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Passive Reservoir Monitoring by Use of Inter-well Tracers

Olaf Huseby
VP Technology & Interpretation, Restrack

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Overview

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- **Introduction / recap of inter-well tracer technology**
- Tracer chemicals and lab
- Interpretation options
- Field examples reservoir information from tracers
- EOR applications
- Questions and discussion

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30 years of tracer development

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1950 – 1970	Use of radioactive tracers in O&G and ground water studies
1971-	Chemical tracer tests developed to evaluate residual oil saturation inter-well (PITT) and single well tests (SWCTT)
1991 –	North Sea offshore water, gas and WAG injection implementation lead to development of chemical water and gas tracers tracer development and application.
2012 –	Increased interest in EOR projects spur further development of partitioning tracers to measure oil saturation (single well and inter-well)

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Basic tracer concept

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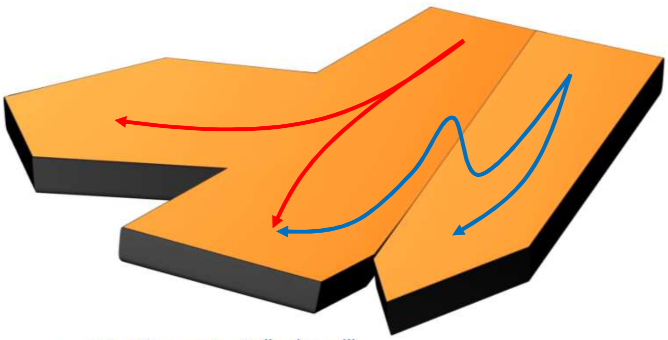

- Injection water is "colored" by tracers
- Water from specific injector identified
- Sealing / non-sealing faults
- Topology of the reservoir
- Tracers can explain unexpected water breakthrough

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Tracer chemicals and lab

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Chemical tracers

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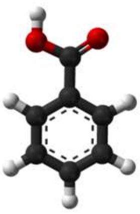
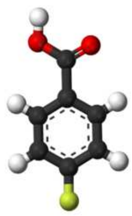
Tracers available to O&G reservoirs:

- Strict requirements for HSE, stability, temperature and phase behavior
- Limited number of tracers available
- Gas tracers are typically fluorinated hydrocarbons and water tracers are typically fluorinated organic acids
- For oil/water partitioning tracers: stability and suitable partitioning is challenging

Benzoic acid





Fluorinated Benzoic acid

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Gas and water sampling

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- Production sampling required for gas and water tracers
- Flow line or test separator samples may be used
- For shipment from field site standard water bottles can be used
- For gas tracers unpressurized sample tubes are advantageous over pressurized cylinders

Unpressurized sample tubes

Pressurized samples

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Ultra sensitive tracer analysis development

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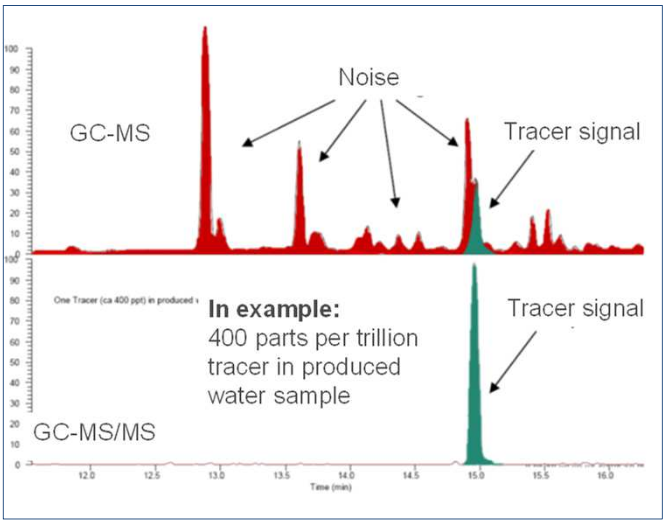

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Impact of detection limits

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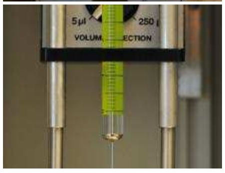

