INTRODUCTION TO

FLUIDIZED BEDS

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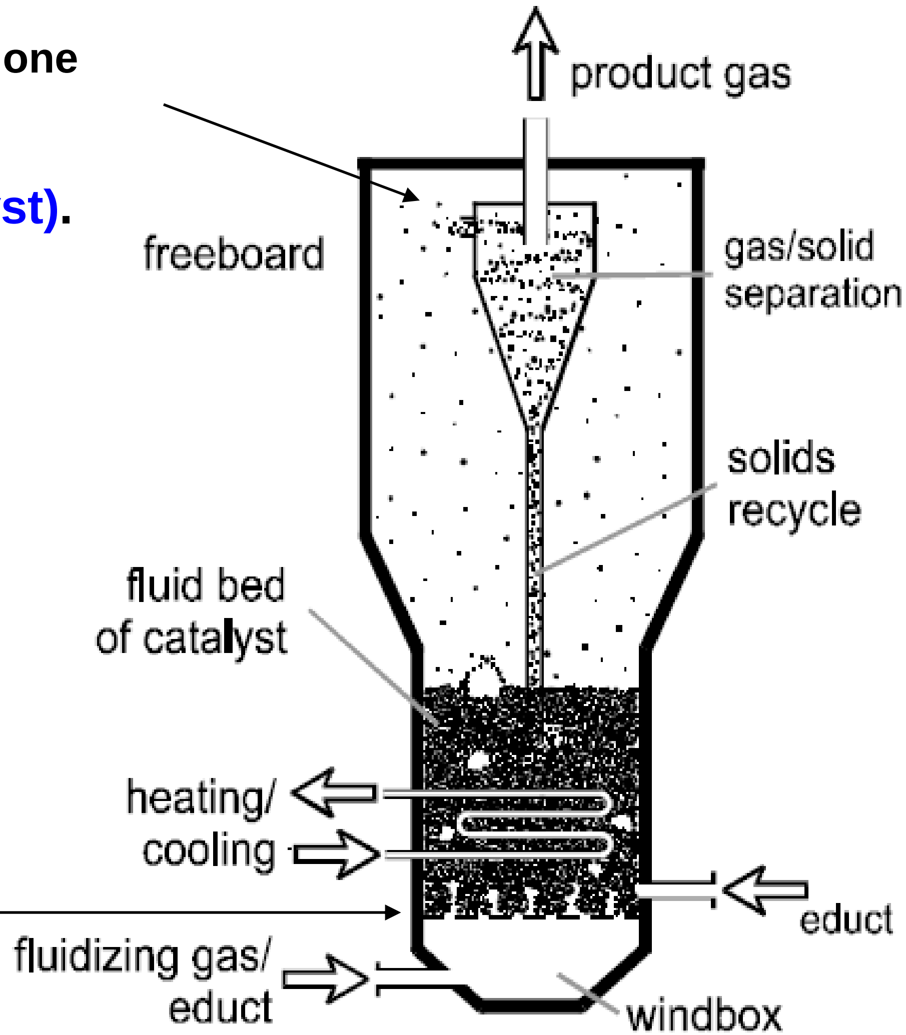
Outline/Contents

- ✓ Introduction.
- ✓ Fluidization Flow Regimes.
- ✓ Overall Gas (Voidage) and solids Hold-up.
- ✓ Radial and Axial Solids Hold-Up Profiles.
- ✓ Radial and Axial voidage distribution.
- ✓ Gas and Solid Mixing.
- ✓ Scale-Up.
- ✓ Reactor Modeling.

Fluidized Bed Reactor Components

The material fluidized is a solid (catalyst).

The fluidizing medium is either a gas or a liquid.



Advantages

- It has the ability to process large volumes of fluid.
- Excellent gas-solid contacting.
- Heat and mass transfer rates between gas and particles are high when compared with other modes of contacting.
- No hot spot even with highly exothermic reaction.
- Ease of solids handling.

Disadvantages

- Broad or even bimodal residence time distribution of the gas due to dispersion and bypass in the form of bubbles.
- Broad residence time distribution of solids due to intense solids mixing.
- Erosion of internals.
- Attrition of catalyst particles.
- Difficult Scale-up due to complex hydrodynamics.

