

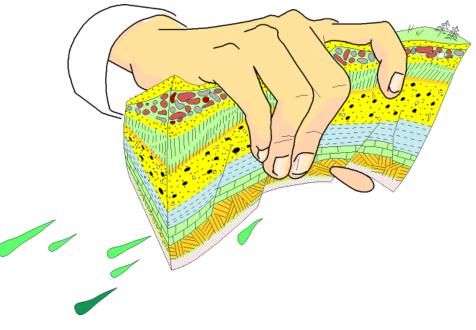
Snorre FAWAG

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





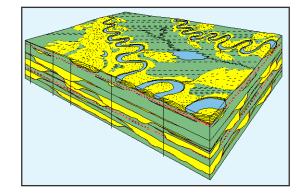
Partners

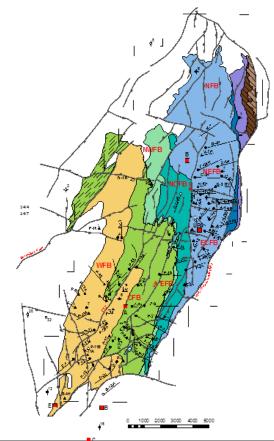
Statoil (operator)	33.32 %		
Petoro	30.00 %		
Esso	17.76 %		
Idemitsu	9.60 %		
RWE Dea	8.28 %		
Core Energy	1.03 %		



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

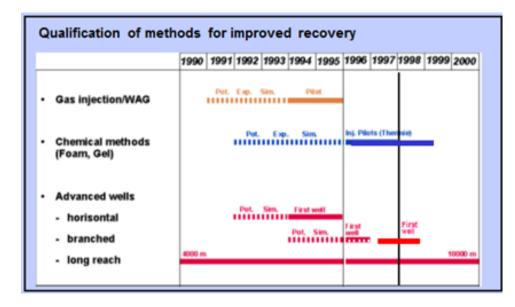
- Early realized that Snorre had a significant potential to add value by recovering more resources
 - High STOOIP and low Recovery Factor
- IOR Qualification Plan established in 1991
- Initial technologies included:
 - WAG
 - Advanced D&C Technologies
 - Chemical Methods
- Plan covering entire Project Lifecycle for each IOR technology
 - Potential for IOR
 - Schedule
 - Qualification cost