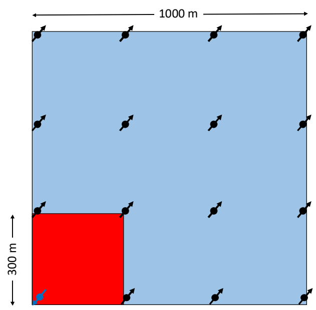

Illustration of investigation area for a TQF=1e6 m^3 (corresponding to limit of detection of 5 ppb) and a TQF = 1e8 m^3 (corresponding to limit of detection of 50 ppt) and the same amount of tracer injected

- 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
- Off-site analysis provide the best detection limits whereas on-site analysis has shorter turn-around time

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Interpretation options

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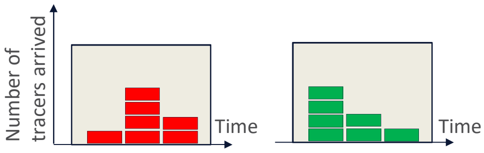
Residence time distribution (RTD) analysis

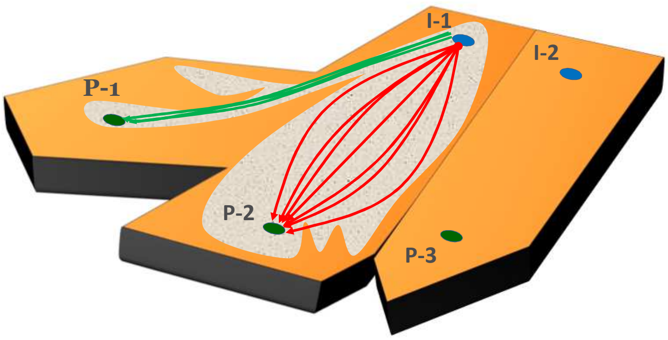
Moments of the distribution:

$m_0 = \int_0^\infty E(t)dt$

$$m_1 = \int_0^\infty t \cdot E(t)dt$$

Swept volume: $V_s = Q_i m_1 / m_0$





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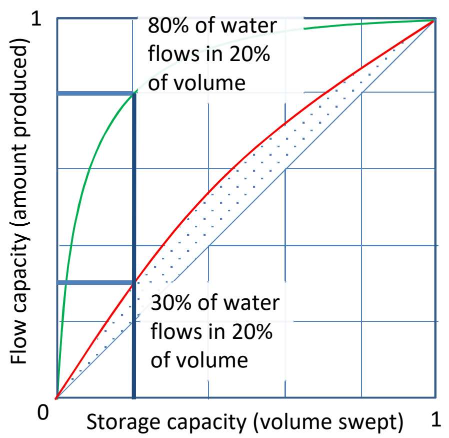
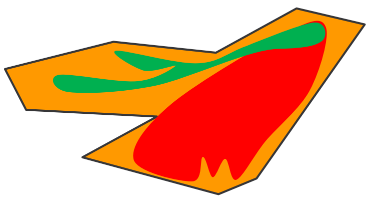
Characterize the heterogeneity





- Heterogeneous flow yields curve far from diagonal
- Homogeneous flow yields close to diagonal curve
- Area between diagonal and curve gives Lorentz coefficient

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Field examples

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Quantification of heterogeneous flow (carbonate)

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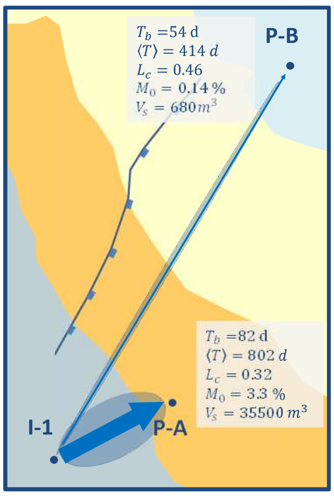

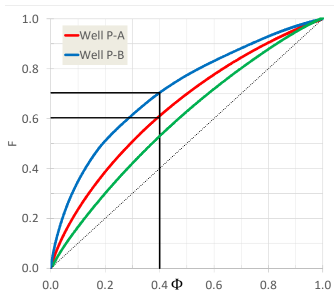

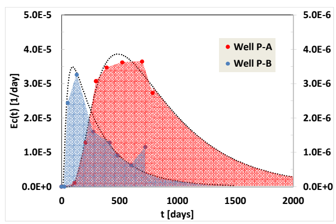

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Tracers to assess significant effect of polymer