Industrial Applications of Fluidized Bed Reactor

Yang 2003

- ✓ Acrylonitrile by the Sohio Process.
- ✓ Fischer-Tropsch Synthesis.
- ✓ Phthalic anhydride synthesis.
- ✓ Methanol to gasoline and olefin processes.
- ✓ Cracking of Hydrocarbons (Fluid Catalytic Cracking, etc).
- ✓ Coal combustion.
- ✓ Coal gasification
- ✓ Cement clinker production.
- ✓ Titanium dioxide production.
- ✓ Calcination of AL(OH)3.
- ✓ Granulation drying of yeast.
- ✓ Heat exchange
- ✓ Absorption
- ✓ Nuclear energy (Uranium processing, nuclear fuel fabrication, reprocessing of fuel and waste disposal).

Fluidization Flow Regimes

Geldart's Classification of Powders

- ✓ **Group A (Aeratable) :- (e.g., Ammoxidation of propylene) small mean particle size and/or low particle density (<~1.4 g/cm3), gas bubbles appear at minimum bubbling velocity (Umb).**

- ✓ **Group B (Sand-Like) :- (e.g.,Starch) particle size 40 µm to 500 µm and density 1.4 to 4 g/cm3, gas bubbles appear at the minimum fluidization velocity (Umb).**

- ✓ **Group C (Cohesive) :- very fine particle, particle size < 30 µm, difficult to fluidize because inter-particle forces are relatively large, compared to those resulting from the action of gas.**

- ✓ **Group D (Spoutable) :- (e.g., Roasting coffee beans) large particle, stable spouted beds can be easily formed in this group of powders.**

Kunii and Levenspiel (1991)

