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EGU2019: A critical review of the existing models in granular flows driven by gravity

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ABSTRACT

Models of granular flows generally assume a uniform distribution of the particle diameter. However, this is a gross simplification that is acceptable only in idealised conditions. Thus, a compelling, presently still open issue is to develop reliable models capable of representing two-size mixtures, that would be suitable for real-world cases.

In granular flows involving material different in size, density and geometry, the bulk solid evolves spatially in a non-uniform state, which is called segregation. The largest particles are found at the surface and the smallest at the bottom, as they percolate due to gravity. Segregation causes a different spatial distribution of particles and the recirculation of grains in the avalanche front, and the formation of lateral levees. Our starting point is an accurate literature review of the state of art. Most existing non-dimensional, continuous models for segregation in bidisperse mixtures (see, e.g., Bridgwater, 1994; Savage and Lun, 1988; Gray et al., 2018, and references therein) show a similar structure for the mass-balance equation, that results in an advection-diffusion equation. The two processes that define segregation (kinetic sieving and percolation) are represented in these models by the diffusion and the infiltration coefficient. However, the adopted values for these coefficients vary quite significantly across models, which may indicate that the underlying physics is not entirely understood. With the aim of improving the physical basis of these coefficients, (i) we identify the infiltration coefficient as depending on percolation velocity and particle concentration, and (ii) the diffusion coefficient as a function of the particle diameter and the granular temperature. Unlike in the reviewed models, along with the advection-diffusion equation for mass balance, we introduce the momentum and the kinetic balance equation, depending on the granular temperature.

We want to propose a comparative critical analysis of the models present in the literature to define the infiltration and diffusion processes, the underlying hypotheses and their consequences.

1. AIMS OF THE RESEARCH

Derivation of a mathematical model for segregation in two-dimensional flows (Fig. a, b) of a two sediment fraction mixture, based on:

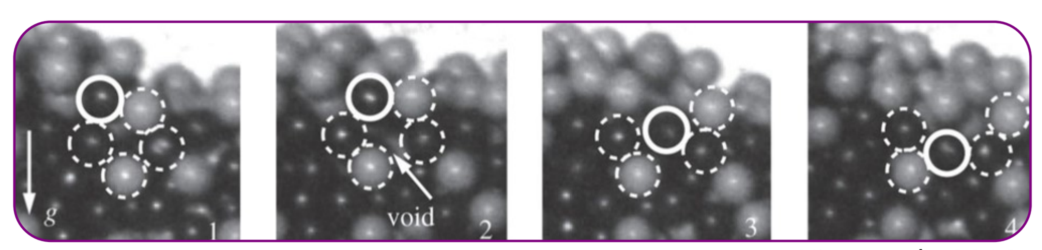
* Analysis of the existing models
* Improvement of physical description
* Laboratory experiments

a) Debris flows

b) Snow avalanches

2. LITERATURE REVIEW

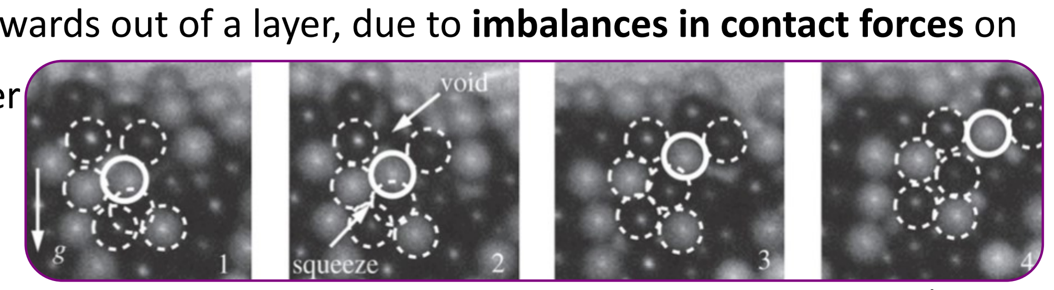
* PHYSICHAL MECHANISMS OF SEGREGATION



Xiao et al., 2016

➡ **percolation**: smaller grains percolate due to **gravity** through the smallest cavities formed by large particles (Drahun & Bridgwater 1983; Savage and Lun, 1988; Ottino & Kahakar, 2000)

➡ **kinetic sieving**: the process by which particles are squeezed upwards out of a layer, due to **imbalances in contact forces** on an individual particle (Middleton, 1970; Drahun & Bridgwater 1983, Gray & Chugunov, 2006)



