Hydrodynamics of Multiphase Reactors

Where are we now?

What is ahead?

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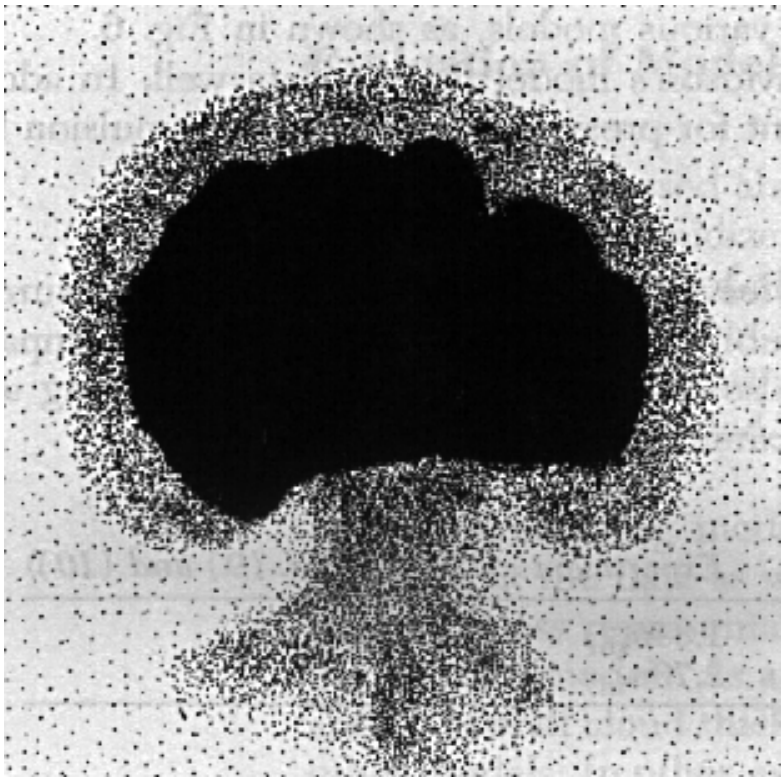
COMMON ISSUES RELATED TO HYDRODYNAMICS

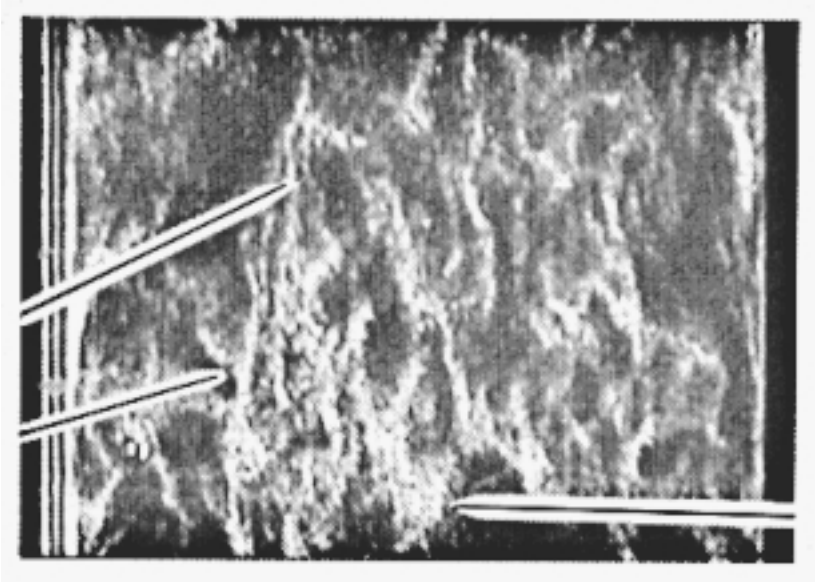
- Maldistribution
- State of uniform flow is frequently unstable
  - spatio–temporal meso–scale structures
  - macro–scale nonuniform structures

- Origin?
- Minimum Physics?

