High-stress elastic filaments control 2D creeping flows of viscoelastic fluids through porous media

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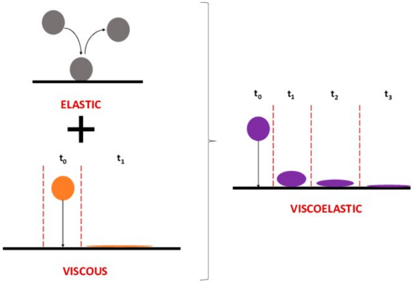
Introduction
Viscoelastic Behavior of Polymer Solutions

A "viscous/elastic" behavior



Viscoelastic fluid, *Rock et al. (2020)*

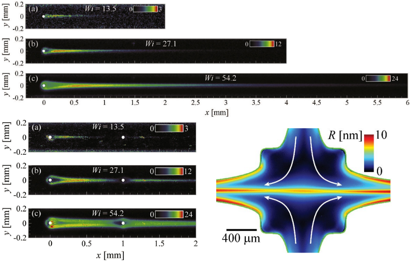
λ polymer relaxation time

- $t_c > \lambda$ viscous behavior
- $t_c < \lambda$ elastic behavior

Weissenberg number

$$Wi = \frac{\text{elastic forces}}{\text{viscous forces}} = \lambda\dot{\gamma} = \frac{\lambda\langle U\rangle}{L}$$

Birefringent strand

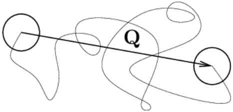


Experimental results,
Haward et al. (2013 & 2018)

$$\rho\,\partial_t \boldsymbol{u} = -\boldsymbol{\nabla} p + \eta_s \mathrm{div}\left(\boldsymbol{\nabla}\boldsymbol{u} + (\boldsymbol{\nabla}\boldsymbol{u})^t\right) + \frac{\eta_p}{\lambda}\mathrm{div}\left(\boldsymbol{c} - \boldsymbol{I}_d\right),$$

$$\mathrm{div}\ \boldsymbol{u} = 0,$$

$$\partial_t\, \boldsymbol{c} + \boldsymbol{u}\cdot\boldsymbol{\nabla}\boldsymbol{c} - (\boldsymbol{\nabla}\boldsymbol{u})\,\boldsymbol{c} - \boldsymbol{c}\,(\boldsymbol{\nabla}\boldsymbol{u})^t + \frac{1}{\lambda}(\boldsymbol{c} - \boldsymbol{I}_d) = 0.$$

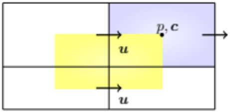


A Dumbbell

Conformation tensor
$\boldsymbol{c} =< \boldsymbol{QQ} >$

Overview of our scheme, Mokhtari et al. (2020)

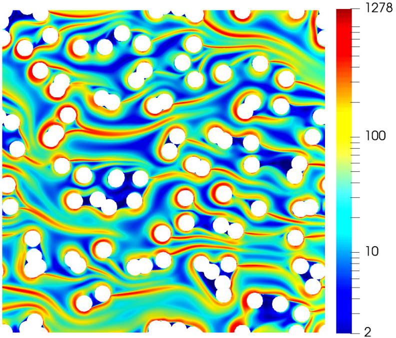
- **Conservation equations**
  Prediction-Correction scheme
- **Constitutive equations**
  Splitting+Log-conformation
  - $\partial_t\, log(\boldsymbol{c}) + \boldsymbol{u}\cdot\boldsymbol{\nabla}\, log(\boldsymbol{c}) = 0$
  - $d_t\, \boldsymbol{c} = (\boldsymbol{\nabla}\boldsymbol{u})\,\boldsymbol{c} + \boldsymbol{c}\,(\boldsymbol{\nabla}\boldsymbol{u})^t - \frac{1}{\lambda}(\boldsymbol{c} - \boldsymbol{I}_d)$