Xiao et al., 2016

* STATE OF ART

- **Bridgwater, 1983**: first studies on segregation (defined as an impediment in maintaining homogenous mixture) and physical mechanisms of the particles (inter-particle percolation, particle migration, free surface segregation);
- **Savage & Lun, 1983**: definition of kinetic sieving mechanism, physical experiments an random fluctuating sieve model;
- **Atkine & Craine, 1976:** continuum theories approach to the mixtures starting from two ideal gases;
- **Gray & Chugunov, 2006, Thornton & Gray, 2008, Wiederseiner et al., 2011, Gray, 2018, van der Vaart et al., 2018:** starting from water-satured debris flows (Iverson, 1997) and mixtures theories (Trusdell, 1984; Morland, 1992), they define the breaking size-segregation waves by solving the convection-diffusion equation by the method of characteristics: physical based?
- **Jenkins, 1998, Arnarson & Jenkins, 2000, Rognon et al., 2007; Tripathi & Khakhar, 2011, Jenkins & Larcher, 2015**: rheology of binary granular mixture in the dense flow regime using kinetic theories, dissipation energy term?

3. MODEL DEVELOPMENT: SIZE SEGREGTION MODEL FOR A BINRY MIXTURE GRANUAL FLOW

* Parameters definitions: granulometric infiltration and diffusion coefficient:

$$F_y \propto S\,\frac{\partial u_x}{\partial y}\left(1-c_{s,l}\right)$$

percolation length scale; convection velocity scale; concentration of the particles

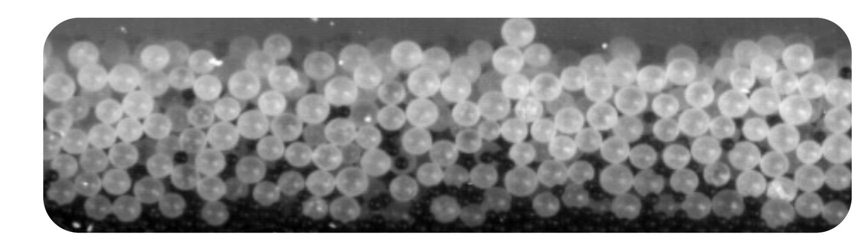
$$D \propto d\, d\,\frac{\partial u_x}{\partial y}$$

particle diameter (diffusion length scale); diffusion (shear rate dependent) velocity scale

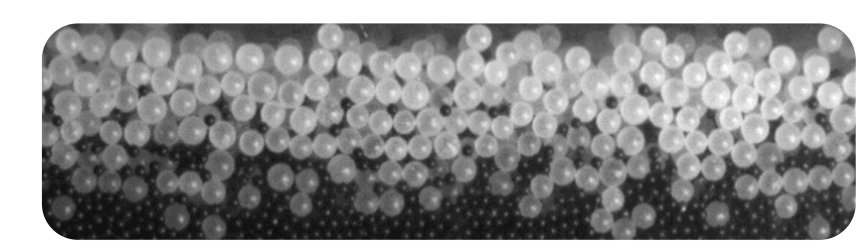
* Mass, momentum and kinetic energy balance equations also depend on the granular temperature of both each class particle and the mixture;

  ➡ granular temperature: measurement of the fluctuations of the velocities of the granular phase, θ= 1/2 <u_i u_i>

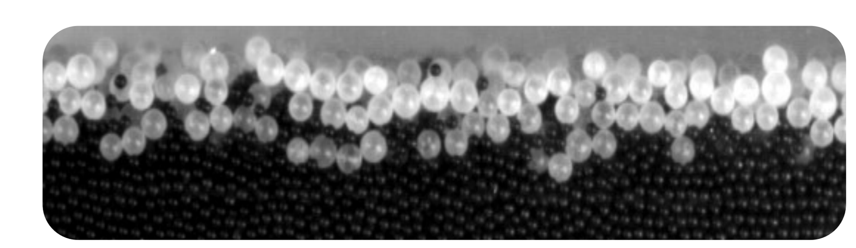
* Closure relations account for the dissipation rate and the interaction force between particles;
* Laboratory experiments with particles different in size (d_1= 0.075 mm, d_2= 1.40 mm);
* Photographic measuring technique for particle tracing;



a) Frame of the flowing of binary mixture in 75% white and 25% black particle concentration;



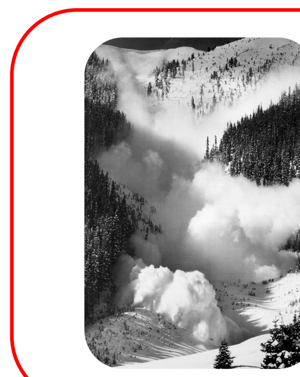
b) Frame of the flowing of binary mixture in 50% white and 50% black particle concentration;



c) Frame of the flowing of binary mixture in 25% white and 75% black particle concentration;

d) Laboratory flume for the preliminary tests and lighting system

4. FUTURE STEPS



➡ 1. Numerical solution of the mathematical model

➡ 2. Model calibration and test against laboratory experiments

➡ 3. Model extension to three fractions

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