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Ask Joe! Column

Attrition : DEM Simulation for Breakage and Degradation of Particulate Solids

Guest article by Dr. Ting Han, Carnegie Mellon University

Scientific Background

The breakage and the degradation of particulate solids widely exist in various industrial processes. In practical terms, particle breakage and degradation are described as attrition (if undesired, as in pneumatic conveying) or comminution (if desired, as in jet milling). Both attrition and comminution, however, are the same process during which larger particles are broken down into smaller ones either by fragmentation or wear. Unfortunately, very little quantitative analysis and modeling have been reported in the literature about the attrition or the comminution of particles because of these problems' complexity.

Numerical Study

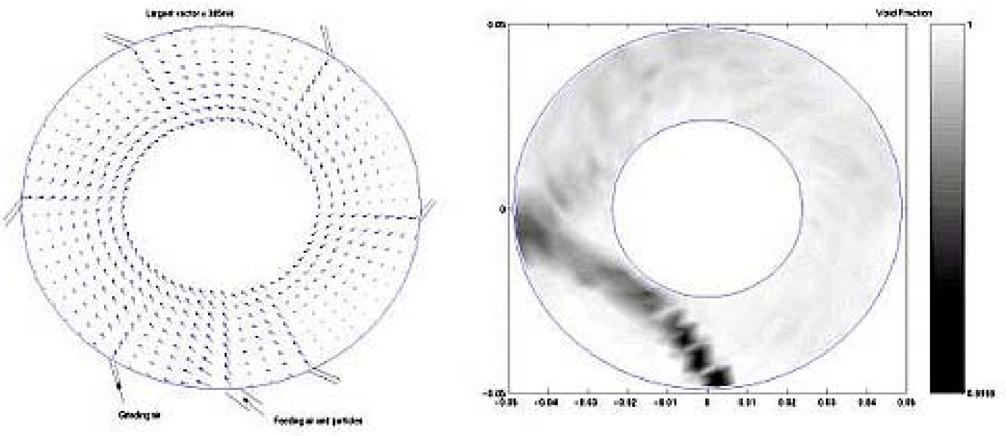
Because the Discrete Element Method (DEM) allows investigation of a wide variety of problems including particles in Newtonian or viscoelastic fluids with constant or varying properties, DEM was used here to describing the motion of particles in gas flow, while the gas flow was described by the compressible Reynolds Averaged Navier-Stokes (RANS) equations in a given size's system (two dimensional model).

The equation describing the motion of particles is written by:

$$m_s \frac{d\vec{u}_s}{dt} = \vec{F}_C + \vec{F}_D + \vec{F}_S + \vec{F}_R + \vec{F}_{cf} + m_s \vec{g} \qquad (1)$$

The forces appearing at the right hand side of the above equation are: Contact force, FC (acting between a particle and other particles or walls), three forces from gas flow, (including drag force, FD , shear lift force FS, rotational lift force, FR), centrifugal force, Fcf, when appropriate in jet milling and gravitational force, ms g, respectively.

In addition, models for attrition/breakage, such as Ghadiri's model, can be optionally implemented in the simulation to decide the reduction of the particles' size.

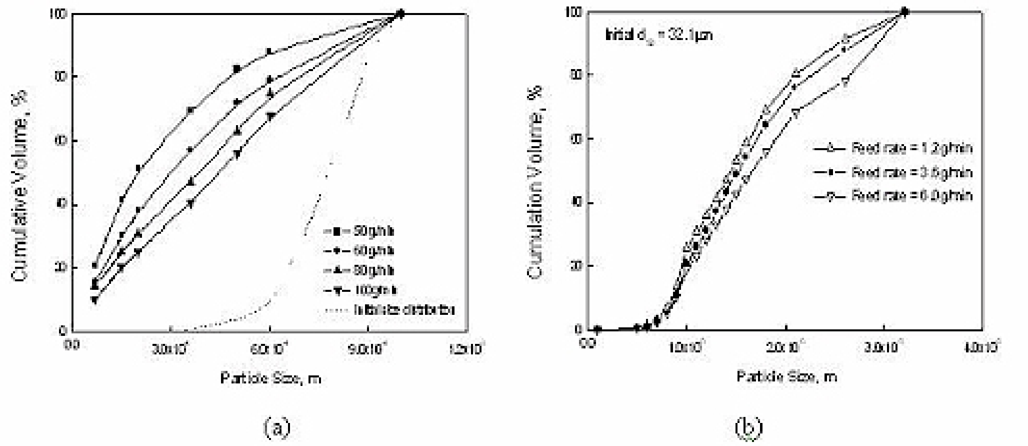


(a) (b)

Fig. 1 Gas velocity vector (a) and void fraction (b) in jet milling

Numerical Results and Discussions

In this paper, the numerical results will be discussed for jet milling (particle breakage process) and pneumatic conveying (particle attrition process), respectively, based on the above numerical study. Figs. 1(a)-(b) show gas velocity vector and void fraction in jet milling. It can be seen in Fig. 1(a) that the gas velocity vector increases with decreasing the radii of the jet mill except in the nozzle area. In addition, from the nozzles to the center of the jet mill, the gas velocity vector is larger than the other areas'. In Fig. 1(b), it is shown that the particles leaving from feeding nozzle still keep the concentration trend firstly and then gradually diffuse to the whole inner of jet mill because of the strong mixed motion.



