zones provided a better understanding of the subsurface geological features, which appear to affect injection performance over times.

8. Reservoir simulations show estimated pressure and variable density effects of injection are present mostly near the injection well. There appears to be little additional brine migration related to variable density effects after injection stops.
The End. Thanks!