POTENTIAL OF MICRO-CHANNEL FLOW FOR AGGLOMERATE BREAKAGE

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Summary

Direct simulations of solid-liquid flow in micro-channels have been performed. The solids phase consists of simple agglomerates, assembled from monosized, spherical particles. The simulations keep track of the flow-induced forces in the agglomerates. The effects of solids loading, channel geometry, and agglomerate type (doublets, triplets, and quadruplets) on the flow-induced forces has been investigated. By comparing these forces with agglomerate strength, we are able to assess the potential of micro-channels as agglomerate breakage devices.

Keywords

Micro-reactors, multiphase and particulate reactors.

Introduction

In many processes involving solid particle formation or solids handling, particles have a tendency to stick together. Examples are related to crystallization, suspension polymerization, colloids, and asphaltene deposition. The agglomerate size distribution evolves as a result of agglomeration and also de-agglomeration (i.e. breakage of agglomerates).

For an agglomeration event to occur, particles (primary particles and/or agglomerates) need to collide first. Typically collisions are induced by Brownian motion, gravity, and velocity gradients in the fluid carrying the particles since these phenomena bring about relative velocities between particles. Also particle inertia can be a source of collisions. Next to promoting collisions, fluid velocity gradients and particle-particle interactions also are potential reasons for agglomerate breakage since they cause mechanical loads on agglomerates. In this paper we focus on the latter aspect: We investigate the mechanical load on agglomerates due to deformation of the surrounding liquid and the presence of other particles/agglomerates. Interactions with other particles / agglomerates can be either direct (collisions) or indirect, e.g. transmitted by the interstitial liquid.

To date, agglomerate breakage modeling in a turbulent flow uses relatively simple scaling concepts based on energy dissipation rates and the assumption of the agglomerates being smaller than the Kolmogorov scale[1]. In order to refine and generalize breakage modeling, we are developing a framework for determining flow-induced forces in agglomerates based on direct simulations. As a sample application we consider agglomerate suspensions flowing through narrow channels. Micro-channels have been proposed recently as potential breakage devices[2].

In our computational approach, agglomerates are assembled of primary spherical particles all having the same size, and released in a flow field. We directly solve the flow around the agglomerates by means of the lattice-Boltzmann method, and fully couple flow and agglomerate motion. The force and torque required to keep a primary particle attached to the agglomerate follow from this computational procedure. Comparing that force and/or torque with a measure of the agglomerate strength allows for assessing the breakage probability. Usually a primary sphere has more than one contact point with the other primary spheres in the agglomerate. This in general makes it fundamentally impossible to calculate the force and torque at each contact point. However, for a few simple agglomerate configurations the force and torque per contact point can be determined with minimal assumptions.

It should be noted that during the simulations the agglomerates keep their integrity; we do not actually break them. The results of the simulations comprise detailed representations (time series, probability density functions) of the flow induced forces and torques in agglomerates as a function of process conditions. From this detailed information breakage probability can be assessed once data regarding the mechanical strength of the agglomerates is available.

Flow Systems

The basic flow geometry in this study is a square channel with width H. The flow in the channel is driven by a body force f_0 acting in the x (=streamwise) direction mimicking

a pressure gradient. At the four side walls a no-slip boundary condition applies; the flow system is periodic in streamwise direction. A Reynolds number characterizing the flow in the channel can be based on the wall shear velocity. Since the average wall shear stress relates to f_0 via an overall force balance we can write $\mathrm{Re}_w = \frac{1}{2}\frac{H^{3/2} f_0^{1/2}}{\rho^{1/2}\nu}$.

Inspired by the work due to Zaccone et al[2], in some of the simulations the channel has a contraction. The contraction is two-dimensional, i.e. the channel is only contracted locally in the *z*-direction; the width in the *y*-direction remains *H*. The Reynolds number definition for the contracted channel cases we take the same as for the uniform channel.

In the liquid that fills the channel, agglomerates are released. They consist of equally sized spheres with radius *a*. Three types of agglomerates have been considered: (1) two touching spheres forming a doublet; (2) three touching spheres (triplet) forming a triangle (two contact points per primary sphere); (3) four touching spheres (quadruplet) forming a tetrahedron (three contact points per primary sphere). The introduction of the agglomerates in the channel gives rise to three additional dimensionless numbers: an aspect ratio $\frac{a}{H}$, a density ratio $\frac{\rho_s}{\rho}$, and a solids volume fraction ϕ.

Sample Results

Figure 1 shows typical flow situations with (in this case) quadruplets in a square channel with and without contraction. The channel width *H* is 10 times the primary sphere diameter.

In the triplets and quadruplets considered, primary spheres have more than one point of contact with the other spheres in the agglomerate. For these special cases the simulation procedure allows us to determine the forces and torques per contact point. As examples, time series of radial contact forces in quadruplets are shown in Figure 2. The smooth parts of the fluctuations shown are due to motion of the rotating agglomerate through the channel thereby sampling variations in the local liquid deformation rate. The spikes and discontinuities are due to encounters with other agglomerates; the denser the suspension, the more encounters. One way of summarizing the detailed information provided by the simulations is in the form of probability density functions (PDF's) of contact forces and torques. In Figure 3 we show that the radial force PDF gets wider for denser agglomerate slurries.

References

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(2) Zaccone A.; Soos M.; Lattuada M.; Wu H.; Bäbler M.U.; Morbidelli M. Breakup of dense colloidal aggregates under hydrodynamic stresses. *Phys. Rev. E*, **2009**, 061401.

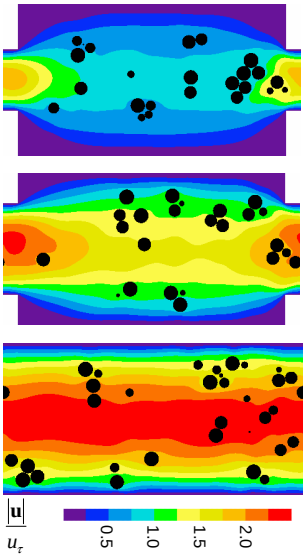

Figure 1. Cross sections through channels with quadruplets in terms of absolute liquid velocity contours. The top two channels have a contraction. In all cases $\mathrm{Re}_w = 2.6$, $\frac{\rho_s}{\rho}$=2.5, ϕ=0.062, $\frac{a}{H}$=0.05.

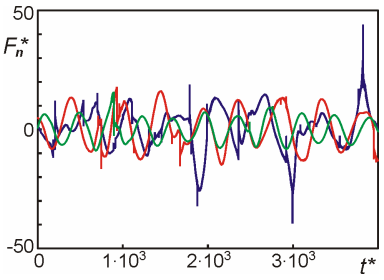

Figure 2. Time series of the dimensionless normal force in one sphere-sphere contact point in a quadruplet. Comparison for different slurry densities. Blue: solids volume fraction 9.3%; red: 6.2%; green: 3.1%. The channel has no contraction.

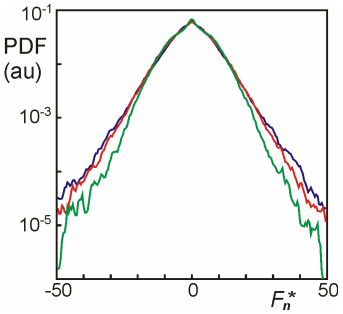

Figure 3. PDF of the normal force in sphere-sphere contact points in quadruplets. Same color coding as Figure 2.