Snorre IOR Qualification Plan

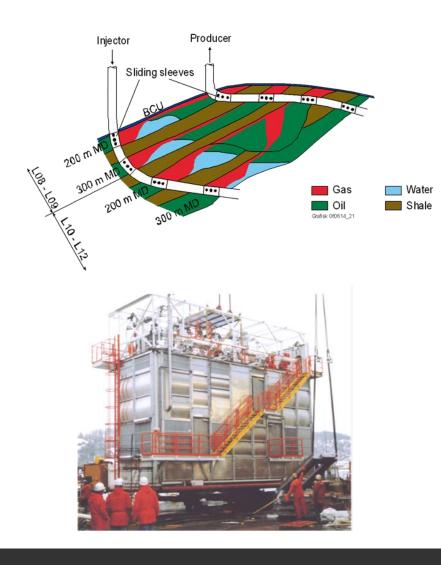
IOR Project Lifecycle

- 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



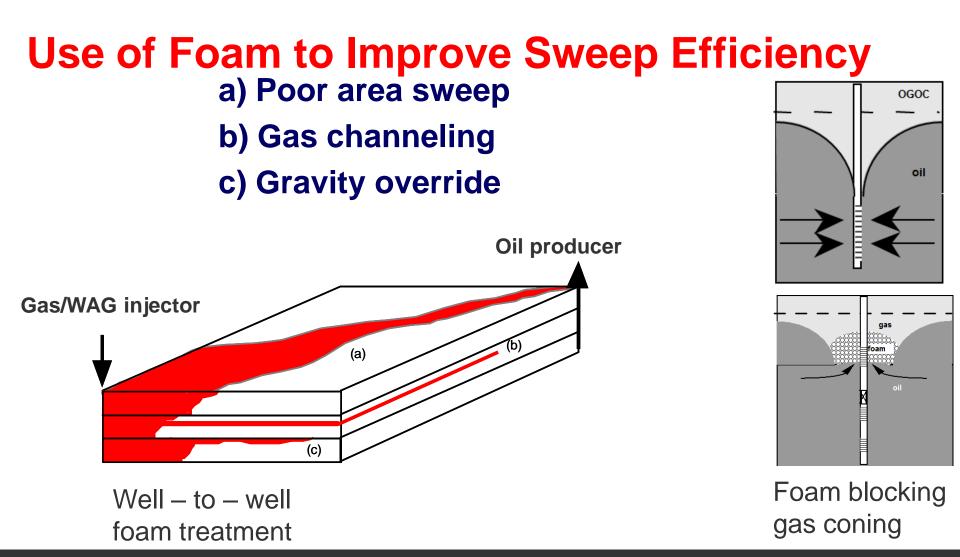
 Increased focus on qualification of foam technology



Why FOAM?

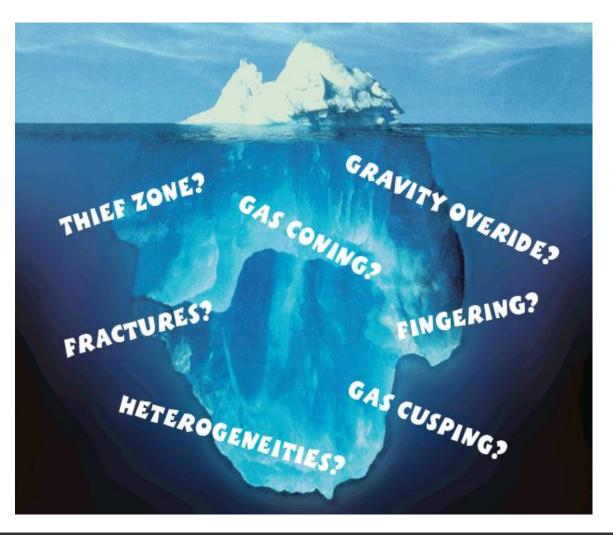


Foam application





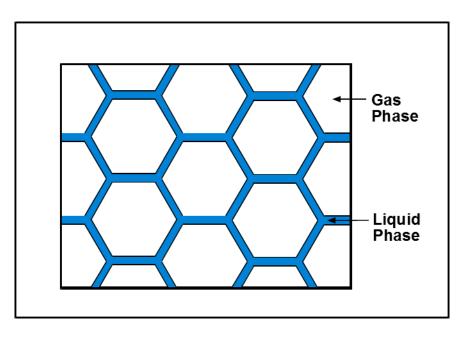
What is Your Sweep Efficiency Problem?

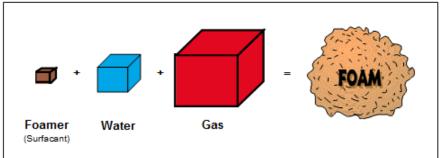




Foatt is a substance where air or gas bubbles are trapped inside a liquid or solid

What is Foam?



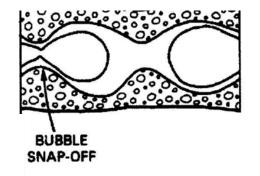


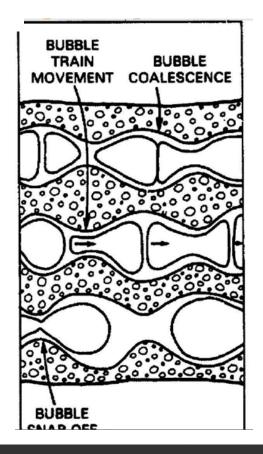
- A structured two-phase, compressible fluid
- Large gas volume dispersed as bubbles throughout a continous liquid phase
- Liquid film is stabilized by surfactants to prevent bubbles coalescence
- Apparent viscosity depends on shear rate, quality, texture and liquid phase rheological properties