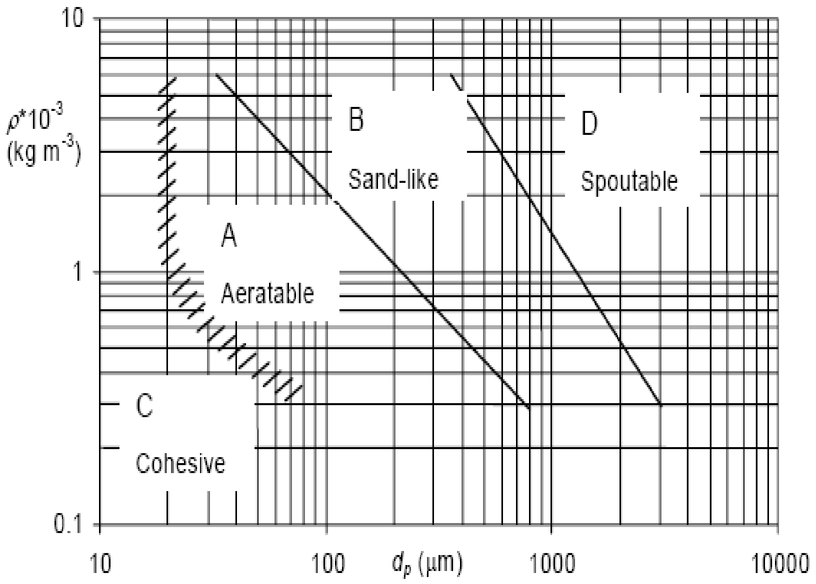
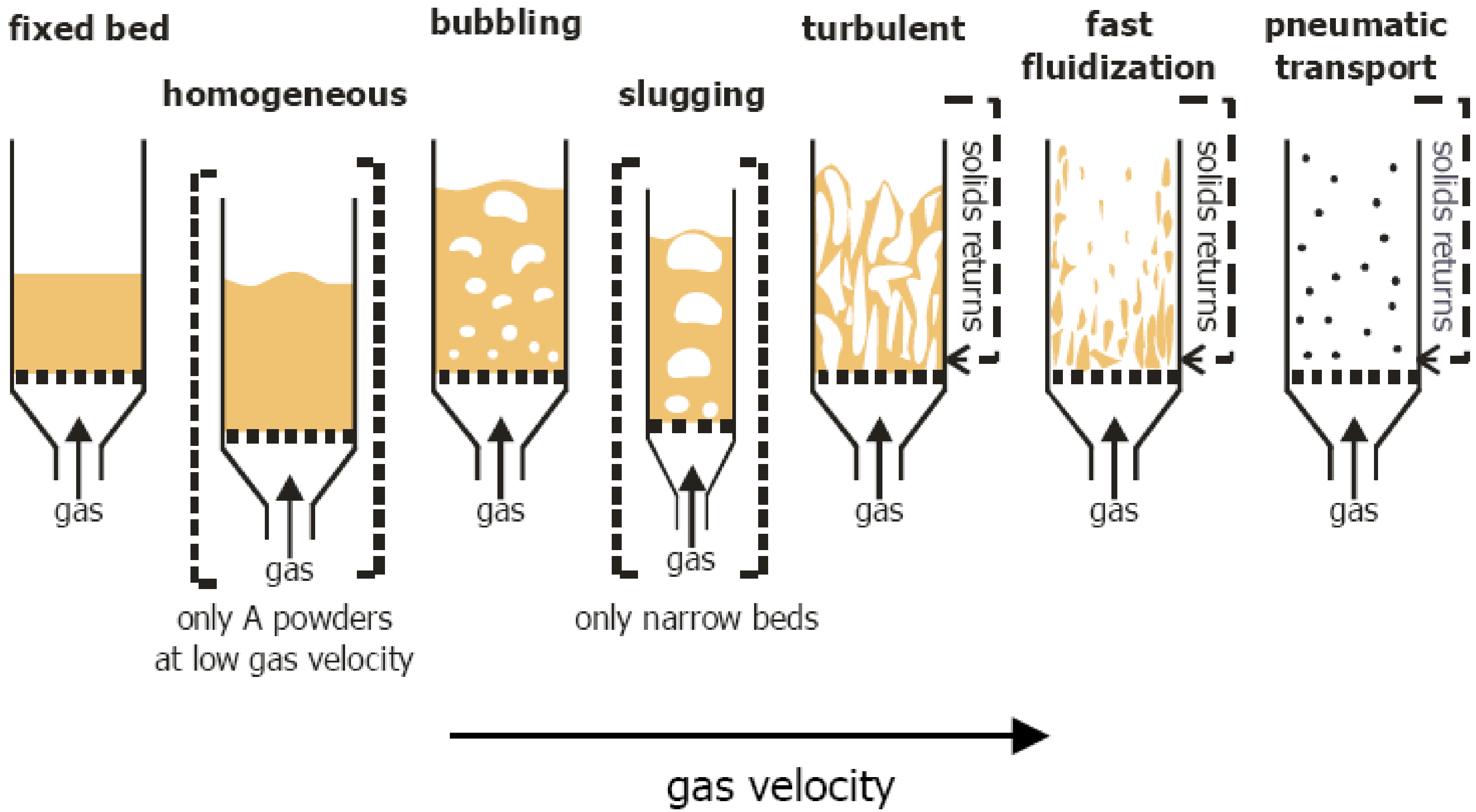


Diagram of the Geldart classification of particles, Geldart (1973).

