Simulation Tests of the Constitutive Equation of a Nonlinear Viscoelastic Fluid

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Outline

- Rheometry of viscoelastic fluids
  - Measurements with a rotational rheometer
  - Motivations for FEM modeling
- Simulation of shear flow rheometry with COMSOL Multiphysics
- Results:
  - Normal force simulation
  - Rod climbing (Weissenberg effect) simulation

Rheometry of viscoelastic fluids

- Shear flow tests: non-Newtonian flow
- Small Amplitude Oscillation Shear (SAOS) tests: loss and storage modulus, linear properties
- Large Amplitude Oscillation Shear (LAOS) tests: anharmonic analysis, nonlinear viscoelastic properties

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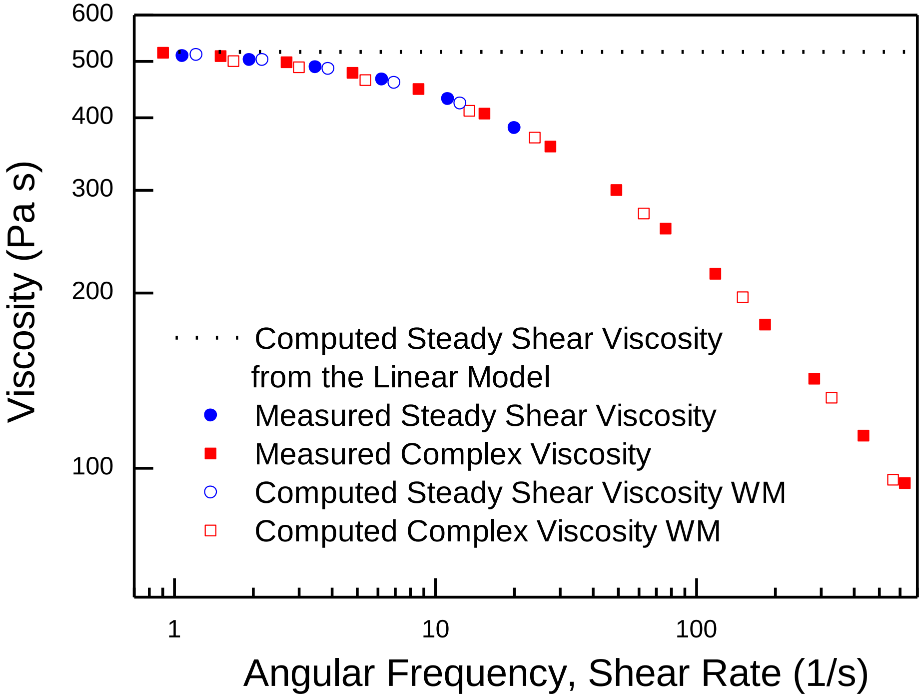
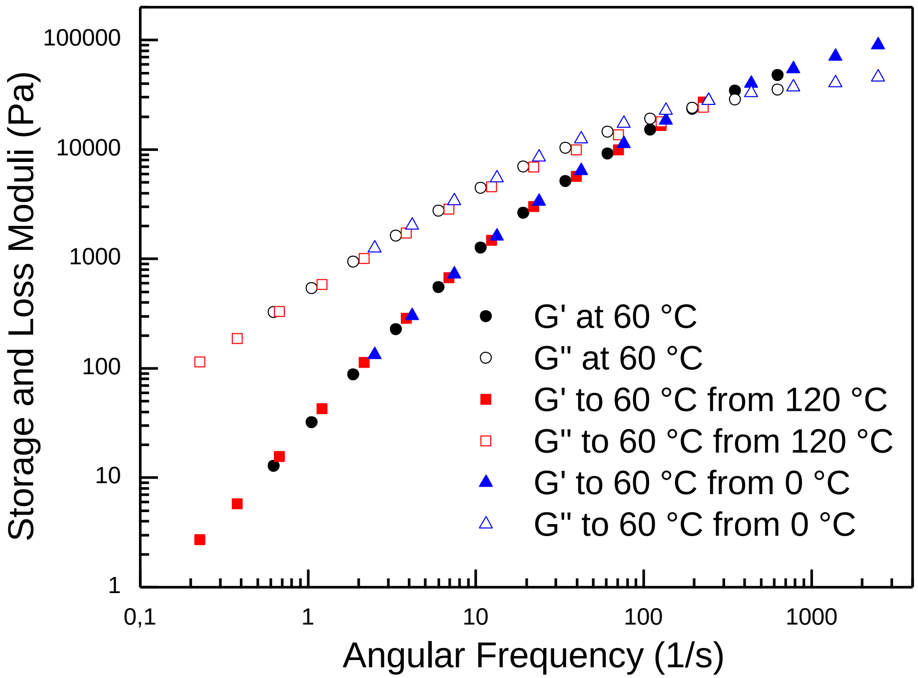
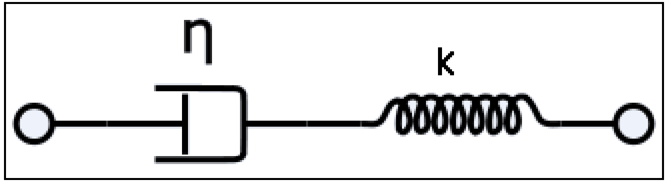
Rheometry of viscoelastic fluids