Foam in Porous Media

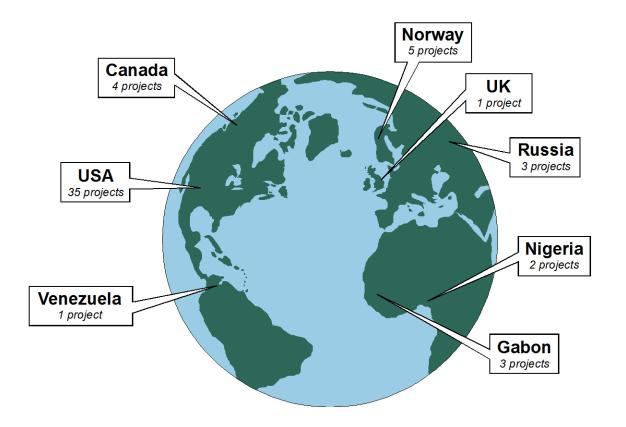
- Gas mobility controlled by foam texture (bubble size)
- Films created continuously by leave-behind, snap-off and lamella division
- Films destroyed by film drainage and rapture
- Foam propagation by breaking / reforming (weak foam), or bubble movement (strong foam)
- Foam generation is complex, involving different mechanisms under different conditions
- Controversy about basic nature of foam in porous media (Rossen, Delft Uni.)







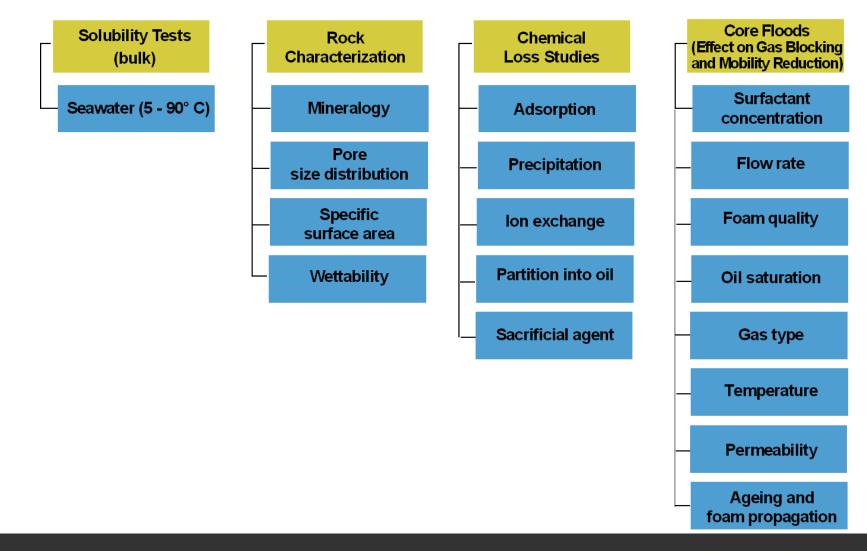
Reported Field Foam Projects (Year 2000) CO₂, N₂, Steam and HC Gas Foam



At least 277 SPE papers on Foam Flooding today (Schlumberger, 2011)



Snorre Foam - Experimental Work



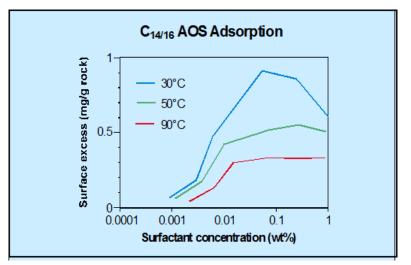


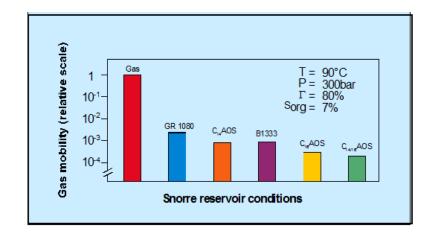
Foaming Agents Screening

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

AOS surfactants most attractive

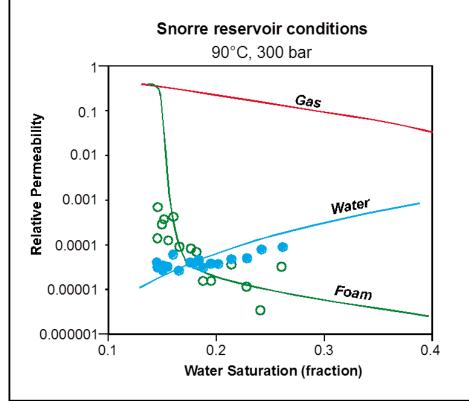
- Blocking and mobility control
- Price and availability
- Environment



