Polymer Flooding – Field Development Projects in Statoil

6th. November 2013

Dag Chun Standnes

Leading advisor Advanced Recovery Methods

Outline

- Field development projects
  - The gain of applying polymer technology
  - EOR qualification steps
  - Hurdles and important tasks
- Example
  - Polymer injection test at Heidrun field

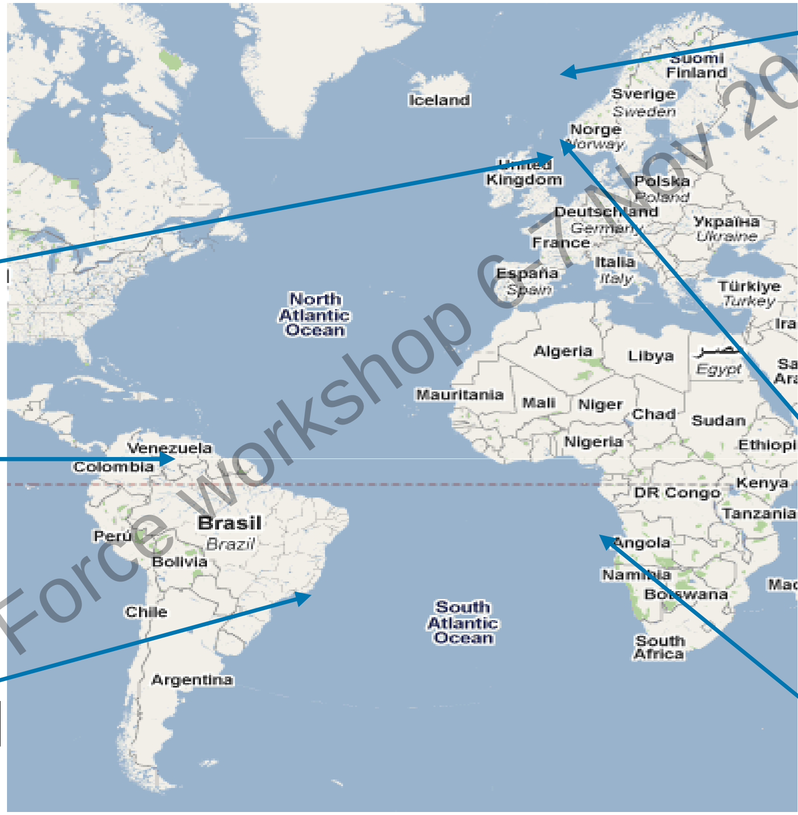
Ongoing Polymer flooding development projects in Statoil

Bressay, UK

Mariner, UK

Petrocedeneo, Brazil

Peregrino, Brazil



Heidrun, NCS

First NCS offshore polymer injection test 2010!

Johan Sverdrup, NCS

Dalia, Angola

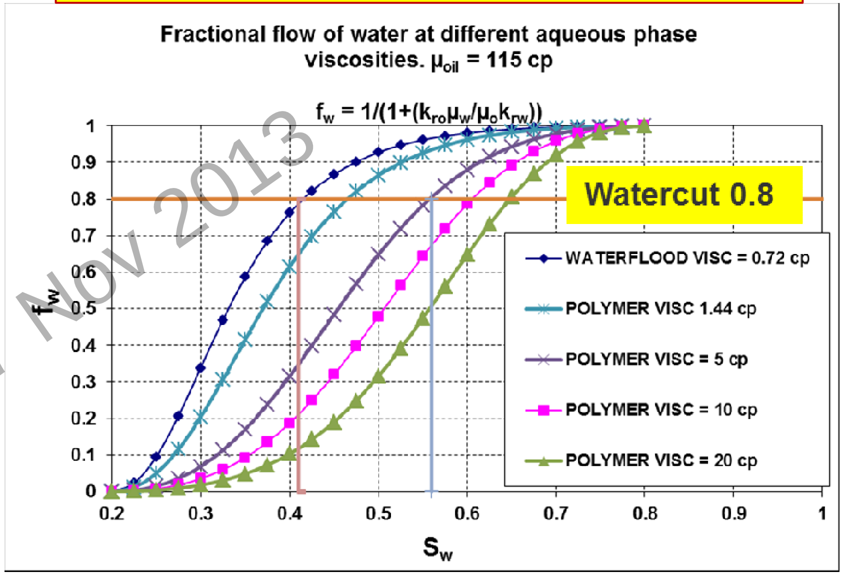
Oil recovery improvement by polymer injection

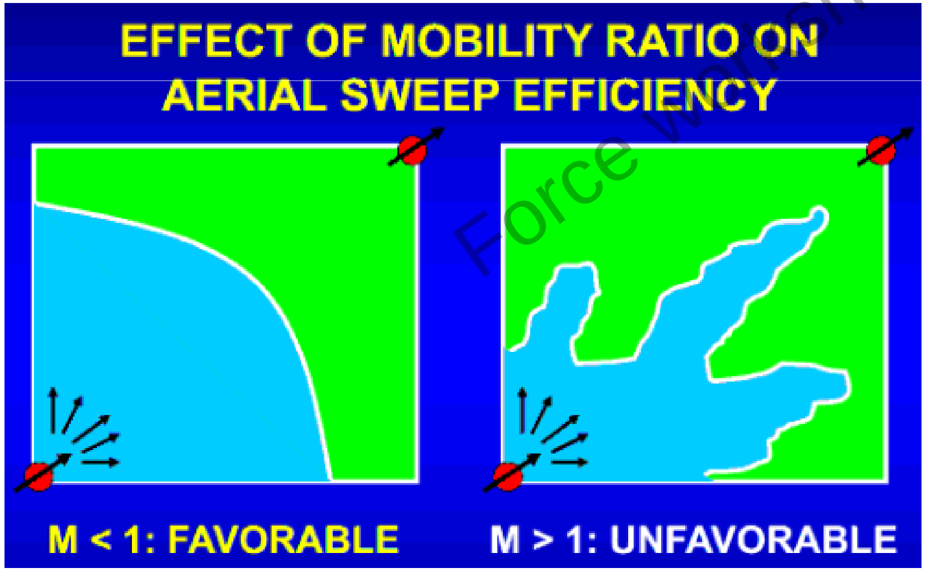
$$M = \frac{\lambda_w}{\lambda_o} = \frac{\mu_o k_{rw}^*}{\mu_w k_{ro}^*}$$