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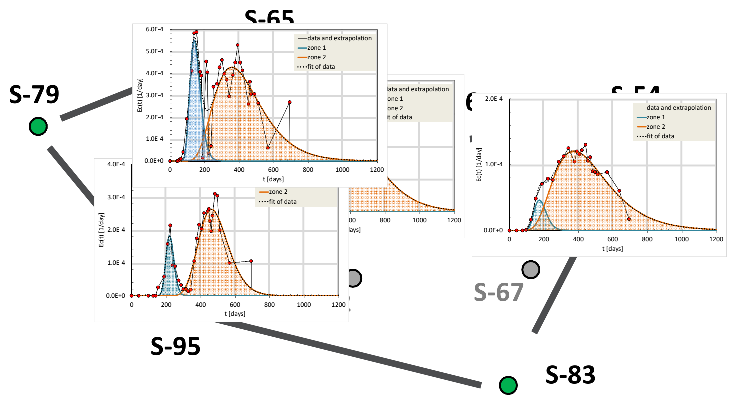

- Methodology:
  - inject tracers before polymer and find sweep volume
  - repeat tracer test after polymer flood, find new sweep volume and compare
- Tracer injections (2kg) in S-81 and SC-1
- Legacy tracer (2000 kg) in S-81

After Huseby; Clemens; Lueftenegger; Puls and Zarruk, IEA's 37th EOR Workshop & Symposium, Rueil Malmaison, France, 2016

Main flow directions and sweep volumes

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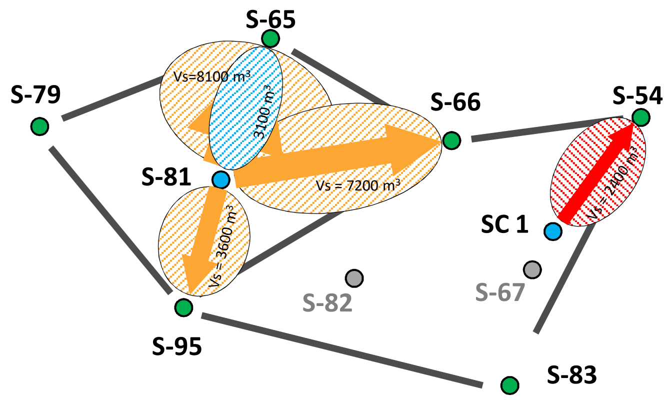
- Post-polymer sweep almost three times that of pre-polymer sweep
- Main flow directions and allocation of injection water also found from the tracer curves



Heterogeneity of flow

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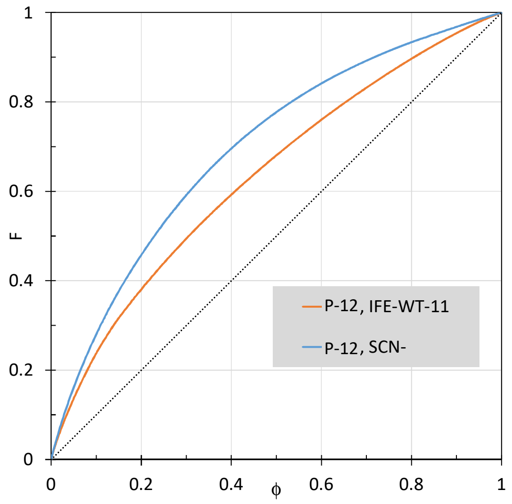

- Flow before polymer more heterogeneous than flow after polymer
- Clear indication of effect of polymer

Well	Tracer	Lc
P-12	SCN-	0.39
P-12	IFE-WT-11	0.27
P-13	IFE-WT-11	0.11
P-14	IFE-WT-11	0.16
P-21	IFE-WT-12	0.22

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Case: Bypassed oil detected by tracers

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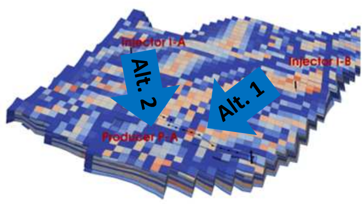
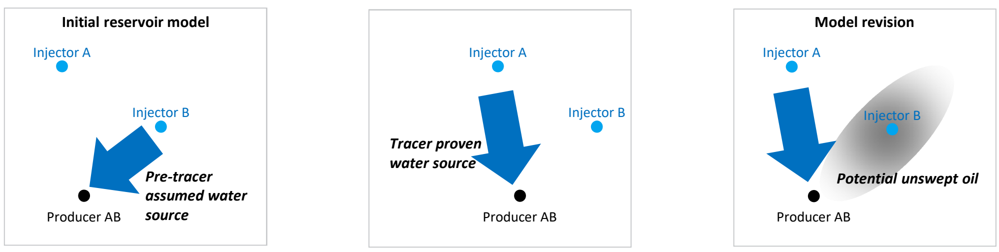


