The National IOR Centre of Norway

# Improved oil recovery molecular processes

Project 1.3.2

Project manager: Aksel Hiorth
Postdoc: Teresa Palmer
Key personnel: Roar Skartlien, Arne Stavland,
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Project duration: September 2015 – September 2017

Final Project Report

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Project number and location (UiS, IRIS, IFE):    Number?, UiS, IFE
Project duration: September 2015 - September 2017
Project manager: Aksel Hiorth
PhD students and postdocs: Teresa Palmer, 2 years
Other key personnel: Roar Skartlien, Arne Stavland, Espen Jettestuen, Jan Ludvig Vinningland
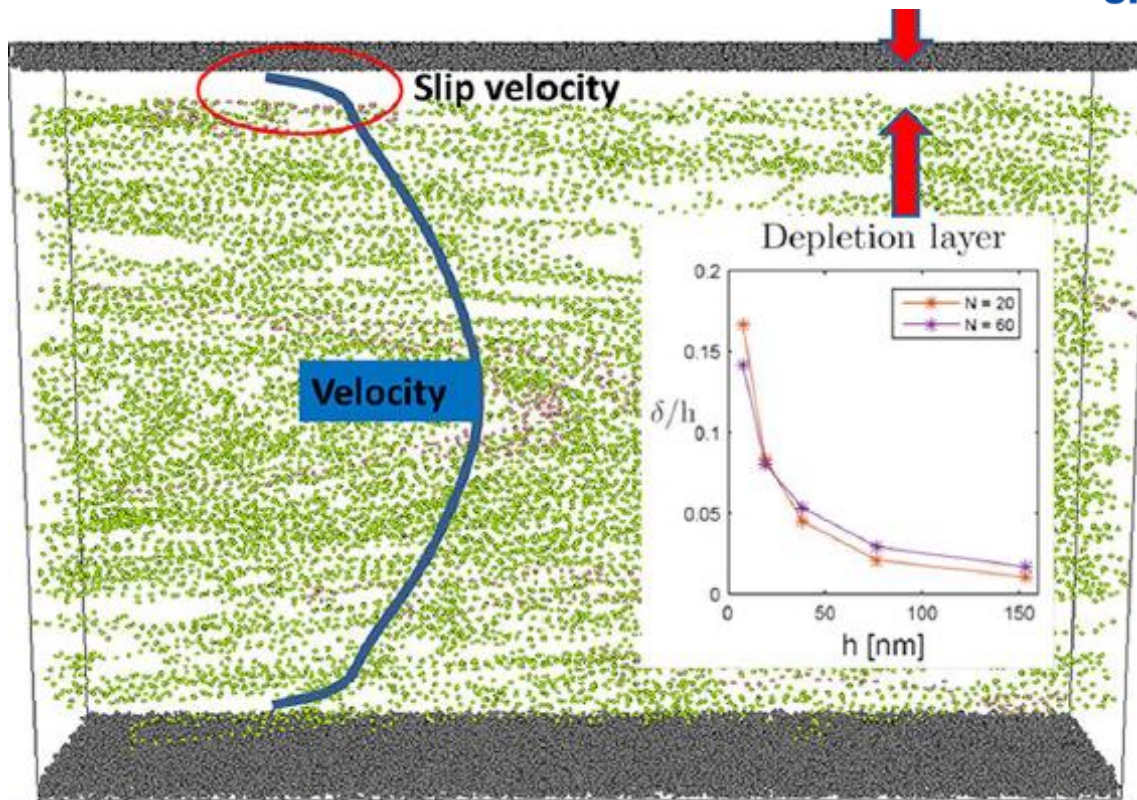
1.   Executive summary

Many polymer solutions, including partially hydrolyzed polyacrylamide (HPAM), exhibit lowered effective viscosity in micron sized pores due to migration away from the mineral surface. Molecular dynamics simulations (dissipative particle dynamics–DPD) were developed and used to quantify wall-normal migration of polymer chains and the interaction with adsorbed layers. Algebraic models for the effective viscosity were developed, based on our simulation results and hydrodynamic theory for polymers. These models can be used for polymer flooding applications. History effects in connection to polymer adsorption and desorption were found to be important.  Two scientific papers were generated.