- **Fluid systems where M > 1 (water has higher mobility than oil):**
  - Improve the microscopic sweep efficiency (reduced fractional flow of water) without altering the residual oil saturation
  - Reduce viscous fingering
  - Improve macroscopic sweep efficiency if severe reservoir heterogeneities exists
- **Fluid systems where M ~ 1 (approximately equal mobility for both water and oil)**
  - Improve the macroscopic sweep efficiency if significant reservoir heterogeneity exists

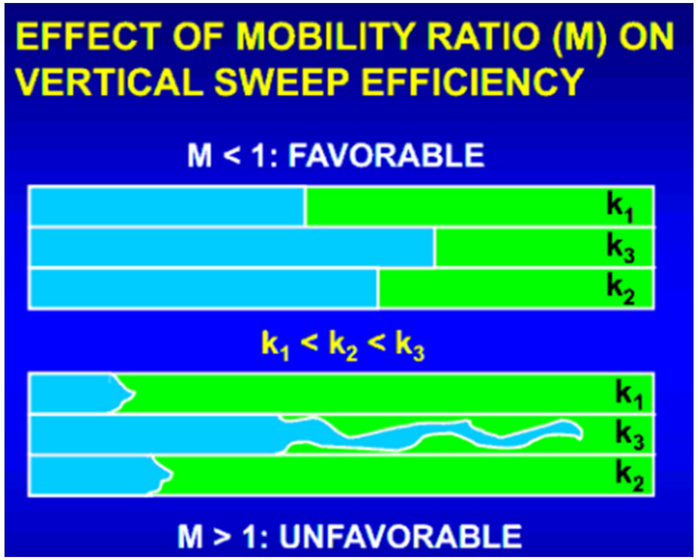
Theory of polymer flooding

- Fluid systems where M > 1
  (water has higher mobility than oil):
  - Accelerate the microscopic sweep efficiency
    (reduced fractional flow of water)
  - Reduce viscous fingering
  - Improve macroscopic sweep efficiency if severe
    reservoir heterogeneities exists





Randy Seright's Homepage



Statoil

Viscosity of heavy crude oil

Source

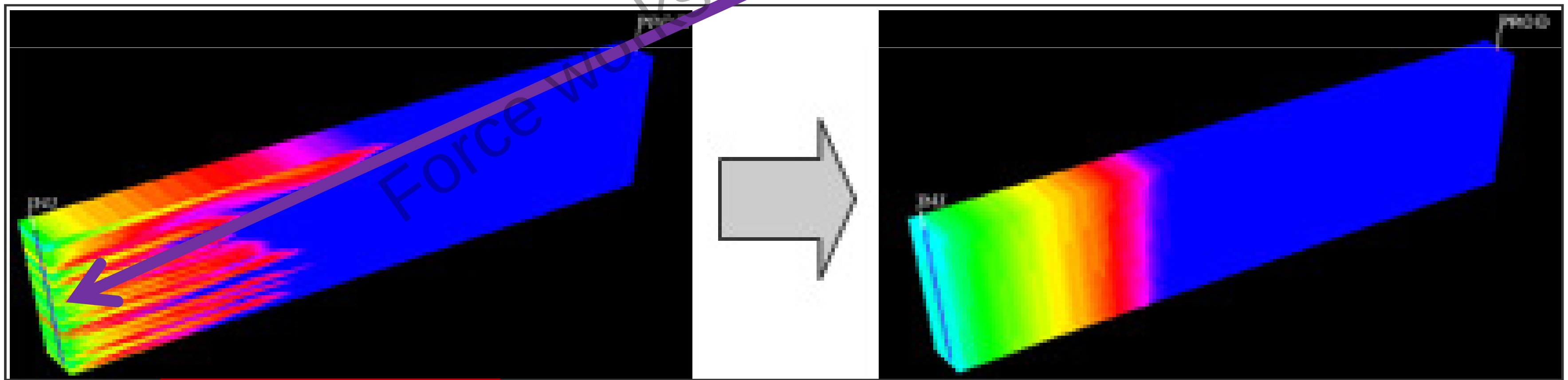
Source

Source

Theory of polymer flooding cont.

- Fluid systems where M ~ 1 (no viscous fingering):
  - Improve the macroscopic sweep efficiency if significant reservoir heterogeneity exists

Layers with strong contrast in permeability



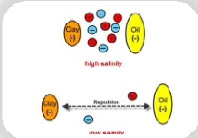
Waterflooding

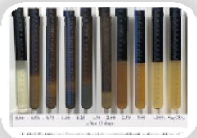
Waterflooding with polymers

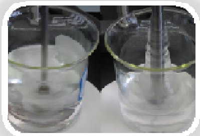
Building a toolbox for offshore EOR

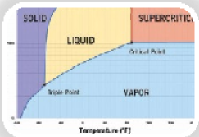
Screening → Lab → Large-scale test → Multi-well pilots → Commercial deployment


Gas diversion by foam

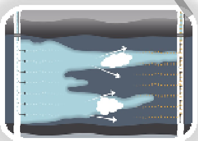

Design water for injection

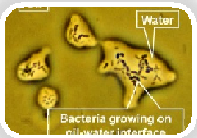

Surfactant flooding


Polymer flooding



CO_2 injection


Water diversion by chemicals

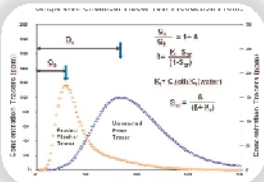


Microbial




Yard tests polymer and chemical flow diversion


Injection tests:
Heidrun polymer (2010)
Snorre diversion (2010)


