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# Study of Geldart's Group A behaviour using the discrete element method simulation

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**Abstract**

Here we report on a study using a simulation of fluidized beds of spherical particles whose size and density place them in Group A of Geldart's classification. The 2D soft-sphere discrete element method simulations use up to 106,400 particles, giving bed dimensions of the order of several centimetres. Simulations have been performed in the absence of any interparticle cohesive force and with an imposed cohesive force equivalent in magnitude to several times the single particle weight.

Homogeneous fluidization is observed for a significant range of gas velocity and minimum bubbling velocity is found to be greater than minimum fluidization velocity, even when there is no interparticle force. This is evidence of true Group A behaviour in the absence of interparticle cohesive force. Smaller particles, further from the boundary between Groups A and B, showed more expansion before the start of bubbling and a higher ratio of minimum bubbling velocity to minimum fluidization velocity.


*Keywords:* DEM simulation; Geldart's Group A behaviour; Homogeneous fluidization; Interparticle force

## 1. Introduction

Based on fluidization characteristics, Geldart [1] classified powders into four different groups. A fluidized bed of Group B powders does not show any homogeneous fluidization and starts bubbling as soon as the minimum fluidization velocity is reached, whereas a bed of Group A powder shows a distinct region of homogeneous fluidization with significant bed expansion before the start of bubbling. According to the fluidized bed stability theory proposed by Jackson [2], the existence of homogeneous fluidization can only be explained by the inclusion of an extra factor in the equation of motion for the particulate phase. This factor, which is in addition to the drag and inertia, is termed as particulate pressure. Wallis [3] used the concept of bed elasticity to explain the homogeneous fluidization. Verloop and Heertjes [4], Rietema et al. [5–7] and Foscolo and Gibilaro [8] built up their concepts of homogeneous fluidization on the basis of Wallis's idea. However, there are differences on the origin of the bed elasticity. According to Rietema et al. the bed elasticity is due to the existence of interparticle forces among the bed particles. Whereas, Verloop and Heertjes and Foscolo and Gibilaro see the bed elasticity as a purely hydrodynamic characteristic of the bed. Studies by Agbim et al. [9], Seville and Clift [10], McLaughlin and Rhodes [11], and Rhodes et al. [12] show that in the presence of artificial interparticle force, homogeneous fluidization and bed expansion can be observed in a bed of Group B powders. Therefore, these studies highlight the importance of cohesive interparticle forces in homogeneous fluidization. Studies by Molerus [13], Geldart et al. [14] and Chaouki et al. [15] have suggested the importance of naturally occurring interparticle forces in determining the behaviour of a fluidized bed. Theories based on interparticle forces are very difficult to apply, as it proves difficult to determine the magnitude of interparticle forces and their relationship with the macroscopic physical properties of the bed. The Foscolo and Gibilaro theory is based on pure hydrodynamics considerations. The partial success of this

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theory in predicting homogenous fluidization demonstrates the need for further research on the role of interparticle forces in fluidization.

In recent years, the simulation technique based on the discrete element method (DEM) has become popular for simulation of gas-particle systems. In DEM simulation, the particles are traced individually by solving Newton's equations of motion, while the fluid phase is treated as a continuum. There are two approaches for simulating particle–particle collisions in DEM simulation: the soft sphere approach e.g. by Tsuji et al. [16] and the hard sphere approach e.g. by Hoomans et al. [17]. In the soft sphere model it is possible to estimate the interaction forces using multiple particle contacts. The requirement of large CPU time and memory are the main limitations of the DEM simulation. Because of this most of the studies using the DEM simulation were done with beds of large particles belonging to Group B or Group D. However, with the increased availability of high speed computing resources with large memory it is now possible to simulate beds of Group A powders. In recent work Kobayashi et al. [18] and Ye et al. [19] studied the behaviour of Group A powders. However, these authors took very low value of particle stiffness and thus obtained unrealistically high values of the minimum bubbling velocity. On the other hand, Mukai et al. [20] simulated a bed of very small size ($2 \times 2$ mm) with only 870 particles. In the present work, we use the DEM simulation to study the fluidization behaviour of Group A powders with and without imposed interparticle cohesive forces in a 2D rectangular bed. The current DEM simulation is based on the soft sphere model of Tsuji et al. [16].