BUBBLES AND CLUSTERS IN GAS–SOLID FLOWS



(Rowe, 1964)

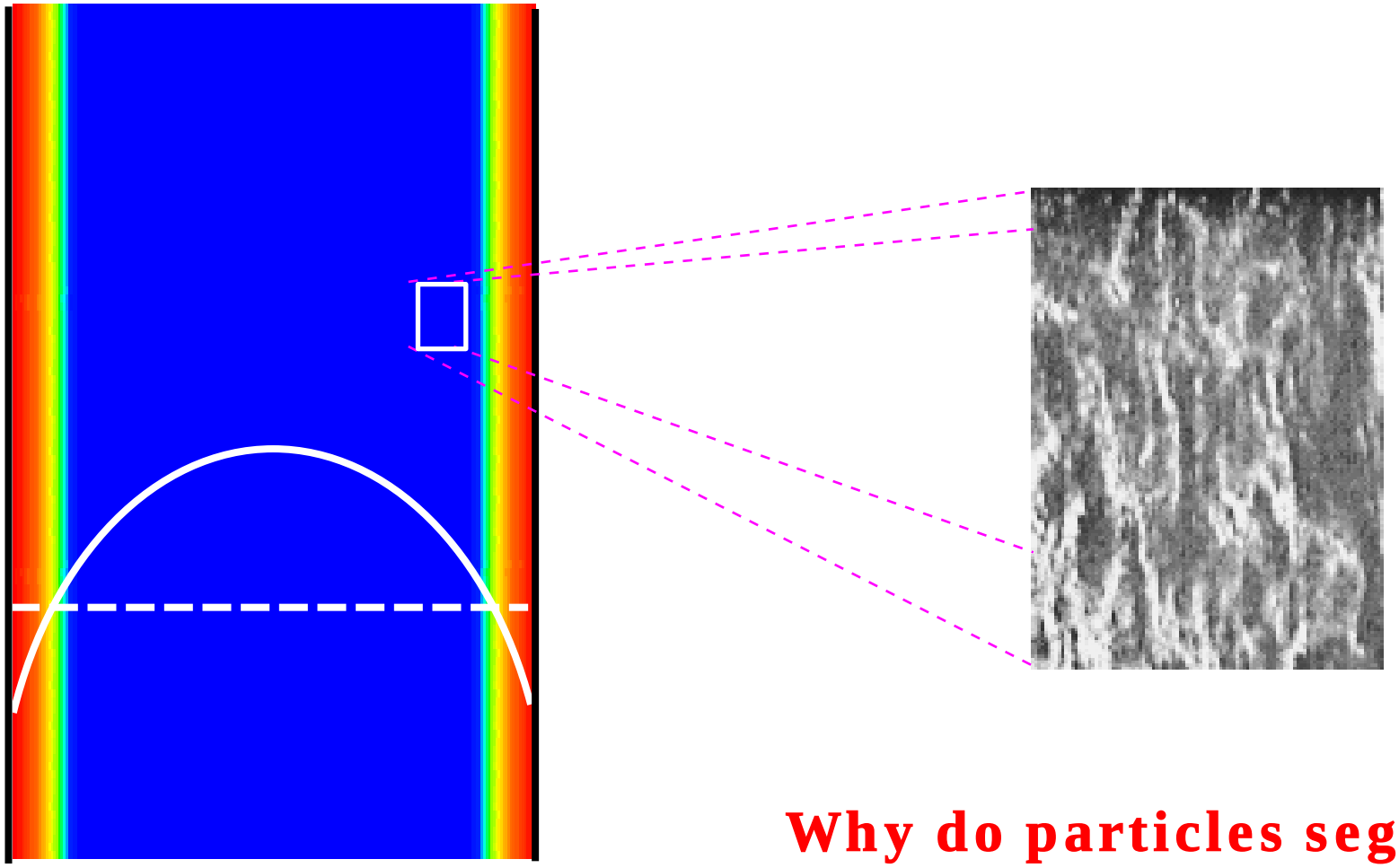


Vertical laser sheet image

(Tsukada, 1995)