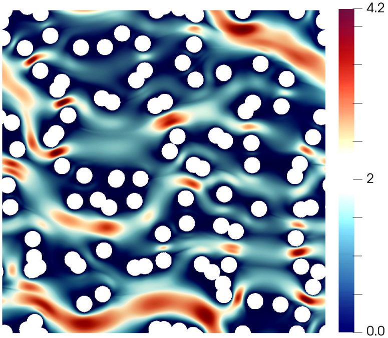
Staggered Grid

Implementation in the CALIF3S open-source platform
https://gforge.irsn.fr/gf/project/calif3s

Biperiodic disordered array of cylinders, $Wi = 5$ (stationary)



$tr(\mathrm{c})$, in log-scale

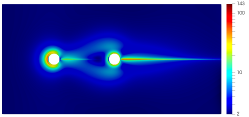


$\|\mathrm{u}\| / \|\langle \mathrm{u} \rangle\|$

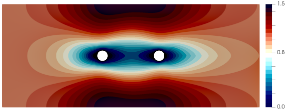
What is the impact of the “membranes” on the flow?

Flow Around Aligned Cylinders

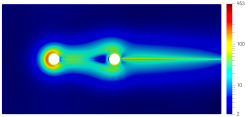
Role of the Weissenberg number ($D = 9$)



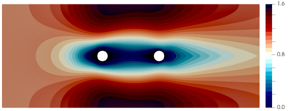
$tr(\mathrm{c}),\ Wi = 5$



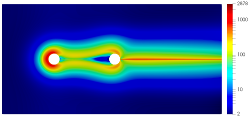
$\|\mathrm{u}\|/\|\langle \mathrm{u} \rangle\|,\ Wi = 5$



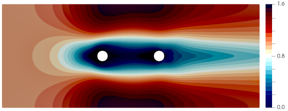
$tr(\mathrm{c}),\ Wi = 10$



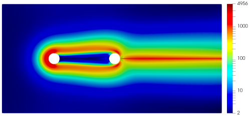
$\|\mathrm{u}\|/\|\langle \mathrm{u} \rangle\|,\ Wi = 10$



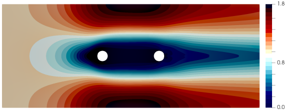
$tr(\mathrm{c}),\ Wi = 20$



$\|\mathrm{u}\|/\|\langle \mathrm{u} \rangle\|,\ Wi = 20$



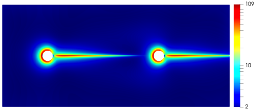
$tr(\mathrm{c}),\ Wi = 30$



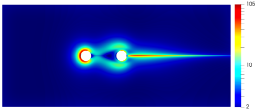
$\|\mathrm{u}\|/\|\langle \mathrm{u} \rangle\|,\ Wi = 30$

Flow Around Aligned Cylinders
Filament to Envelope Transition

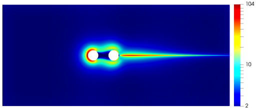
Aligned cylinders, $Wi = 5$



$tr(\mathrm{c}),\ De = 0.25$



$tr(\mathrm{c}),\ De = 1$



$tr(\mathrm{c}),\ De = 5$

Weissenberg number

$$Wi = \frac{\text{elastic forces}}{\text{viscous forces}} = \lambda\dot{\gamma} = \frac{\lambda\langle U\rangle}{R}$$

R: radius of the cylinders

Deborah number

$$De = \frac{\text{relaxation time}}{\text{solicitation time}} = \frac{\lambda}{t_c} = \frac{\lambda\langle U\rangle}{D}$$

D: distance between the cylinders

- Appearance of stagnation zones
- Transition Filament $\mapsto$ Envelope with $De > 1$

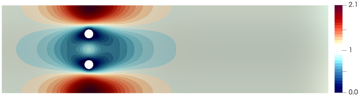
Flow around Side-by-side Cylinders

Role of the Weissenberg number ($D = 5$)

