

# 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

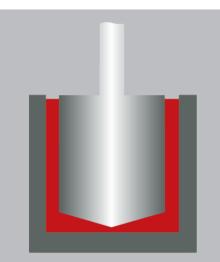


- Shear flow tests: non-Newtonian flow
- Small Amplitude Oscillation Shear (SAOS) tests: loss and storage modulus, linear properties
- Large Amplitude Oscillation Shear (LAOS) tests: anharmonic analysis, nonlinear viscoelastic properties



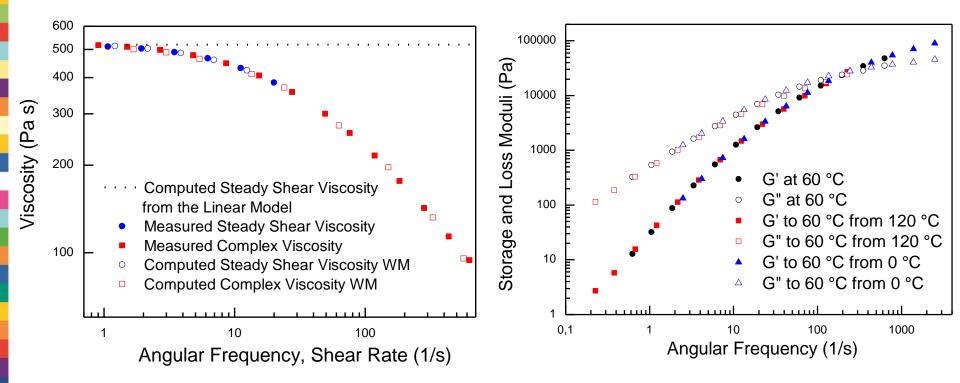


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Concentric Cylinder (CC)

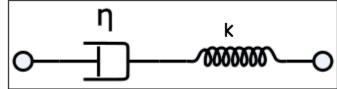






- Silicone oil, (Polydimethylsiloxane, PDMS)
- High viscosity: 100 2000 Pa\*s
- Viscoelastic fluid: 3 5 Maxwell elements for lumped parameters models

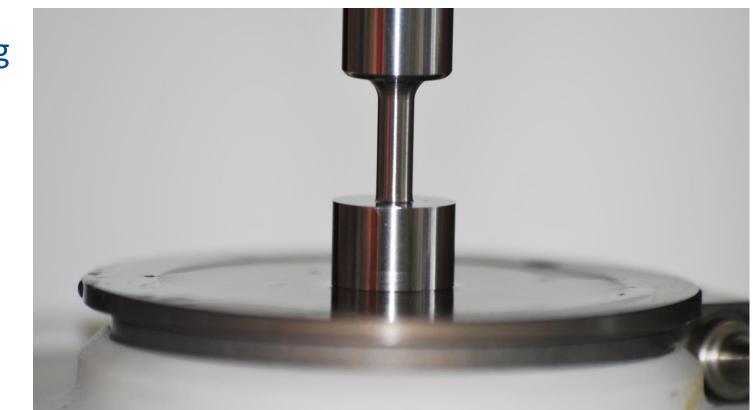
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- Shear thinning, Cox-Merz rule, Nonlinear viscoelasticity
- Normal force measurements with CP geometry, Weissenberg-effect

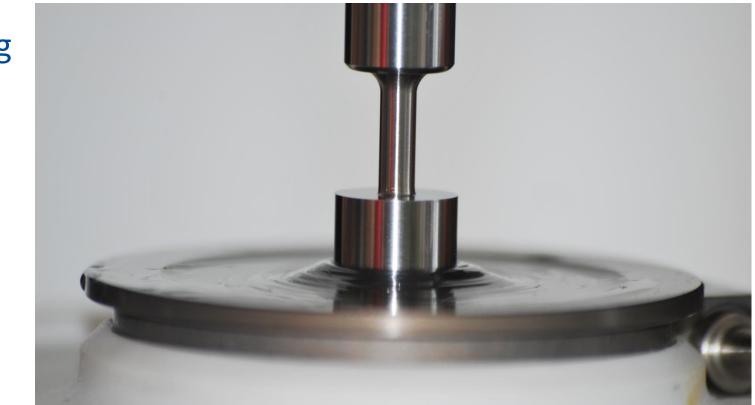


Weissenberg effect:



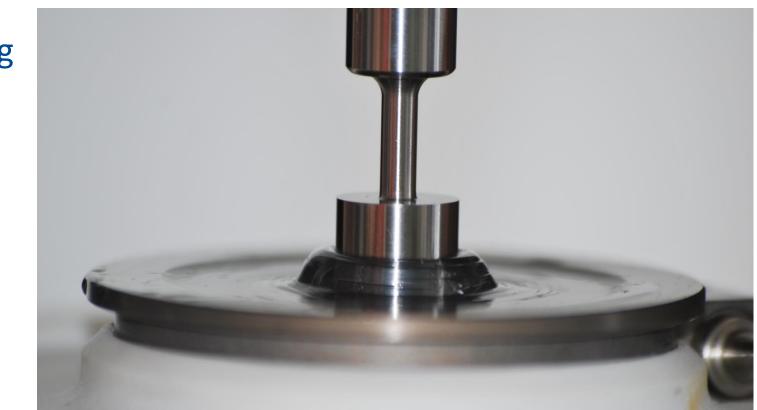


Weissenberg effect:





