Effective viscosity of microswimmer suspensions
S Rafaï, L Jibuti, P Peyla; `arXiv:0909.4193v1`
Recommended and with a commentary by Sriram Ramaswamy, IISc, Bangalore

Collections of active particles, such as bacterial suspensions or active cytoskeletal extracts, are forms of nonequilibrium matter *par excellence*. They are driven internally at the scale of each particle, and in a direction set by the orientation of the particle. The hydrodynamic laws governing the mechanics of such living matter [1] should apply on any scale from subcellular to fish shoals. However, apart from recent microrheological studies [2], experiments on swimming organisms [3] have tended to focus on spatial patterns and flow fields, and mechanical response has been studied mainly in cytoskeletal extracts [4]. The subject of this Commentary makes an important addition to the programme of treating collections of live organisms as a material, by showing that the mere fact that they are swimming contributes to the macroscopically measured viscosity of the system.

Rafaï *et al.* study suspensions of chlamydomonas reinhardtii, a motile spheroidal alga with two front-mounted flagellar arms that pull fluid backwards, propelling the cell at about 40 μm/s. The leading associated force density is a contractile force dipole. Thermal Brownian of the 10 μm cell body is altogether negligible, although that of the slender flagella could play a role, especially for dead cells. Microscopic observation shows the cells are motile, diffusing on long timescales for predominantly hydrodynamic reasons (S Rafaï, personal communication). The mean swimming speed varies inversely with viscosity, consistent with a constant force density associated with each cell. The central result of the paper is that the macroscopic viscosity of a suspension of living chlamydomonas, measured in a conventional rheometer, is substantially larger than that of one composed of dead chlamydomonas at the same volume fraction ϕ. Suspensions of dead cells show the same viscosity behaviour as passive non-Brownian beads. The fractional excess viscosities of live-cell suspensions, relative to the solvent, grow as 4.5ϕ (much faster than Einstein's [5] 2.5ϕ) at small ϕ and more steeply at large ϕ, shear thinning appreciably for shear-rates of a few s^{-1}. The excess viscosity relative to dead cells reaches a factor of 2 for $\phi = 15\%$. Oddly, dead cells tumbled in the plane of the shear flow, while live cells did not.

The presence of self-propelling activity within a fluid is thus seen to modulate its macroscopic mechanical properties. Activity, moreover, is found to produce a *larger* stress for a given macroscopic flow-rate – whereas one might have expected self-generated internal flows to promote fluidity. These observations confirm – gratifyingly – the rheological predictions of coarse-grained active hydrodynamics [6], in which flow-aligning contractile filaments pull back on the very flow that aligned them. Less direct measurements [7],

which appeared after this Commentary was essentially complete, show that *tensile* swimming organisms *reduce* viscosity, again confirming [6]. The experiment of Rafaï *et al.* nonetheless presents a puzzle – why should swimmers and non-swimmers with the same nominal aspect ratio and at the same volume fraction respond so differently in a flow? I suggest this is because live chlamydomonas, because of systematic flagellar beating, act like particles with a much larger effective hydrodynamic aspect ratio than their round bodies would suggest, and thus show substantial alignment in flow. This is consistent with the remark in the paper about drag due to the filaments. Dead chlamydomonas are effectively spherical and hence tumble.

The widely differing shear response of live and dead cells of the same apparent geometry contains an important lesson for theoreticians. The flow-orientation coupling and the orientational relaxation time, which determine the shear response, must themselves depend on the strength of activity, thus limiting the predictive power of coarse-grained hydrodynamic models. This is no worse, however, than our ignorance of the temperature dependence of coefficients in Ginzburg-Landau models at thermal equilibrium, only now we have one more control parameter to worry about, namely, activity.

References

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