Introduction to Fluidization

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Fluid bed simulation

Chemical looping Fluid-bed reactor at NETL

Commercial Fluidized Catalyst Cracking (FCC)
An introduction to fluidization

- Fluidization is used widely in the chemical industry
  - Fluid Catalytic Cracking (Hydrocarbons)
  - Catalytic reactions.
  - Drying and calcining.
  - Many reactions.
- Coal, biomass, and waste combustion or gasification.
- Chemical looping.

### Main topics

- Physical description of fluidization.
- Key velocity parameters: minimum fluidization, bubbling, and terminal.
- Fluidization regimes, application, and components.
- Effect of particle morphology
- Reactor configurations.
References


Excellent treatment of practical issues in design of fluid bed combustors and gasifiers.


A classic text on fluidization – get a copy if you work on multi-phase flows.
Physical Description of Fluidization

- A granular material does not typically flow like a fluid; it can form a “pile”; (a).
- But, if you supply fluidizing gas, granular material can behave as a liquid:
  - Horizontal surface (b)
  - Flow from holes (c)
  - Equalizes levels (d)
  - Floats light objects (next slide)
Physical description of fluidized beds (cont.)

- Lighter objects float.
- The bed volume is larger in a fluid state:
  \[ \text{void fraction } \varepsilon = \frac{V_{\text{gas}}}{V_{\text{gas}} + V_{\text{solid}}} \]
- The gas flow rate is typically described by the superficial velocity* \( U \):
  \[ \frac{(\text{Gas volume flow rate})}{(\text{Cross-section area, no solids present})} \]
- The bed pressure drop balances the overhead weight
  \[ \Delta P A_{xc} = A_{xc} L_b (1 - \varepsilon_{mf}) (\rho_{\text{solid}} - \rho_{\text{gas}}) \]

* Typical \( \varepsilon \) values ( - ), \( U \) values [ m/s]: Packed Bed (0.4-0.5) [1-3], Bubbling Bed (0.5-0.85)[0.5-2.5], Circulating Bed (0.85-0.99) [4-6], Transport Reactor(0.98-0.998)[15-30], Basu pp. 22
Velocity parameters

• **Minimum Fluidization Velocity** $U_{mf}$:
  - The superficial velocity that “just” fluidizes; the point where the bed weight balances the pressure drop.
  - Typically you measure $U_{mf}$ to get an accurate value for a new granular material.

• **The minimum bubbling velocity** $U_{mb}$:
  - The velocity where bubbles first appear.
  - Can be equal or greater than $U_{mf}$.

• **The particle terminal velocity** $U_t$:
  - Note the velocity is NOT a uniform profile.
  - What happens if $U > U_t$?

Fluidization regimes: smooth, bubbling, turbulent, fast, pneumatic transport
Application to chemical looping

- Air reactor (right), fuel reactor (left).
- Solids are transported from the air reactor where \( U > U_t \).
- Solids are fluidized in the fuel reactor where \( U_{mf} < U < U_t \).

Questions to discuss:
Where is the pressure the greatest and why?

What controls the solids circulation rate?

What does the loop seal do, and how does it work?
Loop seal and L-valve components

**Loop seal** – Isolates process gas above (A) from process gas below (B).

**L-Valve** - controls the solid flow delivered to the right.

Solid flow

Fluidizing gas

(A)

(B)
The particle properties: effect on fluidization

Fluidization regimes depend on the particle morphology, size, density.

**Geldart Classification A, B, C, D**

A = Aeratable. Can achieve smooth fluidization, low density (<1.4 g/cm³).

B = Bubbles form at \( U_{mf} \). Behaves like sand, particle sizes 40-500 microns, density 1.4 – 4gm/cm³.

C = Cohesive: hard to fluidize, very fine (<40 microns). Behaves like flour, starch.

D = Dense, large particles (+500 microns). Can be difficult to fluidize, will channel and spout. Drying coffee beans, grain, etc.

Mixtures of particle sizes & properties are complicated! Can segregate, de-fluidize, and may not react as expected.
Types of gas-solid reactors

- **Fixed bed**: Not fluidized, $U < U_{mf}$
  - Ex: Stoker.

- **Bubbling fluid bed**: operates $U < U_{tr}$, the particles stay in the bed.
  - Ex: BFB boiler.

- **Circulating fluid bed**: operates $U > U_{tr}$, the particles are carried out of the bed, and are re-cycled.
  - Ex: CFB Boiler, FCC for hydrocarbon cracking.

- **Moving bed**: Not necessarily fluidized, but the solid moves countercurrent to the process gas.
  - Ex: Lurgi gasifier.

- **Entrained**: no “bed”, dilute phase.
  - Ex: Pulverized coal boiler
Discussion-

• The preceding fluidization introduction has covered just hydrodynamics. Also need to consider reactions, conversion, heat transfer.

• If you want to design a solid fuel boiler, what combination of gas-solid reactors is the best?

• What are the tradeoffs for small or large reacting particles?

• Some of these issues are best addressed with validated CFD simulations and system models.
Modeling of Fluidized Beds

(Courtesy: F. Shaffer, NETL)

Movie

DNS  LBM  DEM  MP-PIC  Multi-Fluids  Filtered-Eqs  ROM

www.mfix.netl.doe.gov
Comparison of CFD and Cold Flow Rig

Lighter ash carried out with fluidizing steam or CO₂

Solid fuel into this bed

Oxygen carrier

Air reactor

Movie
Summary

• Introduced the main physics and terminology:
  – Minimum fluidization, pressure drop “lifts” bed
  – Different fluidization regimes
  – Different particle morphology: A, B, C, D
  – Different types of reactors

• Did not cover reactions, heat transfer
  – CFD modeling can address joint processes
  – More discussion in subsequent presentations