Weissenberg effect:





## Motivations for a FEM simulation

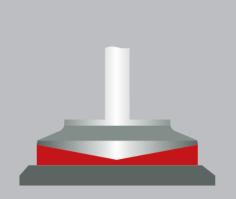
• Which 3D constitutive equation (e.g. UCM, Jeffreys, White-Metzner, Oldroyd, ...) is the best to model the fluid?

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

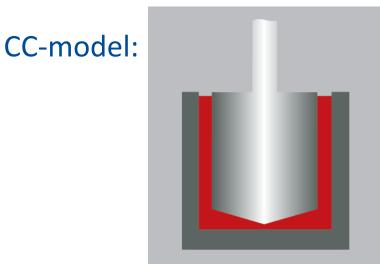


## Simulation of shear flow with COMSOL

CP-model:



Cone-Plate (CP)

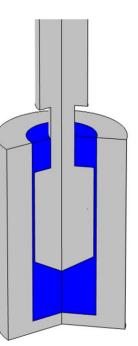


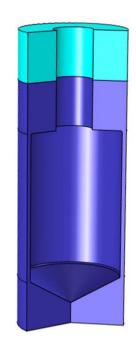
Concentric Cylinder (CC)



# 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.)







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   2D axial sym., level set
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   2D PDE modes (cyl. coo.)

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u}\nabla)\mathbf{u} = \nabla \left[-p\mathbf{I} + \mathbf{\tau}\right] + \mathbf{F}$$
$$\mathbf{\tau} = \sum_{j=1}^{n} \mathbf{\tau}_{j}$$

$$\boldsymbol{\tau}_{j} + \frac{\eta_{j}(|\dot{\gamma}|)}{k_{j}} \boldsymbol{\tau}_{j} = -\eta_{j}(|\dot{\gamma}|) \cdot \left[\nabla \mathbf{u} + (\nabla \mathbf{u})^{T}\right]$$

$$\stackrel{\nabla}{\mathbf{\tau}}_{j} \equiv \frac{\partial \mathbf{\tau}_{j}}{\partial t} + (\mathbf{u}\nabla)\mathbf{\tau}_{j} - [\mathbf{\tau}_{j}(\nabla\mathbf{u}) + (\nabla\mathbf{u})^{T}\mathbf{\tau}_{j}]$$

Simulation of shear flow with COMSOL

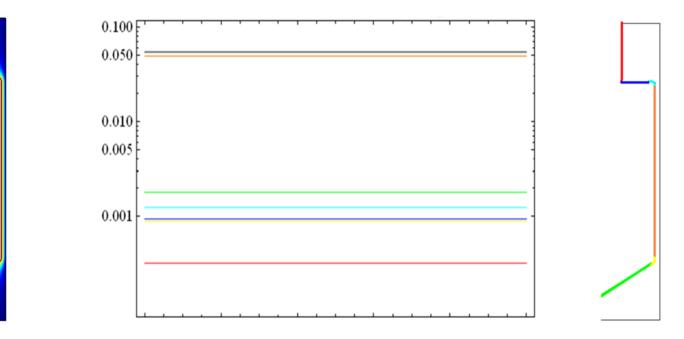
- Boundary conditions
- Variable scalings
- Time dependent solution, initialization
- Ramping up the azimuthal velocity
- Ramping up the coupling (Volume Force)
- Many variables, large RAM

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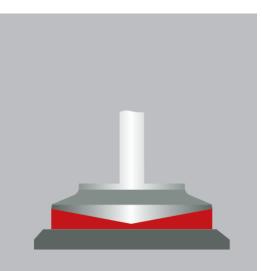
# Simulation of shear flow with COMSOL

• Reference simulation: Newtonian fluid, torque





#### Results – CP



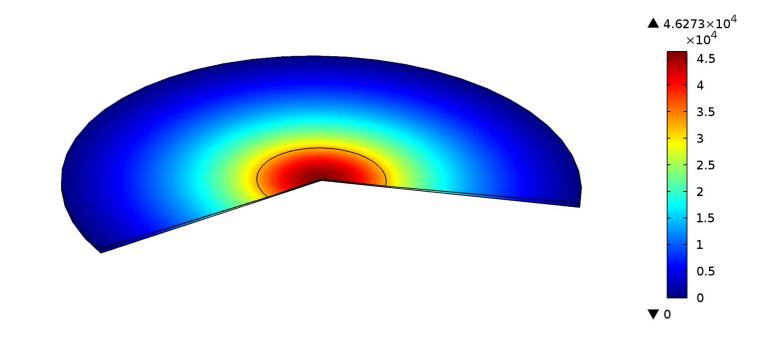
Cone-Plate (CP)

