Polymer flooding –improved sweep efficiency for utilizing IOR potential

Force seminar April 2016

IRIS

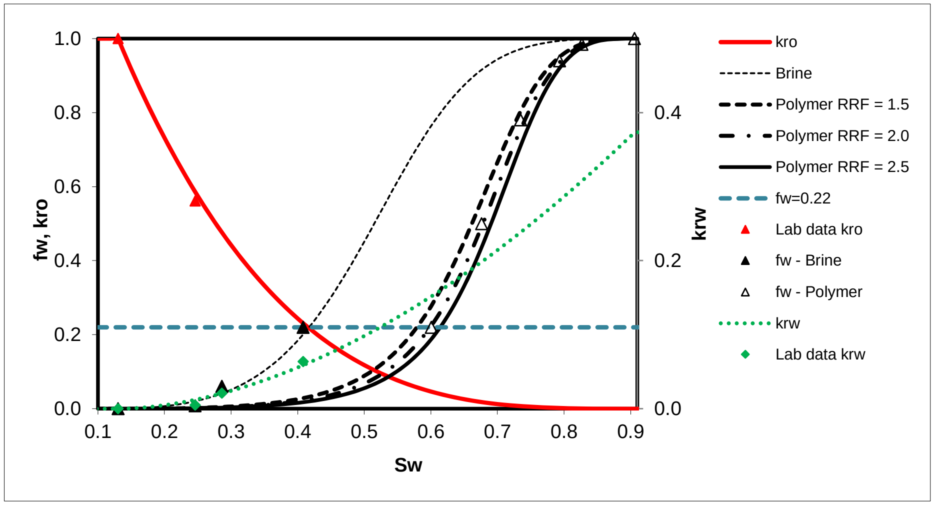
8 April 2016

Classic polymer screening

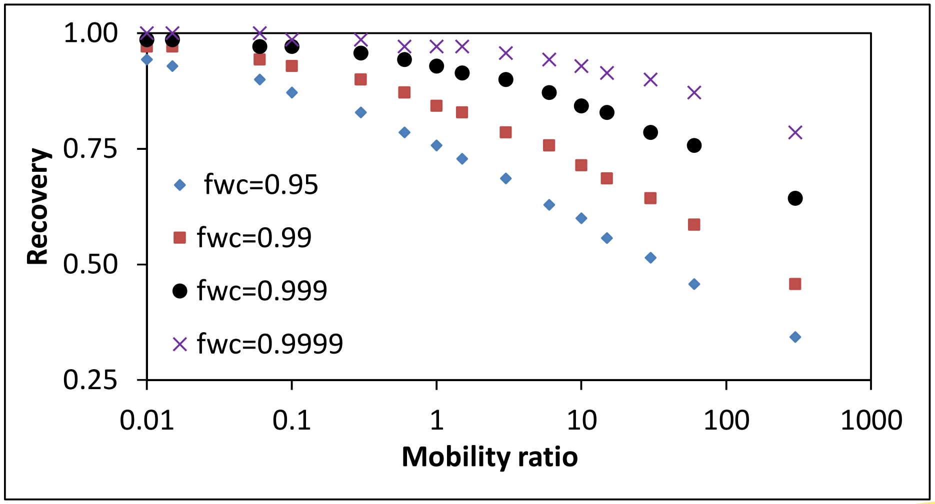
- Viscosifying effect
  - Solution preparation
  - Bulk rheology
- Flow properties in porous media
  - Filterability
  - Screen factor
  - Mobility reduction
  - Permeability reduction
  - Inaccessible pore volume
  - Retention
- Stability
  - Shear stability
  - Thermo-chemical stability

IOR mechanism – Improve sweep by reducing mobility ratio

- $M_p = {}^{\lambda_w}/_{\lambda_o} \cdot {}^{1}/_{RF}$
- $f_w = \frac{q_w}{q_w+q_o} = \frac{\lambda_w}{\lambda_w+\lambda_o} = \frac{k_w/\eta_w}{k_w/\eta_w + k_o/\eta_o}$
- Water-cut depends on polymer viscosity and permeability

