Implementation and validation of a DPM model accounting for shear-thinning fluid viscosity

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Problem

- Trajectory of a single particle in shear flow of a shear - thinning fluid as subproblem of wellbore flows.
- Improve ANSYS Fluent‘s DPM model such that particle trajectory is correctly predicted and validate with experimental findings of Khatibi et al. (2016).

Fluid

Viscous stress tensor

Continuity $\nabla \cdot (\rho_f \mathbf{u}) = 0$

Momentum $\frac{\partial}{\partial t}(\rho_f \mathbf{u}) + \nabla \cdot (\rho_f \mathbf{uu}) = -\nabla p - \nabla \cdot \underbrace{\mathbf{T}_f}_{\mathbf{T}_f = -2\eta_f(\dot{\gamma})\mathbf{D}_f} + \rho_f \mathbf{g} + \frac{1}{V}\sum_{p \in V} \mathbf{F}_i$

Particle

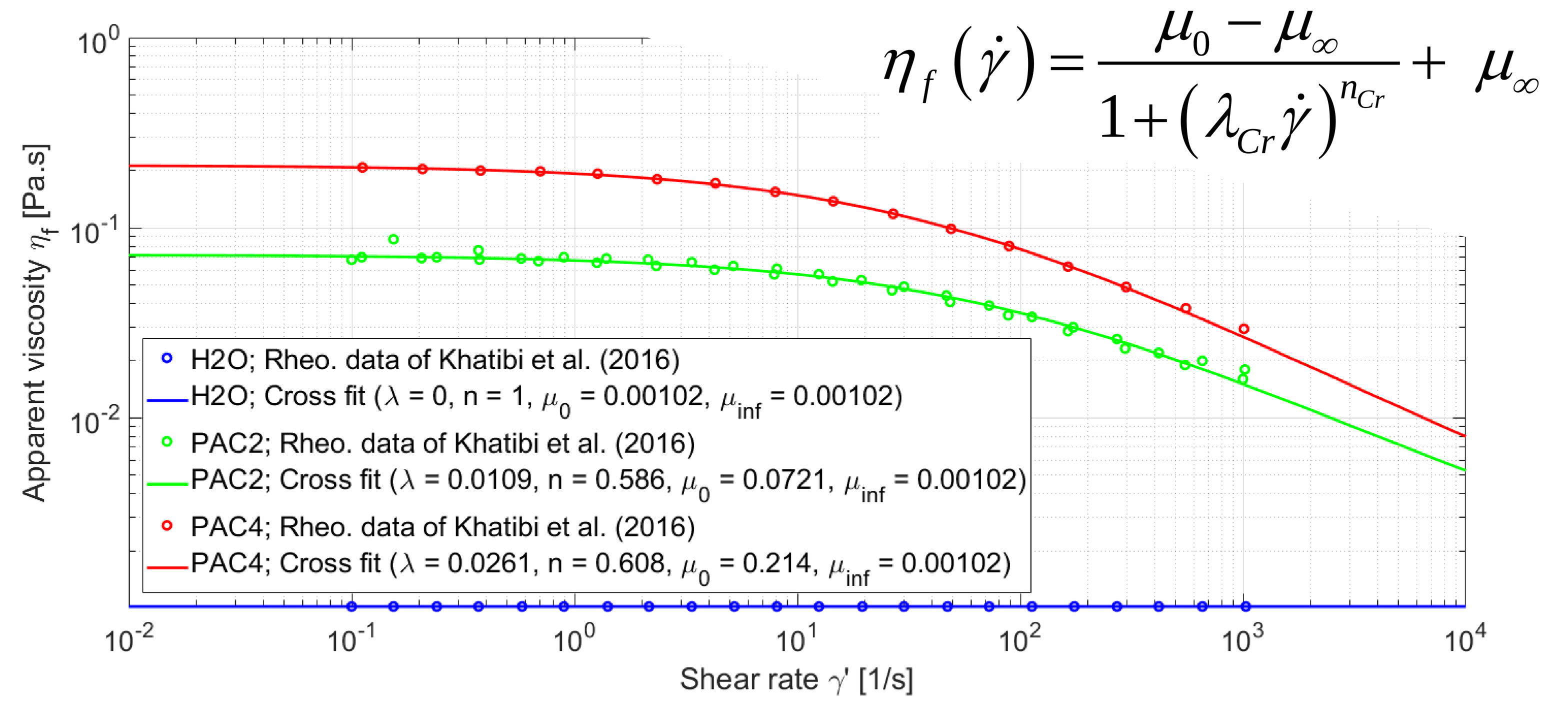
Equation of motion $$\frac{d\mathbf{v}}{dt} = \underbrace{\frac{3c_D \mathrm{Re}_p \eta_f \mathbf{v}_r}{4\rho_p d_p^{\,2}}}_{\mathbf{F}_D/m_p} + \underbrace{\frac{\mathbf{g}(\rho_p - \rho_f)}{\rho_p}}_{\mathbf{F}_{GB}/m_p} + \frac{\sum \mathbf{F}_j}{m_p}$$

