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A simple shell model for the break-up of agglomerates in turbulent flows

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We describe and evaluate a stochastic model for the break-up of an agglomerate in a turbulent flow in which the agglomerate is subjected to a random sequence of straining and rotating flows simulating the Kolmogorov small dissipating scales of turbulent motion that are responsible for the agglomerate breakup. The agglomerate is considered to be composed of shells of primary particles, the total breakup rate of the agglomerate depending on the breakup rate of each shell forming the agglomerate. The breakup is thus very similar to the onion peeling mechanism for break up by erosion. In this context, of particular relevance is the modelling / simulation of multi layer resuspension of particles attached to surfaces in a turbulent boundary layer in which the multilayer resuspension is related to the resuspension rate from a single layer [1] . The latter is based on a primary removal rate constant $p(\xi)$ for the escape of particles from a surface adhesive potential denoted by a parameter ξ, the total removal rate being an integration over a broad range of adhesive potential i.e. values of ξ within the layer due to a distribution of particle sizes, micro-scale roughness and flow exposure. The removal rate of particles from any given layer depends upon the rate at which particles are exposed to the flow from the layers above. In the simplest model it is directly related to the rate of removal from the layer above. So that if $n_i(\xi,t)d\xi$ is the number of particles in layer i with adhesive and flow exposed between parameters ξ and $\xi + d\xi$ with probability density $\psi(\xi)$

$$\begin{aligned} \frac{\partial n_i(\xi,t)}{\partial t} &= -p(\xi)n_i(\xi,t) + \psi(\xi)\int_0^\infty p(\xi')n_{i-1}(\xi',t)d\xi' \\ &= -p(\xi)n_i(\xi,t) + \psi(\xi)\Lambda_{i-1}(t) \end{aligned} \quad (1)$$

where $\Lambda_{i-1}(t)$ is the removal rate of particles from the layer above.

The model we propose for agglomerate breakup is a simple shell model in which the agglomerate is composed of a number of concentric spherical shells, each shell containing a number of primary particles which along with the local volume fraction are related to the fractal dimension of the agglomerate. In determining the way particles are bonded to together within each layer, we make use of the coordination number, i.e., the number of particles a given particle is in contact with. This varies according to the shape and distribution of primary particle size within the agglomerate. In our first approximation, the coordination number is two, which means that the particles are bonded to a particle in the layer above and below it.

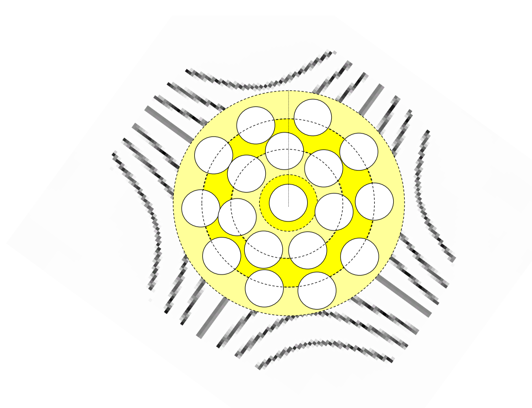

Figure 1: Shell model for agglomerate breakup showing the agglomerate at the centre of a symmetric straining flow

The determination of the single shell primary break-up rate constant, $p(\xi)$ is based on previous work on modelling the resuspension of particles attached to surfaces in a turbulent boundary layer [2].

The agglomerate sits within a random symmetric straining flow as shown in Figure 1, the strain rate having a prescribed Gaussian distribution with the the principal axes of the strain state radomly rotating to produce a statistically isotropic flow field. As in resuspension models for mono layer coverage, the mechanism of removal is based on the rocking and rolling of the particles about their asperity points of contact and as such the the moments derived from the drag force are assumed to be the principal breakup mechanism within each layer. The adhesive force is selected from a log normal distribution, being reduced by a factor $\sim$100 due to the roughness from that for smooth contact.

We first contrast the predictions for breakup based on 3 different models for the primary removal rate constant $p(\xi)$ and use them to make some predictions for the breakup of agglomerates in turbulent flow in a pipe comparing them with experimental measurements for the outer radius of the suspended agglomerates as a function of flow rate. Figure1 shows some results for the break-up of an agglomerate for which the coverage coefficients are assumed to be unity and for which the source of particles in any layer depends only on the removal of particles from the layer above.

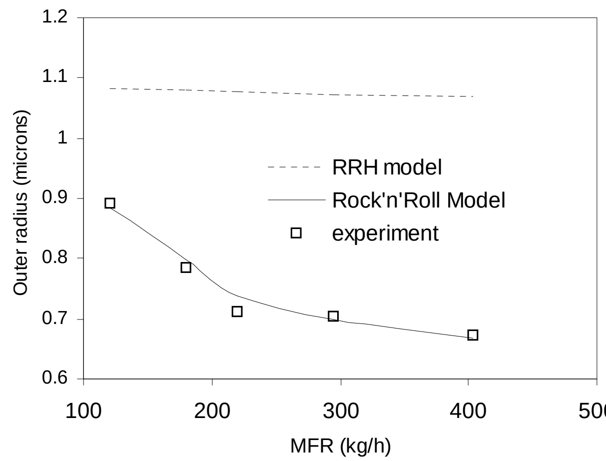

Figure 2: Breakup of agglomerates in turbulent pipe flow : experimental results versus model predictions

References

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