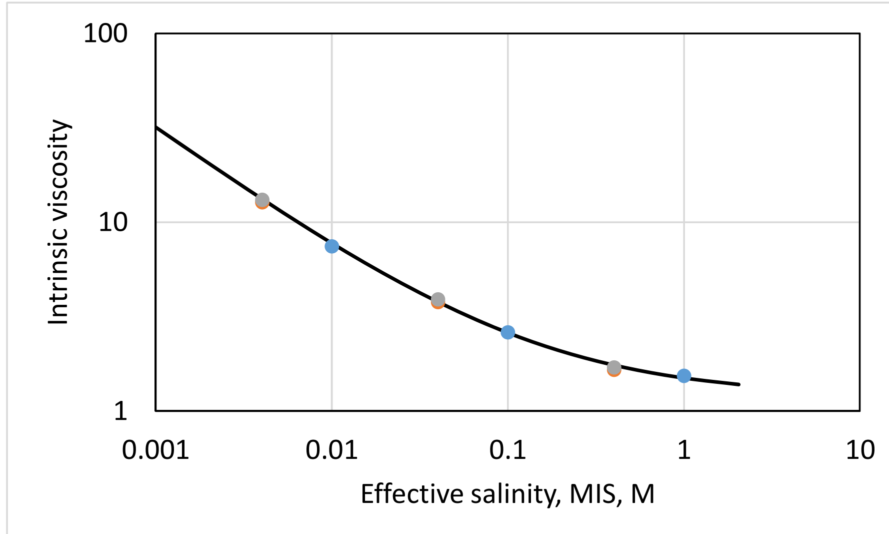


- Will polymer alter Sor?
  - Lab scale – correctly interpret fw = 1, if not recovery increases by reducing M
  - Field scale – the existence of critical fw at which above production is not economic



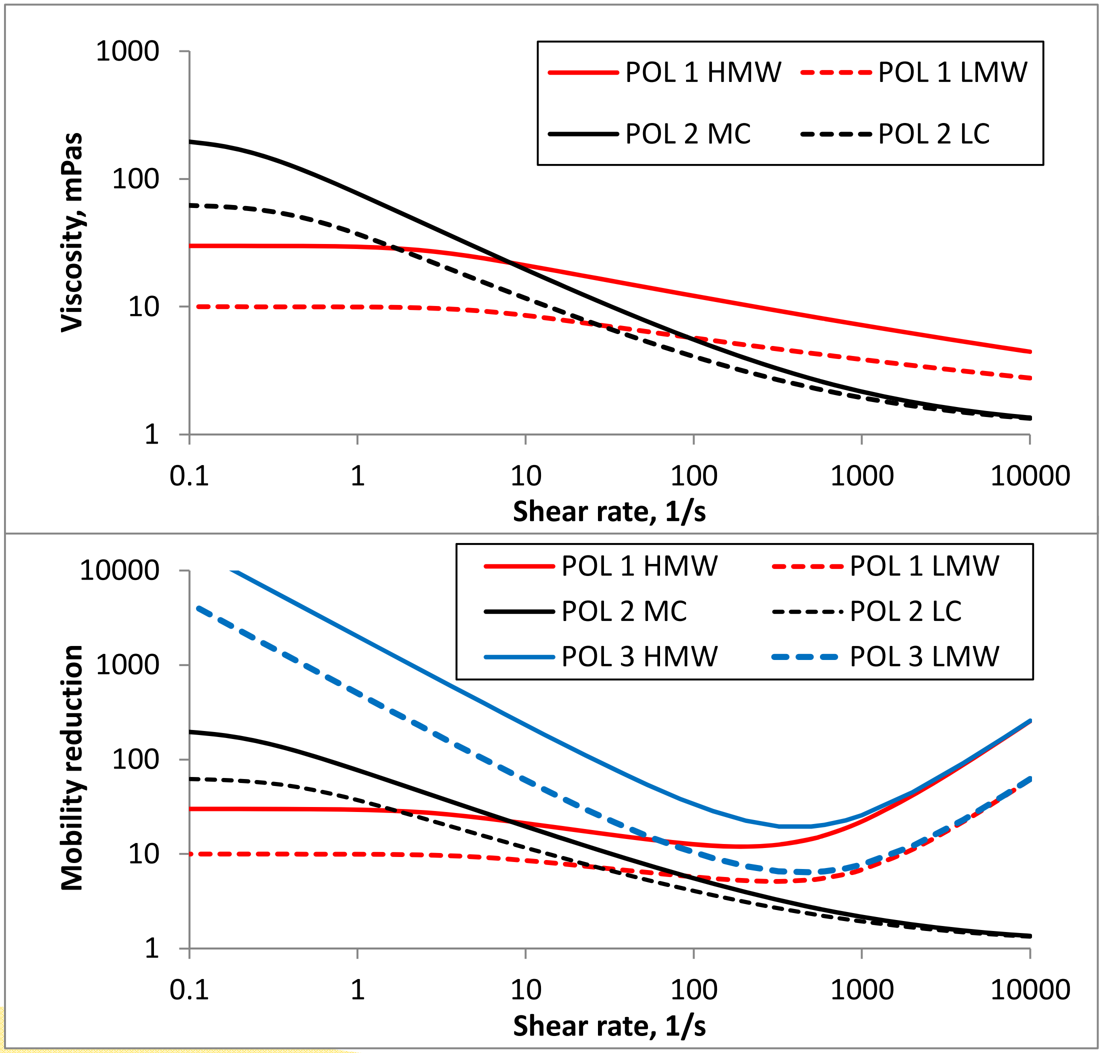
How to optimize mobility ratio

- Polymer viscosity depends on Mw, concentration and salinity
  - $\eta = \eta_{sol}(1 + [\eta]ce^{k'[\eta]c})$
  - Intrinsic viscosity, $[\eta] = A \cdot M_w^a$
  - Intrinsic viscosity depends on effective salinity, $C_{MIS} = \frac{1}{2}\sum_i m_i \, z_i^{2+ki}$



