Simulation of particle migration in viscoelastic fluids using the extended finite element method

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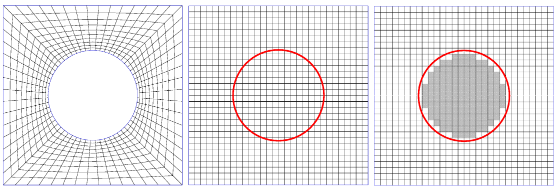
Introduction

In fluid-particle systems, the apparent properties of suspensions depend on the spatial distribution of particles. Hence, we want to know the evolution of multi-particle structures and the mechanisms that induce particle migration, especially in polymeric fluids. We aim to develop an eXtended Finite Element Method (XFEM) for the simulation of the flow of viscoelastic fluids with suspended particles.

Numerical Methods

We incorporate an extended finite element method (XFEM) that can decouple the fluid and particle domains completely to capture discontinuities at the interface using a regular (not boundary-fitted) mesh for the whole computational domain including both the fluid and the particle (Fig. 1(c)).



(a) Boundary-fitted mesh (b) Fictitious Domain Method (c) eXtended Finite Element Method

Figure. 1: Comparison of meshes for different numerical methods.

In the XFEM, the approximation space can be written as

$$V = \sum \phi_i(\boldsymbol{x}) H(s) a_i, \quad \text{for all } \boldsymbol{x} \text{ in the domain,}$$

where a_i are degrees of freedom, ϕ_i are shape functions and $H(s)$ is a Heaviside function defined by a scalar level set function s. The XFEM enrichment scheme is shown in Fig. 2 [1].

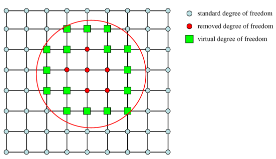


Figure. 2: The XFEM enrichment for a fluid-particle system.

For moving particles, field variables at the previous time can be undefined near the particle boundary. To overcome this problem, we incorporate a temporary ALE scheme as shown in Fig. 3.

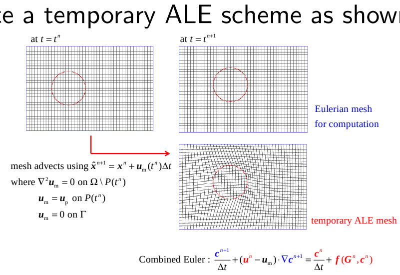


Figure. 3: Temporary ALE scheme using semi-implicit Euler.

Results

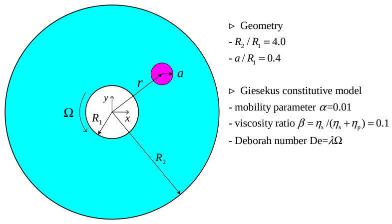


Figure. 4: Schematic description of a rotating Couette flow.

We consider the motion of a freely suspended particle in rotating Couette flow of a viscoelastic fluid (Fig. 4). The radial migration of a particle released at different initial positions for De=1.0 is shown in Fig. 5. The particle migrates to a stabilized radial position near the outer cylinder regardless of its initial position. As the Deborah number increases, the rate of migration increases, and the stabilized radial position of the particle shifts toward the outer cylinder (Fig. 6).

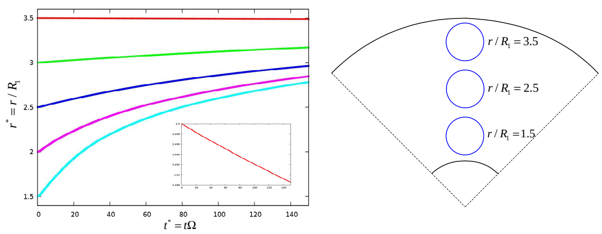
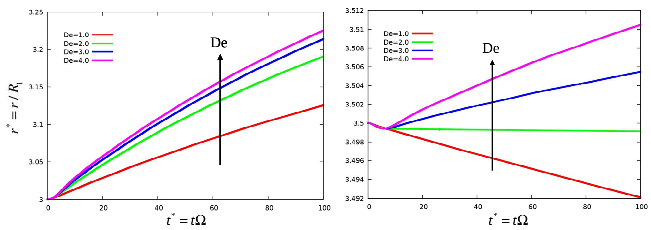


Figure. 5: Radial position of a particle released at different initial positions for De=1.0.



(a) $r_0^* = 3.0$ (b) $r_0^* = 3.5$

Figure. 6: The effect of Deborah number on particle migration.

Conclusions

- An extended finite element method has been developed for the simulation of viscoelastic particulate flows.
- We find a stabilized radial particle position in rotating Couette flow for a given Deborah number.
- With increasing Deborah number, the rate of migration increases, and the stabilized radial position shifts toward the outer cylinder.

References:

[1] Y.J. Choi et al., *International Journal for Numerical Methods in Engineering*, submitted (2009)