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Multiscale modeling in drilling fluids: interactions between cuttings and nanoparticles

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Introduction

Drilling fluids are employed during operations to drill oil and natural gas wells, geothermal wells, or for simpler water wells. They carry out a variety of functions during the drilling operations: cooling and cleaning of drilling machineries, transport of cuttings from downhole while maintaining suspensions during pauses, prevention of formation fluid influx into the wellbore and more. In these operations, the rheological characteristics of drilling fluids play a critical role. Drilling fluids are complex fluids composed typically of more than one type of solid phase and one or more liquid phases (water or water and oil). In the case of single liquid medium, the rheology is principally controlled by the interactions between the different constituents present in the system. The complexity principally lies on the large gamma of particle dimensions (from 10^{-9} to 10^{-2} m) present in such systems which, interacting both during flow and at rest, contribute to the overall rheological response and consequently, on the performance of drilling fluids. In this year and half, we have been working thanks to the support of ACS – Petroleum Research Fund to develop the experimental and modeling tools to probe and understand the dynamics of micro and nanoparticles interacting with larger macroscale particles.

Completed Tasks

- A small angle light scattering (SALS) home-made setup coupled with a flow through channel and syringe pump has been designed, completed and calibrated. See Figure 1.
- A CFD-DEM simulation using the immersed boundary method for settling problem in a viscoelastic fluid has been developed and implemented. Manuscript is currently under review.
- A continuum model to describe the orientation field of nanoparticles interacting with a cutting has been completed (paper titled "Settling dynamics of two spheres in a suspension of Brownian rods" published in Physics of Fluids).

Ongoing Tasks

- The SALS setup is being utilized to obtain measurements of nanoclay suspensions under the effect of an external 2D flow field. Effect of pH, salt and nanoparticle concentration are being quantified.
- Quantification of the flow around an obstacle (cutting) and microstructural analysis of the orientation state of the system.
- Design, fabrication and testing of a settling setup with moving stage for visualization of microstructures in the proximity of the settling particles.

Results

The results that are presented in this section are the results of one year and half of research. An MSc and MEng student have been working on this project from Jan 2019 while a PhD student joined the group in July 2019. We describe below first the modelling results (MSc and MEng students) and later the experimental results obtained (PhD student).
On the modeling side, two approaches have been developed to study the interactions between particles of different length scales.
The first approach consisted in a fully immersed boundary method. The fluid was modelled by an Oldroyd-B model which has been shown to correctly describe he rheological properties of various polymeric solutions. A full study has been conducted on the effect of walls confinement. One of the major finding was the negative wake phenomena (direction of the velocity direction inversion in the wake of the particle) can be tuned by modifying the confinement of the walls of the channel. An illustrative example is reported in figure 2 where a solution with a Weissenberg number of 10 is modelled and the negative wake is shown to fluctuate in time as the particle settles. Moreover, a region of high vorticity is also generated even if the flow is in the low Reynolds number regime. The negative wake has important consequences in applications where hydrodynamic interactions between particles could avoid the formation of clusters. A publication has been submitted on this work to the Journal of Non-Newtonian Fluid Mechanics.

A second set of theoretical investigations were implemented using a continuum model to capture the effect of orientation in the case of anisotropic nanoparticles (such as disks and rods). Here hydrodynamic interactions between two non-Brownian particles settling along the centerline was studied. The presence of Brownian rods and their orientation field during settling of the non-Brownian particles caused an effective repulsive force between the settling particles that increases in magnitude with increasing of rotational Peclet number and lowering of the initial separation between the non-Brownian spheres. These results are relevant in application since effective attractive interactions are often present in polymeric solutions and the addition of anisotropic nanoparticles could enable an easy way to avoid formation of clusters that are often dangerous for operations.