Single-well chemical tracer tests Heidrun,Snorre, Gullfaks & Oseberg


Oil-Water separation tests, 2013


WJSTP silicate flow diversion pilot on Gullfaks


Na-silicate flow diversion pilot on Snorre


Norne Field: Full-field Microbial EOR

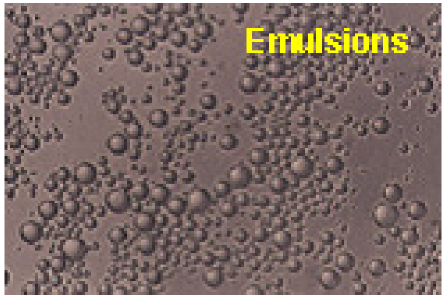
Polymers for enhanced oil recovery

- Purpose: Increase the viscosity of water used in waterflooding

- Two main classes used for polymer flooding:
  - HPAM (Hydrolyzed polyacrylamide)
  - Biopolymers (Xanthan)

Requirements for EOR polymers

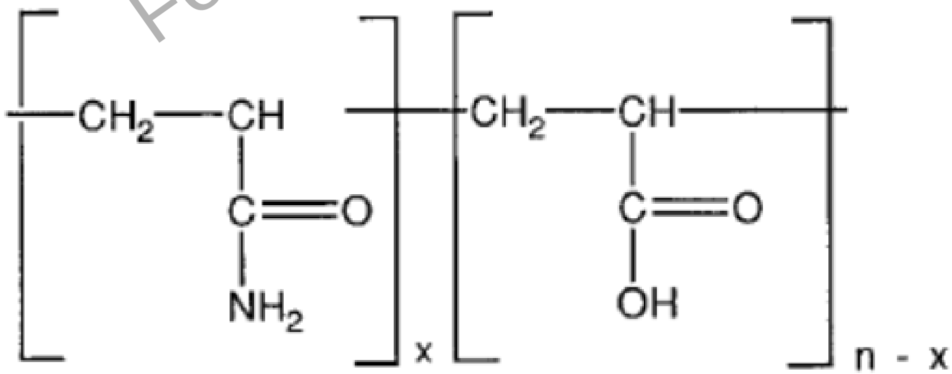
- High viscosity under reservoir conditions
- Good solubility and filterability (injectivity)
- Stable during injection and in the reservoir (no loss of viscosity)
- Compatible with injection chemicals
- Environmentally acceptable (green)
- Minor impact on the oil-water separation process



Statoil

HPAM

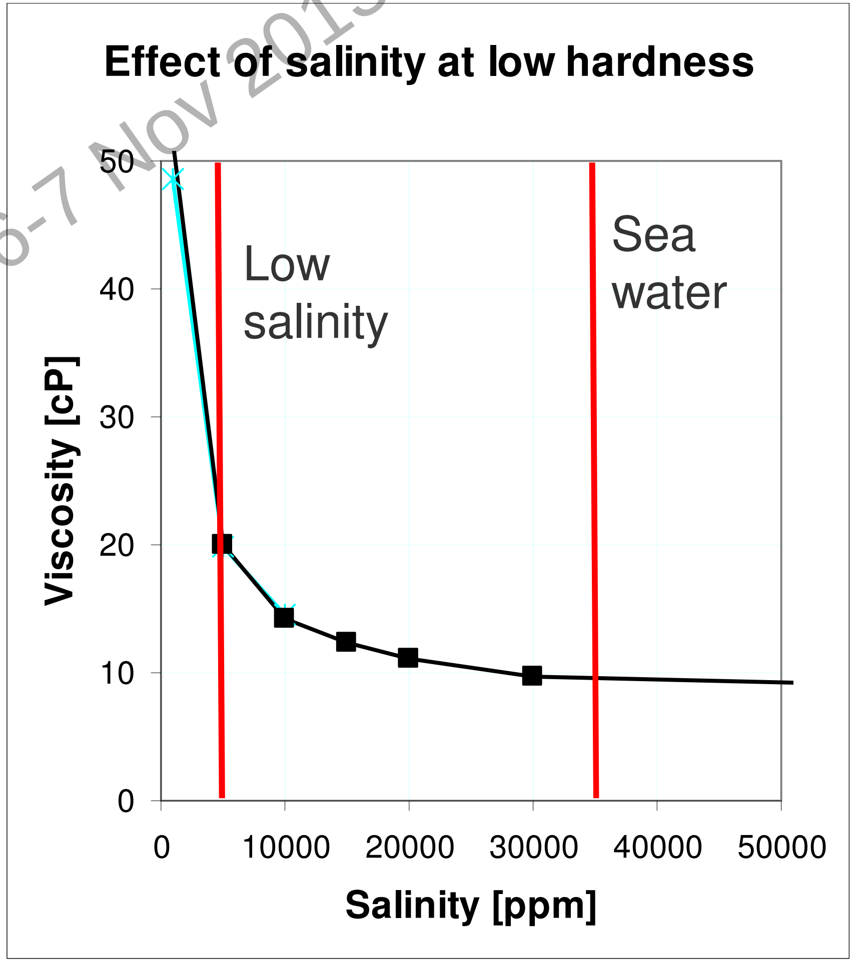
- Synthetic polymer
- High molecular weight, 2 – 20 million Dalton
- High viscosity at low concentration
- Sensitive to temperature, salinity and hardness
- ”Cheap”
- More than 90 % of polymer floods performed with HPAM



