Interwell Tracer Tests:
Understanding Inter-Well Connectivity
Within Your Reservoir

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Stephen Whitaker

Enhanced Oil Recovery Institute
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Two Rules for Being a Successful Oil & Gas Professional

• 1 - You must excel at working with incomplete data sets
• 2 -
Know Your Reservoir

- A key to maximizing recovery efficiency from any reservoir is proper reservoir characterization (know your reservoir).
- Data from logs and cores within a field do not provide the necessary information to map the internal plumbing of the reservoir.
- Interwell tracer tests can greatly increase the understanding of the reservoir architecture, which is needed to maximize production:
  - reservoir flow paths
  - heterogeneities
  - unswept areas of the reservoir
Know Your Reservoir

Example of Tracer Response with Uniform Sweep

- Most operators assume that this is the case with each injection well
- Very rare
An isopach of a traditional oil field with injector wells
Know Your Reservoir

An isopach of a traditional oil field with injector wells and producing wells
Know Your Reservoir

Inter-well tracers can determine the flow paths within the reservoir:
• Measure breakthrough times
• Identify thief zones
• Identify existence of faults
• Indicate extent of formation layering
Know Your Reservoir

and help indicate the locations of barriers to fluid flow
Know Your Reservoir

By measuring the amount of tracer recovered it is possible to quantify:

- Swept Pore Volume
- Sweep Efficiency
- Approximate Remaining Oil
- Conformance Gel treatment volume estimations
When to use Interwell Tracers

• At the pilot stage of new flood projects
  Such as identifying flow behavior prior to full-field planning and project scale-up

• To evaluate specific injector-to-producer flow connections
  Breakthrough times allow the sources of high water-cuts or spurious gas:oil ratios to be determined

• EOR studies
  When evaluating various recovery mechanisms & different conformance treatments (e.g. polymer or chemical floods)
Properties of Waterflood Tracers

- Inert chemicals that will follow and behave as the water flowing through the reservoir:
  - Non-reactive and stable
  - No absorption or retardation with the formation
  - Do not interact with hydrocarbons
  - Have very low detection limits (parts per trillion)
  - Show minimal environmental consequences
  - Cost-effective

- Nearly 50 unique water tracers available depending on reservoir conditions
Properties of Gasflood Tracers

- Inert chemicals that will follow and behave as the injected gas mixture flowing through the reservoir:
  - Non reactive chemical gas tracers used
  - Stable at reservoir conditions
  - No absorption onto reservoir rock
  - Should have vapor / liquid hydrocarbon solubility properties as close to the injected gas as possible
  - Have very low detection limits (parts per trillion)
  - Show minimal environmental consequences
  - Cost-effective

- About 20 unique gas tracers available depending upon reservoir conditions
Tracer Project Design
# Tracer Project Design

<table>
<thead>
<tr>
<th></th>
<th>Pre-Deployment</th>
<th>Tracer Deployment</th>
<th>Post-Deployment</th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>Project objectives</td>
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<td>2.</td>
<td>Tracer selection &amp; compatibility testing</td>
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<td>3.</td>
<td>Tracer quantity calculation</td>
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<td>4.</td>
<td>Initial sampling regimen</td>
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<td>5.</td>
<td>Tracer injection and sampling</td>
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<td>6.</td>
<td>Analytical results</td>
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<td>7.</td>
<td>Data interpretation</td>
<td></td>
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<td>8.</td>
<td>Revise sampling regimen (if needed)</td>
<td></td>
<td></td>
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<tr>
<td>9.</td>
<td>Evaluation of tracer data</td>
<td></td>
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<td>10.</td>
<td>Historic match to fit tracer data</td>
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<td>11.</td>
<td>Repeat tracer application if desired</td>
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Injection & Sampling
Tracer analysis is able to measure very low detection levels (parts per trillion)

This means:

- Low tracer quantity
- Portable equipment
- No disruption to normal operations
- No requirement to shut-in wells
Sample Collection

Collecting samples and sending to the tracer company for analysis is simple, fast, and convenient.

