Radial Solid Fraction in Gas-Fluidised Bed Reactors

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Introduction
In a fluidization process, a bed of solid particles acquires fluid-like properties by passing a gas of liquid through it. An efficient bed-to-surface heat transfer and a temperature uniformity are among the major advantages of a gas-fluidized bed reactor, widely used in chemical processing industries, particularly in separation and in catalytic reactions. Its performance, however, depends highly on its hydrodynamics, where solid fraction ($\alpha$) plays a significant role. Thus, techniques that enable the measurement of $\alpha$ across different sections of the bed are highly important.

The Fluidized bed
In a typical cylindrical fluidized bed, multiple flow patterns can be observed depending upon gas velocity. For low rates of flow, fluid passes through the void space of the particles without disturbing them, thus the bed is fixed. As fluid velocity increases, so does the drag force acting on the particles. At a critical point, the drag force equals the gravitational one (fluidisation point) and the bed fluidises. This process can be represented by Fig.1, where the pressure difference between two points in the bed are plotted against gas velocity.

![Fig. 1 Diagram of pressure drop as a function of gas velocity](Image)

Source: Chemical Engineering Guides of the University of Florida, 2015

Materials
Aluminium oxide (Al₂O₃) commonly known as Alumina, is used. It has an average particle size of 69 μm. The mean bulk density of the powder is 1068 m³/kg (2% CV) while its true density is 2900 m³/kg. A SEM image of Alumina is shown on Fig. 3.

![Fig. 3 SEM Image of Alumina](Image)

Positron Emission Particle Tracking (PEPT)
PEPT is a non-invasive technique based on the movement of a single tracer particle over a prolonged period of time. A radioactively labelled particle and a pair of positron-sensitive γ-ray detectors are used to locate the particle at a specific time, as shown on Fig. 4. The marker used is generally $^{18}$F, $^{64}$Cu or $^{68}$Ga, which decay via β+ and hence emit positrons.

![Fig. 4 PEPT Schematic Diagram](Image)

Source: Seville, 2010

Experimental Minimum Fluidisation Velocity ($u_{mf}$)
Experimental $u_{mf} = 0.661$ cm/s. Wen & Wu model predicts $u_{mf} = 0.499$ cm/s (25% error). Tannaus model predicts $u_{mf} = 0.622$ cm/s (6% error).

![Fig. 5 Experimental Results](Image)

Vertical Velocity Profile, Mass Flux and Solid Fraction
Once PEPT data is generated, there are two different methods of determining the bed density $\rho_b$.

- **Occupancy Method**
  Occupancy is defined as the ratio of time the tracer spends in a determined volume over the total time the experiment is conducted. The bed density is then defined as:
  $$\rho_b = \frac{\text{Occupancy}}{\text{Volume}} \times \frac{\text{Total Mass}}{\text{Volume}}$$
  Thus, the bed density can be calculated by dividing the occupancy by the volume of the determined cell.

- **Mass Flux over velocity Method**
  The velocity in direction $p$ is calculated using the five-point algorithm, where:
  $$v_p(i) = \frac{0.1(\Delta u)_{i-2} + 0.15(\Delta u)_{i-1} + 0.25(\Delta u)_{i} + 0.25(\Delta u)_{i+1} + 0.1(\Delta u)_{i+2}}{4}$$
  The net mass flux in height $H$ of the j cross-sectional area is defined as:
  $$\eta_j = \frac{m}{2} \sqrt{\frac{\Delta u}{H}}$$

Conclusions
Experimental unf agrees with model prediction within 10% error. Occupancy method has shown to be more robust and it did not present any inconsistency. Yet, both methods show similar radial $u$ behaviour, particularly at levels 1 and 3. Results indicate lesser $\alpha$ closer to walls, where particles are moving much faster.

Reference List
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Fluidization: A Unit Operation in Chemical Engineering, University of Florida Chemical Engineering Guides, 2015.

Acknowledgments
Funded by the Brazilian Council for Scientific and Technological Development.
Special acknowledgement to Dr. Pablo Garcia.