- Assumed source of water was wrong.
- Large potential un-swept oil volume detected from tracers and water injected in I-A was re-routed to injector B.
- Close Injector A to produce un-swept oil



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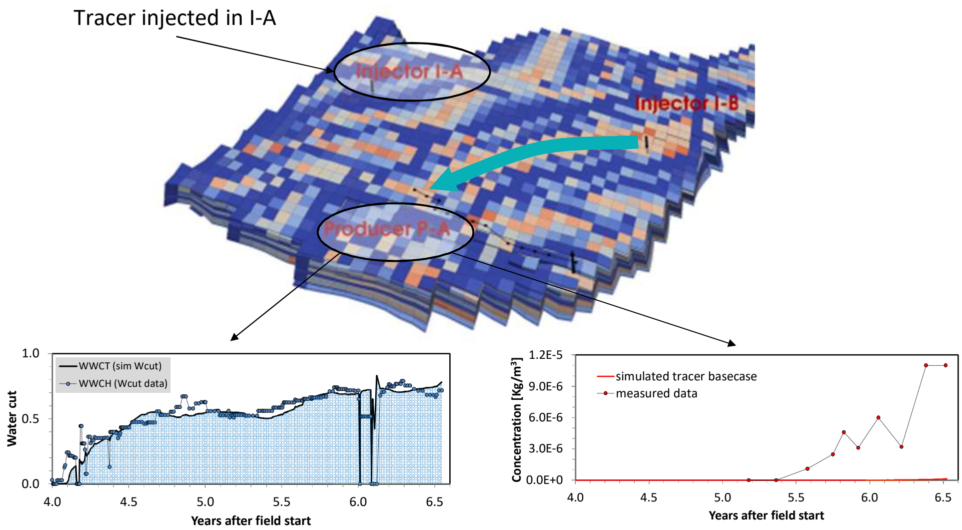
Basecase: no cross-channel movement



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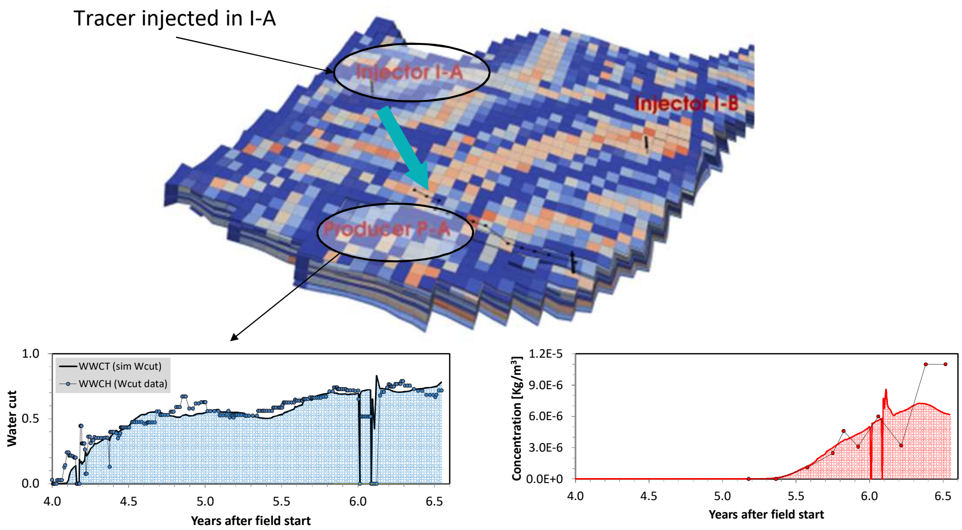
Corrected case allow for cross-channel movement