1. Complete paperwork
2. Fill water sample
3. Or gas sample
4. Label sample
5. Place sample into box
6. Seal box
7. Send box to tracer company
Sample Collection

- Samples taken from producing wells at regular intervals to measure tracer content
- Samples taken more frequently immediately after injection to catch matrix bypass events
- Frequency dependent upon injection rates & formation volume / quality, as well as the distance between injectors and producers
- Special care is required to prevent sample contamination during collection
- For gas, CATS tubes (Capillary Adsorption Tube Samplers) or onsite lab set-up an option if required to ship using constraints
- Not necessary to analyze every sample collected
# Sample Collection

## Days Breakthrough

<table>
<thead>
<tr>
<th>Time after injection</th>
<th>Sample frequency</th>
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</thead>
<tbody>
<tr>
<td>0-3 days</td>
<td>2 hrs</td>
</tr>
<tr>
<td>3-7 days</td>
<td>4 hrs</td>
</tr>
<tr>
<td>7-14 days</td>
<td>6 hrs</td>
</tr>
<tr>
<td>14-21 days</td>
<td>12 hrs</td>
</tr>
<tr>
<td>21-28 days</td>
<td>1 day</td>
</tr>
<tr>
<td>28-60 days</td>
<td>3 days</td>
</tr>
<tr>
<td>60+ days</td>
<td>7 days</td>
</tr>
</tbody>
</table>

## Weeks Breakthrough

<table>
<thead>
<tr>
<th>Time after injection</th>
<th>Sample frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-7 days</td>
<td>1 day</td>
</tr>
<tr>
<td>7-14 days</td>
<td>2 days</td>
</tr>
<tr>
<td>14-28 days</td>
<td>3 days</td>
</tr>
<tr>
<td>4-26 weeks</td>
<td>1 week</td>
</tr>
<tr>
<td>26-52 weeks</td>
<td>2 weeks</td>
</tr>
<tr>
<td>52+ weeks</td>
<td>4 weeks</td>
</tr>
</tbody>
</table>

## Months Breakthrough

<table>
<thead>
<tr>
<th>Time after injection</th>
<th>Sample frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-26 weeks</td>
<td>1 week</td>
</tr>
<tr>
<td>26-52 weeks</td>
<td>2 weeks</td>
</tr>
<tr>
<td>52+ weeks</td>
<td>4 weeks</td>
</tr>
</tbody>
</table>
Data Analysis & Interpretation
Common response at producer to tracer injection
Data Analysis & Interpretation

Tracer Concentration ppt vs Days Post Injection

Mode
Exponential profile shows homogenous flow

Data Analysis & Interpretation

Tracer Concentration ppt vs. Days Post Injection
MRT is used to evaluate sweep efficiencies, heterogeneity, permeability, etc.
Data Analysis & Interpretation

Natural Fracture - 2 Day Tracer Breakthrough

Very High Tracer Concentration

2 Day Breakthrough

Sample Date

Tracer Concentration, ppt

IWT-1700
High Conductivity Thief Zone - 1 Week Tracer Breakthrough

Sample Concentration, ppt

Sample Date

14-Sep-11 4-Oct-11 24-Oct-11 13-Nov-11 3-Dec-11 23-Dec-11 12-Jan-12 1-Feb-12 21-Feb-12 12-Mar-12 1-Apr-12
Data Analysis & Interpretation: Commingled Zones
Data Analysis & Interpretation: Commingled Zones

Graph showing tracer concentration (ppt) over days after injection.
Data Analysis & Interpretation: Commingled Zones
Data Analysis & Interpretation: Commingled Zones

The graph shows the tracer concentration over time after injection. The x-axis represents days after injection, ranging from 0 to 40. The y-axis represents tracer concentration in parts per thousand (ppt), ranging from 0 to 5000. The graph displays multiple peaks and troughs, indicating the movement and mixing of the tracer over time.

The diagrams on the right side of the graph correspond to the above-mentioned data, providing a visual representation of the commingled zones.

EORI
Data Analysis & Interpretation: Commingled Zones

Graph showing tracer concentration (ppt) over days after injection.
Data Analysis & Interpretation: Commingled Zones
Data Analysis & Interpretation: Commingled Zones

**Graph Description:**
- The graph illustrates the tracer concentration (ppt) over days after injection.
- Multiple lines represent different tracer concentrations, peaking and declining over time.
- The x-axis represents days after injection, ranging from 0 to 40.
- The y-axis represents tracer concentration, ranging from 0 to 5000 ppt.