Rheometry of viscoelastic fluids

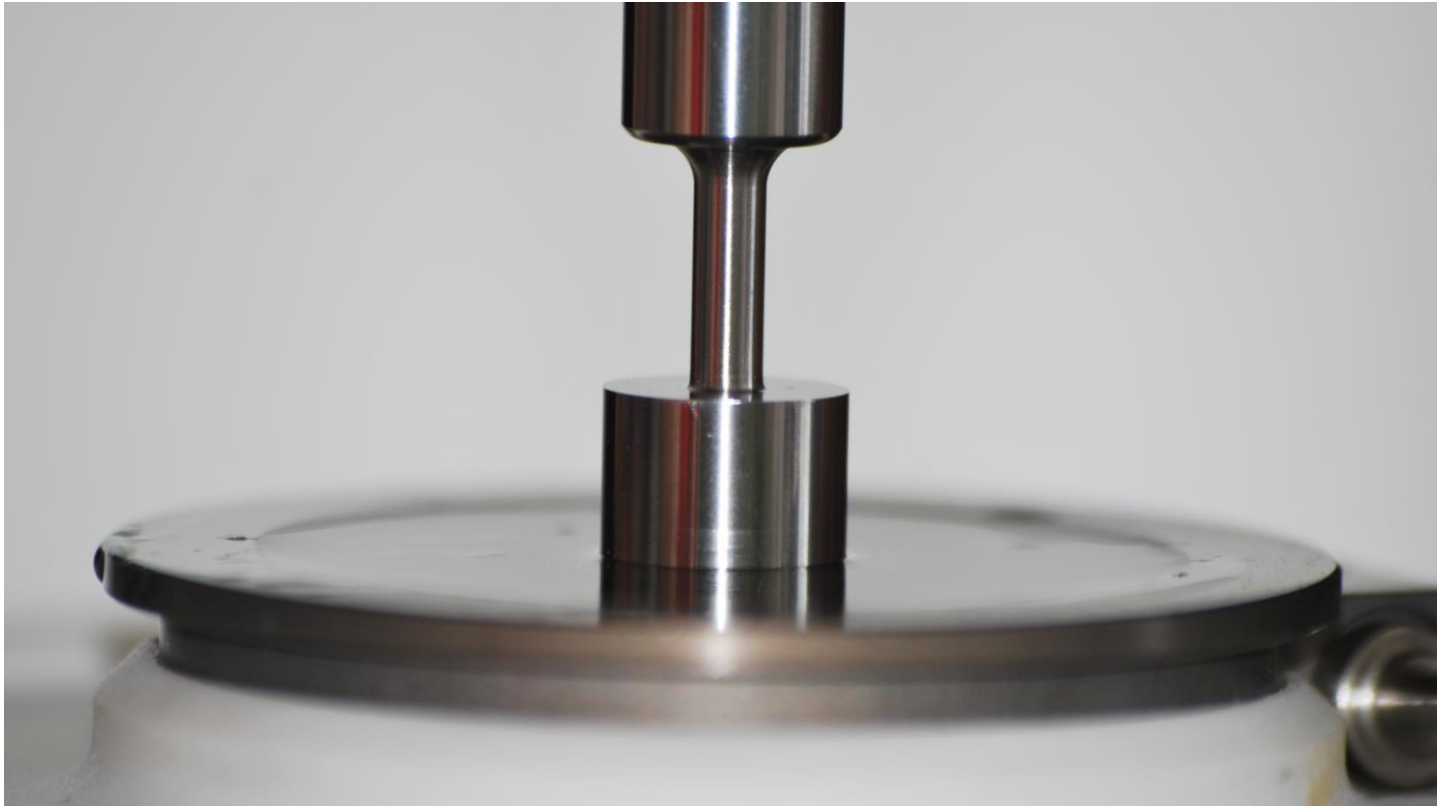
- Silicone oil, (Polydimethylsiloxane, PDMS)
- High viscosity: 100 – 2000 Pa*s
- Viscoelastic fluid: 3 – 5 Maxwell elements for lumped parameters models



- Shear thinning, Cox-Merz rule, Nonlinear viscoelasticity
- Normal force measurements with CP geometry, Weissenberg-effect

Rheometry of viscoelastic fluids

Weissenberg effect:



