Research Problems in Multiphase Flow

Cluster and Particle Turbulence

Dimitri Gidaspow, Distinguished University Professor of Chemical Engineering
Illinois Institute of Technology, Chicago, IL. gidaspow @iit.edu

Three decades ago at an international two week conference (NATO, 1976) multiphase flow was recognized to be a separate new science. Its basis is a set of conservation of mass, momentum and energy laws for each phase, A new variable, not found in fluid mechanics , the volume fraction of each phase was introduced into the new theory .However, constitutive equations for some properties, such as particle pressure and individual phase viscosity, were not properly formulated in the earlier theories. This led to ill-posed equations that could not be solved as initial value problems. (Gidaspow, 1994) .In the 1980's Stuart Savage (1983) and others formulated a granular flow theory based on the classical kinetic theory of dense gases. This theory provided an explanation of the physical meaning of particle pressure and viscosity in terms of a random kinetic energy of particles, the granular temperature. These concepts were discussed at a number of joint NSF/DOE meetings in the 1980's and early 1990's. The granular flow theory was first successfully applied to predict the core-annular flow regime for developed flow in a riser by Sinclair and Jackson (1989). This led the US oil industry to measure the solids volume fractions in their commercial FCC risers and discover to their amazement that their reactors were indeed dilute in the center.

The multiphase flow theory together with the granular temperature equation have been incorporated into commercial codes, such as FLUENT. We (Jiradilok, 2005) have recently shown that the coupled Navier-Stokes equations for each phase together with the granular temperature equation and a drag modified for clusters correctly predict turbulent properties of dense flow in a riser. The computed energy spectrum captured the observed gravity wave and the Kolmogorov -5/3 law at high frequencies. The computed granular temperatures, solids pressures, FCC viscosities and frequencies of oscillations were close to measurements reported in the literature. However, the need for drag modification suggests that the problem of cluster formation has to be resolved before CFD computations can become predictive without experimental input. Sundaresan and Syamlal (Agrawal , et al 2001) had suggested a filtering , high resolution approach to essentially the same problem.

Dense gas-particle flow differs from single phase turbulent flow due to the presence of random motion of colliding particles. This phenomenon can be seen by observing the motion of particles in a liquid-solid fluidized bed. However, under some conditions, usually in dense flow, the particles form clusters, as seen over half a century ago and computed with the CFD codes. We have developed a kinetic theory based particle image velocity meter method of measuring the motion and the stresses of individual particles and of cluster of particles. (Tartan and Gidaspow, 2004). For Geldart group B particles the mixing in the center of the riser is primarily due to random oscillation of the particles, while at the wall it is due to clusters. For the commercially important group A we have a theory, but no measurements. Clearly, the cluster formation needs to be researched in far greater depth than done so far. It will lead to better understanding of mixing in fluidized bed reactors and hence to better designs.

References Cited

Agrawal, K, Loezcos, P.N., Syamlal, M. Sundaresan, S. J. Fluid Mechanics 445,151-185 (2001).

Gidaspow, D. Multiphase Flow and Fluidization, Academic Press, 1994.

Jiradilok, V., Gidaspow, D. Damronglerd, S., Koves,W.J., Mostofi, R.
Kinetic Theory Based. CFD Simulation of Turbulent Fluidization of FCC Particles in a Riser, Presented at 2005 Annual AIChE meeting in Fundamentals of Fluidization 2.

NATO Advanced Study Institute Proceedings, Two-Phase Flow and Heat Transfer, Instanbul, Turkey , Aug 16-27 (1976); Hemisphere Publishing, Kakac, S and Mayinger., F.,editors.(1977) 5 volumes.

Savage, S. in Theory of Dispersed Multiphase Flow ,Meyer.R.E. ed., Academic Press (1983)

Sinclair, J and Jackson, R. AIChE Journal 35, 1473-1486 (1989)

Tartan, M and Gidaspow, D..AIChE Journal 50, 1760-1775 (2004).