Flow Regimes in Fluidized Beds

J. Ruud van Ommen, 2003



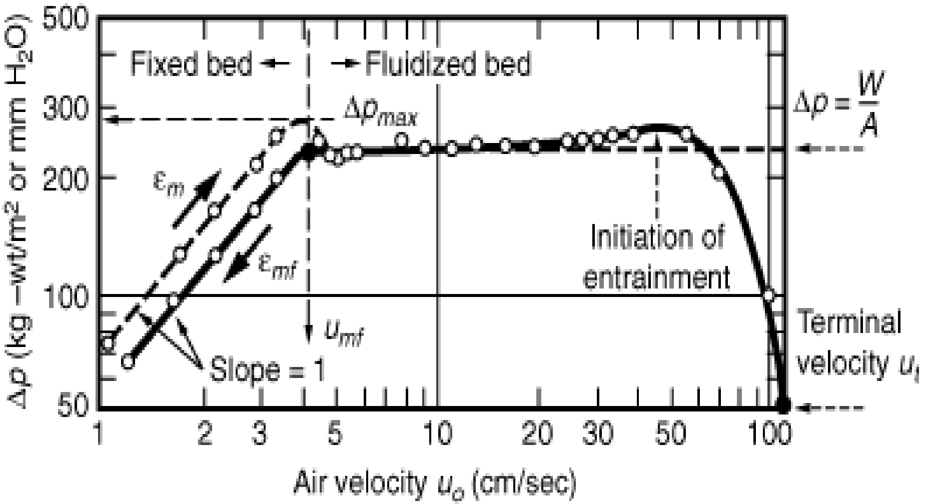
Minimum Fluidization Velocity

This equation can be used to calculate the minimum fluidization velocity U_{mf} if the void fraction ε_{mf} at incipient fluidization is known.

$$(\rho_p - \rho_f)g = \frac{\rho_f u_{mf}^2}{\Phi_s D_p \varepsilon_{mf}^3}\left[\frac{150(1-\varepsilon_{mf})\mu}{\Phi_s D_p u_{mf} \rho_f} + 1.75\right]$$

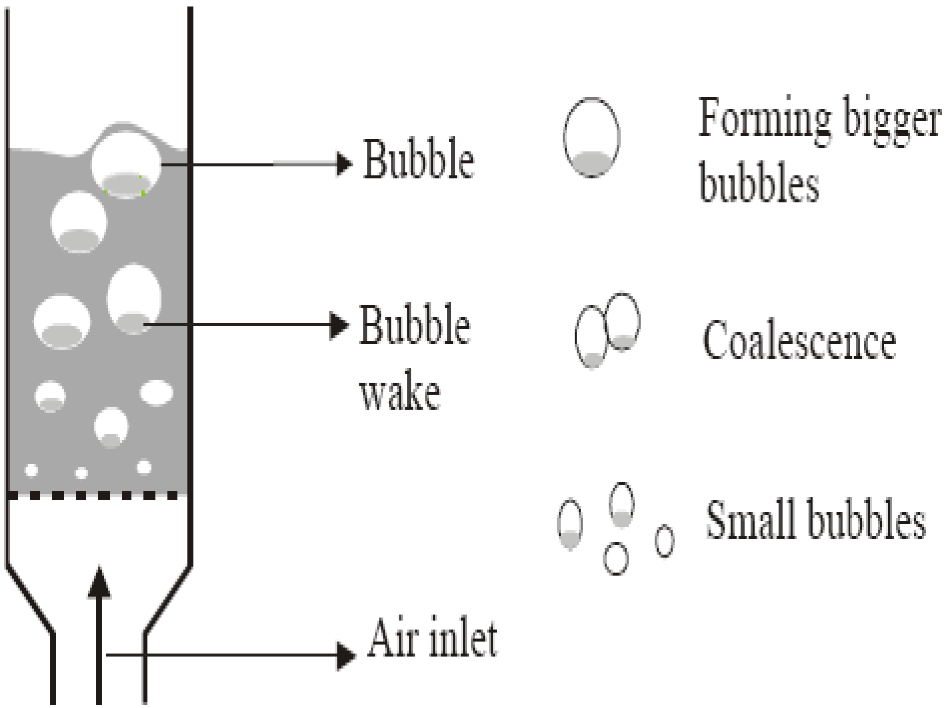
Experimentally, the most common method of measurement requires that pressure drop across the bed be recorded as the superficial velocity is increased stepwise through Umf and beyond, Umf is then taken at the intersection of the straight lines corresponding to the fixed bed and fluidized bed portions of the graph obtained when ΔP_{bed} is plotted against U on log-log coordinates.

Kunii and Levenspiel (1991)