Rheometry of viscoelastic fluids

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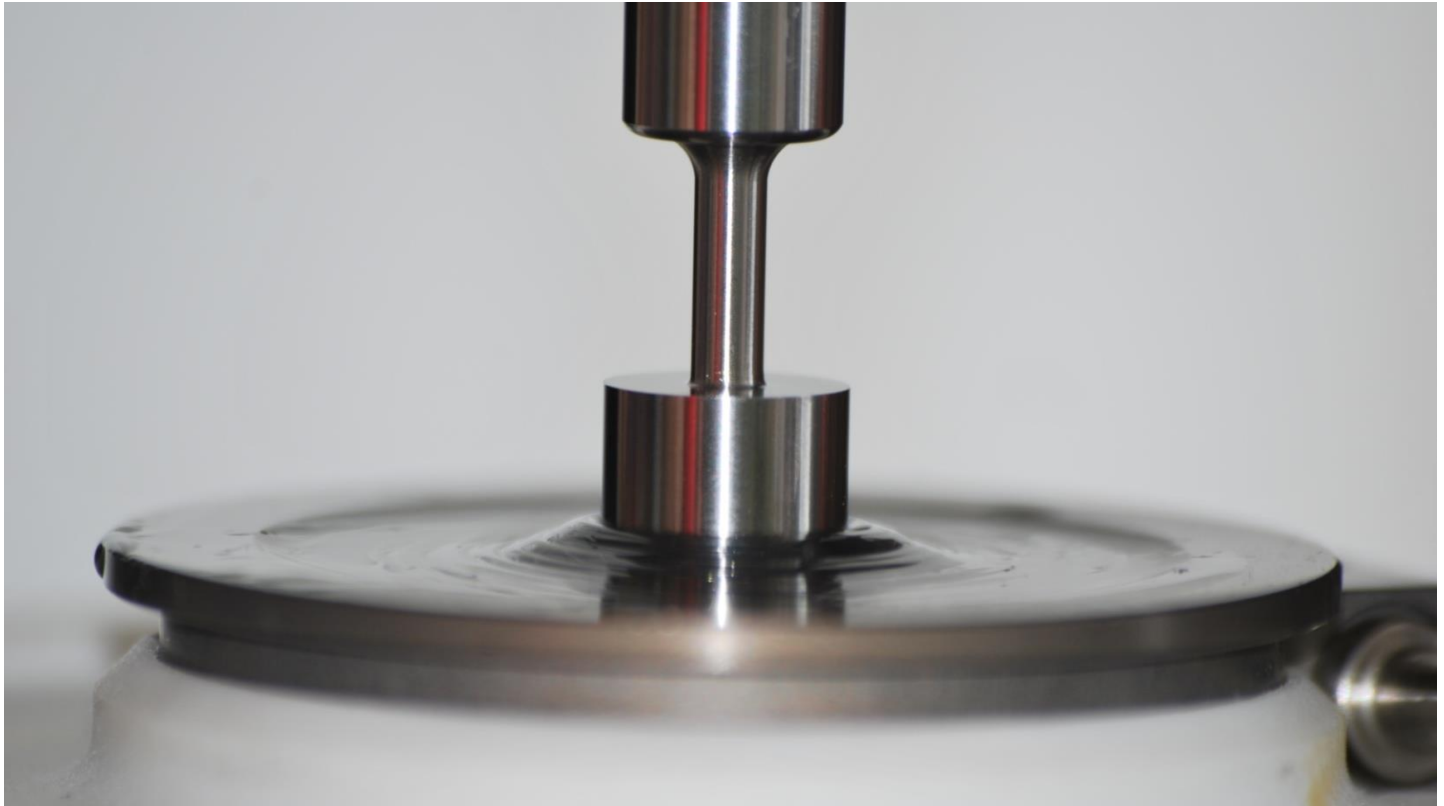

Rheometry of viscoelastic fluids

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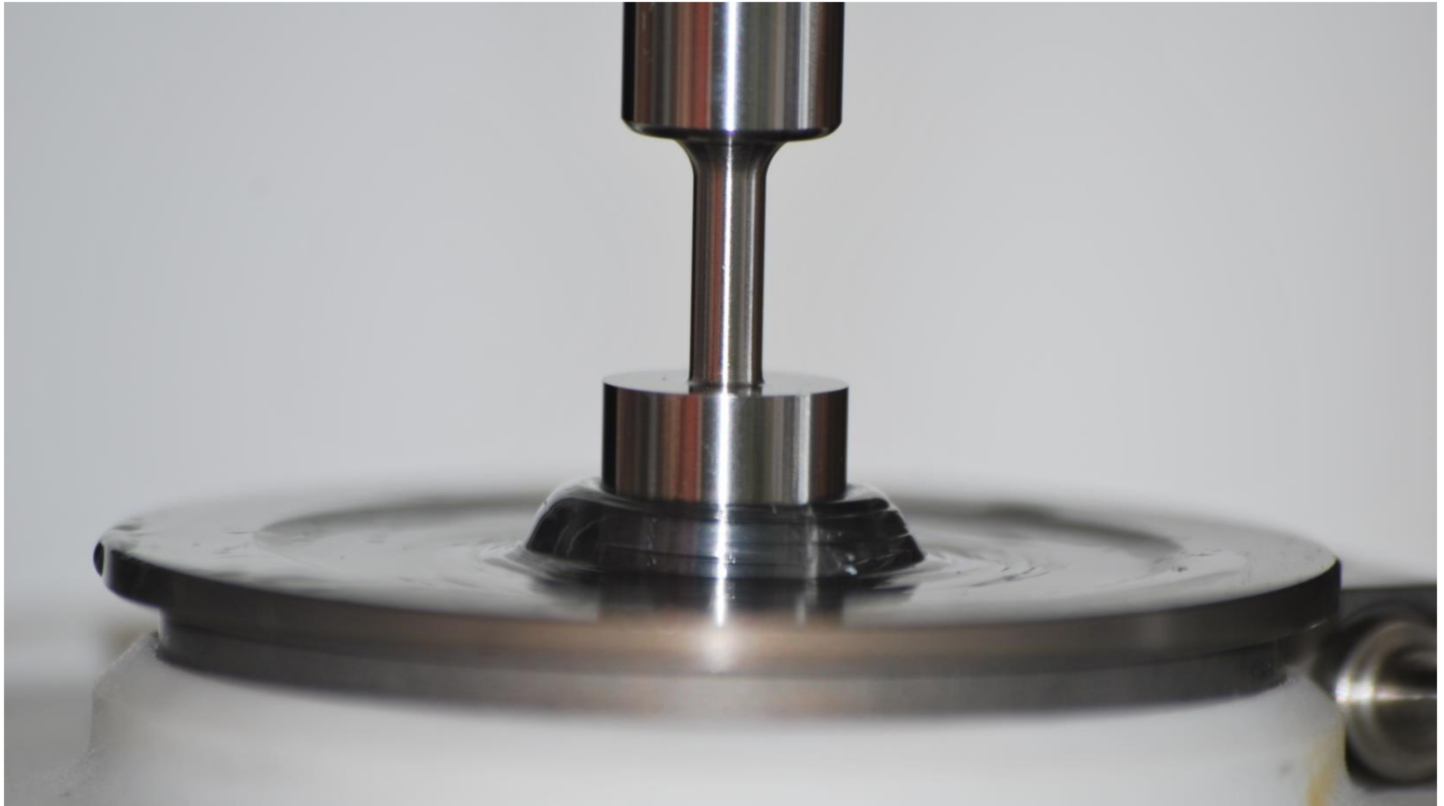


