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Biased swimming cells do not disperse in pipes as tracers: a population model based on microscale behaviour

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There is much current interest in modelling suspensions of algae and other micro-organisms for biotechnological exploitation, and many bioreactors are of tubular design. Using generalized Taylor dispersion theory, we develop a population-level swimming-advection-diffusion model for suspensions of micro-organisms in a vertical pipe flow. In particular, a combination of gravitational and viscous torques acting on individual cells can affect their swimming behaviour, which is termed gyrotaxis. This typically leads to local cell drift and diffusion in a suspension of cells. In a flow in a pipe, small amounts of radial drift across streamlines can have a major impact on the effective axial drift and diffusion of the cells. We present a Galerkin method to calculate the local mean swimming velocity and diffusion tensor based on local shear for arbitrary flow rates. This method is validated with asymptotic results obtained in the limits of weak and strong shear. We solve the resultant swimming-advection-diffusion equation using numerical methods for the case of imposed Poiseuille flow and investigate how the flow modifies the dispersion of active swimmers from that of passive scalars. We establish that generalized Taylor dispersion theory predicts an enhancement of gyrotactic focussing in pipe flow with increasing shear strength, in contrast to earlier models. We also show that biased swimming cells may behave very differently to passive tracers, drifting axially at up to twice the rate and diffusing much less.

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