Statoil

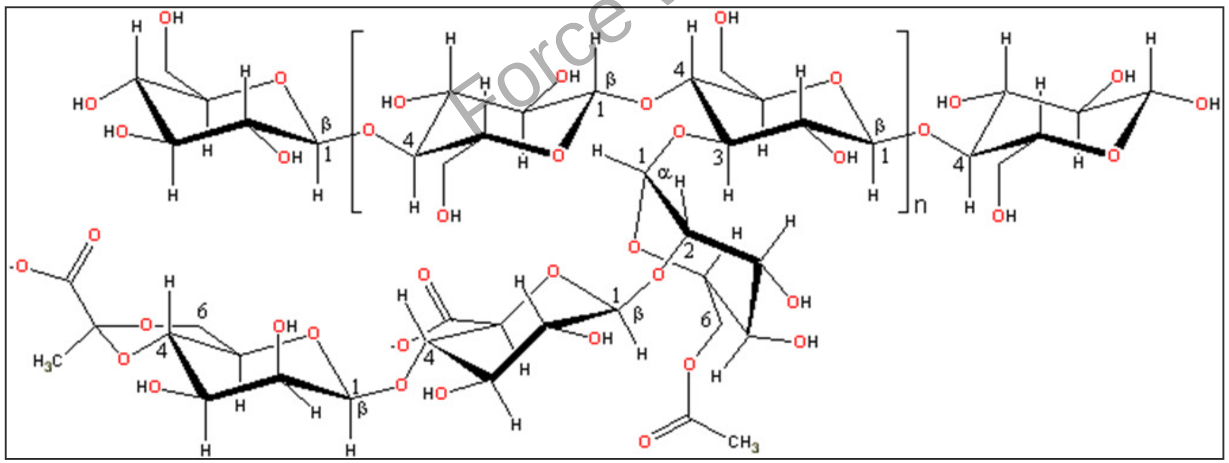
Polymer flooding – Improvement options (desalination of injection water)

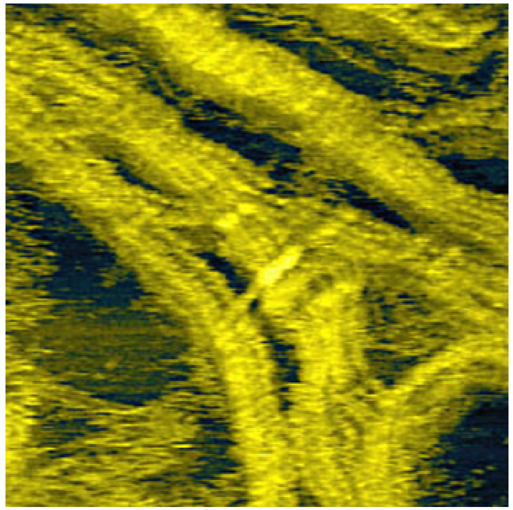
- Desalination of injection water can significantly improve HPAM efficiency
- Qualification programs for nano-filtration (NF) and reverse osmosis (RO) technologies ongoing
- NF plants for removal of sulphate from sea water already in operation at Statoil installations



Biopolymers - Xanthan

- High molecular weight: 2 – 50 million Dalton
- High resistance to temperature
- Less sensitive to salinity and hardness
- Very sensitive to bacterial degradation - Need for biocide
- Expensive





Statoil

Polymer: Stability under injection and in the reservoir

- Chemical degradation: Hydrolysis, oxidation
- Mechanical degradation: Breakdown at high rate, shear
- Biological degradation: Bacterial degradation (not a problem at high temperatures)
- Salinity: Precipitation and flocculation in reaction with mono- and divalent-ions (Na^{+}, Ca^{2+}, Mg^{2+},…)
- Temperature: HPAM degrades at ≤ 80 ℃, Xanthan at ≤ 90 ℃

Statoil

Additional polymer injection issues

- Logistics and mixing offshore
- Compatibility with other injection chemicals
- Shear during injection to minimize degradation
- Production challenges
  - Interference of polymer with oil and production chemicals
- HSE issues
  - Polymer breakthrough in producers
  - No discharge of HPAM to sea (re-injection of produced water)
  - Water management (cleaning of produced water)

Statoil

ATCE 2013 »
SPE Annual Technical Conference and Exhibition
30 September–2 October » Ernest N. Morial Convention Center » New Orleans, Louisiana, USA

SPE 166343
Offshore Polymer/LPS Injectivity Test with Focus on Operational Feasibility and Near Wellbore Response in a Heidrun Injector

Olav M. Selle, Herbert Fischer, **Dag C. Standnes**, Inge H. Auflem, Anne Marie Lambertsen, and Per Einar Svela, Statoil

Amare Mebratu, Elisabeth B. Gundersen, and Ingrid Melien, Halliburton

OUTLINE

- Heidrun field
- Objectives polymer and LPS injection test
- Polymer and cross-linker
- Yard test
- Logistics and operations
- Sampling and analysis program
- Results
- Conclusions

Kjetil Alsvik / Statoil

HEIDRUN

- Discovered 1985, on production since 1995, life time 2045
- Floating tension leg platform + subsea tie-ins
- Water injection: SW, SRP, PWRI
- Planned for 56 well slots + 5 tie-ins
- Oil in place 432 MSm^3 (2 717 Mbbl)
- Reserves: 177 MSm^3 (1 113 Mbbl) oil + gas
- Recovery factors in the range of 10 % to 60 %
- Polymer or linked polymer solution (LPS) injection could increase oil recovery on Heidrun

OBJECTIVES POLYMER AND LPS INJECTION TEST

- Objective I
  - Determine logistical and operational feasibility of polymer/LPS injection
    - Transport, Mixing, Storage, Pumping
- Objective II
  - Observe reservoir and near well bore response
    - Pressures and temperatures versus polymer loading and injection rates

HOW POLYMERS IMPROVE OIL RECOVERY

- Polymer
  - Hydrolysed polyacrylamide (HPAM)
  - *Mobility improvement:* Polymer increases viscosity of injected water from 0.38 cp to ~ 2.0 cp - much closer to reservoir oil viscosity (2 – 4 cp)

- Linked polymer solution (LPS)
  - LPS is HPAM cross linked with aluminium to form nano-sized particles
  - *Diversion:* Nano-sized LPS particles can block water "channels" in the reservoir and divert flow to non-swept areas
  - *Mobility improvement:* As for HPAM

HSE DATA POLYMER AND CROSS-LINKER

- Polymer
  - Hydrolysed polyacrylamide (HPAM)
  - Health: Green, Safety: Green, Environment: Red*)
  - Material is very slippery when wet