- Non-Newtonian fluids
  - Rheology in porous media differs from bulk rheology
    - Slip flow
    - Depleted layer
    - Fåhræus-Linquist effect

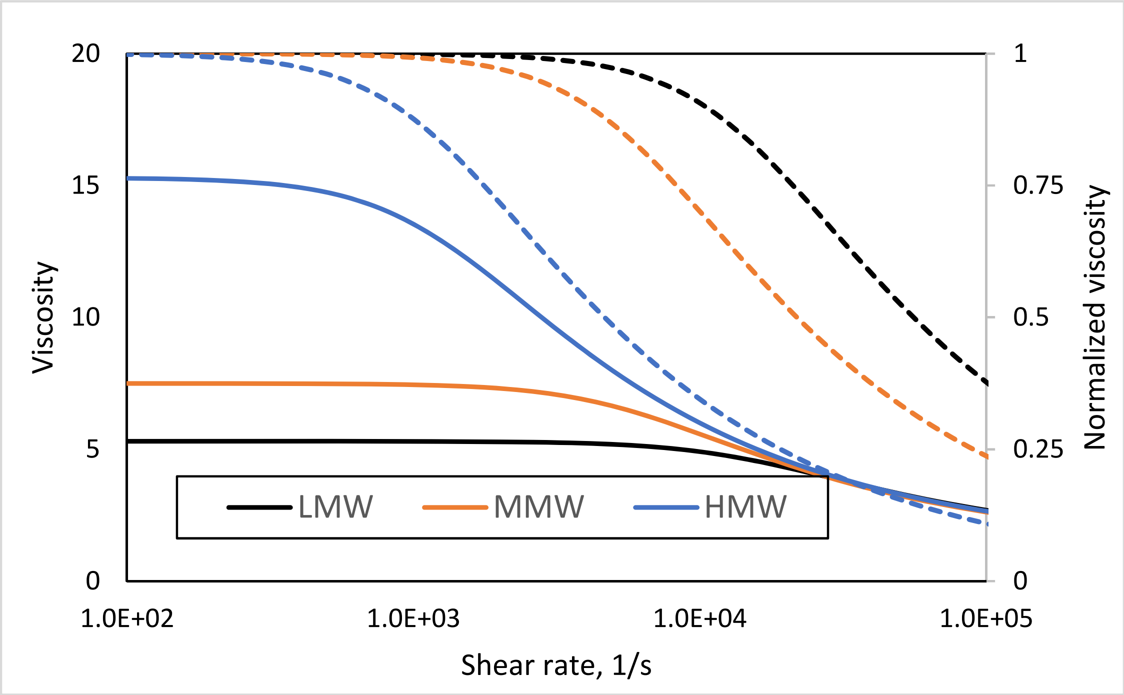
How to optimize



- Polymer 1 - Regular HPAM-based polymer
  - Relatively shear stable viscsosity at moderate shear rates
- Polymer 2 - Biopolymer
  - Shear thinning polymer
- Polymer 3 - HPAM-based polymer with hydrophobic co-monomers (Associative polymer)
  - Highly shear thinning at moderate shear rates

Shear degradation in porous media

- Synthetic polymers are shear senstive
- Onset of degradation above critical shear rate, which depends on Mw
- LMW polymers are more shear stable than HMW
- Replacing HMW polymer with LMW will not improve viscosity, only injectivity



