Aspects of how Tracers Compounds can Contribute to Optimize EOR/IOR Processes

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FORCE seminar
MEOR – from theory to field implementation
Stavanger, 18- Nov. 2014
Outline:

- General on EOR/IOR
- Norwegian IOR Centre
- Tracer technology
- PITT (interwell SOR measurem.)
- SWCTT (near-well SOR measurem.)
- New developments
Traditional oil recovery steps
Given an oil deposit....

What to do about it?
Primary oil recovery

A method of oil recovery whereby the oil flows from the well by its own pressure or is pumped out. This method **recovers at best about 30%** of the oil in the reservoir.
A “dipper collects heavy oil

Photo by S.T. Pees, 1969
Secondary oil recovery

Method of oil recovery whereby the well is flooded with high-pressure water or gas, such as methane, to push the oil out. Recovers additionally about 20-30% of the oil in the reservoir.
Tertiary oil recovery

Method of oil recovery in which the oil is heated by various methods, or adding a polymer or detergent to scrub it out. Typically recovers only an additional 10% of the oil in the well after primary and secondary recovery.
We called this tertiary recovery level for Enhanced Oil Recovery: EOR
The concept of Improved Oil Recovery, IOR, was introduced including EOR but also a number of other topics and aspects like:

- Improved reservoir description
- New well strategy and drilling technology
- Smart well completion methods
- Improved understanding of flow assurance
- Economy, i.e. sound economic processes
- Environmental considerations
- Even social and sociological aspects etc.
Modern strategy is to consider EOR/IOR from day 1 in the field development.
The National Norwegian IOR Centre

The aim:

- Contribute to maximizing oil recovery on the Norwegian Continental Shelf
  - Research and development for field implementation
  - Environmentally friendly technologies

User partners (so far):
Tracers for reservoir characterization
Reservoir compartment studies

- Sealing fault?
- Open fault?
- Fracture/high-permeability streak?
- Fluid flow directions?
Water expelling oil – should be traced
Non-radioactive polyfluorinated interwell water tracers
Non-radioactive gas tracers

Perfluorinated cyclic hydrocarbons with coordinated light hydrocarbon (methyl) groups are excellent gas tracers.

- PDCB
- PMCP
- PMCH
- 1,3-PDMCH
- 1,2,4-PTMCH

CARBON

FLUORINE
Tracing of injection fluids

Injection well

Production well

Stratified reservoir
PITT
**PITT principle**

- Exploits the delay of water/oil or gas/oil partitioning tracers compared to nonpartitioning (passive) tracers between injection well and production well.
- Works by injecting partitioning and passive tracers simultaneously.
- Water or gas contactable average residual oil saturation in swept volume can be estimated by:

\[ S_o = \frac{(T_p - T_{np})}{[T_p + T_{np}(K - 1)]} \]
**K-value (partition coefficient)**

- Non-partitioning tracer exist only in water
- Partitioning tracer distributes in water and oil
- Water moves, oil is (close to) stagnant in EOR cases

\[ K = \frac{(C_{Tr})_o}{(C_{Tr})_w} \]
Phase partitioning

Organic solvant

Aqueous “feed” solution

Phase separation
Passive and partitioning tracer flow in a flooding pore of formation rock

The partitioning tracer becomes delayed with respect to the passive water tracer.
Partitioning tracer – Lab Experiments

Silica-packed column prepared with residual oil

T = 40 °C
P = 170 bar
SOR = 15.7 %

Relative response to peak concentration
Eluted volume

Conc. normalized to peak value

Eluted amount (g)
First PITT: Leduc D-2A Pool Outline

Pilot expansion

Pilot Area

Observation well

Pilot injector

Pilot producer

Alberta
CANADA

Edmonton

Calgary

Pilot expansion

38.0 m

63.5 m

Pilot producer
First PITT: Tracer production curves

- Passive tracer: Tritiated methanol
- Partitioning tracer: Tritiated butanol

Tracer concentration (dpm/g)

Cumulative water production (m³)
## PITT SOR results

<table>
<thead>
<tr>
<th>Method</th>
<th>Results SOR %</th>
</tr>
</thead>
<tbody>
<tr>
<td>IWTT</td>
<td>35 ± 1</td>
</tr>
<tr>
<td>SWTT 1 (spm)</td>
<td>40 ± 3</td>
</tr>
<tr>
<td>SWTT 2 (dpm)</td>
<td>35 ± 3</td>
</tr>
<tr>
<td>SWTT 3 (mbm)</td>
<td>35 ± 3</td>
</tr>
<tr>
<td>Sponge coring</td>
<td>33</td>
</tr>
</tbody>
</table>
**PITT operation in the Lagrave field**