- Cross-linker
  - Aluminum Citrate
  - Health: Green, Safety: Green, Environment: Green

*) Approval from Norwegian Pollution Control Authority to inject max. 3 600 kg HPAM classified as red chemical in a Heidrun water injector during 2010

YARD TEST AT ULLRIGG, STAVANGER, AUG. 2008

- Objective:
  - Reveal logistical and operational considerations which may have implications for the offshore test

- Main conclusions:
  - Polymer mixing unit to be improved before the offshore injection pilot
  - Centrifugal pumps onshore, on board the supply vessel, and on the platform need to be replaced or by-passed
  - Dilute the cross linker solution to give accurate dosing

HEIDRUN POLYMER AND LPS INJECTION TEST SEPT. 2010

- Mix 5 000 ppm HPAM "mother" solution onshore in Kristiansund
- Ship "mother" solution offshore and store at Heidrun platform
- Inject "mother" solution downstream wellhead choke to final polymer conc. of 300 ppm and 600 ppm in SRP water
- Inject cross linker, AlCit, downstream wellhead choke at 300:10 and 600:20 polymer:Al ratio in SRP water

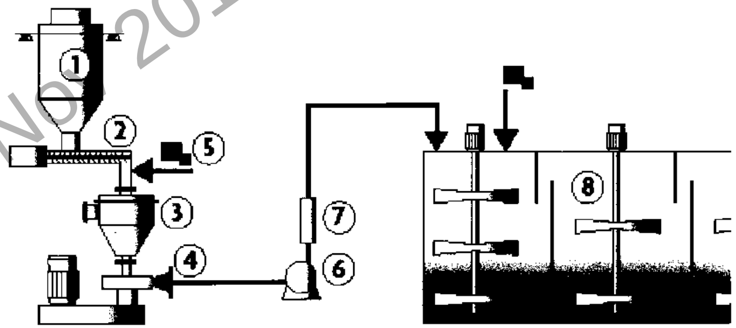
LOGISTICS AND OPERATIONS - ONSHORE

Dissolution Test April 2009

- Polymer slicing unit for wetting the polymer powder
- Capacity 100 kg/h powder

Upgrading Onshore Facilities

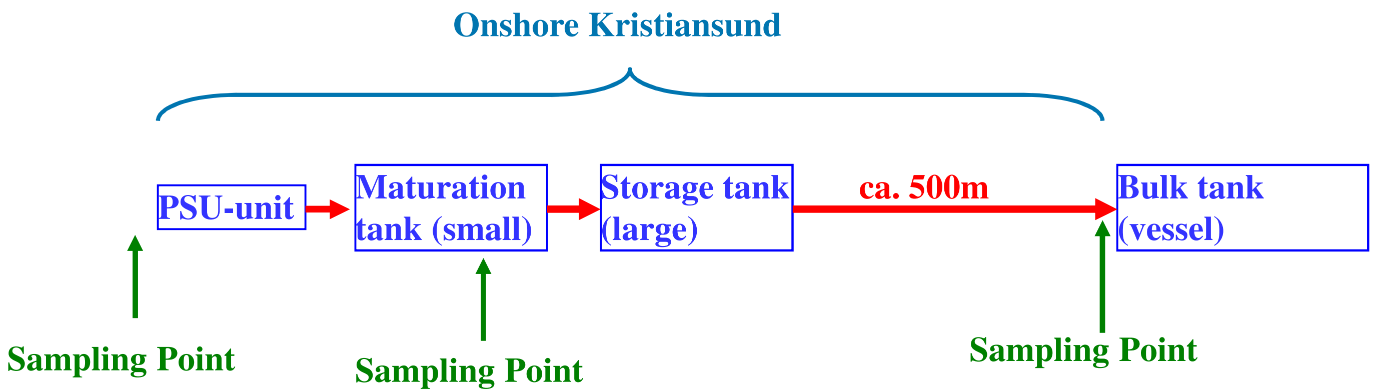
- Stainless steel tanks with paddles to mature and store the “mother” solution
- Screw pump for loading the polymer solution to the supply vessel
- Tanks and lines tested for iron, < 5 ppm
- Required 700 m^3 of 5 000 ppm “mother” solution (3 500 kg powder)
- Polymer powder from May 2009 rejected; filter ratio 3 – 3.7 (1.5 recommended in API 63)
  - Freshly produced polymer delivered 5 days later



FLOQUIP PSU™ Schematic

SAMPLING AND ANALYSIS PROGRAM

- High quality polymer solution is challenging
  - Shear degradation, chemical degradation and biological degradation
- Quality control (QC) of polymer powder
  - Water content, insoluble particles, viscosity and filter ratio
- Quality control (QC) of polymer “mother” solution and diluted solutions (300 ppm, 600 ppm)
  - Viscosity, filter ratio, iron content, pH, temperature, and samples for chemical analysis



LOGISTICS AND OPERATIONS - OFFSHORE

- Supply vessel with screw pumps identified
- No need for biocide in “mother” solution
  - 3 months before bacterial activity
- Insignificant degradation over time in a 3 weeks rolling test
- The vessel’s mud tanks inspected and re-washed
- “Mother” solution in the platform’s completion storage tanks and mixing tanks
  - Total volume available 300 m^3
- Vessel and platform lines and tanks tested for iron
  - < 10 ppm