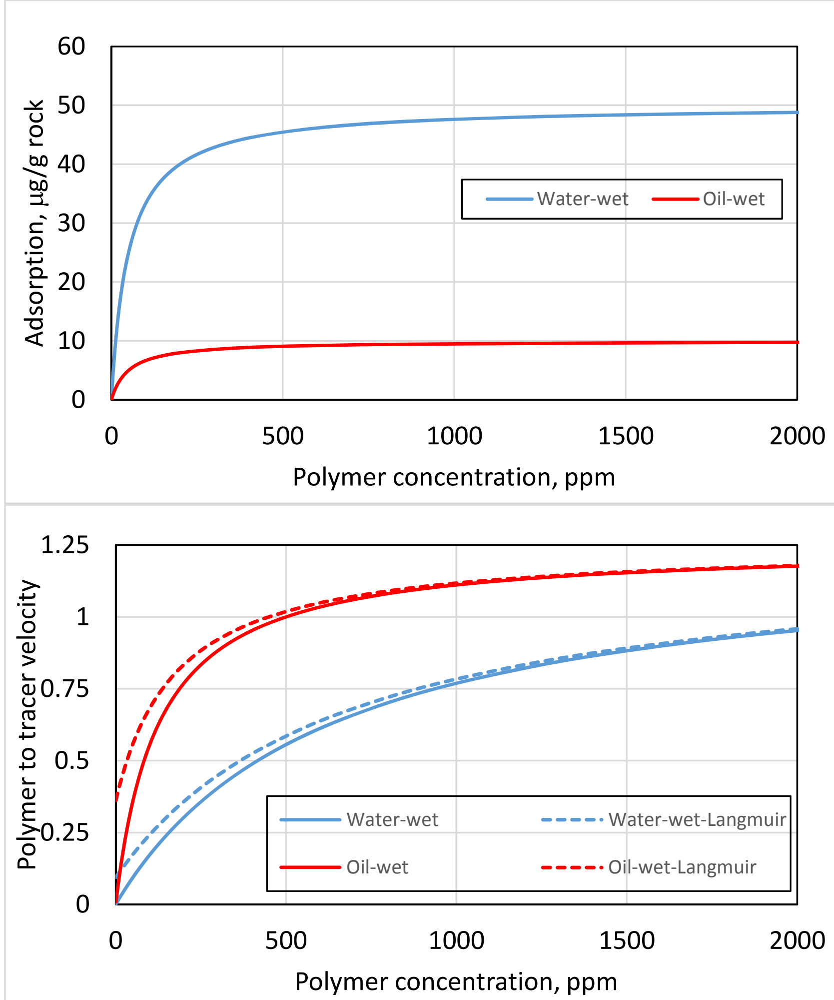
Polymer transport in porous media

› Polymer retention
- Assume Langmuir isotherms
- Adsorption depends strongly on wettability

› Inaccessible porevolume (IPV)
- Fraction of pores too small for polymer invasion, depleted layer
- Here, IPV = 0.20

› Effective transport properties
- Oil-wet reservoir (low adsorption)
  $v_p/v_T > 1$ for $c > 500$ ppm
- Water-wet reservoir
  $v_p/v_T < 1$, critical only at ultra-low concentration (e.g., in low salinity water)

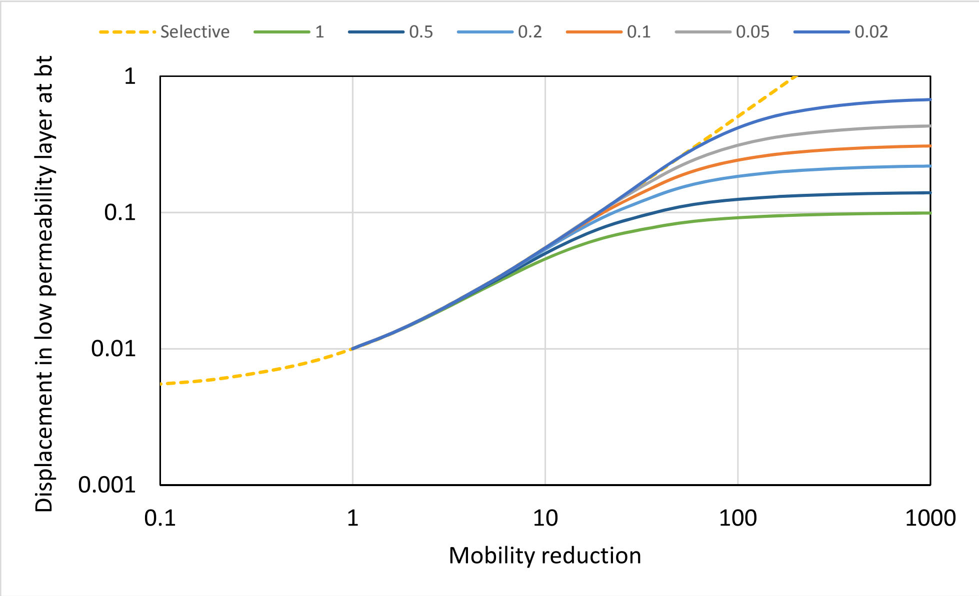
› Minimize produced polymer
- Use retention and injected concentration as design criterion

