Polymer work-shop on 25th of June at University of Stavanger

The National IOR Centre of Norway

Agenda:

1. Highlights from The National IOR Centre of Norway - What do we know now regarding polymer flooding that we did not know four and half years ago?
2. From the IOR Centre - What is missing in our understanding of polymer flooding?
3. From the Industry Partners - What is missing in our understanding/implementation of polymer flooding?
4. Discussion/Group work - Do we have a common understanding? What should the focus be the final three years

The following slides are the presentations given by various IOR Centre researchers addressing 1. and 2. in the agenda:

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Research questions

- Can we use Darcy law to descripe polymeric liquids in porous media?
- Do we understand flow of polymeric liquids at the relevant scales?
- How is polymers affected by the composition of the brines?
- Can we simulate polymer injection for realistic field cases?

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Highlights from The National IOR Centre of Norway - What do we know now regarding polymer flooding that we did not know four and half years ago?

- Confirmed that IOR polymer is understood by altered mobility ratio
  - Viscosity vs. Mw and brine salinity
  - Apparent viscosity in porous media differs from bulk viscosity
- Confirmed that synthetic polymers are sensitive to mechanical degradation
  - Results from large scale degradation tests in choke valves revealed that degradation depends on ∇P, not ΔP
  - In linear geometry in porous media, degradation depends on length
  - Mechanical degradation depends on Mw, salinity and polymer structure
- Confirmed that polymer injectivity can not beat water injectivity

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Highlights cont.

- Major part of our polymer knowledge has been gathered in IORCoreSim
  - Covers all shear regimes: Newtonian, shear thinning, shear thickening and mechanical degradation
  - Includes effects of polymer concentration, varying reservoir properties (k and ϕ) and temperature in all models
  - Polymer adsorption and permeability reduction depending on Mw, k and ϕ
  - Salinity effect on polymer intrinsic viscosity
  - Appropriate for synthetic and bio-polymers
- Polymer models tested through simulations of numerous experiments
- Allows investigating polymer in various geometries and scales
  - In radial flow, shear thickening and degradation is limited to a small near well region
  - Field models: shear thickening and degradation only in well blocks
    - Not easily captured by grid refinement of well block (require unrealistic refinement)
    - Can be approximated with a numerical inegration of model of the well block volume

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Highlights cont

- We have a tool that can be added to Eclipse (IORSim)
  - Can simulate geochemical reactions in the reservoit, and sodium silicate injection, and tracer transport
  - Several new numerical algorithms have been developed to achieve this, including protocols for interacting with Eclipse
- Insight into production of taylored water (low sal) for polymer
  - Power consumption

From the IOR Centre - What is missing in our understanding of polymer flooding?

- What is the shear rate in a porous media and its impact on vertical sweep efficiency
- The use of thermo-thickening associative polymers, through network formation, have a potential for improving mobility ratio
  - Complex behavior – must be included in simulators to evaluate field-scale effects
- How will mechanical trapping of polymer in low permeable part of the reservoir affect polymer flooding
- Injectivity is considered a major limitation for polymer in North Sea fields
  - How much additional injectivity is required
  - Impact of methods for improving injectivity
    - Utilizing e.g. pH dependency on viscosity
    - Inject polymer with low hydrolysis degree, rely on in-situ hydrolysis for increased viscosity
    - With several injectors available, is there a smart injection strategy?

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What is missing cont.

- Implement IORCoreSim models into field scale simulators
  - IORSim/Eclipse
  - IORsim/OPM
  - Effective upscaled models → improve well model

Research questions

- What is the effect of pore geometry on polymer transport?
- How is oil mobility affected by polymer fluids on the pore scale?

