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Simulation of Particle Suspensions in Bi-periodic Domains

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Introduction

A new finite element model has been developed for direct simulation of inertialess particle suspensions in simple shear flow. Distinctive features are:

- ☐ The force-free torque-free rigid body motion is assigned by the Lagrangian multipliers, but on the particle boundary only.
- ☐ A sliding window concept is introduced to impose the bi-periodicity of simple shear flow and it is implemented by mortar element methods.

The project was initiated by the need to understand the micro-structural rheological behaviour of the particle-filled polymer melt flow, especially for the application to flow-induced crystallization kinetics of such systems.

Mathematical Modeling

Problem definition

- ☐ Freely suspending disk-like particles in simple shear flow of a highly viscous fluid
- ☐ Relatively translating bi-periodic domain: the sliding window

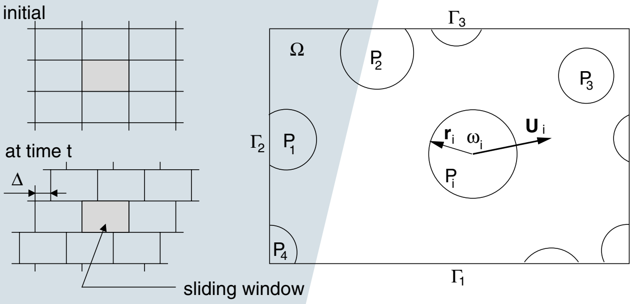

Figure 1 *The sliding window for bi-periodic constraint on the domain boundary (left). The amount of slide is determined by the given shear rate $\dot{\gamma}$, the elapsed time t, and the height of the window H, i.e., $\Delta = \dot{\gamma}\, H\, t$. The sliding window is the domain of this problem and a possible particle configuration is indicated (right).*

Formulation and implementation

- ☐ Both fluid and particle domains are modelled as a (generalized) Newtonian fluid and discretized by the standard velocity-pressure formulation with the bi-quadratic velocity and discontinuous linear pressure.
- ☐ The rigid body motion of the particle is assigned by a 'rigid ring' constraint on the particle boundary and it has been implemented by Lagrangian multipliers with a point collocation method.
- ☐ The time and shear-rate dependent sliding boundary constraint is imposed on the fluid domain boundary: bi-periodic constraint by the 'sliding window' concept, which has been implemented by mortar element techniques.

Numerical Results

1. Two particles in a bounded domain of simple shear flow:

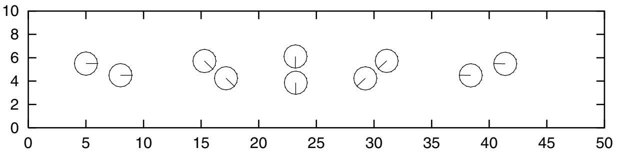

Figure 2 *Two particles in simple shear flow ($\dot{\gamma}$=1): (from the left) t=0, 1.95, 3.40, 4.80, and 6.75. The velocity on the domain boundary is specified by a simple shear flow.*

2. Velocity and pressure distribution in a bi-periodic domain:

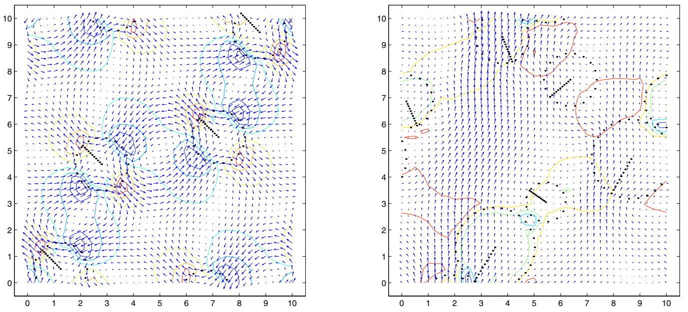

Figure 3 *The fluctuation velocity and pressure distributions: Four symmetric particles (left); six random particles (right).*

3. Viscoelastic stress evolution of four symmetric particles in a bi-periodic domain (decouped analysis with the UCM model):

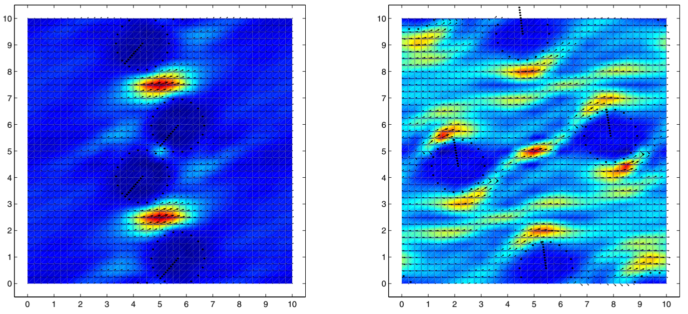

Figure 4 *The magnitude and direction of the maximum principal stress relative to G. The effect of aligning particles (left): $t\dot{\gamma}$= 4, De = 1 [max.=22.3]; the effect of departing particles (right): $t\dot{\gamma}$ = 8.5, De = 5. [max.=309.5].*

Conclusion

A new finite element formulation has been developed and implemented for direct simulation of inertialess particle suspensions in simple shear flow. The present formulation is well suited for the nano-particle suspension problems and can be easily extended to viscoelastic flows.

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