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Gas tracers for WAG tracing

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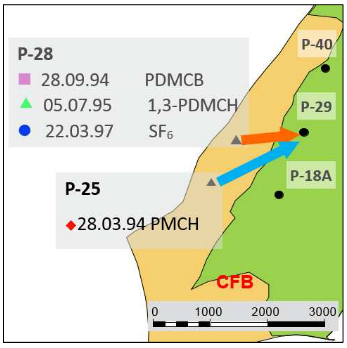

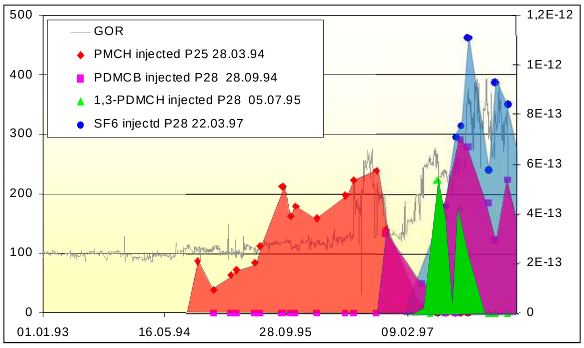

In P-29 gas tracers injected in three separate WAG cycles in P-28 arrive simultaneously. A gas tracer injected in P-25 arrive before GOR increases.

Interpretation: P-25 tracers moves with oil / associated gas - P-28 tracers are mixed in an attic gas volume

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Simulation of Snorre WAG attic volume

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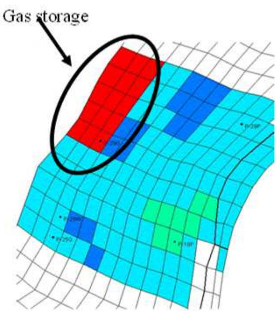

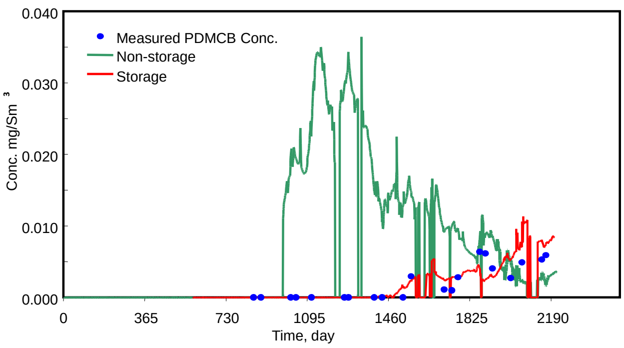

- Adding an attic gas storage volume to the simulation case, it was possible to match the tracer data
- Qualitative interpretation verified by simulation

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EOR applications

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Oil saturation from tracer data

Simultaneous injection of partitioning and passive water tracer

The time delay of partitioning tracer depends on oil saturation (So) and the tracer's oil/water partitioning coefficient K (K=Co/Cw)

$$S_o = \frac{t_p - t_w}{t_p - t_w(K-1)}$$

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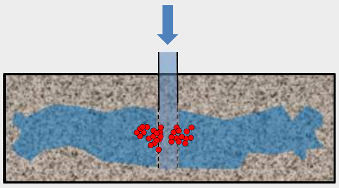
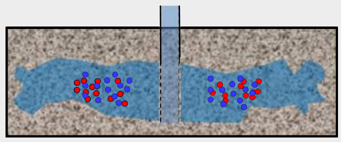
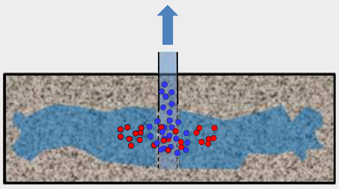
SWCTT - principle



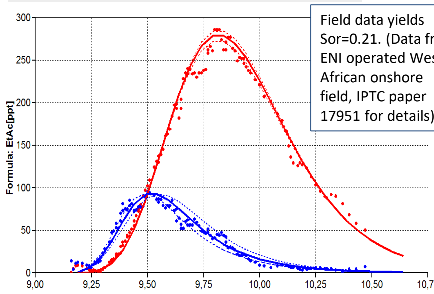
Ester (partitioning tracer) is injected in watered-out zone (1 day)



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)

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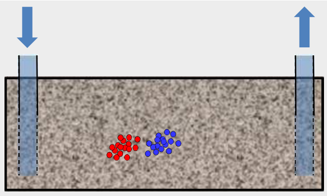
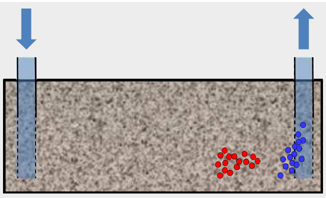
Sor - Partitioning Interwell Tracer Test - PITT