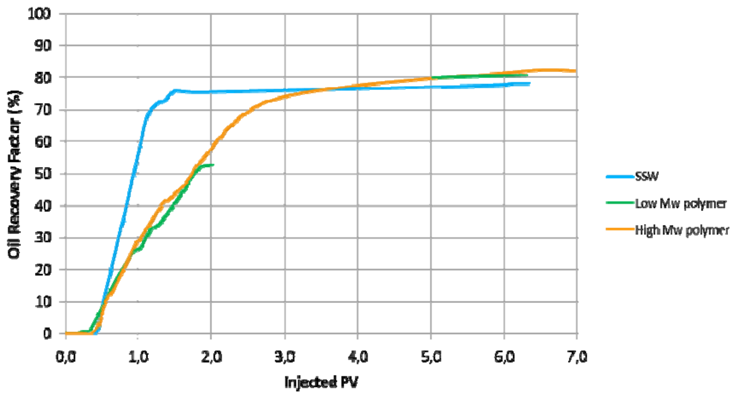


Vertical sweep efficiency

Delay breakthrough time

- Example: $\frac{k_1}{k_2}$ = 100, at unit mobility reduction, $E_i = \frac{1}{2}\left(1 + \frac{k_1}{k_2}\right) = 0.505$ and at infinity viscosity $E_i = \frac{1}{2}\left(1 + \sqrt{\frac{k_1}{k_2}}\right) = 0.55$
  - Selective viscosity will dramatically improve sweep efficiency
  - Selectivity exploited by salinity, temperature and permeability contrasts

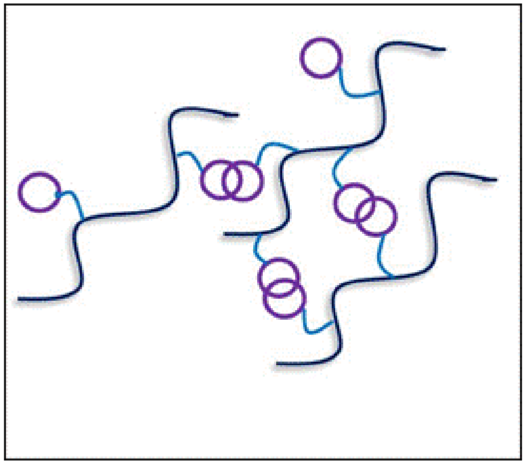


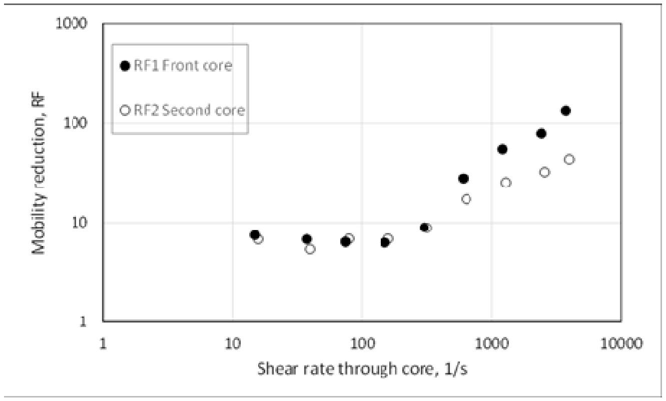


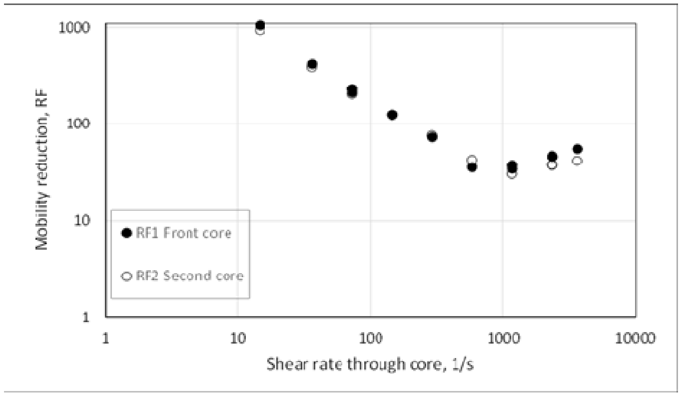
The new class of EOR polymers

› Hydrophobically modified water solubles copolymers

- Hydrophobic groups added to regular polymer backbone reacts with each other leading to intermolecular polymer network
- Mobility reduction can in porous media due to formation of polymer network increase significantly
- Mobility reduction depends at least on amount of associative groups, Mw, salinity and temperature