Bubbling Fluidization

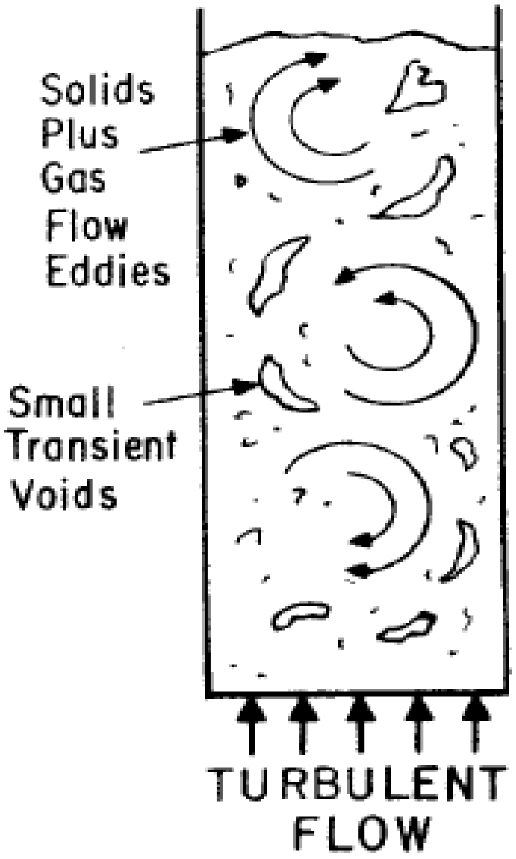
- ✓ This type of fluidization has been called 'aggregative fluidization', and under these conditions, the bed appears to be divided into two phases, the bubble phase and the emulsion phase.
- ✓ The bubbles appear to be very similar to gas bubbles formed in a liquid and they behave in a similar manner. The bubbles coalesce as they rise through the bed.



Turbulent Fluidization

Turbulent regime has the following features:-

- ✓ **High solid hold-ups (typically 25-35 % by volume).**
- ✓ **Limited axial mixing of gas.**
- ✓ **Suitable for exothermic and fast reactions.**
- ✓ **Good gas-solid contact and hence, favors reactant conversion.**
- ✓ **high gas flow-rates operation and good for isothermal operation.**
- ✓ **Favorable bed to surface heat transfer.**



Canada et al. 1978

Some commercial processes in turbulent fluidization

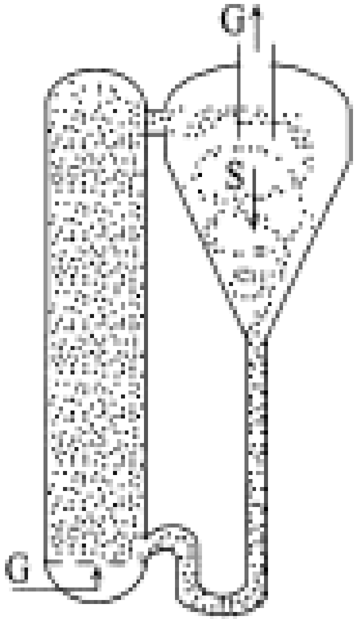
Process	Particle classification	Typical gas velocity (m/s)
FCC regenerators	Group A	0.5-1.5
Acrylonitrile	Group A	~0.5
Maleic anhydride	Group A	~0.5
Phthalic anhydride	Group A	~0.5
Ethylene dichloride	Group A	~0.5
Roasting of zinc sulfide	Group A	~1.5

Bi et al. 2000

Fast Fluidized Bed

- ✓ The fast fluidization occurs as a result of continuing increasing in operating velocity beyond that required at turbulent fluidization, a critical velocity, commonly called the transport velocity (Utr), will be reached where a significant particle entrainment occurs.

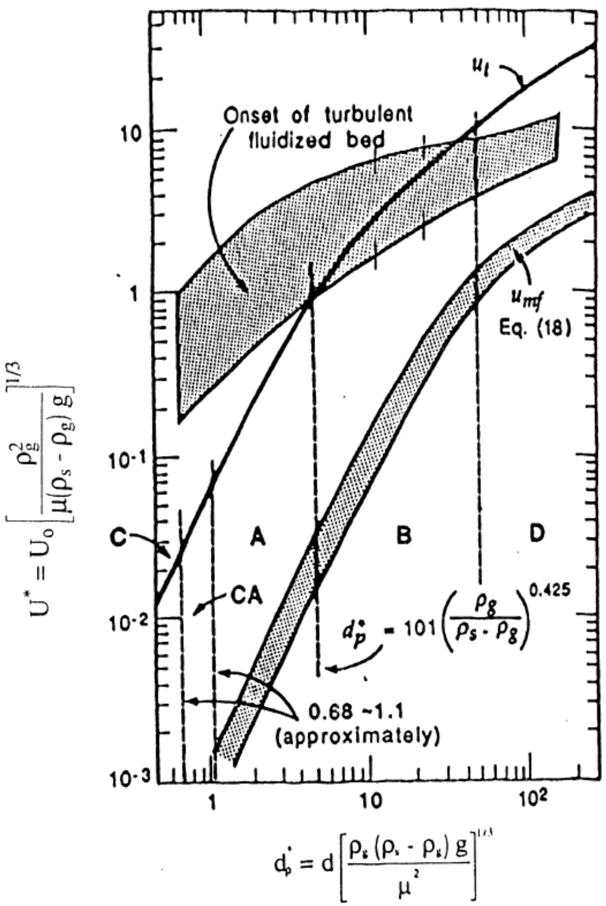
- ✓ The CFB has significant industrial applications because of its efficiency, operational flexibility, and overall profitability (Berruti *et al.*, 1995).



