Snorre FAWAG
Tore Blaker, Statoil
Outline

• Snorre Field background
• Snorre IOR Qualification Plan
• Some foam basics
• P-18 gas shut-off
• FAWAG project
• Summary

FAWAG = Foam Assisted Water Alternating Gas
Snorre - Backdrop

- Spanning blocks 34/4 and 34/7 in the Tampen Area of the Norwegian Sea
- Production start-up August 1992
- Developed by 2 PDQ platforms, a TLP and a semi-submersible
- Water depth 300 – 350 meter
- Oil and gas is piped to Statfjord A and B for export
- Part of produced gas is injected for IOR and rest is exported through Statpipe

Partners

<table>
<thead>
<tr>
<th>Company</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statoil (operator)</td>
<td>33.32 %</td>
</tr>
<tr>
<td>Petoro</td>
<td>30.00 %</td>
</tr>
<tr>
<td>Esso</td>
<td>17.76 %</td>
</tr>
<tr>
<td>Idemitsu</td>
<td>9.60 %</td>
</tr>
<tr>
<td>RWE Dea</td>
<td>8.28 %</td>
</tr>
<tr>
<td>Core Energy</td>
<td>1.03 %</td>
</tr>
</tbody>
</table>
Snorre Subsurface

- EUR 1.6 billion Barrels (source: NPD Fact Sheet)
- Statfjord and Lunde Formations
- Faulted, channelized sandstone reservoirs
- Reservoir depth 2000 – 2700 meter
- 100 – 3,000 mD permeabilities
- Light and undersaturated oil
- Limited aquifer support
- Pressure support by water injection as drive mechanism
- WAG injection added in 1995
Snorre IOR Qualification Plan

• Early realized that Snorre had a significant potential to add value by recovering more resources
  – High STOOIP and low Recovery Factor

• IOR Qualification Plan established in 1991

• Initial technologies included:
  – WAG
  – Advanced D&C Technologies
  – Chemical Methods

• Plan covering entire Project Lifecycle for each IOR technology
  – Potential for IOR
  – Schedule
  – Qualification cost
Snorre IOR Qualification Plan

IOR Project Lifecycle

• Screening
• Laboratory studies
• Technology development
• Opportunity framing
• Value prediction
• Pilot testing
• Phased / Full implementation
WAG Pilot Success

Snorre WAG Extension

- Full field implementation decided in 1995
- Gas injection rate increase 35 → 265 MMSCFD/d
- Challenge to control
  - producer GOR
  - gas sweep efficiency
- Foam main candidate
- Increased focus on qualification of foam technology
Why FOAM?
Foam application

Use of Foam to Improve Sweep Efficiency

a) Poor area sweep
b) Gas channeling
c) Gravity override

Gas/WAG injector

Oil producer

Well – to – well foam treatment

Foam blocking gas coning
What is Your Sweep Efficiency Problem?

THIEF ZONE?

GRAVITY OVERIDE?

GAS CONING?

FINGERING?

FRACTURES?

GAS CUSPING?

HETEROGENEITIES?
“Foam is a substance where air or gas bubbles are trapped inside a liquid or solid”
What is Foam?

- A structured two-phase, compressible fluid
- Large gas volume dispersed as bubbles throughout a continuous liquid phase
- Liquid film is stabilized by surfactants to prevent bubbles coalescence
- Apparent viscosity depends on shear rate, quality, texture and liquid phase rheological properties
Foam in Porous Media

• Gas mobility controlled by foam texture (bubble size)
• Films created continuously by leave-behind, snap-off and lamella division
• Films destroyed by film drainage and rapture
• Foam propagation by breaking / reforming (weak foam), or bubble movement (strong foam)
• Foam generation is complex, involving different mechanisms under different conditions

Controversy about basic nature of foam in porous media (Rossen, Delft Uni.)
Reported Field Foam Projects (Year 2000)
CO₂, N₂, Steam and HC Gas Foam