Motivations for a FEM simulation

- Which 3D constitutive equation (e.g. UCM, Jeffreys, White-Metzner, Oldroyd, ...) is the best to model the fluid?

- How much is the effect of rod climbing on the measured viscosity?

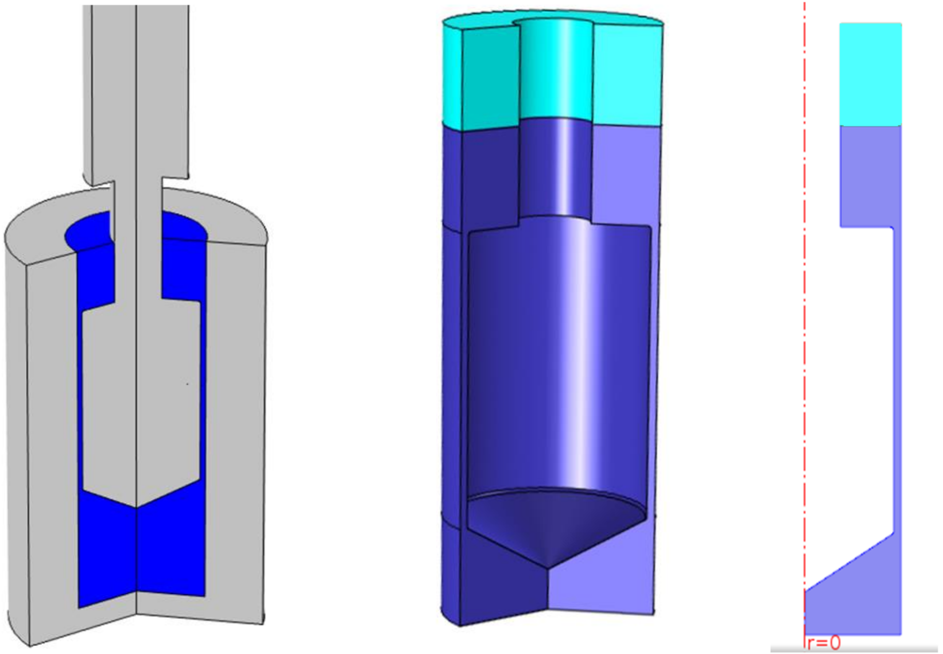
Simulation of shear flow with COMSOL

CP-model:

CC-model:

Simulation of shear flow with COMSOL

- Swirl flow with two phases: silicone oil and air, surface tension and gravity included ->
  2D axial sym., level set
- Silicone oil: White-Metzner with 3 elements ->
  2D PDE modes (cyl. coo.)



Simulation of shear flow with COMSOL

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$$\rho\frac{\partial \mathbf{u}}{\partial t}+\rho(\mathbf{u}\nabla)\mathbf{u}=\nabla\left[-p\mathbf{I}+\boldsymbol{\tau}\right]+\mathbf{F}$$

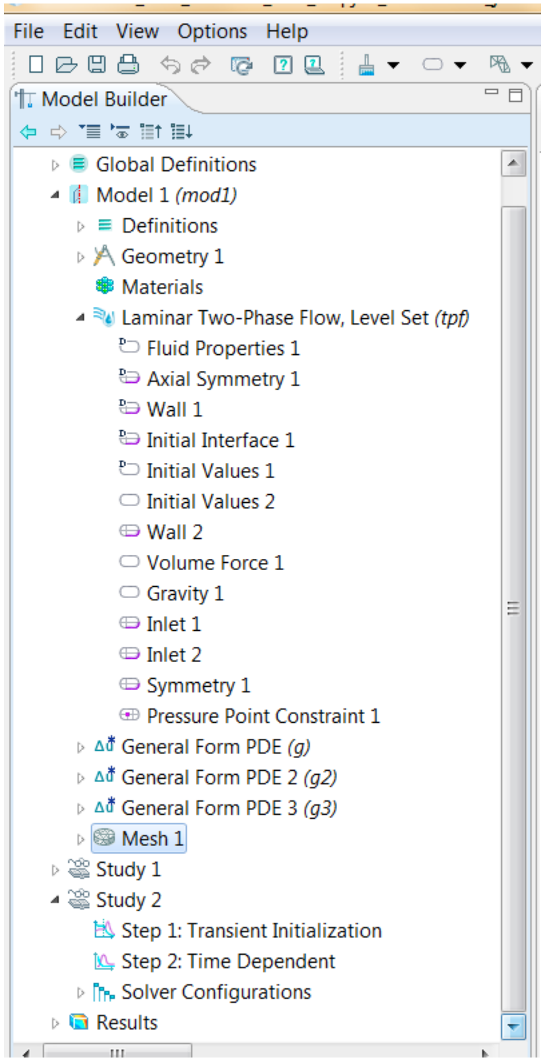
$$\boldsymbol{\tau}=\sum_{j=1}^{n}\boldsymbol{\tau}_j$$