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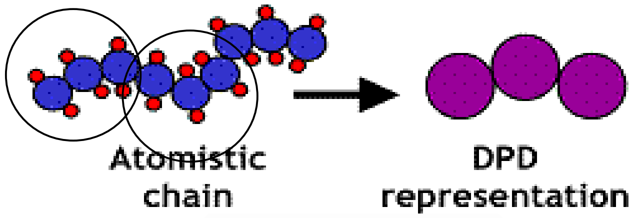
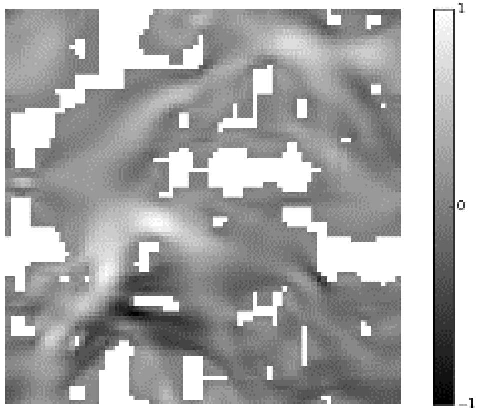
Highlights from The National IOR Centre of Norway - What do we know now regarding polymer flooding that we did not know four and half years ago?

- Dissipative Particle Dynamics
  - Depletion layer effect -> reduce viscosity
  - Quantification of the depletion layer thickness dependence on channel width and polymer model
  - Effective viscosity models were generated
- FENE-P polymer model
  - Analytical derivation of constitutive model from simplified atomistic polymer models
  - Analytical derived expressions for fluid flow and surface stresses in basic geometries shows the non-Newtonian effects in polymer standard rheological experiments
  - Bundle of tube models shows a that higher moments of the radius distribution is need to describe the effective viscosity
- Lattice Boltzmann model
  - Navier-Stokes solver for complex geometries
  - Implementation of power-law and Carreau-viscosity (lookup tables)
  - Same approach can be used for Bingham-like material (cement->large viscosity ratios)
  - Observed power-law viscous fluids behave as power-laws in porous media
  - Implemented higher order boundary conditions (Higher impact of boundary conditions on stability and accuracy than for standard Newtonian approach)





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From the IOR Centre - What is missing in our understanding of polymer flooding?

- Full polymer rheology
  - Numerical implementation of the FENE-P model
- Two-phase flow
  - Non-Newtonian stress-effects on remaining oil

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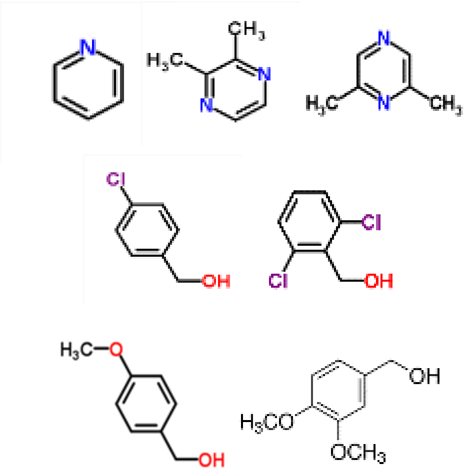
Research questions

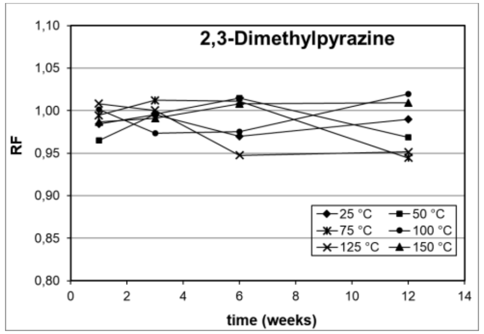
- How can tracers be used to identify IOR targets?
- How can tracers be used to monitor the effect of polymer flooding?

Highlights from The National IOR Centre of Norway - What do we know now regarding polymer flooding that we did not know four and half years ago?

Interwell partitioning tracers

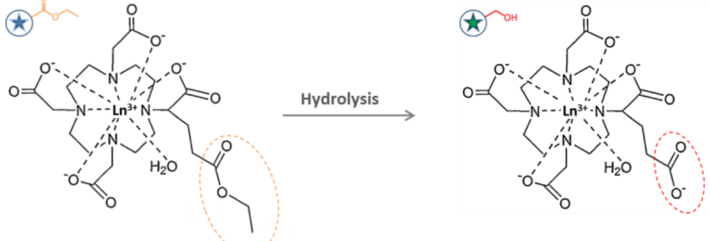
- 6-7 new interwell tracers qualified in lab.