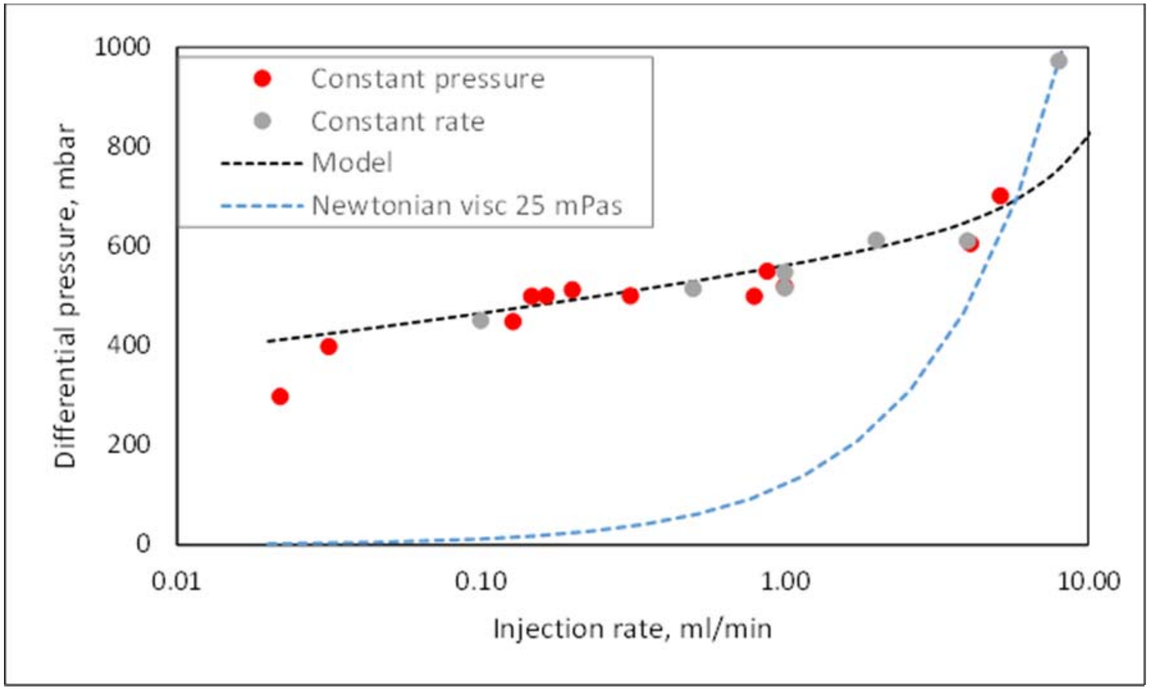




Mobility reduction in porous media

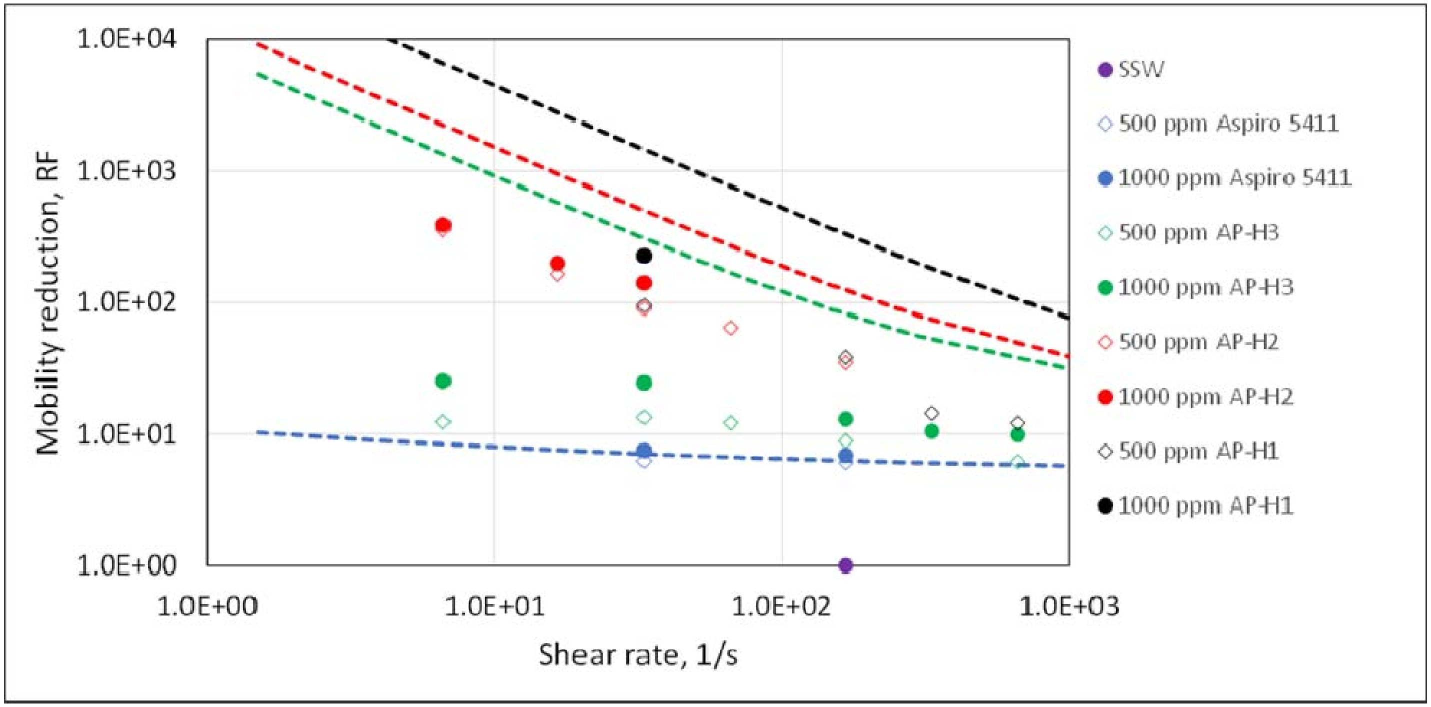
› Constant rate vs. constant differential pressure

