Tracer technologies to assess and monitor EOR and IOR projects

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Outline

• Restrack - tracer service based on Institute for energy technology (IFE) research
• Information from tracer data
• Field application of the partitioning inter-well tracer test
• Summary
**IFE legacy**

1950ies  IFE started work with radioactive tracers, ground water studies

1983 – 86  offshore use of tracers at Ekofisk started

1991 –  development for application of chemical tracers


1995 –  world-wide project expansion

2005  IFE established Resman together with Sintef

2011 –  deployment of Single Well Chemical Tracer Test (SWCTT)

2012 –  Introducing tracers for partitioning Inter-well Tracer Test (PITT)
Inter-well tracer test

- Injection water is "colored" by tracers
- Water from specific injector identified
Inter-continental tracer test

Injectors

Tracer distribution
Connectivity from tracer data

- Sealing / non-sealing faults
- Topology of the reservoir
- Tracers can explain unexpected water breakthrough
Residence time distribution (RTD) analysis

Moments of the distribution:
\[ m_{\downarrow 0} = \int_0^\infty E(t) \, dt \]
\[ m_{\downarrow 1} = \int_0^\infty t \cdot E(t) \, dt \]

Swept volume:
\[ V_{\downarrow s} = Q_{\downarrow i} m_{\downarrow 1} / m_{\downarrow 0} \]
Characterize the heterogeneity

- Heterogeneous flow yields curve far from diagonal
- Homogeneous flow yields close to diagonal curve
- Area between diagonal and curve gives Lorentz coefficient
Heterogeneity from RTD (sandstone)

BOCK 081

\[ T_{\downarrow m} = 516 \text{ d} \]
\[ \langle T \rangle = 590 \text{ d} \]
\[ L_{\downarrow c} = 0.18 \]
\[ M_{\downarrow 0} = 19 \% \]
\[ V_{\downarrow s} = 13000 \text{ m}^3 \]

BOCK 056

\[ T_{\downarrow m} = 478 \text{ d} \]
\[ \langle T \rangle = 637 \text{ d} \]
\[ L_{\downarrow c} = 0.15 \]
\[ M_{\downarrow 0} = 86 \% \]
\[ V_{\downarrow s} = 66000 \text{ m}^3 \]
Heterogeneity from RTD (carbonate)

P-B

$T_{\downarrow b} = 54 \text{ d}$

$\langle T \rangle = 414 \text{ d}$

$L_{\downarrow c} = 0.46$

$M_{\downarrow 0} = 0.14 \%$

$V_{\downarrow s} = 680 \text{ m}^3$

P-A

$I-1$

$T_{\downarrow b} = 82 \text{ d}$

$\langle T \rangle = 802 \text{ d}$

$L_{\downarrow c} = 0.32$

$M_{\downarrow 0} = 3.3 \%$

$V_{\downarrow s} = 35500 \text{ m}^3$

BO-81 (sandstone)

$E(t) [\text{L/day}]$

Well P-A

Well P-B

RESTRACK™
Oil saturation from tracer data

Saturation given from

\[ S_{\text{oil}} = \frac{t_{\text{lp}} - t_{\text{lw}}}{t_{\text{lp}} + t_{\text{lw}} (K-1)} \]
Ester (partitioning tracer) is injected in watered-out zone (1 day)

Ester partly hydrolyses to alcohol during shut-in (2-3 days)

Ester and secondary tracer is produced (2 days)

Field data yields Sor=0.21. (Data from ENI operated West African onshore field, IPTC paper 17951 for details)
Partitioning tracer (red) and water tracer is co-injected.

Partitioning tracer (red) is delayed if oil is present.

Partitioning tracer time delay gives amount of oil present.

