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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

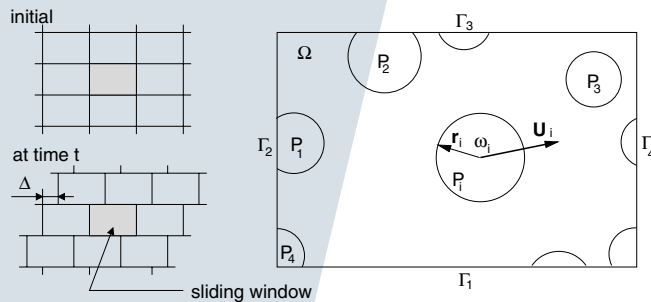


Figure 1 The sliding window for bi-periodic constraint on the domain boundary (left). The amount of slide is determined by the given shear rate  $\dot{\gamma}$ , the elapsed time  $t$ , and the height of the window  $H$ , i.e.,  $\Delta = \dot{\gamma} H t$ . The sliding window is the domain of this problem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

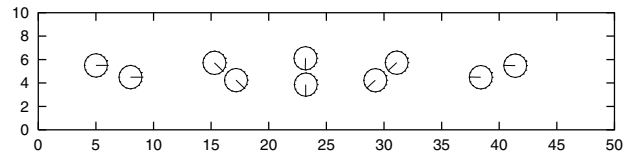


Figure 2 Two particles in simple shear flow ( $\dot{\gamma}=1$ ): (from the left)  $t=0, 1.95, 3.40, 4.80,$  and  $6.75$ . The velocity on the domain boundary is specified by a simple shear flow.

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

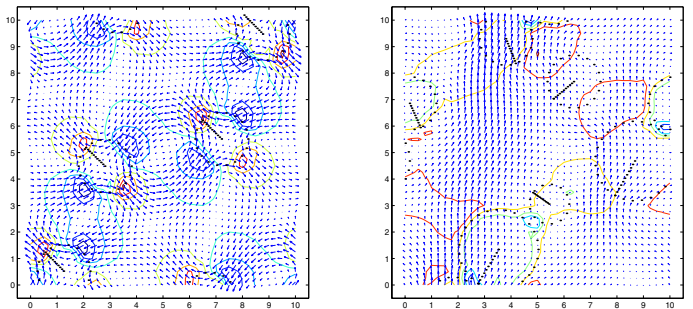


Figure 3 The fluctuation velocity and pressure distributions: Four symmetric particles (left); six random particles (right).

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

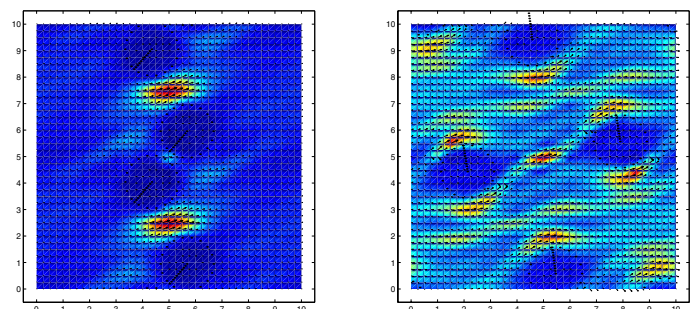


Figure 4 The magnitude and direction of the maximum principal stress relative to  $G$ . The effect of aligning particles (left):  $t\dot{\gamma} = 4, De = 1$  [ $max.=22.3$ ]; the effect of departing particles (right):  $t\dot{\gamma} = 8.5, De = 5$ . [ $max.=309.5$ ].

## 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.