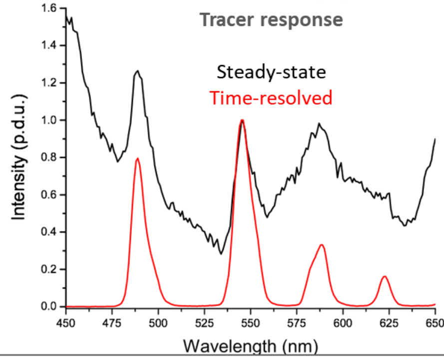




Single well tracers

- Possible fluorescent tracers -> easy detection

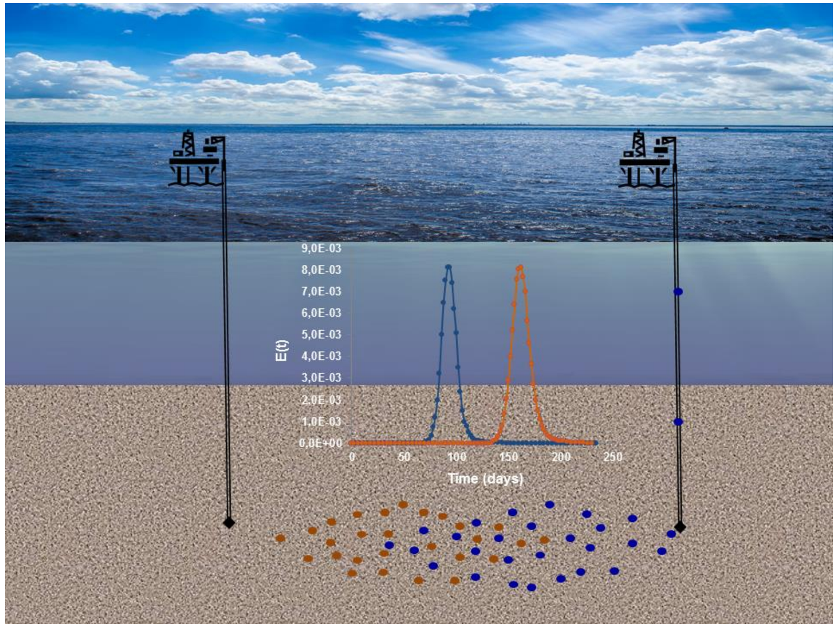




Portfolio of tracers optimized for different reservoir conditions

From the IOR Centre - What is missing in our understanding of polymer flooding?

- Compatibility of tracers with relevant polymers
- Make use of tracer data in IOR decision making.



Research questions

- What is missing in full field simulators to efficiently simulate polymer flooding on field scale?
- How important is the improved resolution, given by higher order methods, when simulating polymer flooding at field scale?
- Do higher order methods have a big impact on decision making for improved oil recovery?

Highlights from The National IOR Centre of Norway - What do we know now regarding polymer flooding that we did not know four and half years ago?

- We have established higher order finite volume methods for polyhedral grids (corner point) grids
- The higher order methods work in a fully coupled fully implicit setting which is standard in reservoir simulation
- Implementation in open source code OPM is ongoing

From the IOR Centre - What is missing in our understanding of polymer flooding?

- Combination of new technologies, higher order methods and ensemble based history matching & optimization & forecasting
- Fine scale numerical simulation of polymer flows for improved understanding and derivation of upscaled models
- Coupling and upscaling of reservoir mechanics to field scale simulation in an efficient way

Research questions

- How can a set of history matched models taking all available information into account, in particular 4D seismic, improve polymer flooding
- How can we optimize polymer flooding given an ensemble of (history matched) reservoir models

Highlights from The National IOR Centre of Norway - What do we know now regarding polymer flooding that we did not know four and half years ago?

