Flow field data processing for the oscillating conical bob rotational rheometer

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Rotational bulk rheometers may be used as interfacial shear rheometers (ISR) by supplementing them with proper accessories that allow one to impose a shear on a fluid-fluid interface in a controlled manner. Actually, most rotational rheometer manufacturers sell fixtures for interfacial shear rheometry measurements, such as the bicone, the Du Nouy ring, or the double-wall ring (DWR) fixtures.

However, recovering the proper values of the dynamic moduli from the torque and angular displacement data is far from trivial due to the coupling between the subphase and the interfacial flow fields. Moreover, a low viscosity fluid is usually chosen for the subphase, and the low interfacial pressure regimes usually have low interfacial viscosity. Therefore, fluid inertia very often comes into play, which results in nonuniform shearing profiles both at the interface and the subphase, further complicating then the data analysis.

Successful strategies to cope with these problems have been devised for the DWR interfacial rheometer [1] and the magnetic rod ISR [2, 3, 4, 5, 6]. The basic ingredients of the strategy are: (i) to find numerically the flow fields at, both, the subphase and the interface, (ii) to separately calculate the drags exerted on the probe by the interface and the subphase, taking into account the flow field solutions obtained, and (iii) to use the equation of the probe dynamics (the rotor in the DWR and the rod in the magnetic rod ISR) to build up an iterative scheme that, upon convergence, allows to recover the proper values of the complex Boussinesq number $\mathrm{Bo}^* = \eta_s^*/L\eta$, where L is a characteristic length scale related to the probe size. Then, the viscoelasticity data can be recovered directly solving for η_s^* in the previous expression. Such an approach includes, and allows to properly account for, the inertia effects corresponding to the probe, the subphase, and the interface, yielding a much better separation of the elastic and viscous components of the interface response.

We will illustrate how such a scheme can be implemented in the case of the old bicone bob rotational rheometer configuration. First, we assume that the interface is flat and horizontal, that the flow is axisymmetric, and that the respective rheological properties of the subphase and the interface can be described by a newtonian viscosity η, and a complex viscosity $\eta_s^* = \eta_s' - i\eta_s''$, which are uniform across the whole sample. Then we are left with a simplified version of the Navier-Stokes equations regarding only the azimuthal component of the velocity field. The boundary conditions are the Boussinesq-Scriven condition for the stress field at the interface, and no-slip elsewhere. The Navier-Stokes equation is solved by a second order centered differences method. An ansatz is made for the steady oscillatory rotational motion of the rotor+fixture assembly, assuming that the torque on the rotor and its angular displacement have the same frequency and a constant phase lag. Such an ansatz allows us to write down the torque balance equation in terms of the drags due to the interface and the subphase, the rotor inertia term, and a complex torque/angle amplitude ratio. Solving for the complex Boussinesq number in the torque balance equation allows us to devise an iterative scheme that, starting from a suitable seed for Bo^*, obtains the flow field solutions at the interface and subphase, uses the flow field to compute the hydrodynamic drags, and obtains a new corrected value for Bo^* out of the torque balance equation. Iterating such a scheme convergence is achieved and the value of Bo^* that accounts for the complex torque/angle amplitude ratio is found.

We will illustrate the performance of this scheme through, both, extensive numerical benchmarking and dynamic measurements with a rotational rheometer and a homemade bicone fixture [7] on several interfacial experimental systems.

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