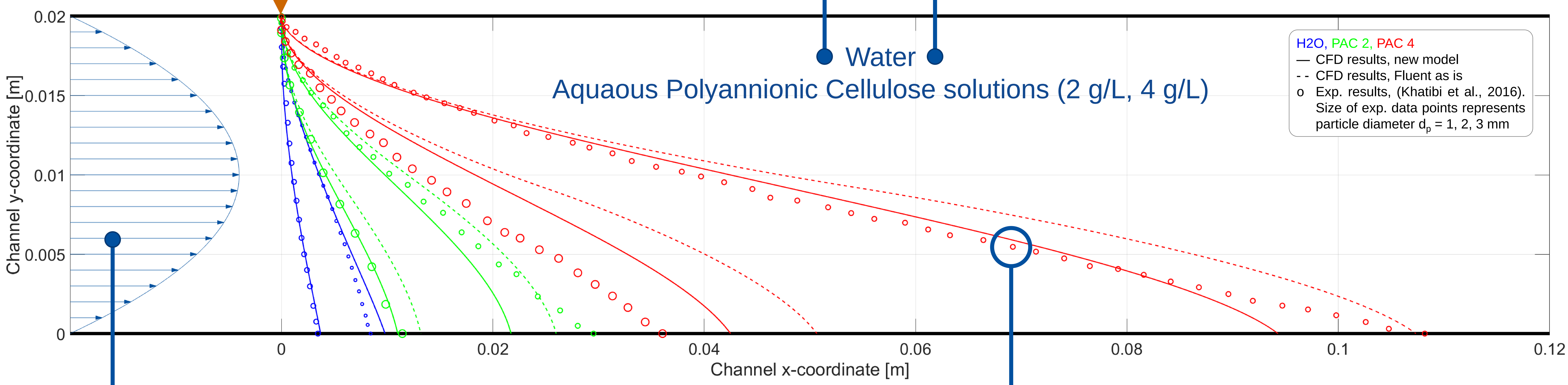
Drag coefficient $\underbrace{c_D = f(\mathrm{Re}_p)}_{\text{Schiller and Naumann (1933)}}$ Reynolds number $\mathrm{Re}_p = \frac{\rho_f \|\mathbf{v}_r\| d_p}{\eta_f}$