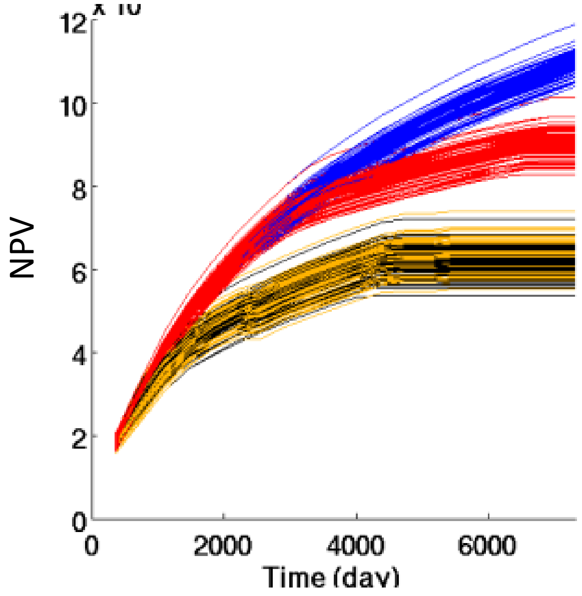
- Developed tools necessary for history matching utilizing 4D seismic data
  - Methodology successfully demonstrated on first real field data set
- Improved methodology for production optimization given an ensemble of reservoir models
  - Better theoretical understanding of methodology
  - Small case study on polymer flooding

From the IOR Centre - What is missing in our understanding of polymer flooding?

- Studies on optimization of polymer flooding given (an ensemble of) reservoir model(s)
- Make optimization robust, given uncertainties in characterization of reservoir, uncertainty of critical factors for polymer models, uncertainty in the chemical modeling, etc.

Uncertainty of critical factors for polymer models :

- Extent of shear degradation
- Temperature
- Viscosity
- Degradation speed



The 2018 user partners and observers:

Acknowledgement:

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Summary of group work

Polymer work-shop 25th of June 2018

The National IOR Centre of Norway

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For discussion in the groups: What should the polymer focus of the National IOR Centre be for the final three years? The groups were asked to come back with the top three or a prioritized list.

Group 1 lead by Leili Moghadasi (Eni):

Main points highlighted during the discussion, given in ranked order of importance:

1. During the Workshop, eni presented pilot polymer application (a real case study). Due to its particularity, some interesting points were brought out. Therefore, by permission from eni, IOR Center could deeply elaborate the case study by considering different aspects related to polymer application.
2. When a polymer solution is injected into a reservoir from an injection well, the flow velocity (as it is related to shear rate), will change from wellbore to in depth, how we can have better prediction on the relationship of in situ viscosity and in situ shear rate?
3. Importance of injectivity and corresponding uncertainties and risks;
4. Importance of water handling and its impact in terms of salinity on polymer stability.
5. Considering the importance of mechanical degradation, how we could investigate the impact of Mechanical Degradation on Polymer Injectivity in Porous media and in consequences what will be its impact on polymer rheological characterization?
6. The impact of polymer injection on residual oil saturation;
7. The range Residual Resistant Factor and Resistant Factor to select the optimal polymer;
8. The best practice for the polymer sampling;
9. Proposing tracer adopted for polymer in Eni case study;
10. Proper upscaling of results from laboratory to filed scale simulation.

Group 2 lead by Ana Todosijevic (Wintershall):

Main points highlighted during the discussion, given in ranked order of importance:

1. Integration of all relevant steps in the EOR project, identification of the critical path, including project de- risking, identification of main uncertainties from pore to full field deployment (5 votes)
2. Polymer EOR Simulation in the fractured rock with identification of upside and uncertainties (4 votes)
3. Environmental qualification of polymers: can we change the existing regulation and test the back produced polymer on biodegradation, toxicity and bioaccumulation) (4 votes)
4. Integration of the already performed laboratory work and the planned onshore yard test with associative polymers in the simulation model (3 votes)