(a) (b)

Fig. 2 Cumulative undersize percentage for the different feed rates in jet milling

Figs. 2(a)-(b) show the cumulative undersize percentage for the different feed rates. The experimental result (Ramanujam et al., 1969/1970) in Fig. 2(a) shows that the cumulative undersize percentage increases with decreasing the feed rates under the same conditions. As the feed rate is increased, the particle concentration increases, thus increasing the frequency of collision. But the collision velocity is also decreased which is more important to influence the breakage of particles.

In Fig. 2(b), the tendency has been acquired by the DEM simulation. At the same time, the median particle size d50 increases with the increase of the feed rates in Fig. 2(b), which has also been proved in the experiment (Gommeren et al., 2000; Tuunila et al., 1998).

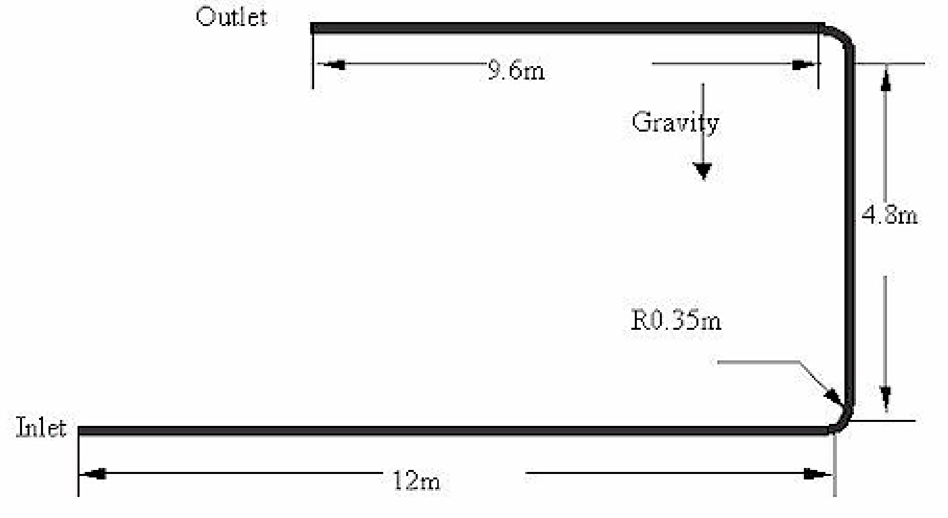


Fig. 3 Sketch of the pneumatic conveying system used in the experiment

Fig. 3 shows the geometry of the calculated pseudo three-dimensional channel whose sizes are the same as the ones of the pneumatic conveying system used in Bell et al.'s experiments (1996). The simulation is performed in a three-dimensional channel with constant thickness equal to the diameter of an initial particle.

The particles were allowed to move only on x and y directions (i.e. two-dimensional calculation). The channel includes three straight parts and two bend parts whose lengths and curvatures are shown in the figure. The height of the channel is equal to inside diameter of conveying system, 8 cm.

