Challenges in dilute gas-particle flows

What further developments are needed to advance our ability to model dilute gas-particle flows?

1) Better mathematical models and constitutive relations to handle particle size distribution (PSD): Most of the developments between 1960 and 2000 were focused on modeling and simulating flow behavior of uniformly sized particles. In practice, however, PSD is always present. We also know from experiments that particle size distribution has a significant effect on the flow characteristics. Being able to handle PSD in the modeling is an important next step. Here, there are two aspects to accounting for PSD.

    a) Develop a computational framework
    b) Develop appropriate, validated constitutive models.

    Arena-flow is well advanced in terms of computational framework. It is conceptually easy to extend two-fluid model based codes such as MFIX to handle many different types of particles. But there must be room for improvement of speed.

    The greater challenges are, however, on the modeling side. Efficient methods to convert a continuous PSD to a small number of particle classes, via e.g., the quadrature method, should be examined. Application of such a quadrature method will lead to multi-fluid type models and we will need good closure models (aka constitutive models) for drag, and stress terms. Development and validation of these constitutive models are important challenges.

    Some work on drag law development through computational methods is in progress – e.g., at Twente, Cornell and Princeton. But more is needed.

    Multi-particle kinetic theories have been developed in the literature; e.g., Li and Gidaspow (and many others) have applied them to study segregation in fluidized beds involving binary mixtures. But more work is needed to construct these models and test them using, say, particle dynamics simulations and experiments.

2) On the experimental side, it would be very useful to have a set of high quality data involving well controlled PSDs in dilute flow conditions. For example, riser flow experiments involving a binary mixture, where one intentionally mixes two different particle types (with different sizes and densitites) while keeping each type to a tightly controlled narrow PSD, will help directly validate models. In such experiments, we will need as many of the quantities measured as possible, with lateral distribution of the different particle types being particularly useful. (Note that a lot of the data that people use to validate are for segregation in fluidized beds involving very large particles. Taking these down to more relaistic particle sizes and also dilute flow regime are important.)

We also need such high quality data with continuos PSDs, so that one can examine the adequacy of quadrature approximations and closures. There are many sets of data in the literature, but not all of them report spatial variation of PSD in the riser and we also do not know how accurate the measurements are.

3) Quite a bit of work has gone in the past century to explore instabilities in fluidized suspensions of uniformly sized particles. We have a reasonable understanding of the heirarchy of instabilities and their length scales. This painstaking work helped us understand better what aspects of the results afforded by computations are robust (and independent of the fine details of the constitutive models) and what aspects are closure-sensitive. This effort also led us at Princeton to conclude that the two-fluid models that we usually write will not be practically useful as we simply cannot afford the grid resolution. This led to our current efforts on coarse-graining (sometimes referred to as filtering) of the two-fluid models. I believe that such coarse-graining will remain important even in more detailed models involving PSDs. Quite a bit of work remains to further develop the coarse-grained two-fluid models for uniformly sized particles, and in my opinion, it is important that these be developed for systems with PSD as well.

   To this end, studies probing the manner in which inhomogeneities arise in multi-fluid models – explored via linear stability and bifurcation analyses – will be useful. Suitable experiments – either laboratory or computational – that will aid in developing rational coarse-grained models are also needed. Finally, all of these need to be validated.