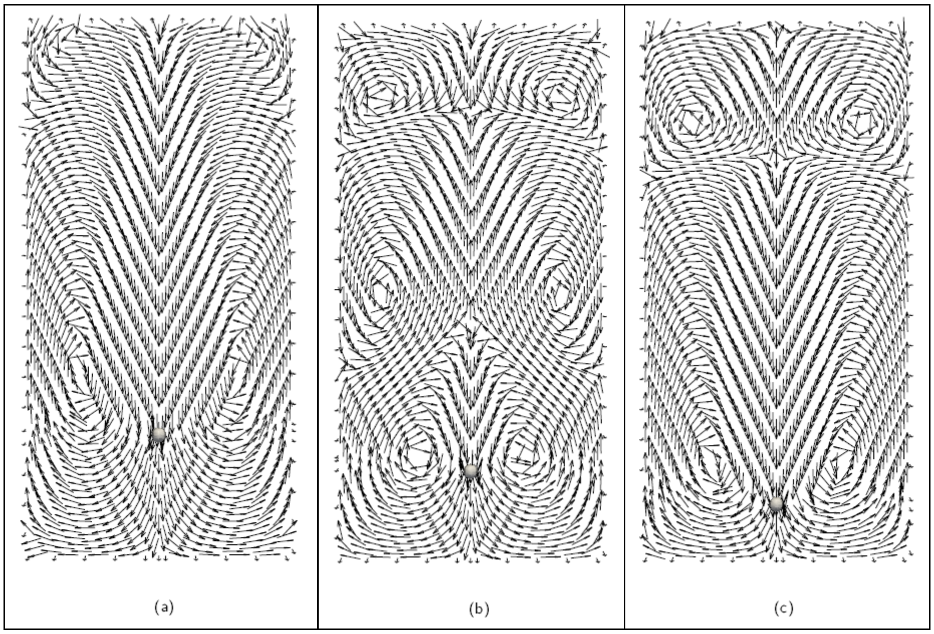

Figure 1 Fluid velocity vectors for a domain W=20D and Wi=10 for an Oldroyd-B fluid applying a CFD-DEM approach. (a) t=0.3 s;(b) t=0.6 s and (c) t=0.9 s.

Experimentally, the design, building and calibration of the home-made small angle light scattering setup has been completed. A picture of the setup is shown in Figure 2 (top left panel). A right-angle setup, rather than a linear setup, it utilized to facilitate the implementation of a moving stage in the next twelve months. In figures 2a-c is shown a study conducted on a suspension of microrods in a capillary flow. A square channel coupled with a micro-syringe pump was used to apply an external and controlled flow field. The scattering pattern moves from isotropic (figure 2a) to elongated (figure 2 b and c) as the externally applied shear rate is increased. The elongation of the scattering pattern represents an alignment in the microstructure of the suspensions of the micro-rods. The initial isotropic pattern is instead representative of an isotropic orientation state induced by the Brownian motion of the particles in the absence of a flow field.

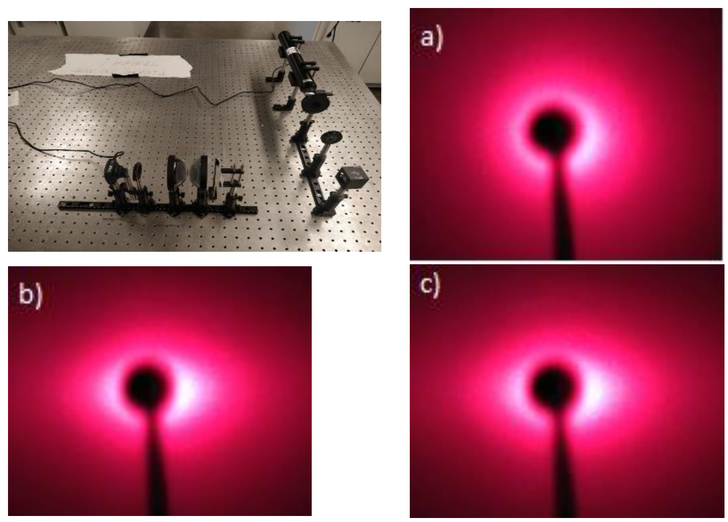

Figure 2 Home-made small angle light scattering device on an antivibration table. a) SALS pattern of a suspension of microrods at rest, b) at shear rate of 1.2 $s^{-1}$and c) at shear rate of 2.7 s^{-1}.

Impact on students and PI

The support of the Petroleum Research Fund has enabled this research program, leading already to several presentations and a published manuscript. During the past year and half, the team was formed. The team is composed of an experimental PhD student and an MSc and MEng student on to the modeling part of the work. The two Master students have earned authorship on two manuscripts (one submitted and the other already published in top journals in the field of fluid mechanics). This level of productivity would be impossible without the PRF funding. Moreover, the MEng student was able to obtain a PhD position in Western Ontario and the prestigious Vanier Scholarship, in part due to experience obtained on this project. The PhD student has learned important experimental skills designing and building the light scattering setup. Moreover, the PhD student has developed skills in colloidal science and rheology as well as think critically, collaborate in a scientific environment and communicate scientific results.

The PIs productivity has also been increased by the support of the Petroleum Research Fund. This funding allowed the PIs to develop a new experimental methodology to probe microstructures during settling that will have an impact in leveraging future funding opportunities. Moreover, Dr. Natale will present the PRF results at the next Society of Rheology meeting in October 2019 (Abstract accepted).