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Shear-induced enhancement of solute mass transport in flows of concentrated suspensions through microchannels

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The transport of a solute carried in the suspending fluid of a particulate suspension flowing in sub-millimeter-sized conduits is an important problem that has relevance in several different fields: metabolite exchange between blood and tissues, design of dialysis machines, drilling mud selection, organic and nutrient transport in microbial suspensions in anaerobic reactors, etc. A mechanism of enhancement of the mass transfer rate of solutes in flowing, concentrated suspensions that is commonly considered in the literature is the self-diffusion of particles arising from shear-induced interparticle interactions. But recently, it was demonstrated by Zrehen and Ramachandran [Phys. Rev. Lett. 110, 018306 (2013)] that the pressure-driven flow of suspensions through non-axisymmetric geometries is not unidirectional; the main flow is accompanied by secondary currents within the cross-section of the conduit, driven by second normal stress differences. This secondary convection, which is more likely to be manifested in microchannels, represents a new advective mechanism for mass transfer of solutes normal to the primary streamlines in flowing suspensions. For small particle sizes, the enhancement of solute diffusivity by shear-induced self-diffusion is weak. However, the magnitude of the secondary currents is unaffected by particle size. Thus, for suspensions with particles much smaller than the conduit size, secondary convection, and not shear-induced self-diffusion, can be the dominant mechanism for shear-induced enhancement of mass transfer. In the limit where shear-induced self-diffusion is the dominant diffusive mode of mass transfer, secondary convection can provide additional enhancement of mass transfer over that due to self-diffusion, doubling the augmentation in some geometries. The relevance of this new mechanism of mass transfer is in the improved modeling of the transport of solutes for situations where the dominant mass transfer resistance is in the suspension phase. This mechanism also suggests the possibility of exploiting conduit geometry to improve the mass transfer rate of solutes.

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