2.   Introduction and background

The project was suggested as an initiative from IFE. The postdoc used a DPD simulation model developed at IFE, but some modifications and developments were necessary for varying pore geometry and parallel processing.   The modelling incorporated polymers in water with the evaluation of the shear-thinning effective viscosity resulting from the coupling between the water and the polymer chains. Development of more knowledge about the influence from migration on the effective viscosity was the general goal.

3.   Results

**Paper1 (published)** "Reduction of the effective shear viscosity in polymer solutions due to crossflow migration in microchannels: Effective viscosity models based on DPD simulations":  A larger fraction of the total flow volume becomes depleted of polymer when the channel width or pore radius $h$ decreases into the submicron range, significantly reducing the effective viscosity by several tens of percent. The effective viscosity was quantified in terms of channel width and Weissenberg number for realistic polymer concentrations.  Algebraic models for the depletion (or slip layer) width and effective viscosity were developed, based on the hydrodynamic theory of Ma and Graham and our simulation results. The model can be applied to polymer flooding and core flooding after a retuning of the polymer persistence length and the corresponding potential/thermal energy ratio.
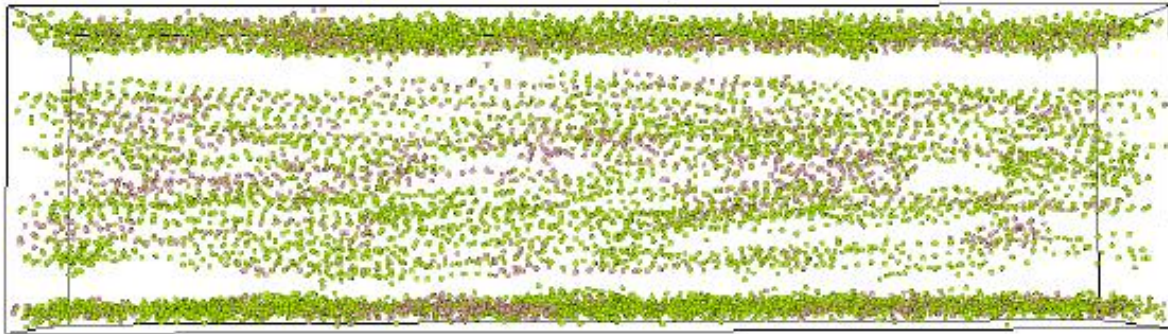
*The depletion layer volume fraction is higher with smaller with channel width, leading to reduced effective viscosity (via the slip velocity). The depletion layer develops as a result of balance between hydrodynamic repulsion from the wall, and gradient diffusion back towards the wall. Polymer chains are shown in green, and the walls are shown in grey. The polymer chains stretches out in the flow direction, resulting in shear thinning. From our parallel code, tailored to polymer flow.*
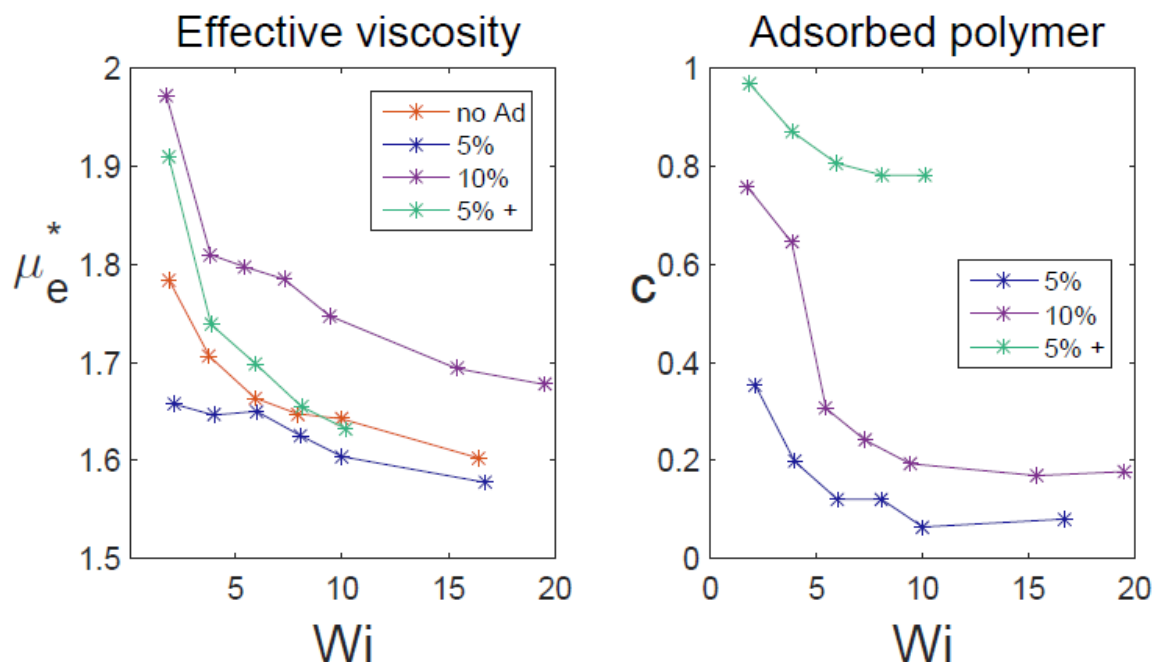
**Paper2 (in progress):** "Rheological effects of polymer adsorption in microchannel flows: phenomenological model of the slip layer from molecular simulations":  This time, we included adsorption. We found that slip- or depletion layers also develop between the flowing polymer and the adsorbed layer of polymer. Polymer-polymer (steric) repulsion (preferentially in low salinity water) between flowing and adsorbed polymer was now important, and expanded the depletion layer compared to no-adsorption cases.  As a result, the effective viscosity was reduced further. A phenomenological algebraic model for the depletion layer thickness, including adsorption effects, was developed also in this case, based on the simulation data.