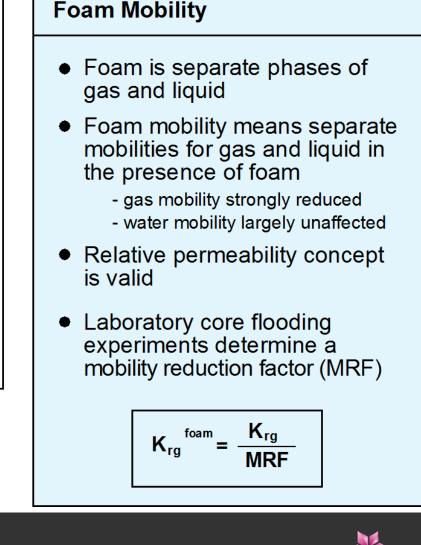




Snorre FAWAG Project

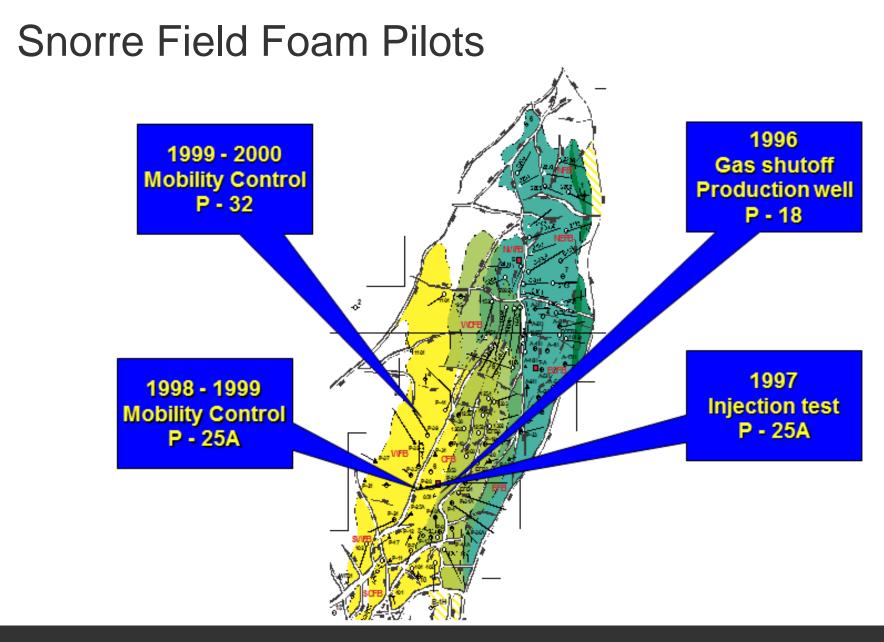


relative permeability 13 April 99 TB DW





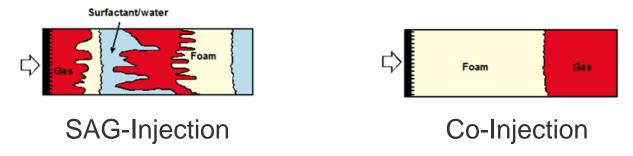






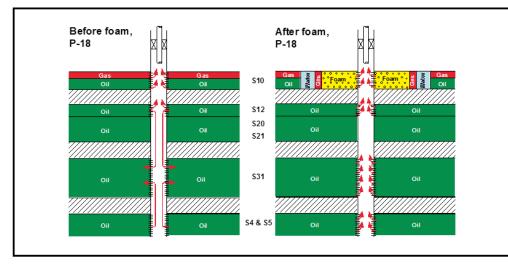
Operational Parameters

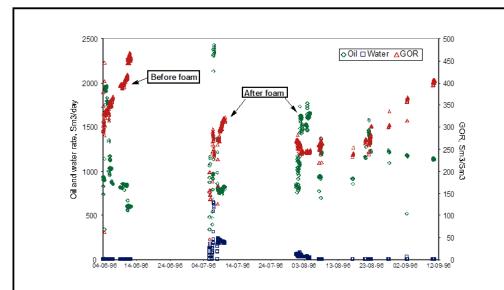
- Injection mode:
 - SAG: Surfactant-alternating-gas. Sequential injection where a slug of surfactant solution is followed by gas. Foam is formed in-situ.
 Operationally similar to WAG and simple, possible segregation
 - Co-injection: Simultaneous injection of water, surfactant and gas.
 Operationally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





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