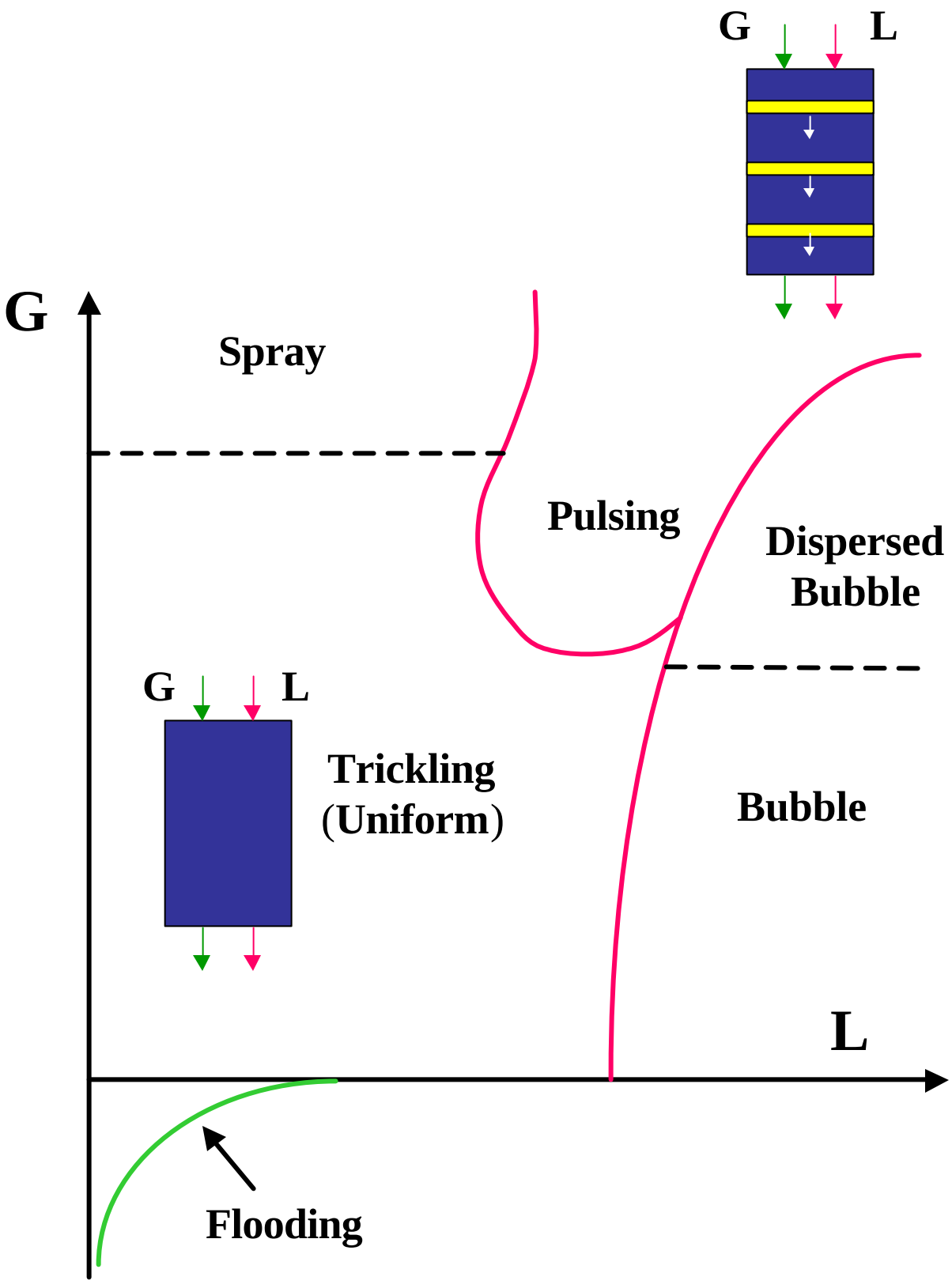
- What is the minimum physics needed to capture these structures ?

FLOW BEHAVIOR IN FAST FLUID BEDS/RISERS

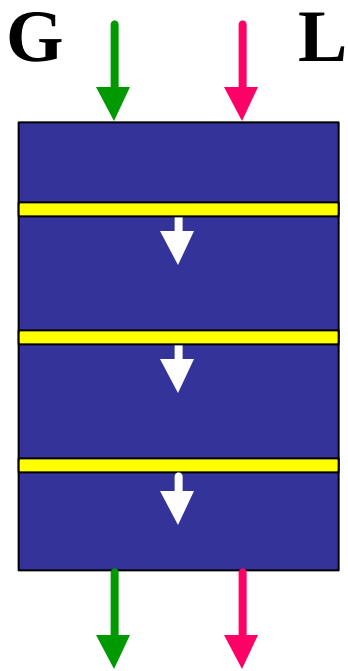


Why do particles segregate ?