#### CP-model:



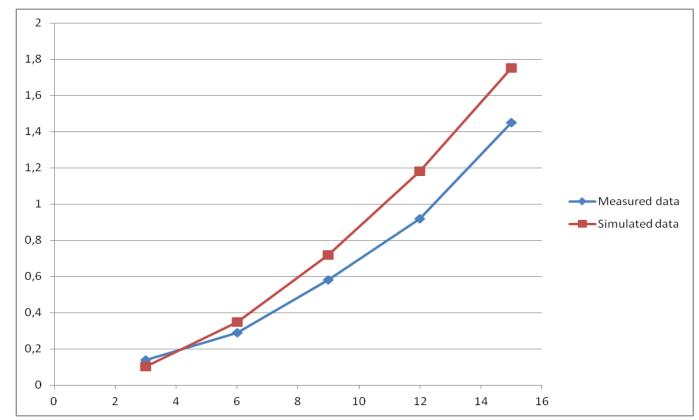
# Results – CP: Normal force

• Pressure distribution on the upper (conical) surface





## Results – CP: Normal force





### Results – CC

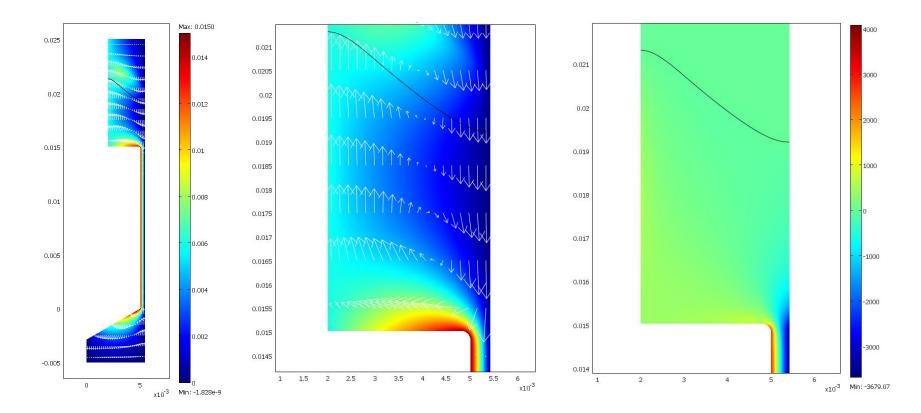


Concentric Cylinder (CC)

#### CC-model:

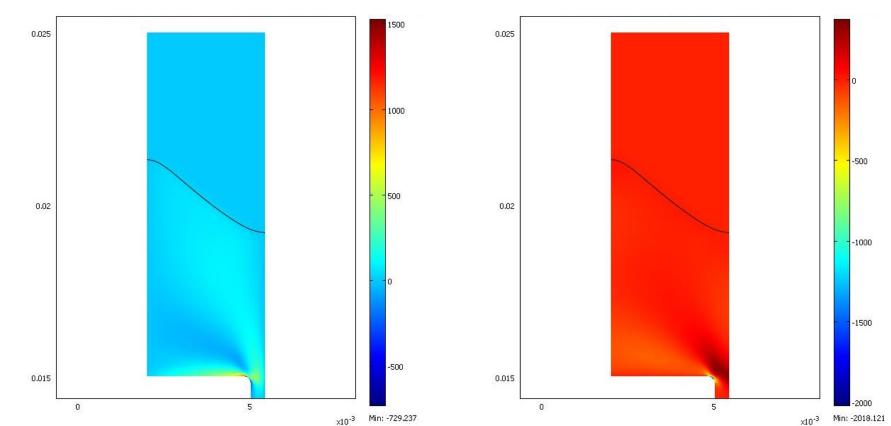


## Results – CC: Rod climbing



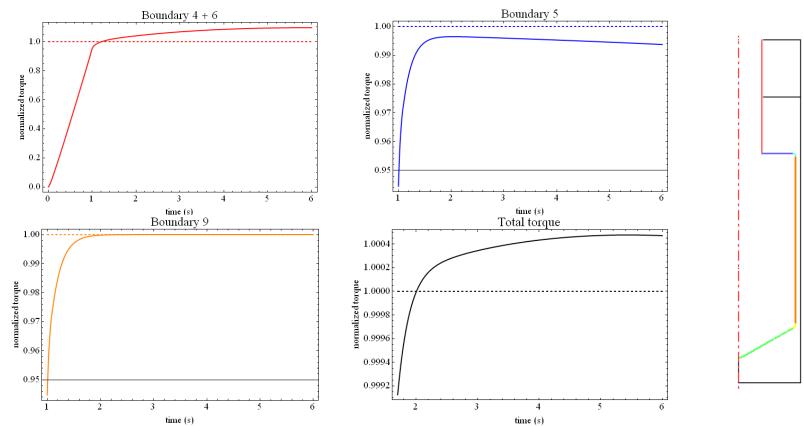


### Results – CC: Rod climbing



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## 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!