The graph shows the dynamic behavior of tracer concentrations in commingled zones, which is crucial for understanding fluid flow and interaction in geological formations.
Application Examples
The Project:
An oil field operator wished to better understand communication pathways within an inverted nine-spot waterflood operation. This study was to establish:

- Sweep efficiency of the field
- Determine if there was preferential flow direction
- Resolve the problem of excessive water production in several wells
The Project:
An oil field operator wished to better understand communication pathways within an inverted nine-spot waterflood operation. This study was to establish:

- Sweep efficiency of the field
- Determine if there was preferential flow direction
- Resolve the problem of excessive water production in several wells

Tracers proved that there was preferential flow to the west-southwest
Interpretation of Results

- There is preferential flow to the west and southwest
- Several areas of the field have not been swept
- Flood can be improved by changing pattern through recompletions or infill drilling
Wyoming Case Study: Gas Flood
Wyoming Case Study: Gas Flood

- ~19 Injection wells
  - Unique gas tracer in each well
- ~18 Producing wells
  - Breakthrough expected in hours or days

Problems
- Breakthrough of gas in several wells
- Suspected poor sweep (fractures, faults, varying reservoir quality)
- Thinking of trying polymer

Objectives
- Track preferential flow
- Identify fractures/faults and other factors that affect sweep
- Identify wells for polymer applications
Wyoming Case Study: Gas Flood

Depth: 7500’
Porosity: 15%
Permeability: 50md

• Sample collection started within hours of injection due to expected breakthrough (BT) timing
• Initial sample frequency on an hourly basis and reduced over time
• One or more tracers produced in most wells
• High connectivity identified in 3 areas (circled)
Depth: 7500’
Porosity: 15%
Permeability: 50md

- Sample collection started within 2 hours of injection due to expected breakthrough (BT) timing
- Initial sample frequency on an hourly basis and reduced over time
- One or more tracers produced in most wells
- High connectivity identified in 3 areas (circled)
- Injectors 5, 7, 8, 11 and 18 identified as potential candidates for polymer trial.
Injectors 5 and 7.

- Both show high connectivity with p6. Poor sweep with BT in day 1.
- 37% of inj 7 tracer produced in p6
- 25% of inj 5 tracer produced in p6
Wyoming Case Study: Gas Flood

**Injector 8**
- Connectivity to p10; 9% of tracer produced Day 1.
- High tracer concentration early and brief pulse indicating channeling through fracture or fault. Tracer not present in other nearby producers.

**Injector 11**
- 37% tracer produced in p10. BT Day 1.
- Channeling and relatively poor sweep.

**Injector 13**
- Communication with p10 detected. Effective sweep.
Injector 18

- Channeling and ineffective sweep to p15
- 35% tracer recovery in 6 days with BT day 1.
Case Studies: CDG Pilot Flood

Incremental Oil Production From Waterflood

- > 50,000 BO
- 30,000-40,000 BO
- 10,000 - 20,000 BO
- 1,000 – 5,000 BO
- 40,000-50,000 BO
- 20,000-30,000 BO
- 5,000 - 10,000 BO
- < 1,000 BO
Reservoir had been under continuous waterflood for 65 years
Case Studies: CDG Pilot Flood

Four Injectors, 7 producers

ASP Pilot Wells
Case Studies: CDG Pilot Flood

RA Tracer survey shows injection fluids all going into one zone withinperf’d interval

Griggs #131
Case Studies: CDG Pilot Flood

- Reservoir had been continuously flooded since 1954
- ASP Pilot project failed immediately to the east of the CDG Project area
- CDG injection contemplated to improve sweep efficiency due to reservoir heterogeneity (work on CDG pilot flood started early 2009)
- RA tracers indicated injectivity profiles must be modified to improve water-flood or chemical-flood performance
- Interwell tracer survey was needed to help determine flow paths and degree of heterogeneity
  - Unique chemical tracers used in each of 4 injectors
  - Potassium, Iodide, Thiocyanate, and Bromide
- A rigid (MARCIT) gel treatment was designed and implemented to plug off thief zones, based on results of interwell tracer survey, prior to injection of any CDG
Case Studies: CDG Pilot Flood (Tracer Survey)

Sandstone Isopach > 18% Porosity

Potassium tracer

10 days
20 days
8 days
Case Studies: CDG Pilot Flood (Tracer Survey)

Sandstone Isopach > 18% Porosity

Iodide tracer

3 days
8 days
20 days
Case Studies: CDG Pilot Flood (Tracer Survey)

Sandstone Isopach > 18% Porosity

Thiocyanate tracer

1 day

15 days

13 days
Case Studies: CDG Pilot Flood (Tracer Survey)