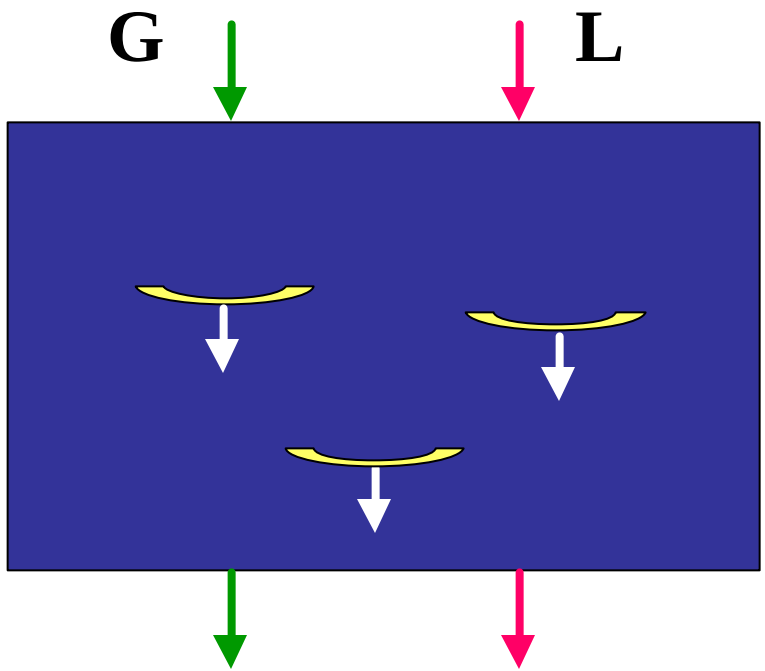
Trickle Bed Flow Regime Map



Pulsing Flow: Scale Effect



Small diameter column

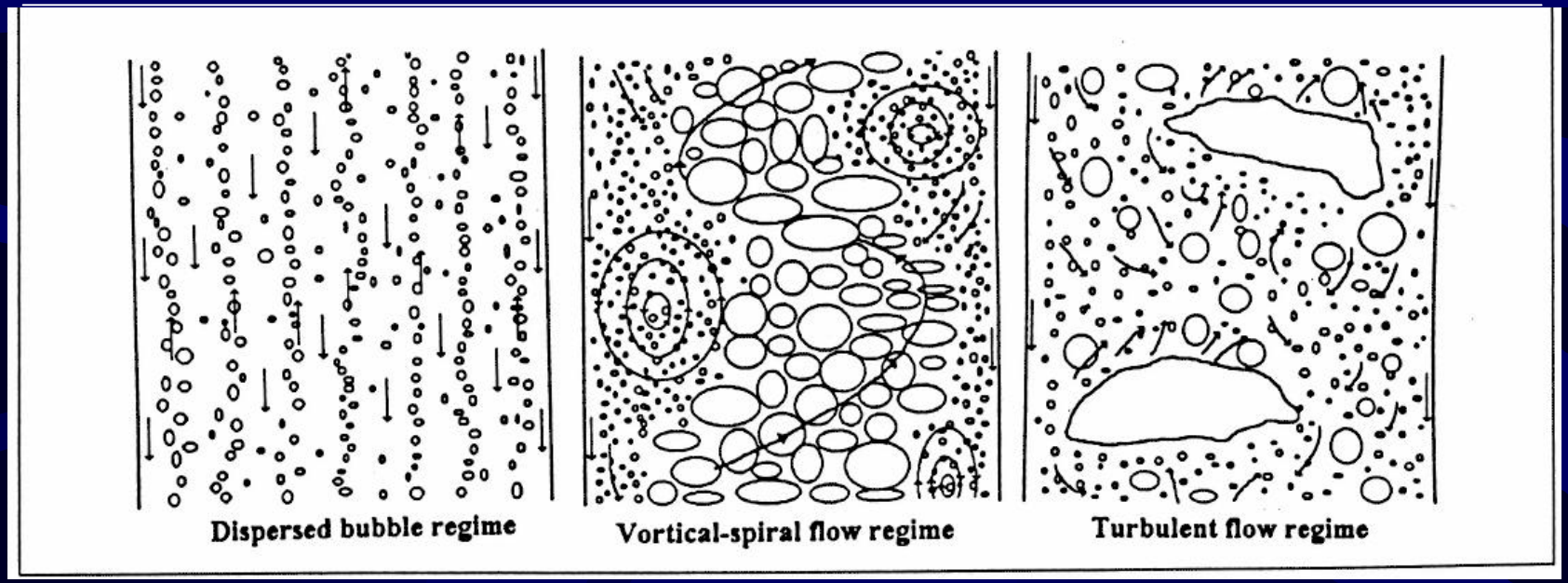


Large diameter column

Christensen, McGovern & Sundaresan (1986)

