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LETTER TO THE EDITOR

DIFFERENTIATION BETWEEN JETTING AND BUBBLING IN FLUIDIZED BEDS

When fluid is forced upwards through an orifice into a bed of fluidized particulate solids with sufficient momentum to cause the particles to move apart, a permanent jet may or may not form at the orifice. When a permanent jet forms, it may penetrate right to the bed surface, or it may form a void from the top of which bubbles break away in an almost periodic manner. When a permanent jet is not formed, elongated bubbles tend to develop and break away from the orifice itself, with a frequency in the range of 5–20 Hz. Knowing which of these types of behaviour will occur is of considerable importance for applications of fluidized beds. Understanding the fluid mechanics and transfer processes in the distributor region is critical to the successful modelling of fluidized bed reactors. Moreover, it is important to distinguish between flows from the orifices of the bed distributor and those from single jets superimposed upon the bed flow. In the former, the bed superficial velocity and local jet exit velocity are inextricably linked by the distributor porosity, β. In the latter, however, the orifice velocity is independent of the bed superficial velocity. Consequently, the two flow types yield completely different fluid- and thermo-dynamic problems, and must be treated separately. In the following, only grid-generated jets will be considered, though some of the comments are applicable to single jets also.

Grace & Lim (1987) suggest a very simple criterion for the formation of permanent jets:

$$\frac{d_o}{d_p} \leqslant 25.4, \qquad [1]$$

where d_o and d_p denote the orifice and particle diameters respectively. Equation [1] is shown to delineate quite effectively between jets and bubbles for a wide range of data. Grace & Lim (1987) were unable to improve on this simple criterion, though they found no improvement in correlation when they examined the influence of a jet Froude number. They did observe, however, that:

(a) Increasing the fluid temperature (decreasing density) destabilized the flow (i.e. more likely to get bubbles).
(b) High superficial (bed) gas velocities tend to destablize the flow.
(c) Large d_o/d_b ($>1/3$) destabilizes the flow (d_b is the diameter of the fluidized bed).
(d) Jet angles away from the vertical are also more likely to destabilize the flow.

Massimilla (1985) does not give any specific criteria, but simply says that jet formation is more likely with:

(a) coarser and lighter particles;
(b) increasing fluid density;
(c) increasing orifice velocity; and
(d) low superficial velocity;

and that bed height also has an influence.

Wen *et al.* (1982) have performed some very interesting and careful measurements in the immediate vicinity of a bed distributor in an effort to differentiate between steady and unsteady flow, here interpreted as jetting or bubbling, respectively. Their data seem to confirm the above trends, and they show further that there is a strong (first-order) effect of wall proximity on the conditions which determine whether a jet or bubble forms.

Based upon the above observations, dimensional analysis suggests that the main parameters which determine whether a jet or bubble forms at an orifice may be written as the following function F:

$$F = F\left(\mathrm{Fr}, \mathrm{Re}, \frac{\rho_p}{\rho_f}, \frac{d_p}{d_o}, \beta\right), \qquad [2]$$

where Fr and Re are some representative Froude and Reynolds numbers and ρ_p and ρ_f are the particle and fluid densities. We may assume that the orifice Froude and Reynolds numbers are sufficiently high that they may be ignored. Moreover, analysis of the data of Wen *et al.* (1982) suggests that a major influencing parameter is the bed Froude number $\mathrm{Fr}_c = U_{bc}/(g\, d_p)^{1/2}$, with no obvious dependence upon Reynolds number (U_b is the bed velocity). The subscript c denotes a critical Froude number above which bubbles are formed and below which jets are formed. Further analysis of their data suggests the following critical relationship:

$$F_c = \frac{U_{bc}}{\sqrt{g\, d_p}} \left[\frac{\dfrac{\rho_p}{\rho_f}}{\dfrac{d_p}{d_o}}\right]^{1/2} = 520\beta^{-1/4}. \qquad [3]$$

This relationship is shown in figure 1 and appears to correlate the data of Wen *et al.* (1982) quite well. This figure shows a dependence upon the grid porosity, and confirms all of the above-expected trends. Above the line, bubbling behaviour is to be found, whilst below the line jetting occurs. There remains significant scatter in these results, though there are indications that some of this is due to the particle shape: the lower data points are mostly derived from spherical particles, whilst the higher data are mostly granular materials.

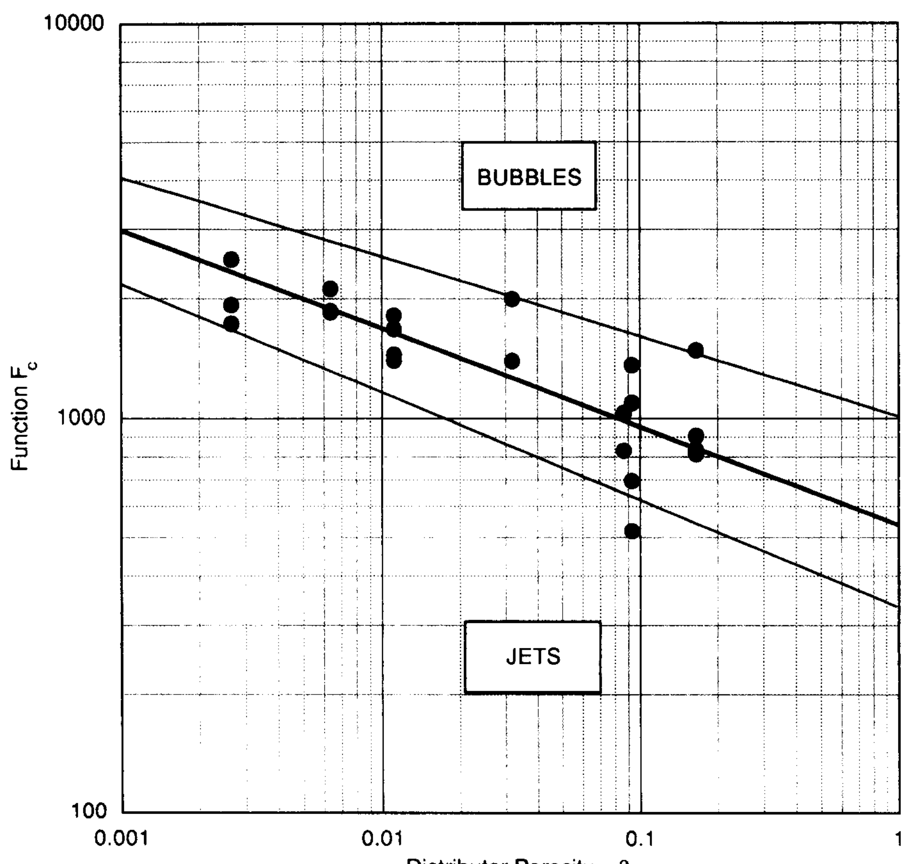

Figure 1. Bubbling and jetting in fluidized beds—multiple jets from the distributor grid; ●, Wen *et al.* (1982).

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