Tracer injection in LAV-7
16.02.2011

<table>
<thead>
<tr>
<th>Tracer</th>
<th>Type</th>
<th>K</th>
<th>Amount [kg]</th>
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</thead>
<tbody>
<tr>
<td>T1</td>
<td>Partitioning</td>
<td>2.1</td>
<td>5</td>
</tr>
<tr>
<td>T2</td>
<td>Partitioning</td>
<td>1.5</td>
<td>5</td>
</tr>
<tr>
<td>T3</td>
<td>Partitioning</td>
<td>1.5</td>
<td>5</td>
</tr>
<tr>
<td>T4</td>
<td>Partitioning</td>
<td>2.9</td>
<td>5</td>
</tr>
<tr>
<td>T7</td>
<td>Partitioning</td>
<td>2.4</td>
<td>5</td>
</tr>
<tr>
<td>T8</td>
<td>Partitioning</td>
<td>1.9</td>
<td>5</td>
</tr>
<tr>
<td>2-FBA</td>
<td>Passive</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

Ref.: SPE 164059
Estimation of $S_0$ by scaling $x$-axis

Scaling $x$-axis of the partitioning tracer: $x' = x / (1 + \beta)$
RTD analysis of PITTs

Must first correct for re-injection & extrapolate to infinity
# LAV-1 results

<table>
<thead>
<tr>
<th>Tracer</th>
<th>$\beta$</th>
<th>$K$</th>
<th>$\overline{S_o}$ [%]</th>
<th>$\overline{S_o}$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFE-WTP8</td>
<td>0.6</td>
<td>1.9</td>
<td>24</td>
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</tr>
<tr>
<td>IFE-WTP7</td>
<td>0.75</td>
<td>2.4</td>
<td>24</td>
<td></td>
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<tr>
<td>IFE-WTP3</td>
<td>0.50</td>
<td>1.5</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>IFE-WTP2</td>
<td>0.50</td>
<td>1.5</td>
<td>25</td>
<td></td>
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<tr>
<td>IFE-WTP1</td>
<td>0.70</td>
<td>2.1</td>
<td>25</td>
<td></td>
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<tr>
<td>IFE-WTP4</td>
<td>0.80</td>
<td>2.9</td>
<td>22</td>
<td></td>
</tr>
</tbody>
</table>

Average saturation measured on cores: 25 %

Results are consistent
**SWCTT principle**

**Chemical reaction**

Ester + Water ⇌ Alcohol + Acid

Hydrolysis reaction
**SWCTT stage 1: Injection**

Partitioning and reacting tracer: Ester

Cover tracer: Passive
SWCTT stage 2: Shut-in with hydrolysis

Formed alcohol water tracer
**SWCTT stage 3: Back-production**

To analysis

\[ SOR \propto \text{Distance (in time/volume) between remaining ester and produced alcohol tracers.} \]
Single Well Chemical Tracer Test

Production Curve

Unreacted Ester

Tracer

Product Alcohol Tracer

Material Balance Tracer

$S_{OR} = \frac{V_2 - V_1}{V_2 + V_1(K - 1)}$

Concentration Tracers (ppm)

Concentration Tracers (ppm)

Volume Produced (bbls)

Volume Produced (bbls)
Single Well Chemical Tracer Test
New developments
IOR center Task 5: Tracer technology:

Main work packages:

- **Further development of PITT technology:**
  - New phase-partitioning tracers
  - Lab. studies on stability
  - Field pilots

- **Further development of SWTT technology:**
  - New concepts including esters and other water-reacting compounds
  - Miniaturization of field process (two steps)

- **Introduction of «smart» nanoparticle tracers for both PITT and SWTT**

- **Improved modeling and interpretation methods**
New SWCTT development:

*Tracer volume reduction*

**Mini-SWCTT**

\[ \text{Mini-SWCTT} = \frac{\text{Tr}_p}{1000} \]

**Micro-SWCTT**

\[ \text{Micro-SWCTT} = \frac{\text{Tr}_p}{1,000,000} \]