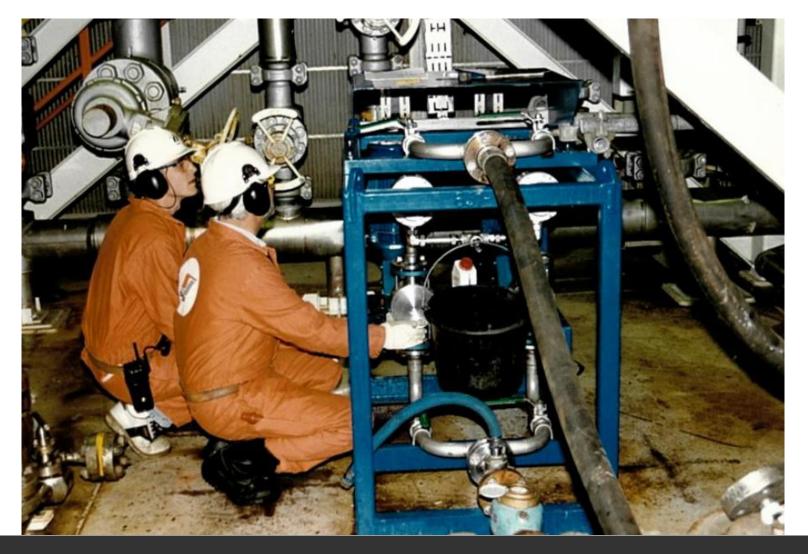
Successful pilot with identified potential for improvement

- foam life extension
- cost reduction



snorre map foam tests 9 April 99 TB DM

LP Surfactant Feed Pump and Flexible piping





FAWAG in Well Pair P-32 / P-39

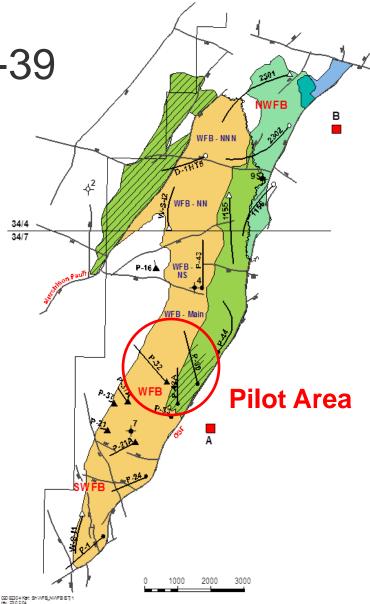
- WFB selected as pilot area
 - P32 (Inj.) and P-39 (Prod.)
- 2 WAG cycles completed, GBT time <30 days
- Pilot period Nov. 1999 Sept. 2000

Objectives

- Reduce gas mobility and thus improve sweep
- Increase oil rate and reduce GOR and thus increse gas starage in reservoir

Performance

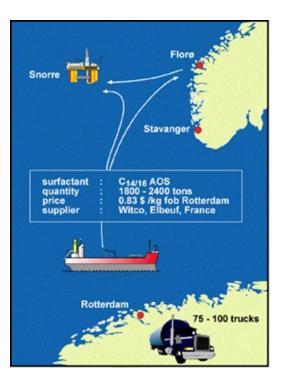
- SAG injection mode with 2 slugs
- Surfactant volume injected ~720 m³ (23%)
- Surfactant concentration ~0.5% and ~0.2%