Rheology

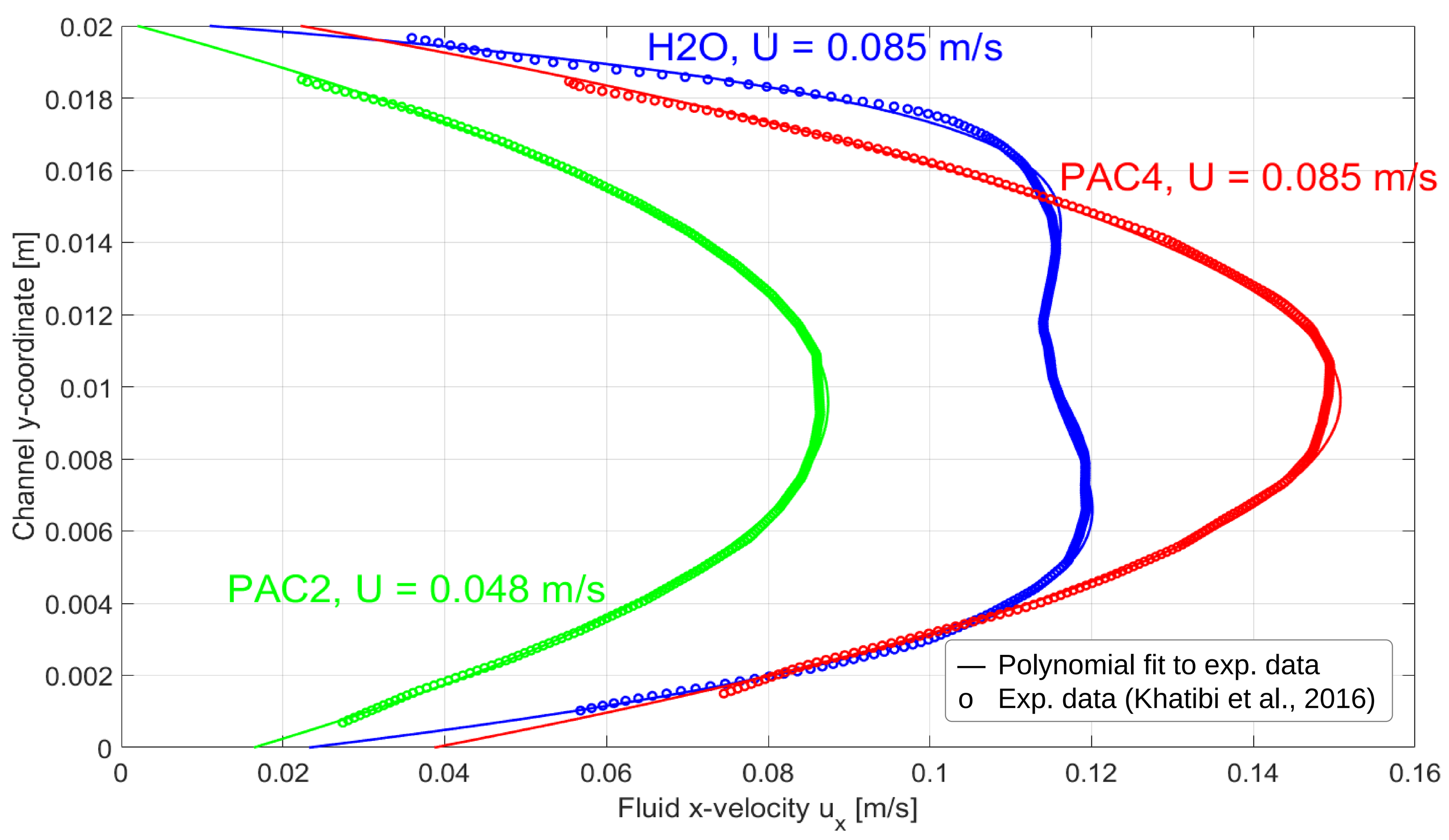
Cross (1965) material function

$$\eta_f(\dot{\gamma}) = \frac{\mu_0 - \mu_\infty}{1 + (\lambda_{Cr}\dot{\gamma})^{n_{Cr}}} + \mu_\infty$$





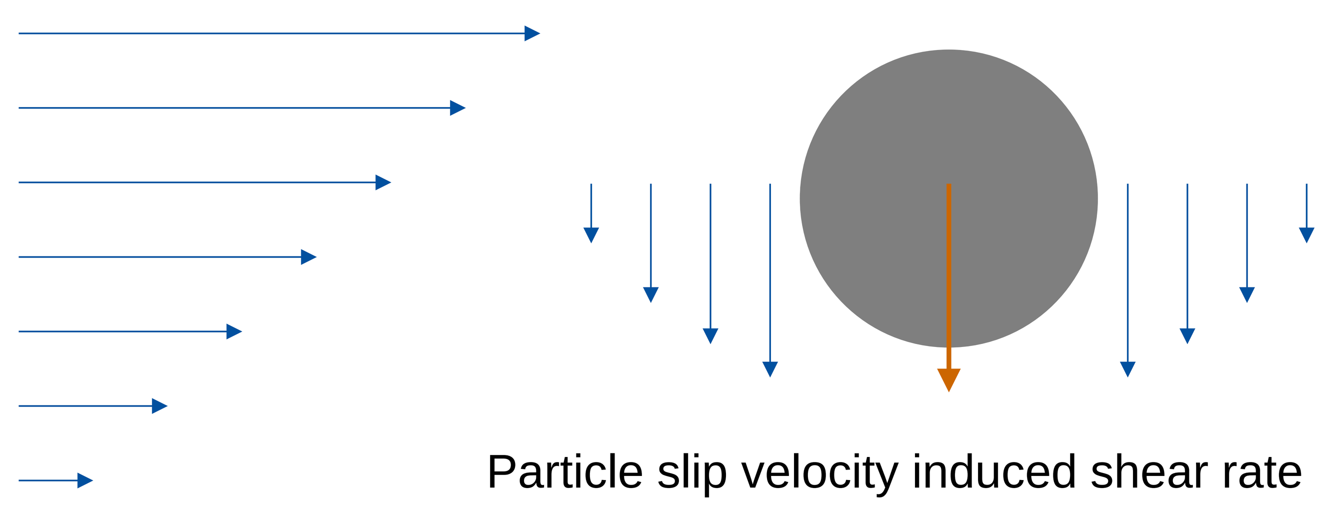
Inlet velocity profiles



Strain rate as seen by the particle

Orthogonal shear (Novotny 1977) $\dot{\gamma} = \sqrt{(\dot{\gamma}_f)^2 + (\dot{\gamma}_p)^2}$

Mean background flow velocity induced shear rate $\dot{\gamma}_f = \sqrt{2\mathbf{D}_f : \mathbf{D}_f}$



Particle slip velocity induced shear rate $\dot{\gamma}_p = \frac{\|\mathbf{v}_r\|}{d_p}$

Conclusions

- Trajectories may be computed fairly well with an apparent viscosity concept.
- Mismatch at lower wall not fully understood yet.
- Wall-near experimental data for and modeling of lift forces for shear-thinning fluids required.

Works Cited

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