Alkaline-surfactant-polymer flooding

Laboratory and single well chemical tracer test (SWCT) results

Rien Faber
Shell International and Production BV
## Fields for ASP single well tracer tests

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Design of ASP formulation for SWCT and learnings from SWCT

- Phase behaviour studies to establish optimum salinity
- Flow experiments in Bentheim/Berea sandstone to determine
  - Activity of ASP formulation
  - Mobility requirements
- Flow experiments in reservoir core material to determine influence of mineralogy on
  - Surfactant retention
  - Caustic consumption
  - Oil recovery efficiency
- Single well chemical tracer tests (SWCT) to determine
  - Handling of chemicals
  - Preparation of ASP and polymer solutions on a larger scale
  - Injectivity
  - ASP formulation effectiveness in reducing the remaining oil saturation after water flooding
Surfactant formulation design for Field A

Phase behaviour studies at University of Texas identified suitable surfactant formulation, based on two of Shell Chemical’s ENORDET™ surfactants.

Solubilisation ratio = 10 $\implies$ ift = $3 \times 10^{-3}$ mN/m
Surfactant formulation design for Field A

Bentheim sandstone core
0.3 PV ASP slug/polymer drive: 100 mPa.s
ROS = 46.4%
Surfactant retention: 0.043 mg/g rock

Reservoir core material
ASP solution: 100 mPa.s
ROS = 21.8%
Surfactant retention: 0.29 mg/g rock
**Single Well Tracer Theory**

**Injection:**
Ester (30 m$^3$) + Push water (120 m$^3$).
Ester partially partitions in oil.

**Shut-in:** 2 days. Ester partially hydrolyses to ethanol. Ethanol in water phase.

**Back production:**
Ethanol travels faster than ester.

**Result:**
Ethanol and ester return as separate peaks.
Peak distance is used to calculate Sor.
Injection schedule ASP flood

- 420 m$^3$ ASP solution overdisplaced with 420 m$^3$ water
- 150 m$^3$ tracer injection of which the first 30 m$^3$ contained the tracer (ethyl formate)
Field A – SWCT operation

Chemical storage

3 x 32 m³ tanks for preparing chemical EOR fluids

Polymer slicing unit
Field A - Tracer test response after water and ASP flooding

CTI performed tracer test and history matching of the tracer response

IPA tracer in the ASP fluid contained ethanol and this affected the tracer profile

Sor after water flooding

Sor after ASP flooding
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Surfactant formulation design for Field B

Phase behaviour with surfactant formulation: 0.3% ENORDET surfactants (two components), 1% co-solvent

Flow experiments in Bentheim sandstone
- ASP solution/polymer drive – 20 mPa.s → 60% recovery
- ASP solution/polymer drive – 30 mPa.s → 92% recovery

Salinity → 1% 2%
Surfactant formulation design for Field B

Improved mobility

20 mPa.s at 6 s⁻¹

30 mPa.s at 6 s⁻¹
Field B - Tracer test response after water and ASP flooding

Injection schedule ASP flood
- 320 m³ ASP solution overdisplaced with 290 m³ polymer drive and 640 m³ water
- 320 m³ tracer injection of which the first 64 m³ contained the tracer (ethyl formate)
- 36 m interval

Sor after water flooding

Sor after ASP flooding
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Surfactant formulation design for Field C
Phase behaviour tests

Phase behaviour results with Field C crude after 3 days at 70°C. WOR = 70/30, KCl salt was added to increase salinity.

ASP formulation
0.7% ENORDDET surfactants (two components)
1.0% SBA
1.0% Na₂CO₃
1500 ppm Flopaam 3230S

Optimum
ASP core flow tests with Field C crude in Berea core. 1 PV ASP injected. Temperature = 70°C

Observations
95% of remaining oil recovered
Relative early oil breakthrough
Most surfactant in water phase (under-optimum)
Field C – Tracer test response after water and ASP flooding

Total tracer volume injected: 200 m$^3$. Total ASP volume: 70 m$^3$ (equivalent to 0.35 PV in core flow test)

Complex tracer response due to crossflow during shut-in.

Tracer response modeled with 3 layers (solid lines)

Before ASP injection: remaining oil = 23 %
After ASP injection: remaining oil = 2%

Layer 1 accepted 22% of the tracer-carrying fluid.
Layer 2 accepted 18% of the tracer-carrying fluid.
Layer 3 accepted 60% of the tracer-carrying fluid.
Conclusions/further plans

- Single well tracer tests showed that the ASP formulations were successful in reducing the oil saturation to very low values
- Moving to pattern pilot tests in Field A and C
- Objectives:
  - Evaluation effectiveness ASP formulation(s), e.g. surfactant retention/propagation and caustic consumption
  - Fast oil recovery response
  - Evaluation of scaling and emulsion problems
- When technical and economical issues are satisfactory resolved then further upscaling