- Flow behaviour at low flow rates deviates strongly from classic Darcy law flow
- Demonstrate the possibility of maintaining nearly constant differential pressure at flow rates varying more the two order of magnitude – and the behaviour is reversible



Mobility reduction – effect of oil

› In presence of oil the associative interactions are weakend resulting in less mobility reduction and lower RF compared to Sw = 1 (dotted lines)



Effect on oil recovery

› High mobility reduction will improve the sweep efficiency towards piston-like displacement and reduce the tail-end production

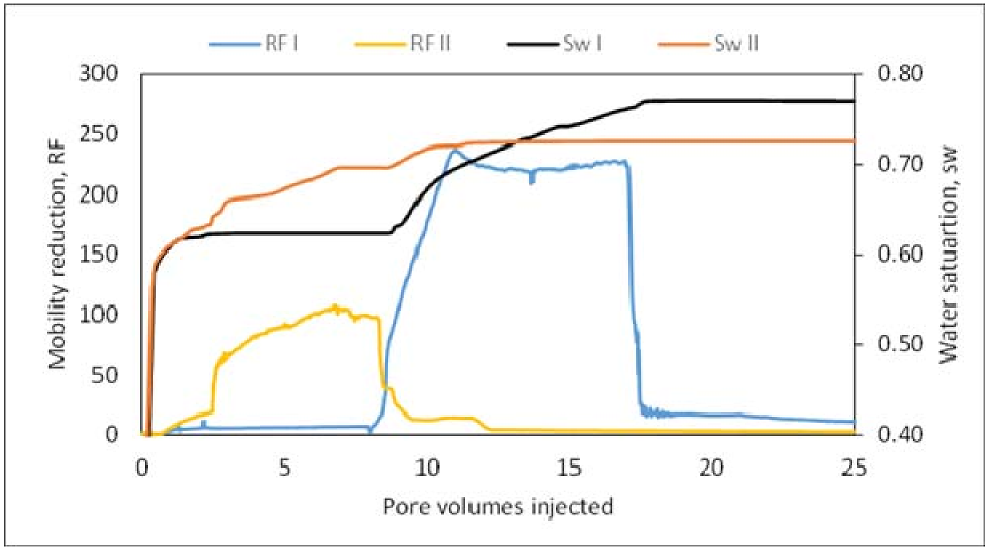
› High mobility reduction may be utilized to increase the capillary number $N_{ca} = k\nabla P/\sigma$, with the possibility of lowering Sor

› Exp I

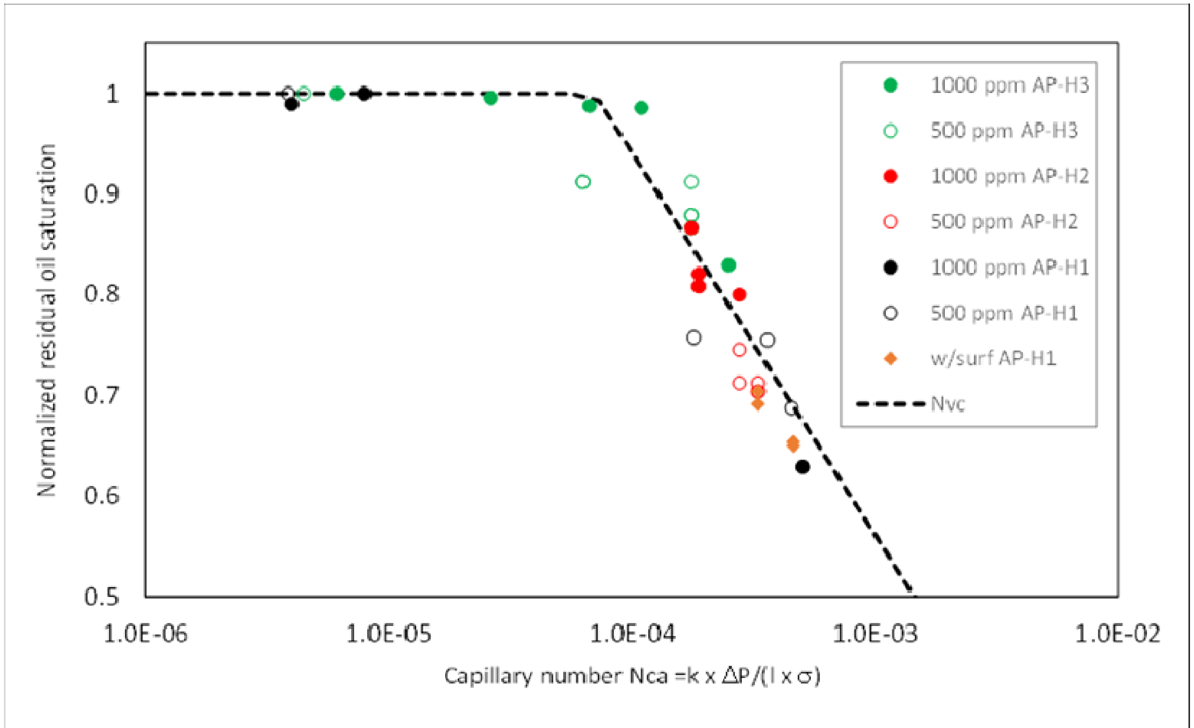
- Brine, followed by regular ATBS followed by 1000 ppm associative polymer