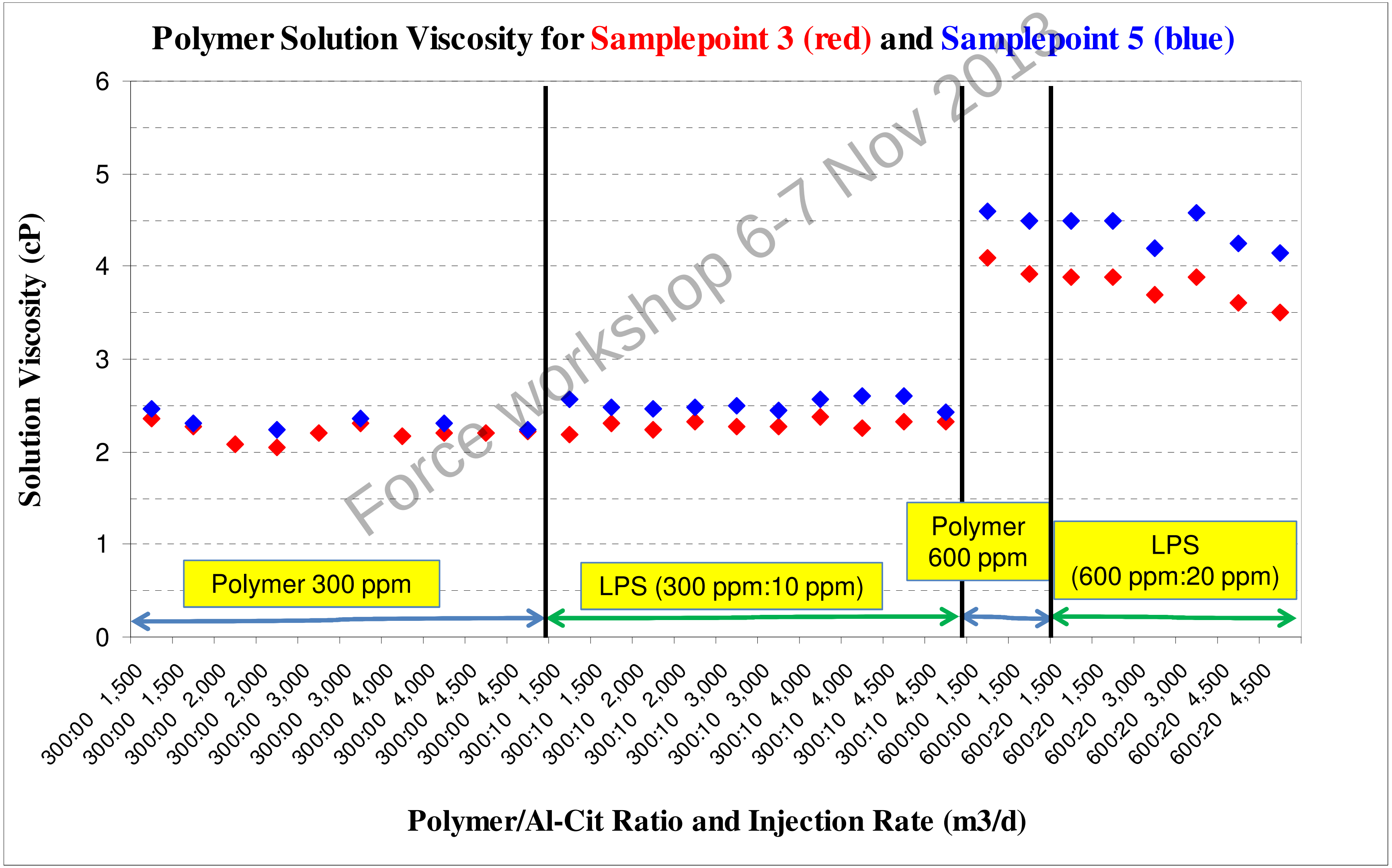
LOGISTICS AND OPERATIONS - OFFSHORE

- Three batches of “mother” solution a 230 Sm^3
- Shipped offshore in 3 separate trips
- Injection batches:
  1. 300 ppm polymer
  2. 300 ppm polymer + 10 ppm x-linker
  3. 600 ppm polymer; 600 ppm polymer + 20 ppm x-linker
- Sampling for QC (viscosity, filter ratio, iron)
  - Before and after mixing onshore
  - After pumping to vessel
  - When arriving offshore
  - During injection
- Well injectivity tested before and after injection

