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Diffusion in Granular Mixtures

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Granular materials, composed of discrete macroscopic particles such as sand, are ubiquitous in both natural and industrial contexts. These materials exhibit unique mechanical and transport properties due to their discrete nature and interparticle interactions through contact forces. Transport of fine particles within granular media plays a central role in processes ranging from chute flows and silos to geophysical flows and powder handling[1]. In such systems, the interplay of segregation[2], confinement[3], and diffusion[4] leads to complex dynamics that are not fully captured by existing models. A particular challenge arises at large particle size ratios, where fines can navigate void networks within the granular bed, resulting in transport mechanisms distinct from those in monodisperse or low size ratio systems[5].

We investigate fine particle diffusion across varying fine-particle concentrations using large-scale Discrete Element Method (DEM) simulations and find that the diffusion coefficient decreases with increasing concentration and size ratio. Drawing inspiration from kinetic theory, we develop a scaling framework that links particle concentration, size ratio, and bed geometry to diffusion behavior in dense granular beds. The framework has broad relevance for both industrial applications, such as mixers, separators, and hoppers, and fundamental studies of diffusion in heterogeneous media.

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