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

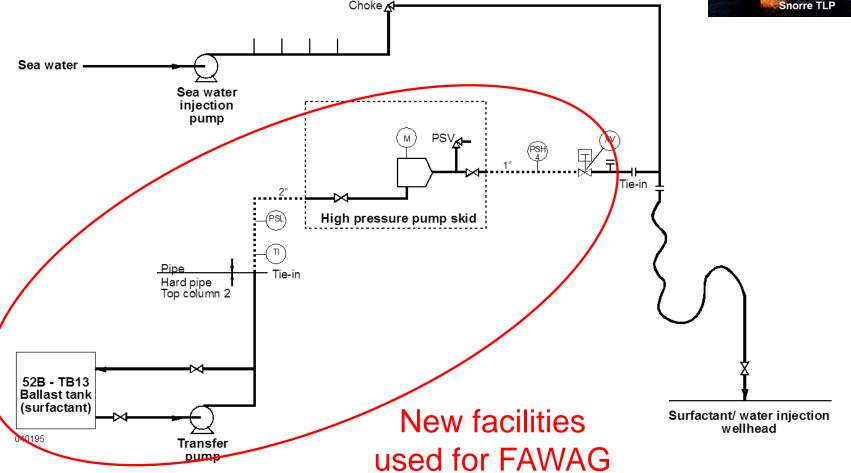






Flow Diagram FAWAG Injection





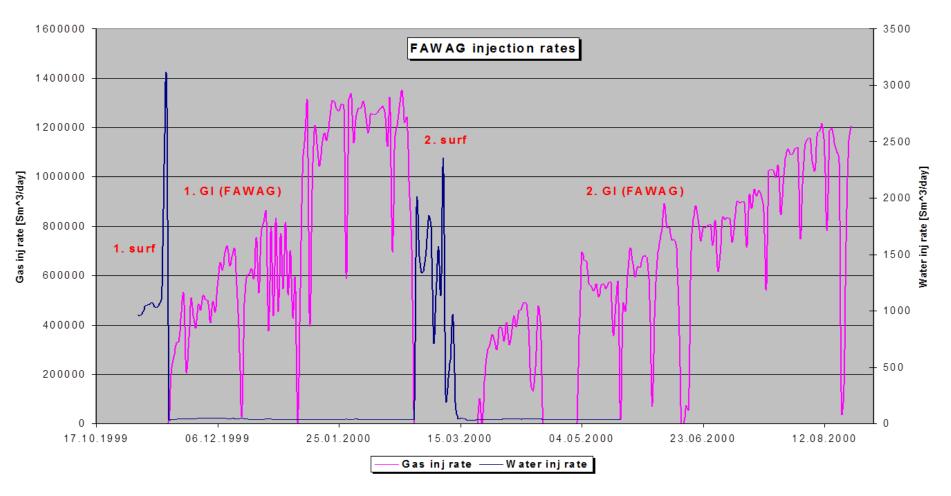


High Pressure Surfactant Injection Pump





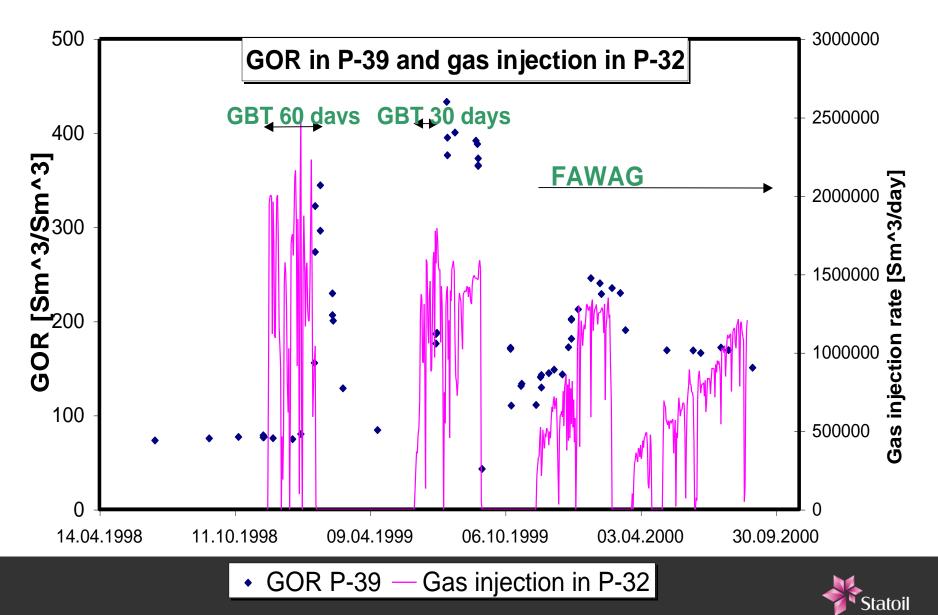
Foam Effects in P-32 (Injection Well)



