Comparison of Single and Multiphase Tracer Test Results From the Frio CO$_2$ Pilot Study, Dayton Texas

GCCC Digital Publication Series #05-04t

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Keywords:
Flow Paths, Tracer Tests, Radial Flow Model, Dipole Model, Fluid Displacement

Cited as:
Fourth Annual Conference on Carbon Capture & Sequestration

Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date

Geologic – Frio Brine Field Project (1)

Comparison of Single and Multiphase Tracer Test Results from the Frio CO₂ Pilot Study, Dayton Texas

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May 2-5, 2005, Hilton Alexandria Mark Center, Alexandria Virginia
Outline

• Single-phase fluorescein tracer test
  – Field method
  – Description of dipole (or Doublet) model
  – Fluorescein data reduction and model match

• Gas-phase krypton tracer experiment
  – Field method/U-tube sampler
  – Description of radial dispersion model
  – Krypton data reduction and model match

• Comparison of single and multiphase tracer results
• Conclusions
• Recommendations & Acknowledgments
Single-Phase Fluorescein Tracer Test Prior to CO₂ Injection

FIELD METHOD

• Brine pumped at 51.4 gpm
• Steady flow was developed 24 hrs. prior to tracer injection
• Fluorescein tracer was added to injection water, c₀ = 21.6 ppm
• Water samples collected every ½ hr. throughout test
• Water samples analyzed on site using a spectrophotofluorometer with detection level of ~ 6 ppb
• Test duration 15.7 days
Single-Phase Dipole Semi-Analytical Model Description
(Grove and Beetem, 1971)

MODEL ASSUMPTIONS AND CONDITIONS
- Horizontal steady-state flow
- Homogeneous, isotropic aquifer of constant thickness
- Constant longitudinal dispersivity $\alpha_L$
- Ignores diffusion, adsorption, retardation and transverse dispersivity $\alpha_T$
- 1-D flow through a finite length column is used to model dispersion along individual streamlines.

ANALYTICAL PROCEDURE
- Analytical solution predicts travel time between wells for a dipole
- Travel time is used in 1-D dispersion solution to yield $c/c_0$ for each streamline
- Each streamline contribution is added to produce total $c/c_0$ at discharge well
- Superposition is used to calculate solution for finite length tracer pulse

Fluorescein Data Match to Dipole Model

- Improved match using longer tracer injection period.
- First arrival predicted by model = 7 days
- First arrival based on data = 8.9 days
- Late time data confirms first arrival based on model prediction

Parameter Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tracer Inj. Time (hr)</th>
<th>Dispersivity, $\alpha_L$ (ft)</th>
<th>Effective Porosity (%)</th>
<th>Saturated Thickness (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.15</td>
<td>0.28</td>
<td>34.2</td>
<td>27.5</td>
</tr>
<tr>
<td></td>
<td>1.69</td>
<td>0.83</td>
<td>34.5</td>
<td>27.5</td>
</tr>
</tbody>
</table>
Gas-Phase Krypton Tracer Test During CO₂ Injection

FIELD METHOD

- CO₂ injected at 69.2 gpm
- CO₂ flow field was developed prior to tracer injection
- Krypton gas tracer was added to injected CO₂, c₀ = 36.9 ppmV
- Gas samples collected every hour using U-Tube sampler
- Gas samples analyzed on site using a quadrupole mass spectrometer with method detection level of ~ 50 ppbV
- Test duration 3 days
Radial Analytical Dispersion Model Description
(Hoopes and Harleman, 1967)

MODEL ASSUMPTIONS AND CONDITIONS

- Horizontal steady-state flow
- Homogeneous, isotropic aquifer of constant thickness
- Constant longitudinal dispersivity $\alpha_L$
- Ignores diffusion, adsorption, retardation and transverse dispersivity $\alpha_T$
- Solution is inaccurate near the injection well for early times
- Model does not account for buoyancy

ANALYTICAL PROCEDURE

- Analytical solution to the radial dispersion equation predicts $c(t, r)/c0$ for constant concentration source
- Superposition is used to calculate solution for finite length tracer pulse

Krypton Data Match to Radial Model

- First arrival in 53.47 +/-0.5 hours
- Departure of late-time data implies back diffusion of krypton into brine after peak concentration passes observation well

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<th>Saturated Thickness (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No delay</td>
<td>0.13</td>
<td>0.16</td>
<td>8.4</td>
<td>10.3</td>
</tr>
</tbody>
</table>
# Comparison of Tracer Test Results

## Single-Phase Dipole Fluorescein Test

<table>
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<td>0.83</td>
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<td>27.5</td>
</tr>
</tbody>
</table>

## Multi-phase Radial CO$_2$ /Krypton Test

<table>
<thead>
<tr>
<th>Tracer Inj. Time (hr)</th>
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<th>Effective Porosity (%)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>0.13</td>
<td>0.16</td>
<td>8.4</td>
<td>10.3</td>
</tr>
</tbody>
</table>

- Saturation estimate = 24% (8.4/34.5)
Conclusions

- Dispersivity values and classic shape of the tracer breakthrough curves imply Frio is a relatively clean, homogeneous sandstone.
- Given the limitation of these simple models:
  - $\text{CO}_2$ moved along preferential pathways representing roughly $1/3$ of the available saturated thickness.
  - $\text{CO}_2$ saturation along these pathways is estimated to be 24%.
  - The $\text{CO}_2$ injection efficiency, defined as the effective volume occupied by the $\text{CO}_2$ divided by the effective volume of the total reservoir, is about 9%
- Models are very sensitive to the porosity value
- Diffusion of gas into the brine could play an important role in sequestering additional quantities of $\text{CO}_2$
Recommendations

- Eliminate wellbore storage effect by collecting downhole samples during tracer injection
- Inject CO₂ containing tracers at different rates to determine corresponding saturations and optimum injection efficiency
- Quantify benefit of sequestering additional CO₂ by *in situ* diffusion mechanism

Acknowledgments

- U.S. Dept of Energy, NETL
- Field Operations:
  - Paul Cook and Alex Morales (LBL), Seah Nance (TBEG), and Ed “Spud” Miller, David Freeman, Bill Armstrong, and Dan Collins (Sandia Technologies)