Water diversion EOR technique –

Challenges related to Technology Development and Field Implementation
Outline

• Introduction – Snorre In-depth water diversion
• Technology development
  – From idea to qualified technology - Challenges
    • Up-scaling
    • Field pilot – Operation/result
  – Factors important for progression
• Field implementation
  – Challenges
• Summary/Conclusions
In-depth water diversion – Sodium silicate

Idea/Goal: Establish flow restrictions in flooded areas to improve lateral and vertical reservoir sweep

Requirement for chemical:

• Flow like water at low temperature
• Gel up and plug formation when heated
• Environmental acceptable (Green, ref. PLONOR list)
• Cost: Allow for injection of large volumes. Commercial available.
Snorre license IOR-workshop (Late 2006): Need for sweep improvement

**Technology development:** In-depth water diversion using sodium silicate

- **2007:** Idea
- **2008-2009:** Lab study (0.3 m and 2 m scale)
  - Conclusion: Promising result (*SPE-143836 and EAGE April 2011*)
- **2011:** Single well field pilot (50 m scale)
  - Conclusion: Successful single well test (*SPE-154004*)
- **2013:** Large scale field pilot (2 km well spacing) (*SPE-169727*)
- **2014-2015:** Field pilot response measurement
- **2016:** Field pilot interpretation
  - Conclusion: Successful “First use” of in-depth water diversion (*SPE-179602 + coming paper in 2016*)
  - Recommendation: “Second use” operation to confirm ability to model and predict diversion and IOR response

**Field implementation**
Technology development/Field pilot challenges

- EOR Technology development challenge: It takes long time.
- EOR Field Pilot challenges:
  - High cost
    - Value earning to come in possible future implementation, not in pilot - Both for owners and service providers
  - Risk of lost production
    - Damage of injection well - Near wellbore plugging
    - Damage of production well – Process problem due to break through of chemicals
  - To obtain reliable and conclusive reservoir response
    - In-depth restriction
    - No near wellbore damage
    - Sweep alteration
    - Reduction of water cut/Increased oil production
Pilot area

Thief zone challenge

Initial injection water front speed: approx. 6 m/d (2002-2003)

Water tracer injection (2008) Tracer front speed: 9-11 m/d
Pre pilot sanction - Simulated response from In-depth water diversion

Improved sweep:
Delayed break through of tracers added to the injected water

Water cut

Segment water cut

-3% points

-2% points

Tracer response

Reference case

Wide thief zone

Narrow thief zone
Injection operation from Siri Knutsen

Main risks:

- Damage of wells.
  - Plugging of injector.
  - Break through in producer.
- IOR response below detection limit.
Snorre – Field pilot operation: June 2013 - October 2013

• 1,5 months Pre-slug: 113 500 m³
  - Desalinated seawater
  - Added concentrated KCl

• 3 months Silicate injection: 240 000 m³
  - Concentrated Silicate
  - Diluted with desalinated water
  - pH adjustment with HCl
    (diluted from concentrated acid)

• 0,5 month Post-slug: 49 000 m³
  - Desalinated seawater
  - Added concentrated KCl

• Continue water injection from the Snorre platform
Calculated reservoir transmissibility between E-4 H and P-15

\[ T = \frac{\Delta p}{q} \]

Pre-pilot level – although with considerable scatter
Snorre silicate pilot – E-4 Tracer injections

Tracer injections - Pre-pilot:
- 2008 and 2012

Tracer injections – Silicate pilot:
- 2013 Early in Pre-slug injection
- 2013 Late in pre-slug
- 2013 During Post-slug injection

Tracer injections after Silicate pilot:
- April 2014

Tracer response proves major sweep alteration
- Early pre-slug tracer: 60 % delayed
- Post-slug tracer: 160 % delayed
- Post job tracer (2014): No Breakthrough yet
P-15 Water cut

