Segregation dynamics in granular suspensions

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The comprehension of the physical mechanisms involved in segregation is likely one of the most challenging problems in the realm of granular mixtures. Segregation has garnered significant attention in the context of dry granular mixtures as it constitutes a nice and interesting application stemming from the derivation of the diffusion transport coefficients. Among the various segregation phenomena, the Brazil-nut effect (BNE) stands out as a prominent example of size-based segregation in vertically vibrated mixtures. In the BNE, a relatively large particle, known as the intruder, tends to ascend to the uppermost region of the sample against the force of gravity. Conversely, alternative experimental investigations have reported a contrasting phenomenon of reverse buoyancy known as the reverse Brazil-nut effect (RBNE), wherein the intruder may sink to the bottom of the container under specific conditions. In this work, we want to study the segregation induced by a thermal gradient and/or gravity. We assume with this aim that gravity and the thermal gradient point in parallel directions (i.e., the bottom plate is hotter than the top plate). The main target is to assess the impact of the interstitial gas surrounding the particles on the segregation criterion previously obtained in the absence of the gas phase [1].

We consider a set of intruders immersed in a granular gas of smooth inelastic hard spheres (grains). The starting point of the present work is the (inelastic) Enskog-Lorentz kinetic equation. The effect of the interstitial gas on solid particles is accounted for in the kinetic equation through two different terms: (i) a viscous drag force proportional to the particle velocity and (ii) stochastic Langevin-like term defined in terms of the background temperature. To obtain the segregation phase diagrams, the kinetic equation is solved by means of the Chapman–Enskog method conveniently adapted to account for the inelasticity of collisions. The transport coefficients are obtained as the solutions of a set of coupled linear integral equations recently derived for binary granular suspensions with arbitrary concentration [2]. Using those results, we consider here the tracer limit of the linear integral equations obeying the corresponding diffusion transport coefficients.

The main goal of the present work is twofold. Firstly, we aim to solve the aforementioned equations to determine the diffusion transport coefficients up to the second Sonine approximation, which involves considering two terms in the Sonine polynomial expansion of the distribution function. Secondly, we intend to evaluate the accuracy of the Sonine approximations by solving the Enskog equation through the direct simulation Monte Carlo (DSMC) method. We use the Einstein relation to compute the tracer diffusion coefficient as a function of the coefficients of (normal) restitution. Although some deviations between the Sonine approximations are noticeable when the grains possess a greater mass and size compared to the intruders, these discrepancies are smaller than those observed in dry granular systems [3]. Notably, the second Sonine approximation enhances the theoretical predictions of the first Sonine approximation, resulting in excellent agreement with the simulation results.

As an application, we study the segregation dynamics of the mixture. In the absence of gravity, our results (see Fig. 1) show that the effect of the gas phase on segregation is in general significant for large mass and/or diameter ratios. The main effect of the surrounding gas is to increase the size of the RBNE region (intruders attempt to accumulate near the hot plate) with respect to the one observed in the absence of the gas phase. Conversely, in scenarios where segregation is predominantly influenced by gravity (namely, when thermal gradient can be neglected) the phase diagrams with and without gas phase are practically identical. In addition, as for dry granular mixtures, the influence of inelasticity of

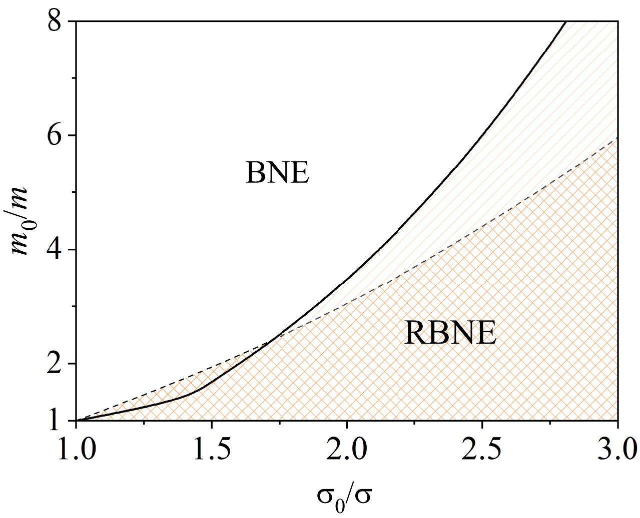

Fig. 1. Segregation phase diagram as a function of the intruder-grain mass (m_0/m) and size (σ_0/σ) ratios. We consider a common coefficient of (normal) restitution ($\alpha = \alpha_0 = 0.8$) in the absence of gravity. The solid line corresponds to the segregation criterion for granular suspensions while the dashed line refers to the one derived for dry granular mixtures.

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[3] V. Garzó, *Granular Gaseous Flows* (Springer Nature, Cham, 2019).