		1. surf	1. GI	2. surf	2. GI*
	Cum injected [Sm ³]	15262	82.0E6	31733	94.6E6
	Time [day]	9.5	100	20.3	153
	Average rate [Sm ³ /day]	1606	820 000	1564	618 300
Classification: Intern		0.49	-	0.20	-
	* Temporary, per 23.08.2000, injection not finished	•			



Production Data: GOR in P-39



Observations

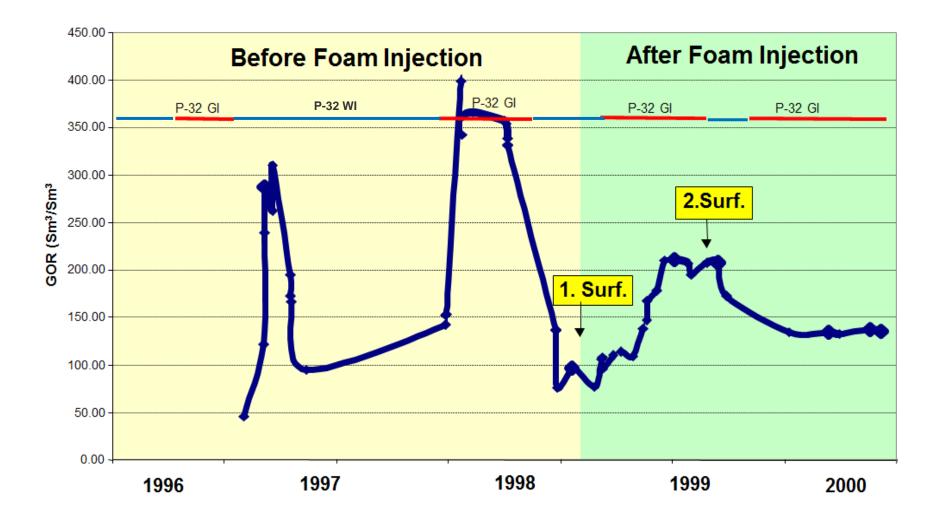
An immediate reduction in P-32 injectivity after SAG injection followed by a slow increase, indicates formation of foam in the reservoir