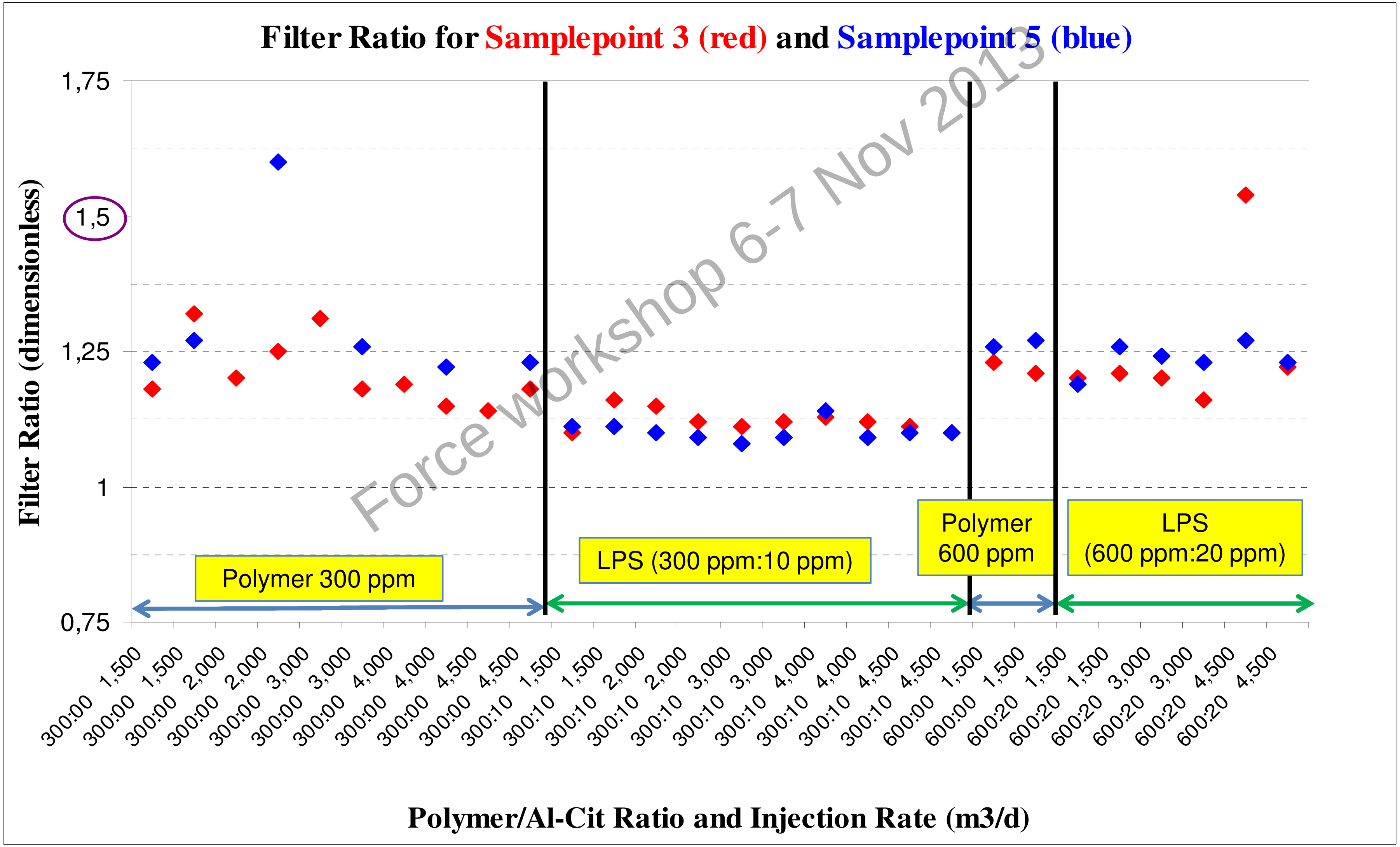
INJECTION VISCOSITY AT WELLHEAD - OFFSHORE

Sample point 3: Polymer feed location upstream cross-linker feeding

Sample point 5: Well-head

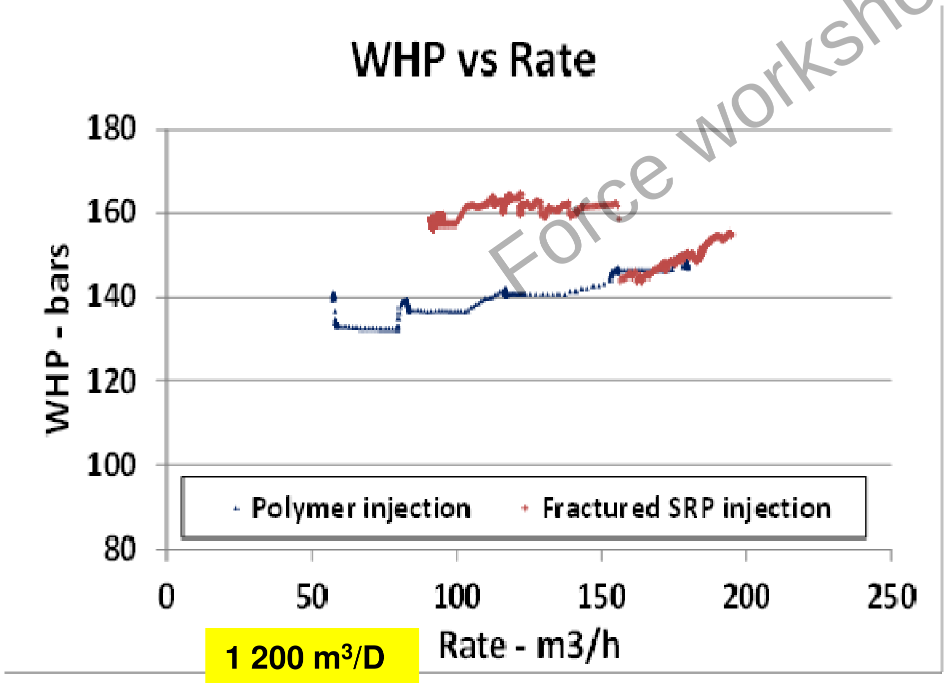


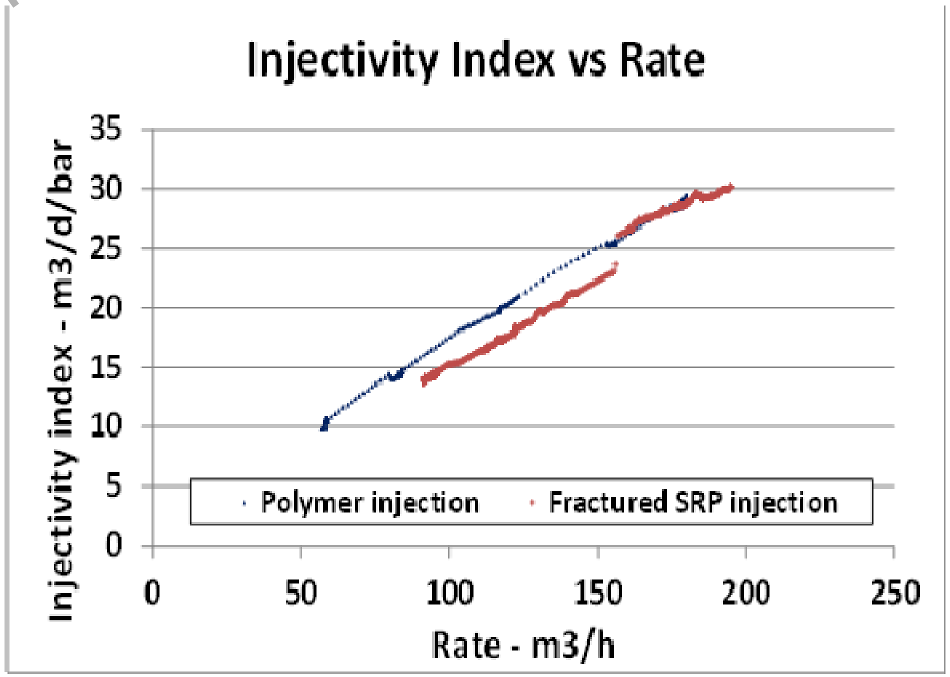
FILTER RATIO DATA AT WELLHEAD - OFFSHORE



INJECTIVITY BEFORE AND DURING POLYMER & LPS INJECTION

- Polymer and LPS injectivity improved compared to water injectivty before the test due to dual fracturing at lower injection rate
- Polymer and LPS injection giving approx. 20 bars lower downhole pressure at rates below 150 m^3/h (= 3 600 m^3/D)

