Life at high viscosity

Swimming is a useful skill for many organisms, from whales to bacteria. Large animals generally push water backwards, and thus move forward because of momentum conservation. For bacteria, however, this does not work because they experience high viscosity. Instead, evolution has some of them equipped with rotating flagella at their rear end. They use these to swim in large swarms that can exhibit complex correlated movements, similar to birds. Nutrients, on the other hand, are passive tracers. As such, they are advected in the fluid flow of the bacteria and diffuse more than they would, were it only for random motions.

The Reynolds number Re is a dimensionless number that expresses the ratio of inertial forces (resistance to change of motion) to viscous ("sticky") forces of a swimmer in a fluid. Knowing the length l of a swimmer, the fluid density ρ, the fluid velocity U, and the viscosity μ, the Reynolds number can be computed via $Re = \rho U l/\mu$. Human swimmers in a lake would have $Re \sim 10^6$ and this means that they can comfortable glide a few meters after a single breast stroke. E. coli bacteria with $l \sim 2\,\mu\mathrm{m}$ in the same lake would have $Re \sim 10^{-5}$ - 100 billion times smaller! This means that they would stop moving immediately after they stopped rotating their flagella, but this they almost never do. However, they do change direction occasionally such that their individual paths look much like that of a drunken sailor - they "run and tumble".

The flagella of course stir up the water around them and the swimmers can feel each others' fluid fields. It is via this connection that swimmers, if there is enough of them, start to swim in a correlated fashion. Also, in the total resulting fluid field, nutrients diffuse more quickly than they would by thermal diffusion alone (random motion resulting from their collision with the fluid's molecules). A point-like particle would simply have the same velocity as the fluid at its position, and would therefore explore much more of the space than if it were in still water. As a result, nutrients can for example cluster while the bacteria move around them, see Fig. 1.

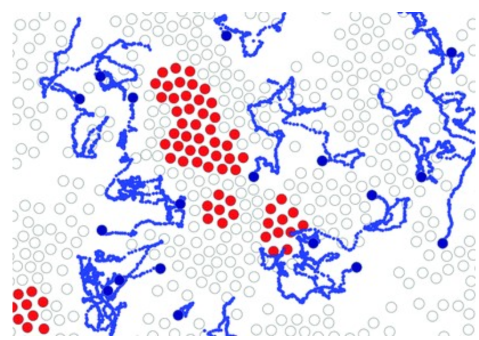

Figure 1: Passive particles (red) cluster as a result from the flow field of active particles (blue). Adapted from *Formation compression and surface melting of colloidal clusters by active particles* by F. Kümmel et al., 2015, Soft Matter.

When the nutrients cannot be considered to be point like anymore, another term must be added to their velocity. This term is proportional to the square of their radius and the change of the velocity field where they are at. In this thesis, this correction was included in large scale simulations to see if it can explain the diffusion seen in experiments. These showed that in some suspensions there is a tracer size that maximizes diffusion. One conclusion from the simulations is that the diffusion is smaller the bigger the passive particle, and that some other effect probably explains the experimental evidence. One reason why it is important to continue this research is because of possible applications in drug delivery using artificial microswimmers. But for that to become reality, many more simulations still need to be run.

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