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

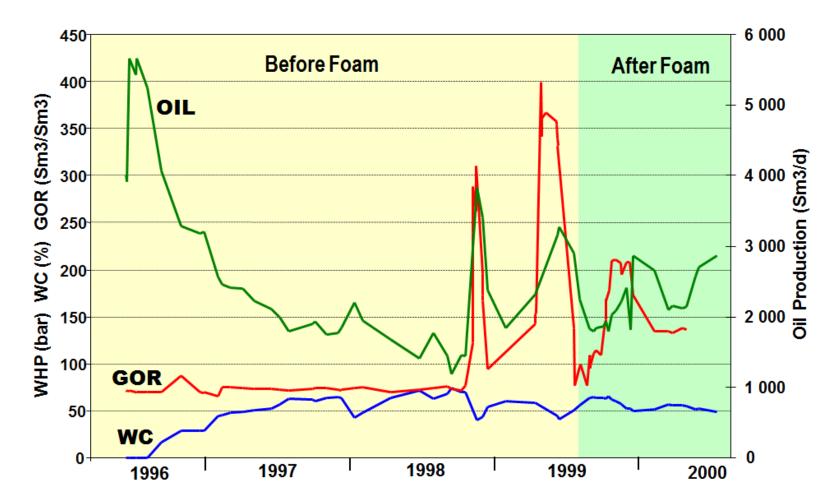


P-39 Gas Production during WI and GI Cycles



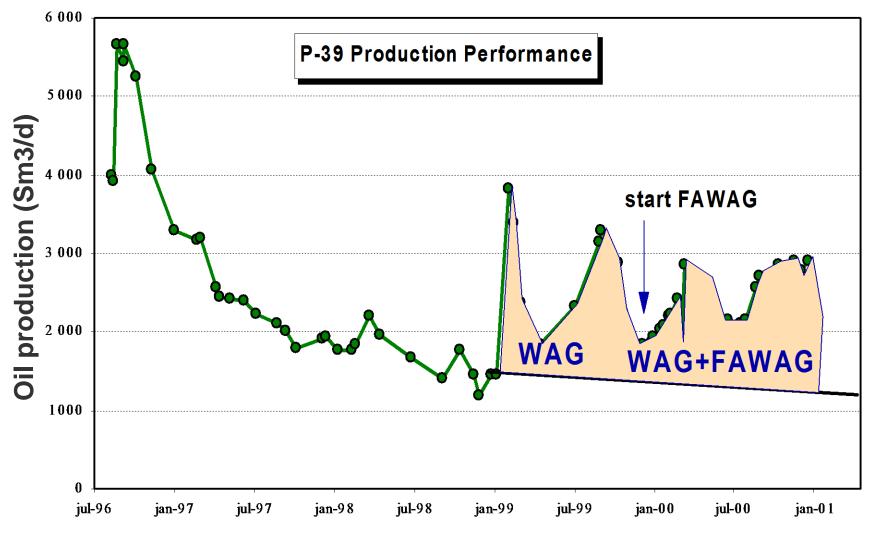


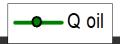
P-39 Production Performance





Water Injection \rightarrow WAG \rightarrow FAWAG







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 \rightarrow 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





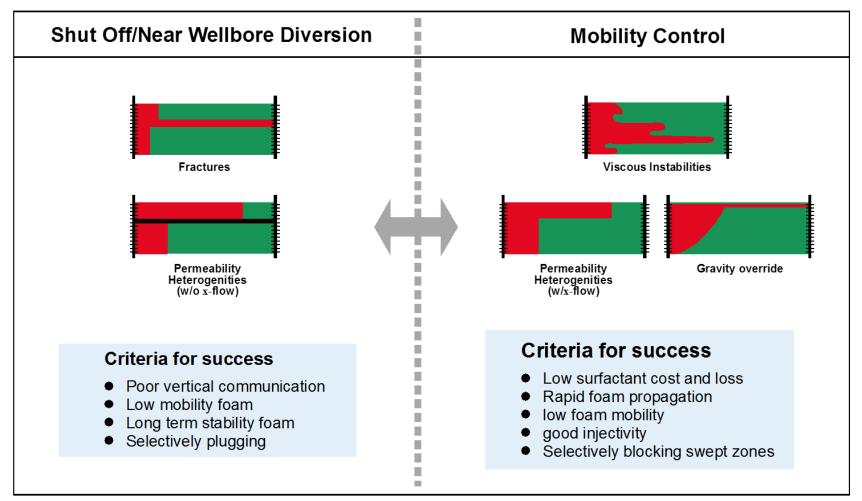




Back Up



Two Different Foam Applications



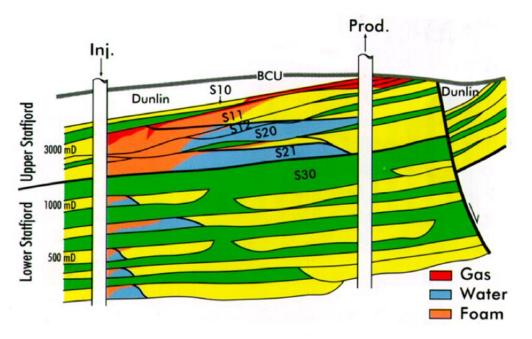
plugging mobility control 12 April 99 TB DW



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