Transition between Fluidization Regimes.

- ✓ Grace (1986a) summarized the effects of particles properties and operating conditions on fluidization behavior and prepared a flow regime diagram. The flow regime diagram was further modified by Kunii and Levenspiel (1997).

- ✓ For given particles and operating velocity, the gas-solid contact pattern can be determined using this diagram. Likewise, for a given flow regime, this diagram could provide available combinations of particle properties and gas velocity.



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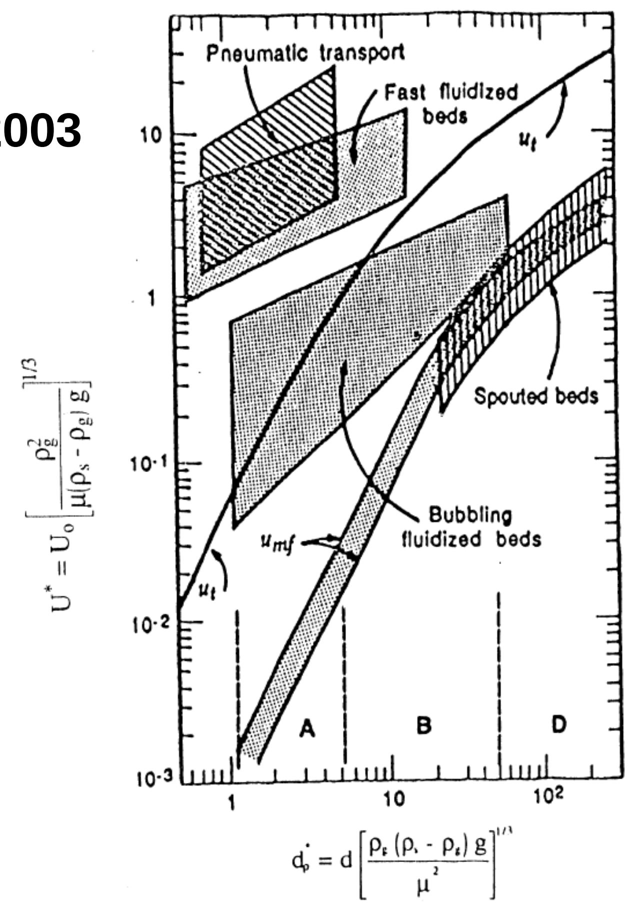