5. Development of the EOR Project workflow guidance from the project initiation up to the full filed implementation (2 votes)
6. Investigation of the thermos triggering zones for associative polymers (2 votes)
7. Optimization of the polymer injection strategy: polymer injection design to only target high perm. layers, to optimize the OPEX (2 votes)
8. Gain better understanding about the injectivity of synthetic polymers. Establish the knowledge about optimal test conditions. How and for which kind of reservoirs are the measurements at 7^{-s} representative (2 votes)
9. Mitigation how to tackle polymer filter cake (2 votes)
10. Qualification of uncertainties in the simulation
11. Reducing the risk of geological uncertainty through tracer connectivity test, 4-D seismic
12. Identification of low polymer degradation choke
13. Gain better understanding of the inversion process for emulsion polymers
14. Screen the market to identify functional online viscosity measurement tool
15. Limitation of Darcy Law on the non-Newtonian fluid
16. Usage of the pressure transient analysis to interpret the reservoir performance during polymer flood

Group 3 lead by Torstein Grøstad (Equinor):

Top three focus areas selected:

1. Optimization of the polymer work-flow which includes:
    a. Understanding of salinity impact of polymer properties and how to model and upscale
    b. Large scale testing
    c. Upscaling to field scale
2. Benchmark: Eclipse/Intersect alone vs. Eclipse+IORSim on a real field case from the companies
3. Utilizing fall off test data / step rate test

All bullet points from the discussion, given in random order:

- BC process, uncertainties in HM and prediction
- Upscaling, polymer effect, testing in larger scale
- Non-Newtovnian in porous media, upscaling, fundamental understanding
- Large scale testing
- Uncertainty quantification
- Upscaling to field scale
- Optimization of the polymer work-flow
- Benchmark: Eclipse/Intersect alone vs. IORSim on a real case from the companies
- Benchmark: Eclipse/Intersect alone vs. IORSim on a real field case from the companies
- Lab evaluation of polymer front detection from acoustic measurements
- Top side implications of back produced polymers
- Best practice of sampling, analysis, lab and field
- Utilizing fall off test data / step rate test
- Understanding of salinity impact of polymer properties and how to model and upscale

MINUTES OF MEETING

Polymer Workshop 25th June 2018
University of Stavanger, 10:00-15:00 hrs

Place: University of Stavanger, Kjølv Egelands hus
Meeting room: C-334

Aksel Hiorth greets welcome, and all participants introduce themselves.

Ana Todosijevic (Wintershall) is chairing the workshop. She comments that the companies should look beyond their own interests only, and realize that The National IOR Centre of Norway is focused on increasing the recovery on the whole Norwegian Continental Shelf.

Aksel gives a brief introduction to Workshop agenda, and the IOR Centre.

Agenda

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4. *Discussion/Group work - Do we have a common understanding? What should the focus be the final three years?*

<u>1. and 2. Researchers from the Centre presented:</u>

Arne Stavland & Aksel Hiorth: Core scale, simulation & upscaling
Espen Jettestuen: Pore scale
Sissel O. Viig: Tracer Technology
Tor Harald Sandve: Field scale simulation
Randi Valestrand: Field evaluation

Q&A:
-Which reservoir should we look for as pilot? We know: No chalk, no fracture. Criteria for choosing the reservoir?
-If we could monitor polymer front in 4D seismic we could test the performance of the modelling.
-Brown field, water treatment system, high permeable reservoirs, viscous oil, favorable with polymer.
-Optimization of well completion; injection of polymer without degradation?

- Arne Stavland: The yard test: SNF type valves

-What is the IORSim advantage over Eclipse or Intersect?

- Aksel Hiorth: Explains IORCoreSim and IORSim. Chemistry simulation with IORSim, feed results into Eclipse. Continuous interaction.

-Good results from polymer injection project in onshore Egypt (ENI). 4D seismic. SPE from Muscat March 2018.

- How well do you understand things if the polymer is not detected?
  ENI: Suggested tracer, but Egyptian partner refused. Should observe polymer after 2 years, but so far nothing. Well spacing 2 km.

-Polymer is also relevant for chalk. Fractures and low molecular weight polymers
-Low sal injection before polymer injection.

