A numerical study of the flow of fluid mud in a cylinder and vane rheometer

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1. Introduction

Fluid mud is a dense cohesive suspension and categorized as a non-Newtonian fluid with time-dependent behaviour. The equilibrium flow curve and structural kinetics parameters describe the fluid mudflow rheology. The former articulates non-Newtonian behavior, while the latter is about thixotropy. Experiments with a concentric cylinder rheometer configuration are used to obtain the mud rheology parameters. This rheometer is based on the principle of rotating Couette flow, wherein the outer cylinder is stationary and the inner cylinder is rotating.
However, the gap is usually too narrow and does not guarantee a linear flow profile.

2. Vane rheometry

The cylinder rheometer may have the disadvantage of forming a thin water layer next to the rotating cylinder due to the structural breakdown of soil when shear is applied, thereby causing a slip effect on the rotating cylinder surface. Therefore, to minimize slip, a vane spindle is considered as an alternative to the inner cylinder. While the vane is rotating, the mud between the vane blades gets trapped and its volume acts as a virtual cylinder. Thus, the vane configuration is assumed to be equivalent to the cylinder configuration.
However, at low rotation speeds, slip may still occur in suspensions due to network collapse when the thickness of the shear layer has become too small, i.e. < 30 particle diameters (Barnes et al., 1989), whereas the typical microfloc size is of the order 10 µm. This is indeed observed in experimental data and we discard them after computing the shear layer thickness according (Toorman, 1994).

2.1 2D simulation of flow in a vane rheometer

To understand and further validate this hypothesis, the present study aims to perform a numerical investigation by modelling the rheological experiments in a two-dimensional horizontal plane in CFD using OpenFOAM as a tool. The constitutive equations to solve and setup the numerical rheology experiments includes the non-Newtonian Navier-Stokes equation and the structural kinetics equation. Furthermore, the results of equilibrium at a certain rotation speed are compared to the analytical solution for a Bingham fluid to validate the model.

2.2 3D simulation

In the next step, a full 3D simulation will be carried out in order to evaluate the contributions to the total torque measurement of the top and bottom of the cylinder as well as the submerged part of the axis. This result will be used to validate the empirical end effect correction used so far (Toorman, 1995) and to fine-tune the calibration of the conversion factor from torque to shear stress.

2.3 Experiments

Experiments are carried out with the Anton-Paar MCR301 rheometer in the sedimentological laboratory of Flanders Hydraulics Research (Antwerp, Belgium). The standard configuration is changed to a wide gap setting (Figure 1). An iterative method has to be applied to process the data (Toorman, 1994). Self-made extensions can be mounted on the blades to increase the diameter. Large diameters reduce the risk of slip formation at low rotation speeds as the shear layer thickness is proportional to the vane radius. Tests on the same sample with three different diameters indeed yield the same equilibrium flow curve and confirm several assumptions made.
The CFD model will be used to increase the accuracy of the data processing and the resulting rheological parameters. The time-dependent behaviour however shows several deviations from the ideal theoretical model and requires further research.

Figure 1: Wide gap vane rheometer setup.

3. Conclusions

Different steps have been undertaken to improve the data processing and interpretation of vane rheometry tests on fluid mud. An important tool for this purpose is the use of CFD. Once the work on the equilibrium flow curve is completed, we will further investigate the thixotropic behaviour in search of proper closure relationships for break-up and restructuring of the clay matrix.

Acknowledgments

This work is funded by the Flemish Science Foundation through the FWO project G0D5319N,.

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