*History effects:* The adsorbed density was modelled by a shear modified adsorption isotherm.  When the Weissenberg number (shear rate) is increased, the adsorbed density is reduced in general. However, the adsorbed amount of polymers in equilibrium is not solely dependent on the Weissenberg number for a given bulk concentration, but rather on the initial level of adsorption before shear is applied. This relates directly to primary and secondary polymer injection, where a secondary injection is already subject to an adsorbed layer. The shear rates needed to induce desorption to a given adsorbed density is greater than the shear rates necessary to limit the adsorbed density to the same level from an initially clean surface. These history effects are consistent with experimental investigations (Lee & Fuller, 1985), and should be considered in polymer injection planning where multiple injections are being considered.

5% preadsorbed. Developed flow



*A depletion layer (upper and lower zones with practically no polymer) is also developing between the adsorbed layers of polymer (upper and lower layers at the wall) and the bulk flow. This time, the polymer-polymer repulsion between adsorbed polymer and polymer in solution plays an important role, expanding the depletion layer. The effective viscosity may be lower than without adsorption (for the same bulk concentration). This repulsion effect is reduced when polymers desorb for higher shear rates.*



*The effective viscosity varies with the amount of polymers adsorbed on the wall. The data are shown as function of Weissenberg number Wi (normalized shear rate). See the paper for further explanation.*

4.   Conclusion

Molecular simulations were used to quantify the effect of polymer adsorption and the slip layer on the effective shear viscosity in microchannel Poseuille flow. The results were consistent with microfluidic experiments with HPAM in microchannels (Cuenca and Bodiguel 2013). Phenomenological "engineering models" for the effective viscosity (as function of shear rate and channel width) were developed based on these results. These models can be applied to core flooding experiments for testing, and then to polymer injection in reservoirs. It would be an advantage to extend the models to varying geometry to also incorporate extensional flow. The DPD molecular simulator that was developed is of large value for IOR studies with oil/water/surfactant/polymer, and other microscale flow phenomena in various geometries. However, new projects need to be generated for further studies related to IOR.

5.  Future work/plans

Paper 2 is in progress. However, the 2 year postdoc period is over and some of the remaining work has been financed by IFE in 2017.  A new application for an extended postdoc is sent to the IOR centre, also including work on various geometries (enabling studies of extensional stresses in pore throats) and on local mobility effects from polymer on residual oil. A VISTA application for a new postdoc hosted by UiS in 2018 was sent in January, waiting for response.

6.  Dissemination of results

Journal publications, presentations upon request.


7.  References

Palmer, T. L., Baardsen, G., & Skartlien, R. (2018). Reduction of the effective shear viscosity in polymer solutions due to crossflow migration in microchannels: Effective viscosity models based on DPD simulations. Journal of Dispersion Science and Technology, 2018, VOL. 39, NO. 2, 190–206 doi:10.1080/01932691.2017.1306784.

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