Water-cut: Pilot sanction simulations and observed response

Pilot sanctioning – Ref. case
Pilot sanctioning – Pilot case

Observed response

Start of silicate injection

Injection volume after pilot start - Sm3
P-15 oil production from start of pilot injection
Modelling: Simulating and matching observed data

Reservoir transmissibility

Black: Obs
Green: Sim (silicate and HM)
Red: Sim (no silicate)

Tracer-data – Post-flush tracer

Without silicate
First observation of the tracer
With silicate

Falloff-data

Green: Observed Mar 2012
Orange: Observed Mar 2014
Purple: Simulated Mar 2012
Black: Simulated Mar 2014

Change in water-cut

First observation of the tracer
Main flow restriction seems to have formed in this area between 100-230 days after the start of silicate injection.

Indications of early moderate flow restriction due to cross-flow of salts. Mitigating actions are possible for future operation.
Modelling: Water cut P-15P
(Sensitivity – Alternative treatment year)
2012 (DG3) – Technology Qualification Pilot (Snorre)
Success criteria

1. Successful large scale transportation, mixing and pumping of silicate. **Confirmed**
   - The new concept with use of shuttle tanker as operation platform was operational robust
   - Field scale desalination, dilution, mixing and injection was successful
   - Gel kinetic of injected fluid reproduced the gel kinetic obtained from lab experiments

2. Proved in-depth flow restriction and minor near wellbore damage. **Confirmed**
   - A significant in-depth flow restriction is established in the reservoir.
   - No near wellbore damage in the injection well
   - No breakthrough of Silicate in the production well even with more than three times displacement volume injected as compared with previous tracer BT volumes
3. Proved significant change in flow pattern. **Confirmed**
   - Restriction has induced a significant change in flow pattern for injected water (tracers)

   **Confirmed lower WCT.**
   - Reduction in water cut in line with the prognosis at pilot sanctioning.
   - IOR-volume from the pilot marginal due to reduced throughput.
   - Mitigations/optimizations possible for future operations.

**Modeling**
- Technique for modeling in-depth water diversion developed and qualified.
Elements important for progression (NB! Case dependent)

- Technology development driven by the license
  - Good support from central organisation.
- Close cooperation with Research institute (IRIS) and Contractors (Halliburton and Knutsen Subsea Solutions).
- Close cooperation with the license partnership
  - Frequent partner involvement
  - Involvement gives ownership and enthusiasm.
  - Support from all the Snorre license partners.
- Systematic approach - Up-scaling
  - Mind set on large field pilot from the start
- Operation: Minor interference with operations on the Platform (Snorre A)
- Sanctioning process:
  - Positive NPV for the pilot for expected case (Not for low case).
Field implementation

Implementation concept depend on field challenge:

- Poor sweep from water injection
  - Geological heterogeneities
  - Unfavourable mobility ratio with injected fluid
- Water production processing limitation
- Stand alone treatments or combined with polymer injection.

Concept for field implementation

- “Full field” implementation - Frequent treatments
- Stepwise implementation – In-frequent treatments
  - Common injection operation service provided for several fields (ref. implementation of LWI - Light Well Intervention vessel services)
  - Cost sharing
Field implementation

• New market situation
  – Break even requirement

• Value estimation
  – Apply current modelling technology for in-depth diversion
  – Further development of modelling technique

• Cost reduction:
  – Optimize operational concept.
    • Re-use of equipment
  – Cooperation across owner licenses/operator companies - Share cost/risk
  – Product and services cost
    • Marked adjustment
    • High volume
Conclusion

- EOR technology development and field implementation
  - Takes long time/High cost
  - Close cooperation needed (Operator(s), License owners, Research institutes, Service companies)
  - Benefits from close cooperation:
    - Early operational involvement
    - Share cost/risk (For field pilots and field implementation)
- Possible contributions from NIOR:
  - Further development of simulation method/tool for modelling of in-depth water diversion.
    - Include effect of divalent salt in dynamic modelling of gel kinetics.
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