› Exp II

- Brine followed by 500 ppm associative polymer

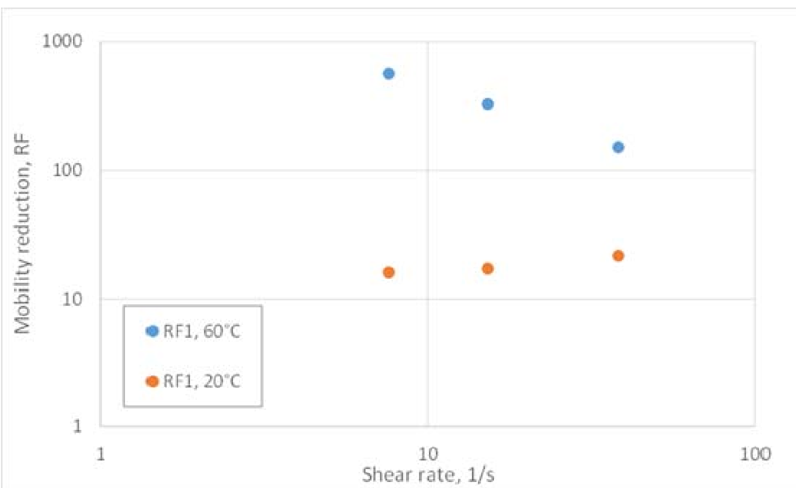


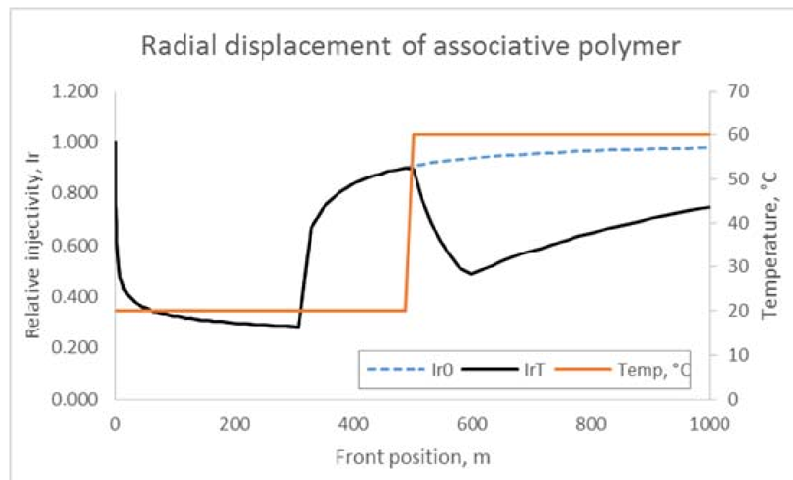
Oil recovery vs. capillary number



Optimization

› Define assosiative polymers which at injection condition behave as regular polymers (low mobility reduction and good injectivity) while high mobility reduction is triggered by temperature





Conclusions

- Main mechanisms for EOR polymer flood are understood
  - Sweep improvement by lowering mobility ratio
- The wide variety of EOR polymers allowing for optimization, e.g.,
  - Injectivity vs. mobility reduction
  - EOR potential vs. mobility reduction
  - Type of injection brine
  - Polymer loss vs. produced polymer
  - Why always choose HMw HPAM polymer?
- Commercial simulators are not fully ready for polymer – does however only partly explain lack of field experience