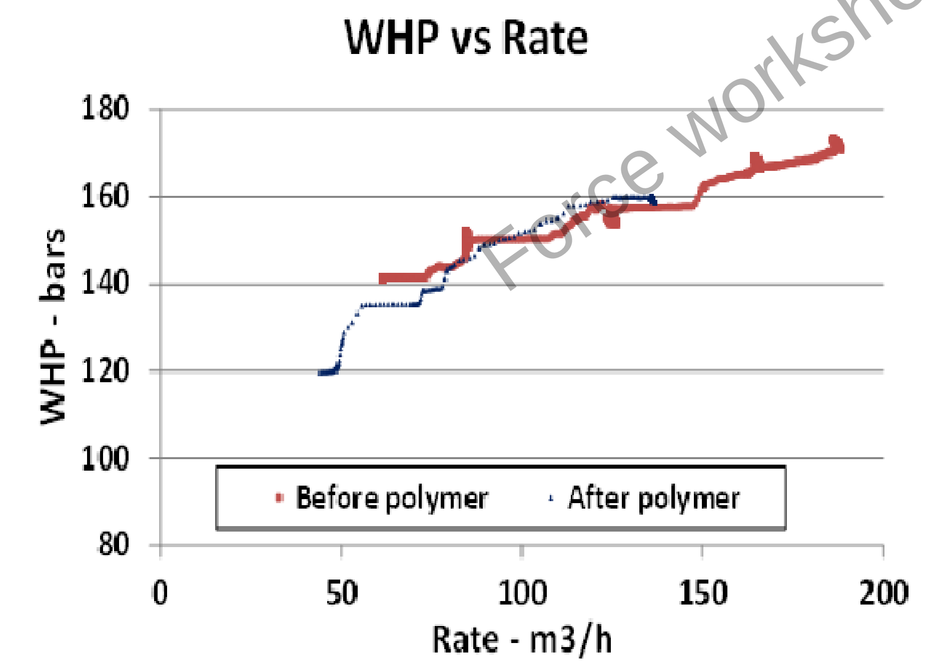


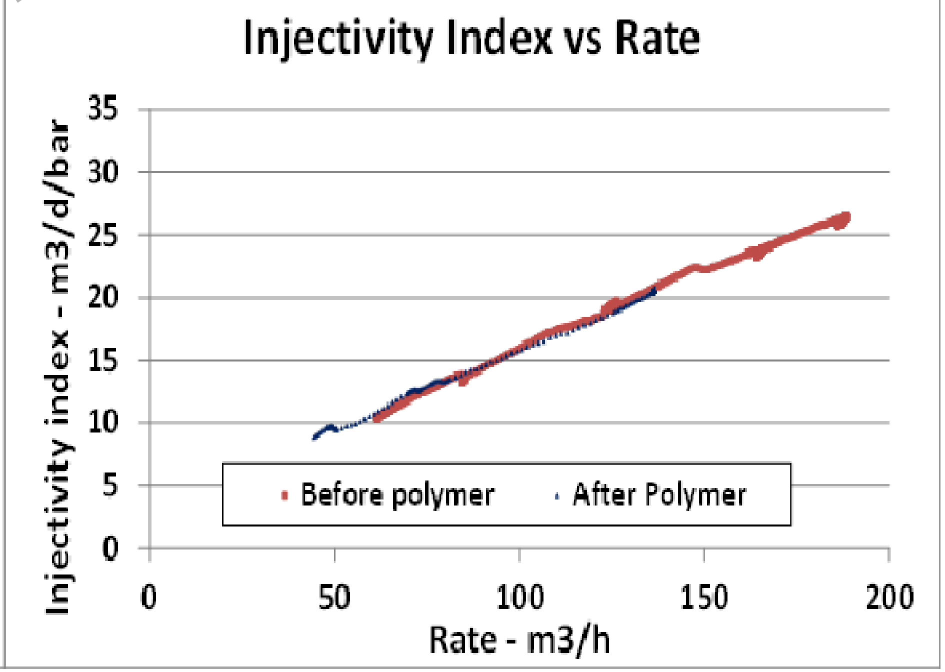


INJECTIVITY BEFORE AND AFTER POLYMER & LPS INJECTION

- After a shutdown the dual fracture system closed, and injectivity and WHP is back to same level as before the test

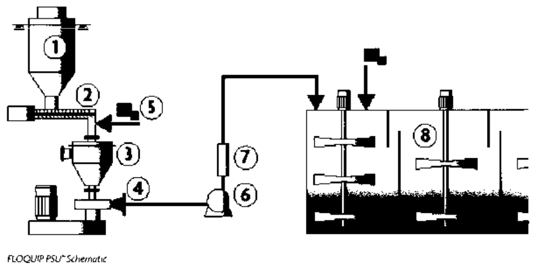
- The polymer/LPS test has not harmed the injectivity





CONCLUSIONS

- Storage, mixing, transport and injection of polymer solution in harsh climate is possible without destroying the polymer
- Maintaining polymer viscosity required proper planning and stringent quality control
- Polymer and LPS injection has not harmed, but improved well injectivity due to dual fracturing
- No viscosity degradation occurred in the tubing during injection
- No discharge of “red” polymer to sea



Acknowledgements

Statoil
Halliburton
Heidrun asset partners
(Petoro; ConocoPhillips Skandinavia, Eni Norge)
IRIS (Yard test)
Einar Hegre and Thomas G. Theting, Statoil

Thank you for your attention!

There's never been a better time for good ideas

Presentation title

Presenters name
Presenters title
E-mail address ……@statoil.com
Tel: +4700000000

www.statoil.com