$$\boldsymbol{\tau}_j+\frac{\eta_j(|\dot{\gamma}|)}{k_j}\overset{\nabla}{\boldsymbol{\tau}}_j=-\eta_j(|\dot{\gamma}|)\cdot\left[\nabla\mathbf{u}+(\nabla\mathbf{u})^T\right]$$

$$\overset{\nabla}{\boldsymbol{\tau}}_j\equiv\frac{\partial\boldsymbol{\tau}_j}{\partial t}+(\mathbf{u}\nabla)\boldsymbol{\tau}_j-\left[\boldsymbol{\tau}_j(\nabla\mathbf{u})+(\nabla\mathbf{u})^T\boldsymbol{\tau}_j\right]$$

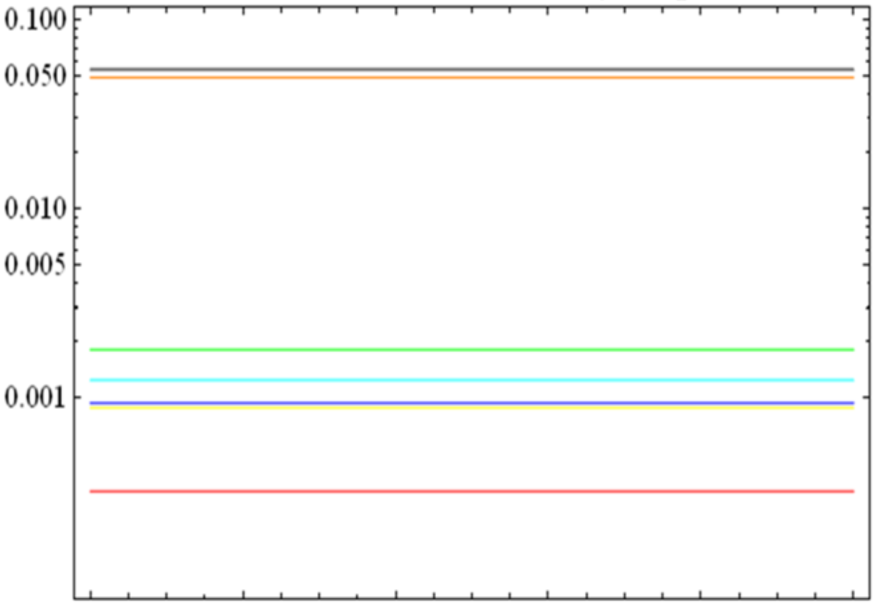
Simulation of shear flow with COMSOL

- Boundary conditions
- Variable scalings
- Time dependent solution, initialization
- Ramping up the azimuthal velocity
- Ramping up the coupling (Volume Force)
- Many variables, large RAM