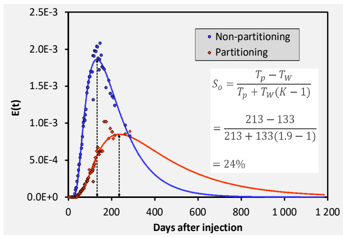
Partitioning tracer (red) and water tracer is co-injected



Partitioning tracer (red) is delayed if oil is present



Partitioning tracer time delay gives amount of oil present



Field data yields Sor=0.24. (Data from Lagrave field, SPE 164059 for details)

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Water, surfactant and SWCTT injection rig-up

- Spot SOR measurements
- Pre and post EOR verification
  - ASP / surfactant
  - low salinity
- Connate water
- Fractional flow

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SWCTT production rig-up and on-site laboratory

- Produced water samples must be analyzed on-site to reduce hydrolysis
- Accurate injection and production rates measurements are important
- Mobile lab with all required instrumentation

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SWCTT results, EOR method evaluation

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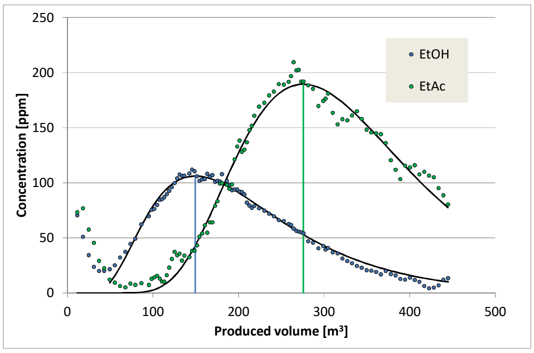

	Sea-water	Low salinity	Surfactant
Ester (EtAc) peak	276+/-10	196+/-10	127+/-7
Alcohol (EtOH) peak	150+/-7	107+/-7	82+/-5
Saturation estimate	0.21+/-0.02	0.21+/-0.03	0.14+/-0.03

$$S_o = \frac{V_p - V_w}{V_p + V_w(K-1)}$$

Sea-water flood → SWCTT 1 → Low salinity flood → SWCTT 2 → Surfactant flood → SWCTT 3

Ref: IPTC 17951

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Field case, PITT with three partitioning tracers.

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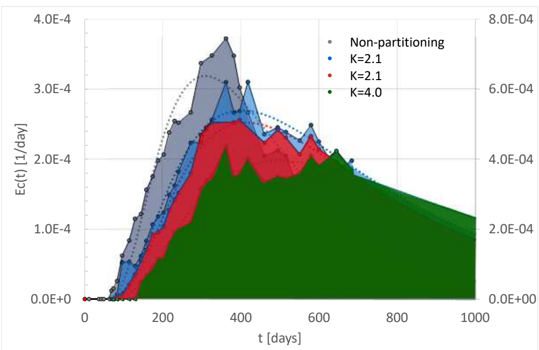

Method	SWCTT	PITT
SOR (%)	21 +/- 1	19-23

- Oil saturation is given from time delay of partitioning tracers vs. the non-partitioning tracer by the relation

$$S_o = \frac{t_p - t_w}{t_p - t_w(K-1)}$$

- S=0.19, 0.19, 0.20 from partitioning tracers 1, 2 & 3
- Same results as SWCTT

- Challenging to find functioning PITT tracers
- Newly patented PITT tracers tested in three carbonate and sandstone reservoirs (SPE 164059, EAGE-IOR Symposium 2015, SPE-ATW 2016 on tracers)

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Summary and outlook

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- **Current status:**
  - Tracer technology is well-proven with many applications world wide
  - Versatile methodology used for reservoir surveillance, production / injection optimization and EOR
  - Provides conclusive flow information
  - Simple in terms of operations and logistics
  - Manual sampling requirements
  - Limited number of tracers available due to harsh reservoir conditions
- **Further developments and research needs:**
  - automatic sampling
  - simplified / on-site analysis
  - on-line analysis (?)
  - nano materials (?) to protect tracers from harsh conditions may provide unlimited number of tracers (e.g. DNA tracers)

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Questions?

Thank you!

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