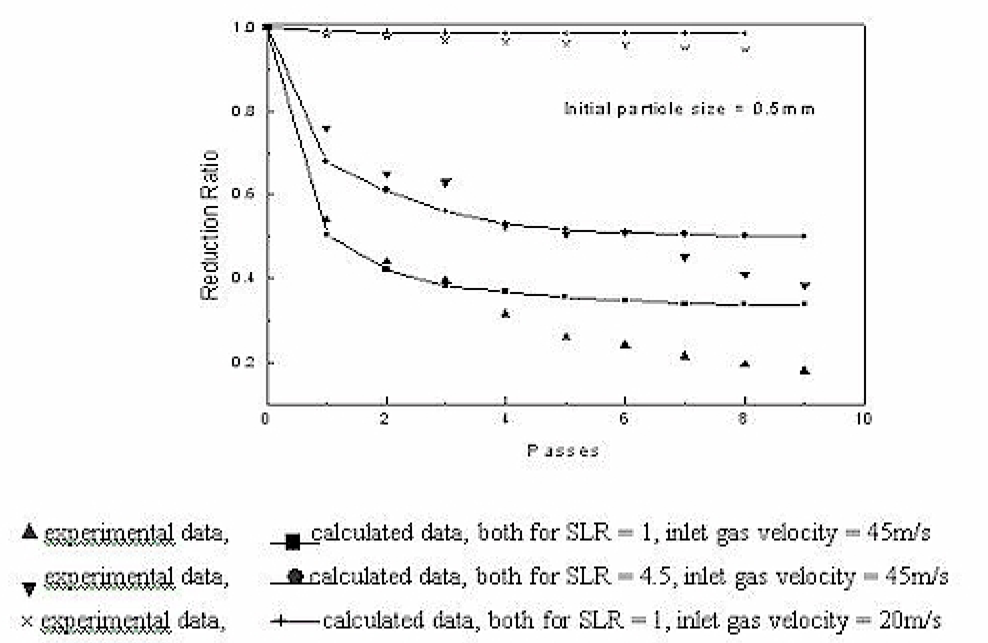


Fig. 4 Comparison between experimental and simulated results of particle's reduction ratio in pneumatic conveying

Figure 4 shows a comparison between the experimental and simulated results of the particle reduction ratio after different passes. Here, the reduction ratio is defined as the ratio of the surface area of initial particles to that of the particles after the passes. This definition is the same as the one defined by Bell et al. (1996).

It can be noted that the difference between the experimental and the simulated results is tolerable. As can be seen, it is much better for the first few passes. The difference in the results can be attributed to five main reasons:

1. Initial particles are given as mono-size in the simulation, while in the experiment they have a size distribution;
2. In the simulation, all the particles before and after collisions are considered to be spherical. However, the particles have various shapes in the experiment;
3. To further simplify the simulation process, some of the small sized particles (less than 10-4 m) are taken out artificially so that in the simulation the smallest particles can not be broken again;
4. In the simulation, the attrition in the baghouse and the screw feeder has not been considered;
5. In the experiment, some big particles might be unbroken under the high impact velocities while their strengths will be decreased (fatigue phenomena).

This will allow the particles to be broken on later impact with the lower impact velocities. However, according to Ghadiri's model in the simulation, a particle must be broken only if the relative impact velocity for the particle is over 4 m/s. As a result, we underestimated the breakage of the particles during the simulation as increasing the number of the passes in Fig. 4.

It should be pointed out that both the experimental and the calculated results show that attrition rates are dependent on both the conveying gas velocity and the solids loading ratio, with the conveying gas velocity being the more influencing factor.

Conclusion

The predictions for the median particle size d50 after grinding in jet milling process were qualitatively compared with experimental results from literature (Gommeren et al., 2000; Ramanujam et al., 1969/1970; Tuunila et al., 1998). Similar behavior and tendency were obtained. The results show that the feed rate (also including angle of feeding nozzle and feeding air's flow rate which are not shown here) has more influence on the breakage and chipping of particles in jet milling. At the same time, the cumulative undersize distributions of the particles after grinding were predicted by numerical simulation.

The predictions for the particles' attrition ratio during dilute phase pneumatic conveying are similar to the experimental results of Bell et al (1996). It was obtained that the inlet gas velocity is the more important factor than the solids loading ratio on the particle attrition. In addition, the present simulation further predicts that the size range of particles tends to a narrow range as the number of passes increases.

In a word, it is possible to use the predictions of the present numerical simulation (DEM) to assist in designing and handling practical gas-particle flow systems, such as pneumatic conveying systems and jet mills, etc.

Acknowledgements

This research was part of Dr. Ting Han's PhD work guided by Prof. Haim Kalman and Prof. Avi Levy in Ben-Gurion University, which was supported by the Israel Science Foundation (No. 23/00-1).

References

[1] M. Ramanujam and D. Venkateswarlu, Studies in Fluid Energy Grinding, Powder Technology 3(1969/70) 92-101.
[2] H.J.C. Gommeren, D.A. Heitzmann, J.A.C. Moolenaar and B. Scarlett, Modelling and control of a jet mill plant, Powder Technology 108(2000) 147-154.
[3] R. Tuunila and L. Nystrom, Effects of grinding parameters on product fineness in jet mill grinding, Minerals Engineering 11(1998) 1089-1094.
[4] Bell T. A., Boxman A. and Jacobs J. B., "Attrition of Salt During Pneumatic Conveying", Proceedings of the 5th World Congress of Chemical Engineering V, pp. 238-243, 1996.

About our Author

Since 2002, Dr. Han has been a Postdoctoral Fellow for the Department of Chemical Engineering at Carnegie Mellon University. He has worked on process modeling and simulation of different processes including: drying and cracking behavior of porous coatings, liquid-solid separation through filtration, gas-particle flow behavior in pneumatic conveying, jet milling & high-speed nozzles and particle breakage in pneumatic conveying. Dr. Han is a Senior Member of the American Institute of Chemical Engineers (AIChE).

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