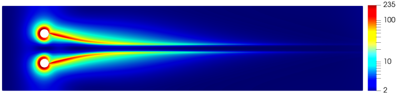
$tr(\mathrm{c})$, $Wi = 1$

$\|\mathrm{u}\|/\|\langle \mathrm{u} \rangle\|$, $Wi = 1$

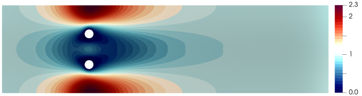
$tr(\mathrm{c})$, $Wi = 5$



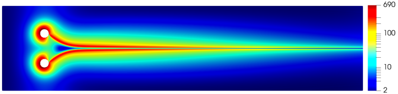
$\|\mathrm{u}\|/\|\langle \mathrm{u} \rangle\|$, $Wi = 5$



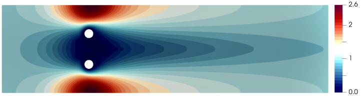
$tr(\mathrm{c})$, $Wi = 10$



$\|\mathrm{u}\|/\|\langle \mathrm{u} \rangle\|$, $Wi = 10$



$tr(\mathrm{c})$, $Wi = 20$

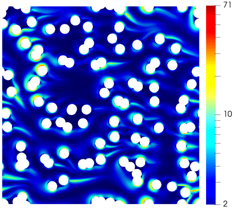


$\|\mathrm{u}\|/\|\langle \mathrm{u} \rangle\|$, $Wi = 20$

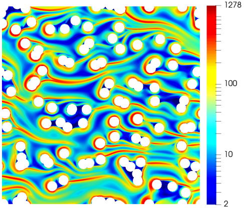
- *Amplification of the pre-existing preferential flows path*
- *Formation of a stagnation zone*

Disordered Arrays of Cylinders

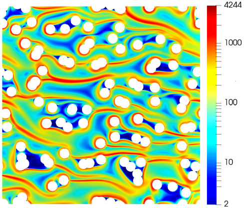
Role of the Weissenberg number



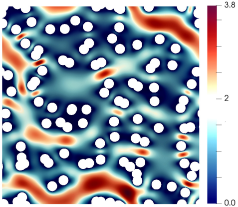
$tr(\mathrm{c})$, $Wi = 0.65$



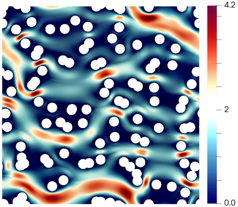
$tr(\mathrm{c})$, $Wi = 4.8$



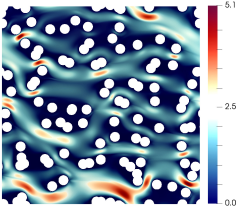
$tr(\mathrm{c})$, $Wi = 9.6$



$\|\mathrm{u}\|/\|\langle \mathrm{u}\rangle\|$, $Wi = 0.65$



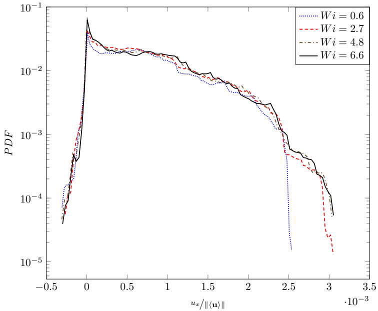
$\|\mathrm{u}\|/\|\langle \mathrm{u}\rangle\|$, $Wi = 4.8$



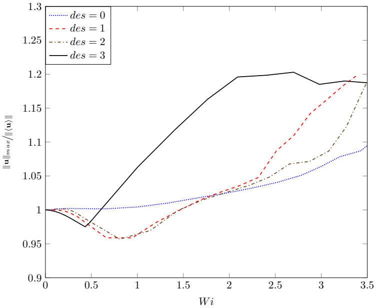
$\|\mathrm{u}\|/\|\langle \mathrm{u}\rangle\|$, $Wi = 9.6$

- *Amplification of the preferential flows path*
- *Flow "Channeling"*

Disordered Arrays of Cylinders
Preferential flow paths



PDF of the normalized velocity



Evolution of the maximum velocity

- *More stagnation zones*
- *Increase of the maximum velocity*

Conclusion and Prospects

In summary

Important role of the "elastic membranes" on the flow:

- *Flow "Channeling"*
- *More stagnation zones*
- *Amplification of the preferential flows path*

Remaining questions:

- Macro-scale properties
- 3D geometries
- Transition to unsteady flows