- Canada: 4 projects
- USA: 35 projects
- Norway: 5 projects
- UK: 1 project
- Russia: 3 projects
- Nigeria: 2 projects
- Gabon: 3 projects

At least 277 SPE papers on Foam Flooding today (Schlumberger, 2011)
Snorre Foam - Experimental Work

Solubility Tests (bulk)
- Seawater (5 - 90° C)

Rock Characterization
- Mineralogy
- Pore size distribution
- Specific surface area
- Wettability

Chemical Loss Studies
- Adsorption
- Precipitation
- Ion exchange
- Partition into oil
- Sacrificial agent

Core Floods (Effect on Gas Blocking and Mobility Reduction)
- Surfactant concentration
- Flow rate
- Foam quality
- Oil saturation
- Gas type
- Temperature
- Permeability
- Ageing and foam propagation
Foaming Agents Screening

- Brine compatibility
  - Solubility and salinity tolerance
- Surfactant loss
  - Adsorption
  - Partitioning to the oil phase
- Foamability
  - Mobility reduction factor (MRF)
  - Oil tolerance
- Injectivity - Shear thinning properties

AOS surfactants most attractive
- Blocking and mobility control
- Price and availability
- Environment
Snorre FAWAG Project

**Snorre reservoir conditions**

90°C, 300 bar

**Foam Mobility**

- Foam is separate phases of gas and liquid
- Foam mobility means separate mobilities for gas and liquid in the presence of foam
  - gas mobility strongly reduced
  - water mobility largely unaffected
- Relative permeability concept is valid
- Laboratory core flooding experiments determine a mobility reduction factor (MRF)

\[ K_{rg, foam} = \frac{K_{rg}}{MRF} \]
Snorre Field Foam Pilots

1999 - 2000 Mobility Control
P - 32

1998 - 1999 Mobility Control
P - 25A

1996 Gas shutoff
Production well
P - 18

1997 Injection test
P - 25A
Operational Parameters

• Injection mode:
  − **SAG**: Surfactant-alternating-gas. Sequential injection where a slug of surfactant solution is followed by gas. Foam is formed in-situ. Operationally similar to WAG and simple, possible segregation
  − **Co-injection**: Simultaneous injection of water, surfactant and gas. Operationally more complicated than SAG. Foam is formed in wellbore. Reduced injectivity

• Bottom hole injection pressure below fracturing pressure for both phases

• Divide volumes of surfactant in at least two slugs

![SAG-Injection](image1)
![Co-Injection](image2)
Foam for Gas Blocking in Production Well

P-18 Foam Pilot Results

- Strong foam generated in-situ
- GOR reduced by 50%
- Well returned to production status
- Earlier foam breakdown than expected
- Payback within 12 days

Successful pilot with identified potential for improvement
- foam life extension
- cost reduction
LP Surfactant Feed Pump and Flexible piping
FAWAG in Well Pair P-32 / P-39

- WFB selected as pilot area
  - P32 (Inj.) and P-39 (Prod.)
- 2 WAG cycles completed, GBT time <30 days
- Pilot period Nov. 1999 - Sept. 2000

Objectives

- Reduce gas mobility and thus improve sweep
- Increase oil rate and reduce GOR and thus increase gas storage in reservoir

Performance

- SAG injection mode with 2 slugs
- Surfactant volume injected ~720 m³ (23%)
- Surfactant concentration ~0.5% and ~0.2%
FAWAG Logistics

• AOS surfactant selected based on lab experiments and previous pilots
• Spec as for standard product, but concentration reduced from 38% to 21% to reduced gelation risk
• Large quantity of surfactant needed to cover flooded area
• Transported by ship to base in Florø and then to Snorre
• Surfactant stored in TLP water ballast tanks
• Only new facilities piping and pumps
Flow Diagram FAWAG Injection

New facilities used for FAWAG
High Pressure Surfactant Injection Pump
Foam Effects in P-32 (Injection Well)