*Present day tracer amount*

Relative value

\[ = \text{Tr}_p \]
Fluorescent and Radioactive Nano-Particles for both IWPTT, RITT SWPTT and SWRTT
Fluorescence of rare earth metals

Fluorescence spectra of selected rare earths

Fluorescence colors of selected rare earths
Fluorescence decay-time of various Eu-complexes

Brichart, 2014
Measuring reservoir pH with «smart» tracers

Retention of various tracers in reservoirs at residual saturation

- Passive
- PIT T
- PITT\_deprotonated
- PITT\_protonated
Examples of possible tracer compounds for pH measurement

<table>
<thead>
<tr>
<th>Name</th>
<th>Structure</th>
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<tbody>
<tr>
<td>2-Chlorophenol</td>
<td><img src="image1" alt="2-Chlorophenol" /></td>
</tr>
<tr>
<td>2,6-DiChlorophenol</td>
<td><img src="image2" alt="2,6-DiChlorophenol" /></td>
</tr>
<tr>
<td>2-fluorophenol</td>
<td><img src="image3" alt="2-fluorophenol" /></td>
</tr>
<tr>
<td>4-fluorophenol</td>
<td><img src="image4" alt="4-fluorophenol" /></td>
</tr>
<tr>
<td>2,6-Difluorophenol</td>
<td><img src="image5" alt="2,6-Difluorophenol" /></td>
</tr>
<tr>
<td>4-(Trifluoromethyl)phenol</td>
<td><img src="image6" alt="4-(Trifluoromethyl)phenol" /></td>
</tr>
</tbody>
</table>
Complex well inflow monitoring

Water inflow

Different tracer-matrix combinations
Tracers in polymer rods - placed in the sandscreen

Sand screen

"Smart" tracer matrix
...showing the polymer matrix
ICD- and tracer-based mass inflow monitoring

Sealing rock  Packer  Production tubing  ICD

Oil-bearing formation

Mass inflow  Tracer inflow  Tracer Container (in pressure contact with the formation)

Tracer inflow resistance
Basis of the patent

The chamber 20 contains tracer compounds with a known concentration. For a given differential pressure $\Delta p$ between the annulus 3 and the inside of the production tubing, the rate of flow of tracer $F_{trac}$ from the tracer reservoir can be described as:

$$F_{trac} = \frac{k \cdot c_{trac}}{\mu} \cdot \Delta p$$

Here, $k$ is a constant related to the characteristics of the flow resistance element representing the inverse of the flow resistance, $c_{trac}$ is the known tracer concentration in the tracer reservoir and $\mu$ is the known viscosity of the tracer liquid at the prevailing temperature. The tracer flow, $F_{trac}$ (amount of tracer/time unit) is thus proportional to the differential pressure between the tubing 10 and annulus 3, and the proportionality constant can easily be determined.
Basis of the patent cont.

The same amount of tracer which enters the production tubing from the tracer reservoir will exit the production tubing topside (tracers are selected so that there is no tracer degradation of the tracer or sorption to the tubing wall during transport). Let the volumetric flow topside be $V_{\text{top}}$ (production flow) and let the tracer concentration in the fluid topside be $c_{\text{top}}$. Then, we have:

$$V_{\text{top}} \cdot c_{\text{top}} = F_{\text{trac}} = \frac{k \cdot c_{\text{trac}}}{\mu} \cdot \Delta p$$

$$\Delta p = \frac{V_{\text{top}} \cdot c_{\text{top}} \cdot \mu}{k \cdot c_{\text{trac}}}$$
Basis of the patent cont.

- One observes that $k$, $c_{\text{trac}}$ and $\mu$ are known (measured in the lab). The total production volume per time unit $V_{\text{top}}$ is also known (measured at the platform). Thus, $c_{\text{top}}$ may be determined by collecting fluid samples followed by tracer analysis. Thus, $\Delta p$ can be calculated accurately.

- Knowing $\Delta p$ and the flow resistance characteristics of the ICD, the production flow entering the tube at the production zone where the tracer release device is installed can be calculated.
Great Simple Formulas

\[ K = ma \quad \text{(Newton)} \]
\[ E = mc^2 \quad \text{(Einstein)} \]

\[ \text{IOR} = \frac{\mathcal{C}}{\mathcal{C}} = (m^2c^2) \times f(x,y,\ldots) \]

Efficiency = manpower x method x co-operation x co-ordination