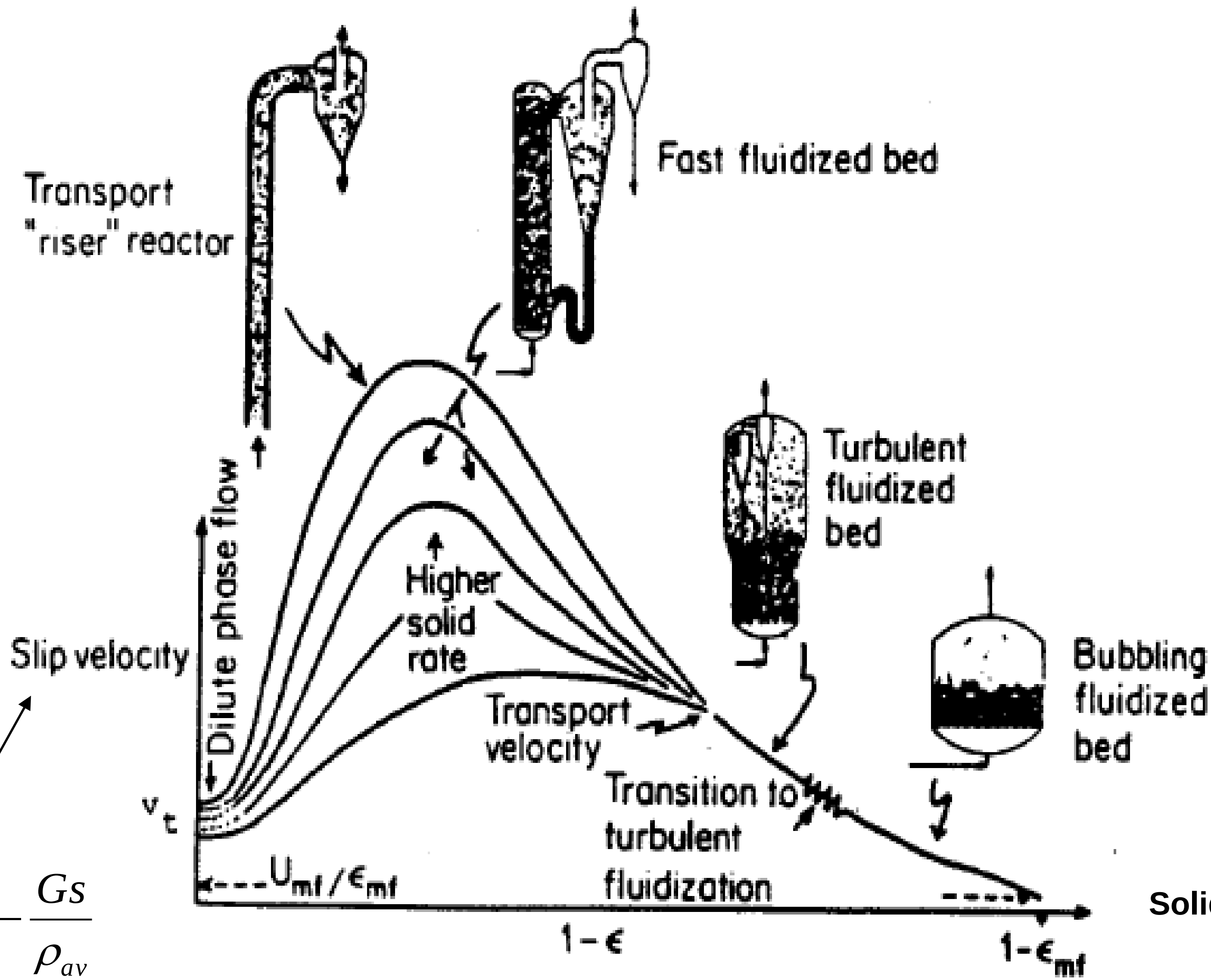


Fluidization diagram



Solid hold-up

$$U_s = \frac{U}{\varepsilon} - \frac{Gs}{\rho_{av}}$$

Yerushalmi and Cankurt, 1970

Methods for Regime Transition Identification

Several measurement methods have been utilized to determine the transition from bubbling or slugging to turbulent fluidization which can be classified into three groups:-

- ✓ Visual Observation,.
- ✓ Pressure Drop-versus Velocity diagram.
- ✓ local and overall bed expansion.
- ✓ Based on signals from pressure transducers, capacitance probes, optical fiber probes, X-ray facilities.