Partioning
Non-partioning

PITT - principle
**PITT vs SWCTT**

**SWCTT:**
- close to the well
- extensive operation, 1-2 week
- test in producer
- interrupt production
- immediate results

**PITT:**
- well to well test
- simple injection operation, 1-2 days
- injector well, no production interrupts
- results after tracer breakthrough
Recap of IFE research to find suitable partitioning tracers

- Several tracers have been used for non-aquous phase liquid (NAPL) remediation
- For oil field applications: problem finding tracers that survive reservoir temperature and biodegradation
- Breakthrough: PITT tracers identified and tested by Viig et al. (SPE164059)

Example of tracer that biodegraded (Dugstad et al., 2013)
Field application, Total operated Lagrave field

- Used to field test new PITT tracers (Viig et al. 2013, SPE 164059)
- Carbonate field with large water production ~ 95% water cut
- Short well distances
- Water cycled
- Residual saturation also known from cores ~ 25%

Lagrave reservoir characteristics:
- Thickness 10-30 m
- Porosity 13-20 %
- Permeability 10-50 mD
Saturation from PITT in Lagrave

From cores: So=25-28 %, i.e. compares well to PITT results

Data from Viig et al. (SPE164059)

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

\[ = \frac{213 - 133}{213 + 133(1.9 - 1)} \]

\[ = 24\% \]
PITT in the Bockstedt Schizophyllan biopolymer pilot\(^1\)

- mature (60+ years) oilfield located about 50 km from Bremen
- poorly consolidated sandstone, mid to coarse grained, well-sorted and fairly homogeneous
- reservoir temperature about 54°C
- formation water: saline brine (186,000 ppm TDS).
- test area is water-flooded (high water cut) with one injector and three producers. Produced water is re-injected

\(^1\) For details:
Leonhardt, B. et al. SPE 169032. SPE 2014 IOR Symp
Ogezi, O., et al. SPE 169158. SPE 2014 IOR Symp
Preliminary PITT results BO-56

\[ S_{lo} = \frac{T_{lo} - T_{lw}}{T_{lo} + T_{lw}} (K - 1) = \frac{801 - 478}{801 + 478}(3.6 - 1) = 0.16 \]
# Summary, tracers for IOR/EOR

<table>
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<th>Technology</th>
<th>Benefit</th>
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| Conventional tracers & RTD | Identify targets for IOR  
• Communication  
• Sweep          |
| SWCTT          | Assess efficiency of EOR chemicals & protocols  
• Reduction in Sor |
| PITT           | Identify targets for EOR  
Assess EOR efficiency on inter-well scale |
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Partitioning vs. non-partitioning

\[ S_{\downarrow o} = T_{\downarrow p} - T_{\downarrow w} / T_{\downarrow p} + T_{\downarrow w} (K-1) = \frac{787-516}{787+516(3.6-1)} = 0.13 \]

\[ S_{\downarrow o} = T_{\downarrow p} - T_{\downarrow w} / T_{\downarrow p} + T_{\downarrow w} (K-1) = \frac{801-478}{801+478(3.6-1)} = 0.16 \]

Travel times used in So estimates corresponds to mode of RTD. Mean times are more fragile as the full tail of the partitioning tracer curves are still not available.
Moving oil for BO-81

Water cut [%]

Bo-56
Bo-81

Mobile oil

BOCK 056
BOCK 081

01.06.2012  30.11.2012  01.06.2013  30.11.2013  01.06.2014  01.12.2014
Effect of moving oil

Moving oil gives a smaller $T_p$

$$S\downarrow o = T\downarrow p - T\downarrow w / T\downarrow p + T\downarrow w \ (K-1)$$

$$S\downarrow o' = \{T\downarrow p + \Delta\downarrow T\} - T\downarrow w / \{T\downarrow p + \Delta\downarrow T\} + T\downarrow w \ (K-1)$$

By trial and error we can find a $\Delta\downarrow T$ that gives $S\downarrow o$ corresponding to that for BOCK-56:

$$S\downarrow o' = (787+80)-516/\left((787+80)+516(3.6-1)\right) = 0.16$$
Ultra sensitive tracer analysis

In example:
400 parts per trillion tracer in produced water sample

Detection limit has significant impact on required tracer injection mass. If 50 kg is needed to investigate a field at 50 ppt, 5000 kg is needed for the same investigation at 5 ppb.

Illustration of investigation area for TQF = 1E6 m^3 (corresponding to limit of detection of 5 ppb) and TQF = 1E8 m^3 (corresponding to limit of detection of 50 ppt) and the same amount of tracer injected.