### Chart: FAWAG Injection Rates

- **1. surf**
- **1. GI (FAWAG)**
- **2. surf**
- **2. GI (FAWAG)**

### Table: Injection Data

<table>
<thead>
<tr>
<th></th>
<th>1. surf</th>
<th>1. GI</th>
<th>2. surf</th>
<th>2. GI*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cum injected [Sm^3]</td>
<td>15262</td>
<td>82.0E6</td>
<td>31733</td>
<td>94.6E6</td>
</tr>
<tr>
<td>Time [day]</td>
<td>9.5</td>
<td>100</td>
<td>20.3</td>
<td>153</td>
</tr>
<tr>
<td>Average rate [Sm^3/day]</td>
<td>1606</td>
<td>820 000</td>
<td>1564</td>
<td>618 300</td>
</tr>
<tr>
<td>Surfactant concentration [wt%]</td>
<td>0.49</td>
<td>-</td>
<td>0.20</td>
<td>-</td>
</tr>
</tbody>
</table>

*Temporary, per 23.06.2000, injection not finished
Observations

An immediate reduction in P-32 injectivity after SAG injection followed by a slow increase, indicates formation of foam in the reservoir.

A moderate increase in P-39 GOR was observed in January 2000, but significantly different from previous gas breakthroughs:
- rate of GOR increase was slower
- GOR stabilised at a lower level, around 200 m3/m3 compared to 350-400 m3/m3
P-39 Gas Production during WI and GI Cycles

Before Foam Injection

After Foam Injection

1. Surf.
2. Surf.

GOR (Sm³/Sm³)

P-39 Production Performance

![Graph showing production performance with labels for Oil, GOR, and WC over years 1996 to 2000, highlighting before and after foam periods. The graph uses a color-coded line graph to represent the data.]
Oil production (Sm3/d)

Water Injection → WAG → FAWAG

P-39 Production Performance

Oil production (Sm3/d)

start FAWAG

WAG

WAG+FAWAG

Q oil
Summary

• Application of foam has been qualified as an attractive gas mobility reduction agent for NCS reservoirs
  – Method’s potential and simplicity has been demonstrated
• Method is robust to certain reservoir uncertainties, but heterogeneities seems to be required
  – foam tend to smooth out permeability contrasts
• Logistics of handling chemicals can easily be solved on most installations in a cost effective way
• No major capital investments require beyond that of WAG
• Limited risk to damage well or reservoir
• Chemicals are non-toxic
Why has not FAWAG been implemented?

Probably several reasons why, but some of them could be..........

• Limited IOR potential - competing with other IOR methods
• High uncertainty → geosciences and surface
• Complex reservoir process
  - Challenging to model giving uncertain predictions
• Incremental oil very sensitive to heterogeneity description
  - baseline may be overestimated and therefore IOR potential underestimated
• New and too exotic technology??
Snorre FAWAG Project

NPD IOR Award 1999 to Snorre License Group for FAWAG
Thank You
Back Up
Two Different Foam Applications

<table>
<thead>
<tr>
<th>Shut Off/Near Wellbore Diversion</th>
<th>Mobility Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fractures</td>
<td>Viscous Instabilities</td>
</tr>
<tr>
<td>Permeability Heterogeneities (w/o x-flow)</td>
<td>Permeability Heterogeneities (w/x-flow)</td>
</tr>
<tr>
<td>Gravity override</td>
<td></td>
</tr>
</tbody>
</table>

**Criteria for success**
- Poor vertical communication
- Low mobility foam
- Long term stability foam
- Selectively plugging

**Criteria for success**
- Low surfactant cost and loss
- Rapid foam propagation
- Low foam mobility
- Good injectivity
- Selectively blocking swept zones
What is FAWAG?

Foam Assisted Water Alternating Gas Injection

- Method for controlling gas mobility in-situ by the use of foam -
P-32 Gas Injectivity Before and After FAWAG