<u>3. From the Industry Partners - What is missing in our understanding/implementation of polymer flooding?</u>

Equinor:

- Existing Polymer projects:
  - Heidrun
  - Peregrino in Brazil
  - Johan Sverdrup phase 2
  - Mariner field, heavy oil, favorable for polymer
- Value chain must work together, we tackle the big risks first. Therefore, we postpone Johan Sverdrup, due to the uncertainties. Polymer in production system, both in oil and produced water. Refineries cannot handle polymer.
- Important to look at the complete business case, not only the reservoir
- Several practical issues on the top-side, logistics, injectivity, environmental impact, handling of back produced polymer
- Our challenges / wish-list
  - Robust on-line viscosity measurement
  - Practical chokes
  - Control injectivity
  - Use bottom-hole and flow data to learn about polymer behavior
  - Sand packs and large-scale test to learn about polymer, but high quality is paramount, repeatability important.
  - Difficult to predict polymer behavior, despite good models and history matching.
- More polymer projects? Look at the whole value-chain. Reduce the biggest uncertainties.
- Comment from AkerBP: The integrated approach is important

ENI, SPE presentation:

- Polymer pilot in Egypt since 2016
- 1000 bpd of polymer @ 1500 ppm
- evaluate subsurface polymer behavior
- HPAM high molecular weight
- No mechanical degradation
- Close to fracturing conditions, micro-fracturing regime
- Vertical Well model of radial grid (15 radial cells), finer resolution close to well
- BHP simulated and compared to downhole measurements
  - Better match if fractures included
- Conclusions

  - Injectivity reduction not enough to just. viscous increase
  - No mechanical degradation
  - Increase of injectivity indicates micro-fractures
  - Double the oil rate
- Ana: What should the Centre tackle in your view?
- Answer:
  - Difficult with polymer in Intersect
  - History match is difficult with current model
  - More robust simulation in a green field? This was a brown field
  - How many PVs to get good baseline measurements
  - Difficult to simulate injectivity, and the values are uncertain
- Ana: polymer stability not an issue?
- Uncertain if we use the optimal sampling strategy
- Ana: well connectivity?
- Good, and it was an argument for the pilot

AkerBP:
- Polymer is not on top of our list
- Collaborate on Johan Sverdrup.
- Want to understand gaps and trade-offs
- Understand subsurface, but also look at whole picture
- Simulator that can handle all processes, risks, and uncertainties

ConocoPhillips:
- Polymers in chalk
- Diversion and scale squeeze must be tested in fields
- Can we reduce the fracture flow? Simple simulations. Can we see an upside?
- Temperature variations will influence the polymer
- Temperature in the range from ambient to 130 °C
- Shearing, not possible to change all valves
- Regarding environmental risk: We always test the polymer we inject, but should we not be testing the polymer we would produce?

DEA:
- Think of everything from the top-side to the reservoir
- Standards, do we use the same?
- What are the shear rates?
- Water quality
- Polymer lost due to degradation, sampling, adsorption...?

Wintershall:
- Economic feasibility is important to convince the management
- Risk of damaging the oil with polymer
- How can we quickly incorporate lab results into simulators?
- Mechanical degradation
- Sampling techniques for polymer downhole
- NMR for polymer viscosity
- Polymer degradation in the reservoir, even with short well distances

Schlumberger:

- Monitoring. Where is the polymer going? How is the front evolving?
- Can we see the polymer with 4D? Synthetic test to illustrate. Difference in P-wave velocity and attenuation, also S-wave attenuation. Signature seen in simulated data, not supported by lab-measurements yet.
- Hypothesis: Polymers improve recovery also through generation of micro-fractures

<u>4. Discussion/Group work - Do we have a common understanding? What should the focus be the final three years?</u>

This is summarized in a separate document.

<u>End comments from the companies:</u>

ENI:

- 1: Important with workshops, we have to continue with low-sal workshop
- 2: Many common problems
- 3: Continue collaboration and share problems
- 4: Sharing is crucial. Organize more workshops the coming years

Equinor:

- 1: Very useful
- 2: off-shore polymer is fragile, must be looked after to stay alive. We have worked a lot with environmental issues in Johan Sverdrup that could be shared.

Schlumberger:

- Looking forward to share real data
- ENI case was the highlight

Wintershall:

- This will also help us internationally
- Open for collaboration, more frequent involvement of industry