NON-BROWNIAN SUSPENSIONS IN PRESSURE-DRIVEN FLOW: NUMERICAL SIMULATIONS WITH FRAME-INVARIANT SUB-GRID CORRECTIONS

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INTRODUCTION

Significant progress in the understanding of the rheology of non-Brownian suspensions has been made during the last decade [1], particularly thanks to the consideration of direct interactions between particles [2,3,4]. Discrete simulations that take into account both these direct interactions and the hydrodynamic ones have played an important role. However, many fundamental questions are still open, often involving heterogeneous flows characterized by a spatially variable volume fraction and shear rate. The simulation of this type of flow requires special treatment.

METHOD

We use the Fictitious Domain Method (FDM) implemented in the OpenFOAM toolbox [5]. In this particle-scale approach, the mesh is Cartesian, regular and fixed, and the Navier-Stokes equations are solved over the whole simulation domain. A specific force density is applied in order to impose the rigidity of the particles. When two particles move at a small distance from each other, a lubrication flow occurs. If the inter-particle distance is smaller than the mesh grid size, this flow cannot be calculated by the solver and sub-grid corrections must therefore be introduced to fully take into account the missing forces and stresses. Classically, the sub-grid corrections are implemented for a linear flow and involve the particle velocity relative to the ambient flow and the local strain rate [2]. In the case of a heterogeneous flow, this formulation is no longer suitable as it requires the local strain rate to be evaluated at each position, at the cost of significant practical problems. We propose a new formulation for which we can remove the terms involving the ambient flow, making it possible to express the stresses on the particles only in terms of a function of the particles velocities, while maintaining the frame-indifference of this relation [5].

RESULTS

Using this new formulation for the sub-grid corrections, we present simulation results of frictional suspensions in a plane Poiseuille flow, investigating different values of the volume fraction. As observed in earlier experimental and numerical works [6,7,8], shear-induced particle migration toward the center of the channel is observed, resulting in a variable volume fraction profile and a blunted velocity profile across the channel (see Figure 1). The results are compared to a modified version of the Suspension Balance Model (SBM) [9,10]. Finally, a detailed local balance of the contact and hydrodynamic stresses, including the fluid pressure, is performed.

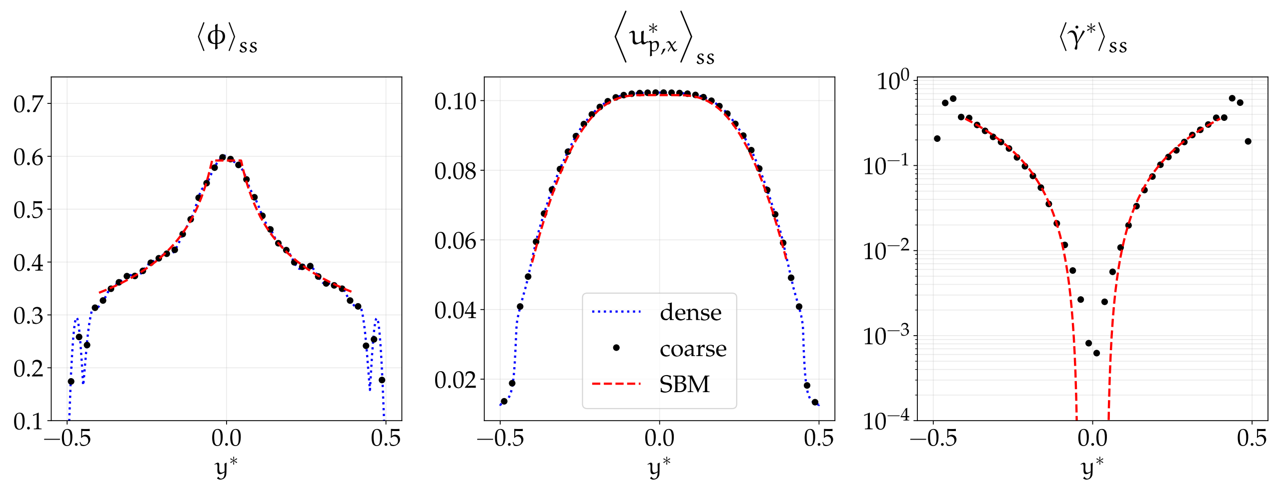

Figure 1: Steady-state results for $\phi_0 = 0.40$ and comparison with a modified version of the SBM. Coarsely- and densely-discretized profiles across the channel ($y^* = y/L$, being y the direction of the gradient of the velocity, and L the channel width): (left) volume fraction, (center) particle velocity, and (right) shear rate.

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