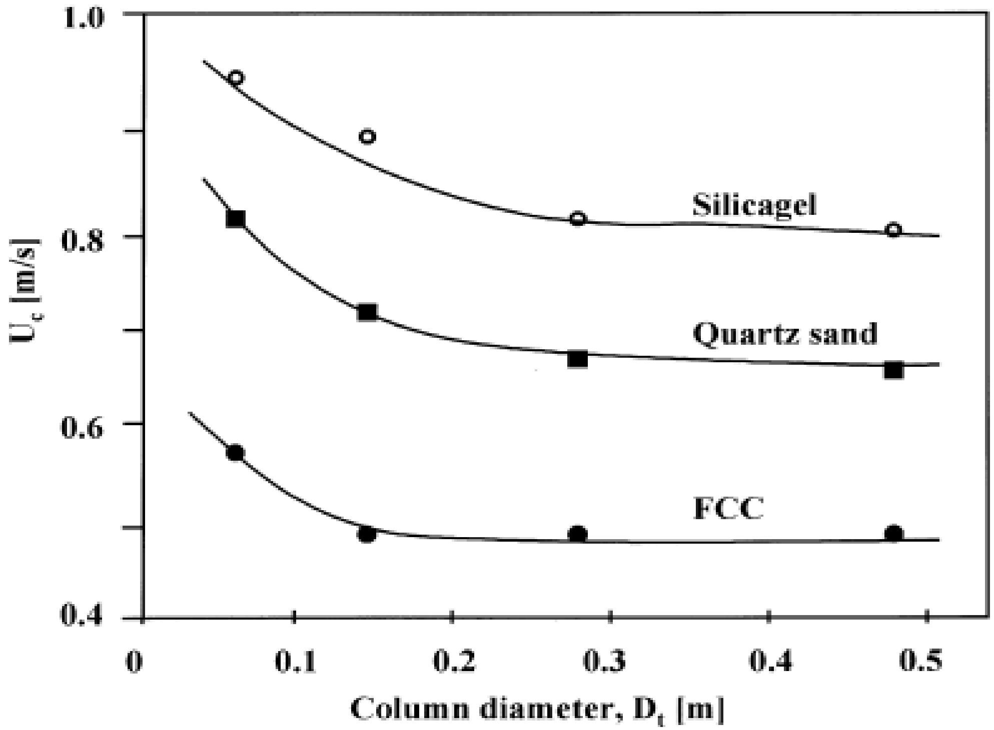
Bi et al. 2000

Generalized effect of operating and design parameters on flow regime transition

Parameter	Effect on flow regime transition
Pressure	In general, pressure accelerates the flow regime transition, thereby decrease transition velocity (Lanneau , 1960, Cai et al. 1989, Yates 1996).
Temperature	Transition velocity increases as the temperature is increased, (Peeler et al., 1999, Cai et al., 1989 and Foka et al., 1996).
Static Bed Height	The transition velocity was almost independent of the static bed height, which varied from 0.4 to 1.0 m (Grace and Sun 1990). Similar results were reported by Cai (1989) and Satija and Fan (1985) with *(Hmf/Dt)* > 2. On the other hand, for a shallow fluidized bed of (*Hmf*/*Dt)* < 2 with Group B and D particles, Canada et al. (1978) and Dunham et al. (1993) found that U*c* increased with static bed height. This could be related to the undeveloped bubble flow in shallow beds before transition to turbulent fluidization can occur (Bi et al. 2000).
Particle Size and Density	U*c* increases with increasing mean particle size and density (Cai et al. 1989, Bi et al. 2000).
Column Diameter	Transition velocity decreases with increasing column diameter for small column, becoming insensitive to column diameter for Dt > 0.2 m, (Cai, 1989). Similar trends were observed by (Zhao and Yang, 1991) with internals.
Internals	Transition to turbulent fluidization tends to occur at lower gas velocities in the presence of internals which usually restrict bubble growth and promote bubble breakup.

Effect of column diameter

Cai (1989)



- ✓ Uc decreases with increasing column diameter for small columns (less than 2 m), becoming insensitive to column diameter for Dt > 0.2 m.
- ✓ Similar trends were observed by Zhao and Yang (1991) in columns with internals.

Some Selected References

- ✓ Cai et al., 1989, "Effect of operating temperature and pressure on the transition from bubbling to turbulent fluidization", AICHE Symposium series, 85, 37-43.
- ✓ Chehbouni et al., (1994), "Characterization of the flow transition between bubbling and turbulent fluidization", Ind. Eng. Chem. Res., 33, 1889-1896.
- ✓ Bi et al., (2000), "A state-of-art review of gas-solid turbulent fluidization", Chemical engineering science, 55, 4789-4825.
- ✓ Andreux et al. (2005), "New description of fluidization regimes", AICHE Journal, 51, No.4, 1125-1130.