## 2. Details of simulation

Simulation of Group A powders are performed in a two-dimensional rectangular bed. Table 1 gives the details of parameters used in the current DEM simulation.

Three types of powders are chosen for the simulation. According to the size and the density, these powders belong to Group A of the Geldart classification. However, these powders are different from real Group A powders because the interparticle force in these powders is set to zero. Table 2 gives the details of the beds and bed particles. To study the bed behaviour, the strategy adopted by Rhodes et al. [21] is applied here, wherein the air velocity to the bed is increased in two stages. As shown in Table 2, the size of the time increment decreases with a decrease in the particle diameter. The numbers of particles contained in the bed are higher for the smaller particles. Smaller time increments and higher numbers of bed particles slow down the progress of the simulation and increase the CPU time and memory requirements. To reach the minimum fluidization condition quickly, we give larger air velocity increments below the minimum fluidization condition. The minimum fluidization condition is reached in 4.75, 4.5 and 1.7 seconds, respectively for the bed of powder A1, A2 and A3. This is acceptable as our main focus is on the bed behaviour above the minimum fluidization velocity.

Table 1
Some parameters used in the DEM simulation

| | | | |
|---|---|---|---|
| Fluidizing gas | Air | Coefficient of friction | 0.3 |
| Air viscosity | $1.77 \times 10^{-5}$ Pa s | Coefficient of restitution | 0.9 |
| Air density | 1.15 kg m$^{-3}$ | Normal spring constant | 800 Nm$^{-1}$ |

Table 2
Details of bed geometry and bed particles

| | Powder A1 | Powder A2 | Powder A3 |
|---|---|---|---|
| *Bed geometry* | | | |
| Bed width (mm) | 75 | 40 | 40 |
| Packed bed height (mm) | 110 | 90 | 55 |
| *Particle details* | | | |
| Particle diameter (micron) | 500 | 250 | 150 |
| Particle density (kg m$^{-3}$) | 400 | 750 | 1000 |
| Number of bed particles | 36,000 | 64,000 | 106,400 |
| Time increment $\times 10^6$ (s) | 3.59434 | 1.74010 | 0.933837 |

Simulations are also performed in the presence of cohesive interparticle force. In these simulations, the interparticle force is expressed as a multiple of the buoyant weight of a single particle. Therefore, the magnitude of imposed interparticle force is,

$$F_{\mathrm{ipf}} = K\left[\pi D_{\mathrm{p}}^{3} g\left(\rho_{\mathrm{p}} - \rho_{\mathrm{f}}\right)/6\right]. \tag{1}$$

## 3. Results and discussion

### 3.1. Bed pressure drop

While simulating beds of Group B particles in the presence of imposed cohesive interparticle force, Rhodes et al. [21] observed three distinct types of bed behaviour i.e. fixed bed, homogeneous fluidization and bubbling bed. These authors observed the formation of spikes in the instantaneous bed pressure drop curve whenever a step increment was given to the bed air velocity and the bed pressure drop fluctuations at the start of bubbling in the bed. Therefore, the instantaneous bed pressure drop curve has three regions corresponding to the three types of bed behaviour. Fig. 1 shows the variation of the instantaneous bed pressure drop and the superficial air velocity with time. In this figure, the typical air velocity increments are within 4% to 8% of the minimum fluidization velocity. Within this limit of the step increments to the air velocity, we cannot see spikes of observable height in the bed pressure drop curves shown in Fig. 1. The bed pressure drop does not show any change with air velocity, after reaching a value that is equal to the bed buoyant weight per unit bed cross sectional area. The minimum air velocity at which the bed pressure drop becomes equal to the bed buoyant weight per unit bed cross sectional area is known as the minimum fluidization