Sandstone Isopach ≥ 18% Porosity

Bromide tracer

- Response @ # 52 (17 days) cannot be confirmed - well had been SI for 2 days
- Response @ # 50 (30 days) cannot be confirmed - well had been SI for 2 days
“Thief” zone is no longer taking much fluid

- **Griggs GH6**
- **RA Tracer**
- **All Runs**

- **Run #1** Inj 225 b/d Sw
- **Run #2** Inj 270 b/d Sw 8 days after Gel Treatment

Perfs 1350-1397
Case Studies: CDG Application

Sandstone Isopach > 18% Porosity

Inter-well Tracer Response 17 weeks after CDG Injection started
Pre-CDG Flood Weekly Average from 8 producers was 18.2 BO / 1008 BW (1.8% oil-cut)
Remaining Oil Saturation Calculations
• Use partitioning and non-partitioning tracers
• Both tracers added to injection at same time
• During transit between wells,
  • Partitioning (passive) tracer moves only with the water
  • Non-partitioning tracer interacts with residual oil, thus altering its progress
Benefits:

- Non-intrusive
- Provides measurement of oil saturation in the region between injectors and producers instead of only near the well bore
- Tests can be run during normal operation
- No loss in production
- Assumes that tracers contact immobile oil along flow-paths of watered-out zones between wells
Ideal candidates have the following properties:

- Relatively mature flooded reservoir
- Injector to producer spacing is relatively close to enable results in a reasonable time period
- Need to know that well pairs are communicating
- Sweep efficiency should be reasonable
  - Only $S_{orw}$ (residual oil saturation to water) will be measured and NOT unswept zones
- Production well must be able to lift fluids to surface
- Formation should be reasonably homogeneous – allows for relatively easy interpretation of key positions along the tracer graphs
Prior to using passive and partitioning tracers the following measurements should be carried out:

- Laboratory based crushed core retention and retardation tests using clean and residual-oil-saturated core
- Partition coefficient testing at reservoir conditions
- Analytical compatibility
- Required data
  - Core sample or access to similar rock
  - Produced oil from field
  - Gas sample from the field or gas composition
  - Formation / produced water close to study area
  - Injection water from injector close to study area (if water is re-injected)
Partitioning Tracers: Sampling & Analysis

\[ S_o = \frac{T_p - T_w}{T_p + (K-1)T_w} \]

\[ = \frac{34 - 22}{34 + (1.06-1)22} = 34\% \]
Discussion & Conclusion
Summary

• Interwell tracer surveys are a powerful tool in determining ways of maximizing recovery efficiencies in IOR and EOR projects
• One of best direct tools to understand fluid movement within a reservoir
• Provide information on:
  • Breakthrough times
  • Communication pathways
  • Thief zones, natural fractures, faults
  • Formation layers
  • Identify sources of excess water
  • Problem injectors
• Quantification of
  • Injected fluid distribution
  • Swept pore volume
  • Sweep efficiency
  • Reservoir geometry (including flow capacity and storage capacity)
Companies: Interwell Tracer Surveys

- Chemical Flooding Technologies, LLC: www.chemicalfloodingtechnologies.com
  24431 E. 61st Street, Suite 850, Tulsa, OK 74136
  (918) 743-7575

- Chemical Tracers, Inc: http://www.chemtracers.com
  Headquarters: 1814 Steele, Laramie, WY 82070
  (307) 742-0418

- Core Lab (Spectraflood): www.corelab.com
  Headquarters: 6510 W. Sam Houston Pkwy. N., Houston, TX 77041
  Contact: David Chastain, Manager Interwell Tracer Services David.Chastain@corelab.com
  (713) 328-2393 office; (281) 352-4697 mobile

- Tracerco: www.tracerco.com
  Headquarters: 4106 New West Dr., Pasadena, TX 77507
  Utah: 2698 S. Redwood Rd, Ste. T., West Valley City, UT 84119
  KC Oren; KC@GeoStarSolutions.com
  (303) 249-9965

- Tracer Technologies International (subsidiary of Chemical Flooding Technologies):
  sales@tracer-tech.com
  26800 Fargo Ave # B, Cleveland, OH 44146
  (216) 464-9300
Thank You

Questions and Comments:

Stephen Whitaker, Senior Geologist
swhitak2@uwyo.edu
Office 307-315-6446

Lon Whitman, Petroleum Engineer & Outreach Manager
eoribiz@uwyo.edu
Office 307-315-6450

www.eoriwyoming.org