Simulation of shear flow with COMSOL

- Reference simulation: Newtonian fluid, torque

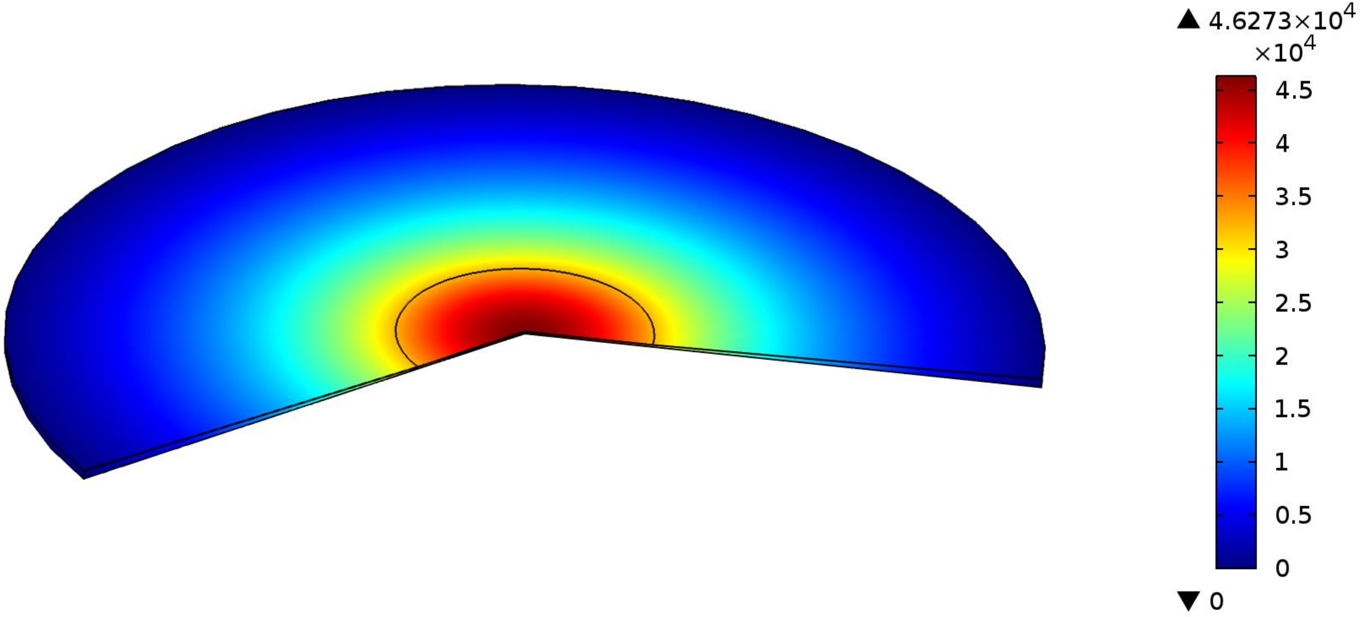


Results – CP

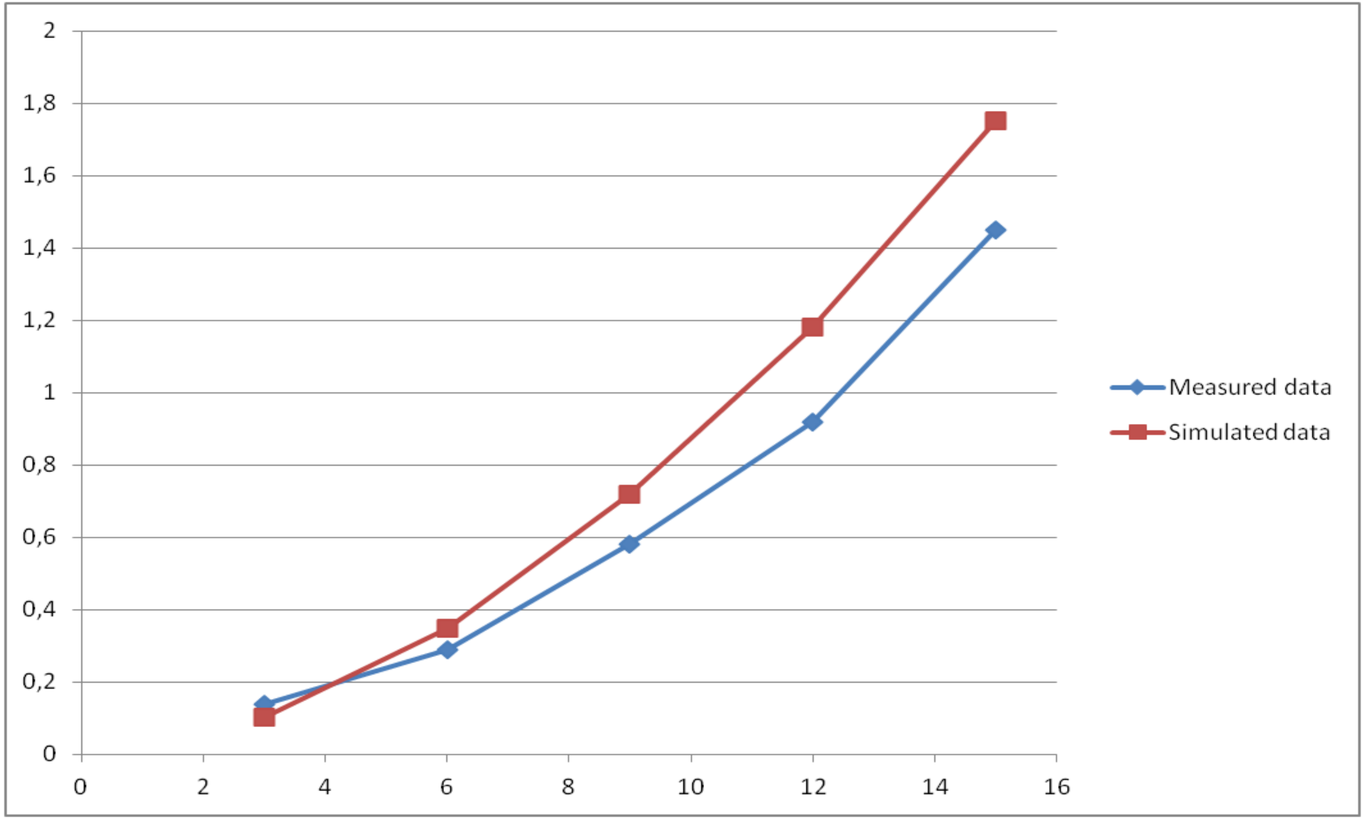
CP-model:

Results – CP: Normal force

- Pressure distribution on the upper (conical) surface



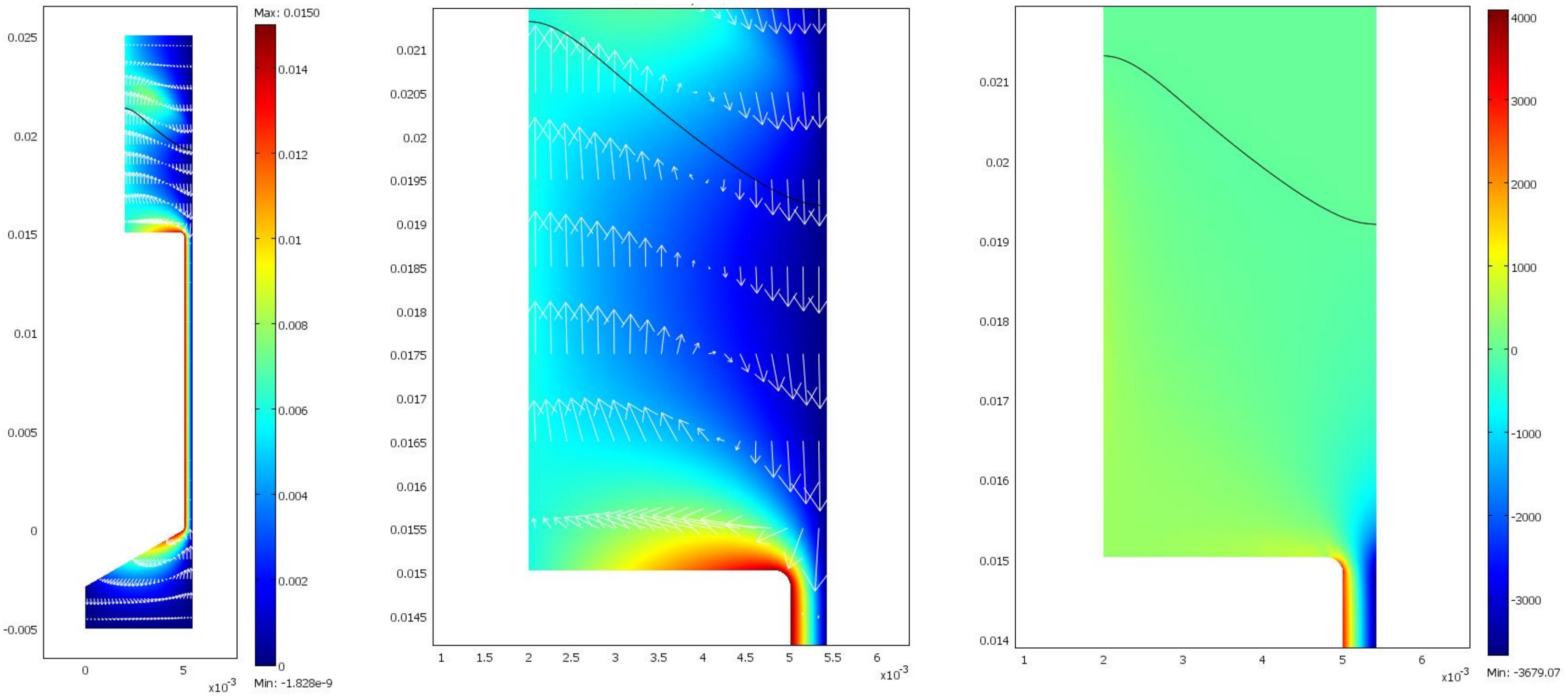
Results – CP: Normal force



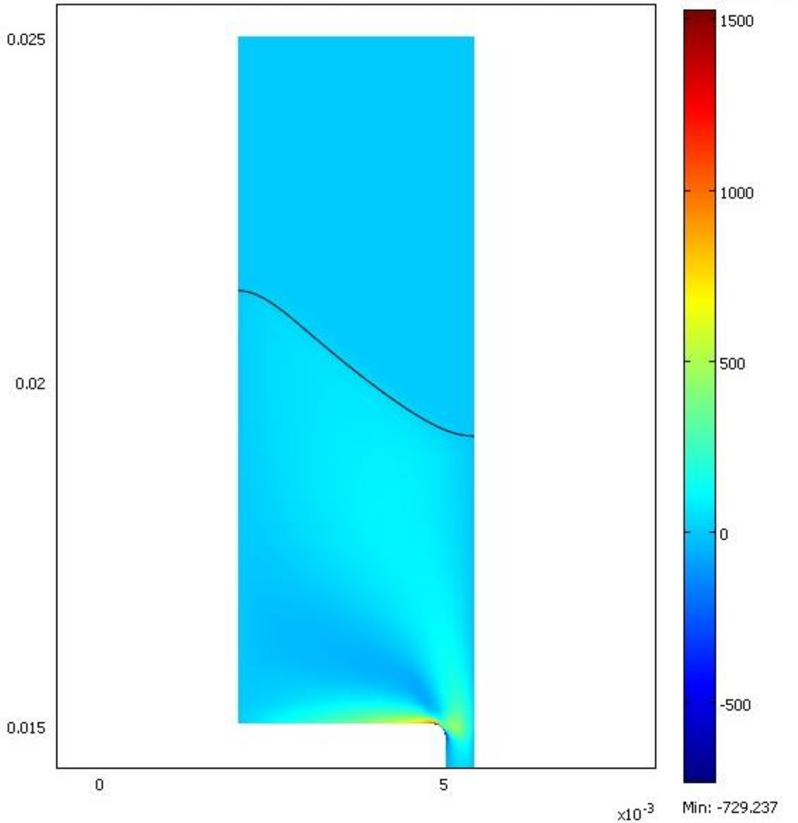
Results – CC

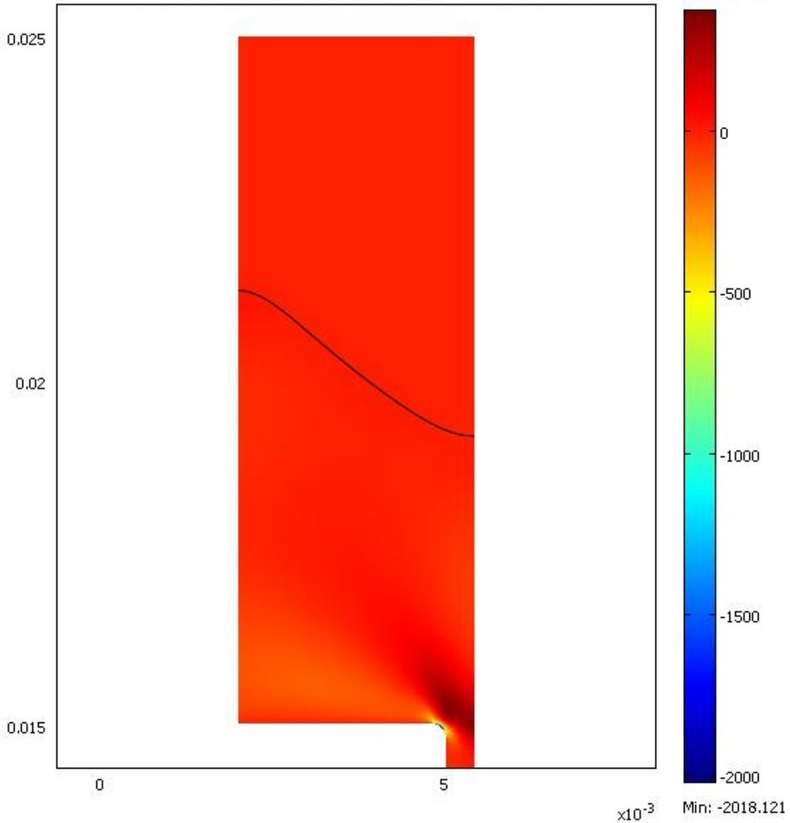
CC-model:

