Interaction between a falling sphere and the structure of a non-newtonian yield-stress fluid

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Abstract

Although the falling of an object through a Newtonian fluid is a classical and well-known problem in fluid mechanics where it is a way to measure the viscosity of the fluid, the same problem for Non-Newtonian fluids is less known due to their various rheological and structural proprieties. For the same reason, within the framework of an elasto-viscoplastic Earth's deep interior, complex rheologies can influence, for instance, shape and dimension of thermal plumes in the mantle (Davaille et al., 2018), the nature (e.g. fracturation, viscous flow) and morphology (fractures, dikes, diapirs) of intrusions in the lithosphere (e.g. Sumita and Ota, 2011), the time-evolution of fracture filling (e.g. Ledevin et al., 2015), or the settling of crystals and nodules in a magma chamber (e.g. Moitra and Gonnermann, 2015) or of iron drops in a partially molten magma ocean (e.g. Wacheul et al., 2014).

Here, we study the free-fall of spheres of different diameters (between 3 and 30 mm-diameter) and densities (between 2000 and 8000 kg/m^3) in mixtures of aqueous superabsorbent polymers. In water, these polymer powder grains swell up to 200 times and form gel grains whose size can be controlled by controlling the size of the initial powder. The typical size of the gel grains was varied between 1 and 8 mm, so that it becomes comparable to the size of the falling spheres. Moreover, the effective rheology of the gel mixtures is expected to combine viscous, elastic and plastic aspects.

We observe three different regimes. (1) A steady-state motion with a constant terminal velocity, as in Newtonian fluids, is reached only for high density contrast between sphere and fluid and for spheres that are large enough compared with gel grain sizes. (2) A no-motion regime appears when spheres are not buoyant enough to overcome the yield stress of the fluid. (3) In between, a "stick-slip" regime develops where spheres have an irregular vertical motion and horizontal oscillations due to the coupling between the flow and the fluid structure.

References:

Davaille, A., Carrez, P., & Cordier, P. (2018). Fat plumes may reflect the complex rheology of the lower mantle. *Geophysical Research Letters*, *45*. https://doi.org/10.1002/2017GL076575.

Ledevin, M., N. Arndt, A. Davaille, R. Ledevin, and A. Simionovici (2015) The rheological behaviour of fracture-filling cherts: example of Barite Valley dikes, Barberton Greenstone Belt, South Africa, *Solid Earth*, 6, 253-269, www.solid-earth.net/6/253/2015/ doi:10.5194/se-6-253-2015.

Moitra, P., and H. M. Gonnermann (2015), Effects of crystal shape- and size-modality on magma rheology, *Geochem. Geophys. Geosyst*., 16, 1–26, doi:10.1002/2014GC005554.

Sumita, I., Ota, Y. (2011) Experiments on buoyancy-driven crack around the brittle-ductile transition, *Earth Planet. Sci. Lett*., 304, 337-346.

Wacheul, J. B., Le Bars, M., Monteux, J., & Aurnou, J. M. (2014). Laboratory experiments on the breakup of liquid metal diapirs. *Earth and Planetary Science Letters*, *403*, 236-245.