Results – CC: Rod climbing

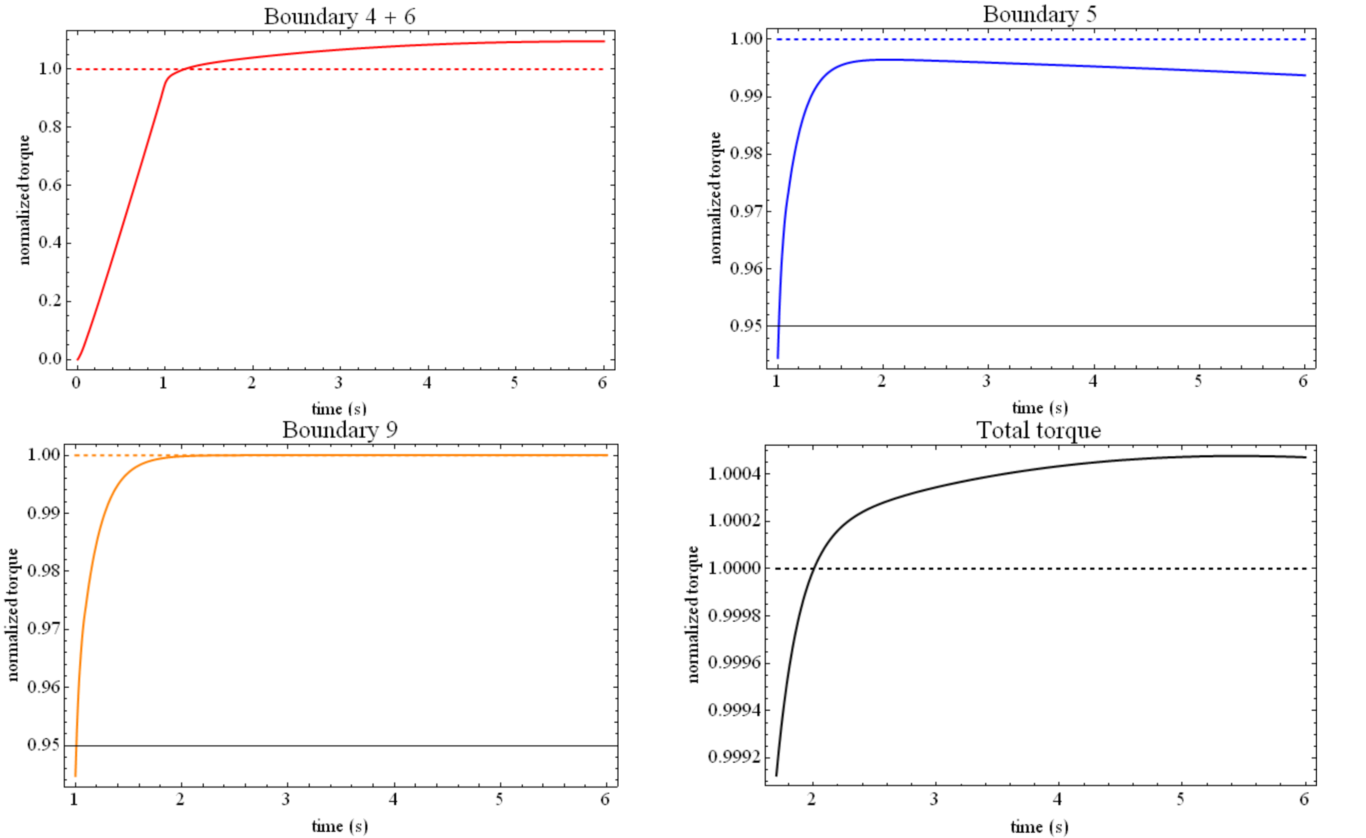


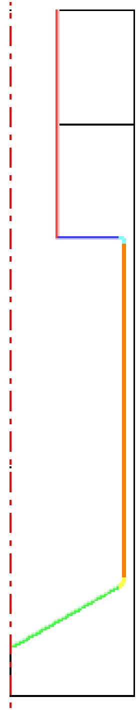
Results – CC: Rod climbing





Results – CC: Torque, viscosity





Conclusions

- COMSOL is able to give the solution of this difficult problem
- Normal force values from CP simulation are in good agreement with measurements
- Rod-climbing in CC simulation is close to reality, computed changes in torque values mostly cancel, therefore viscosity measurements are not disturbed

Thank you for your attention!