Dankworth & Sundaresan (1994)

Bubble column flow regimes



Chen *et al.*, 1994

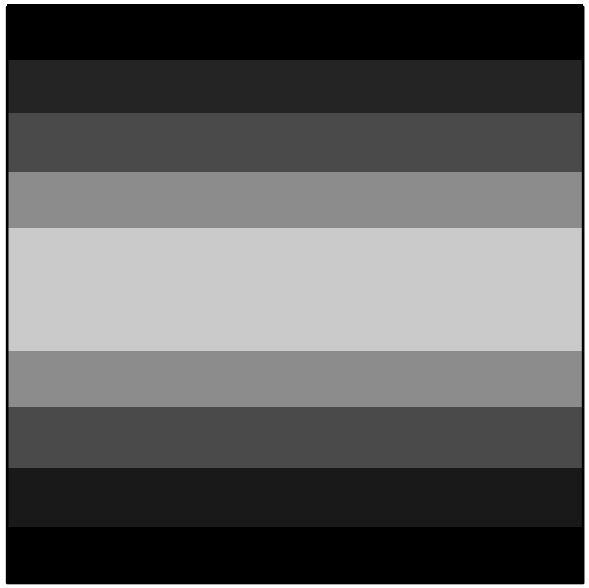
HYDRODYNAMIC MODELING APPROACH

- Locally–averaged Equations of Motion
- For each phase
  - Gravity
  - Inertia
  - Effective stress
- Interphase Interaction
  - Drag
  - Added Mass

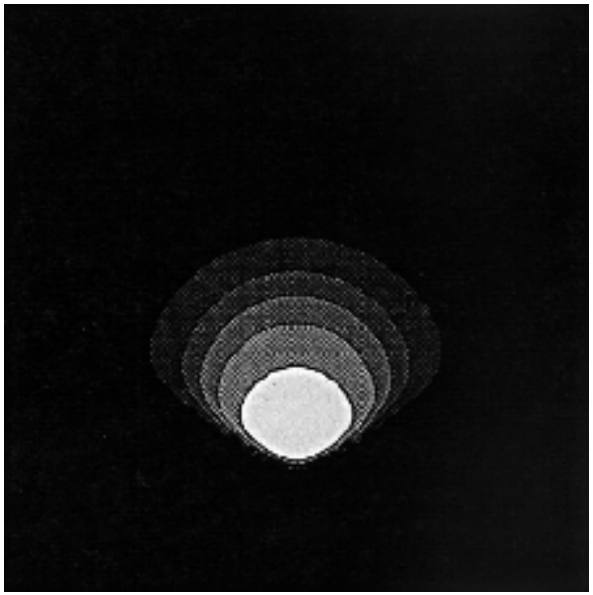
BIFURCATION ANALYSIS OF STRUCTURES IN DENSE FLUIDIZED BEDS

Uniform

1–D Wave

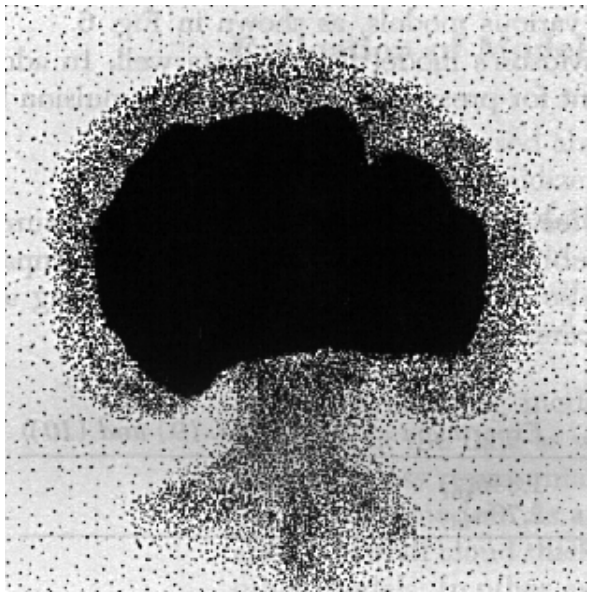


2–D Wave



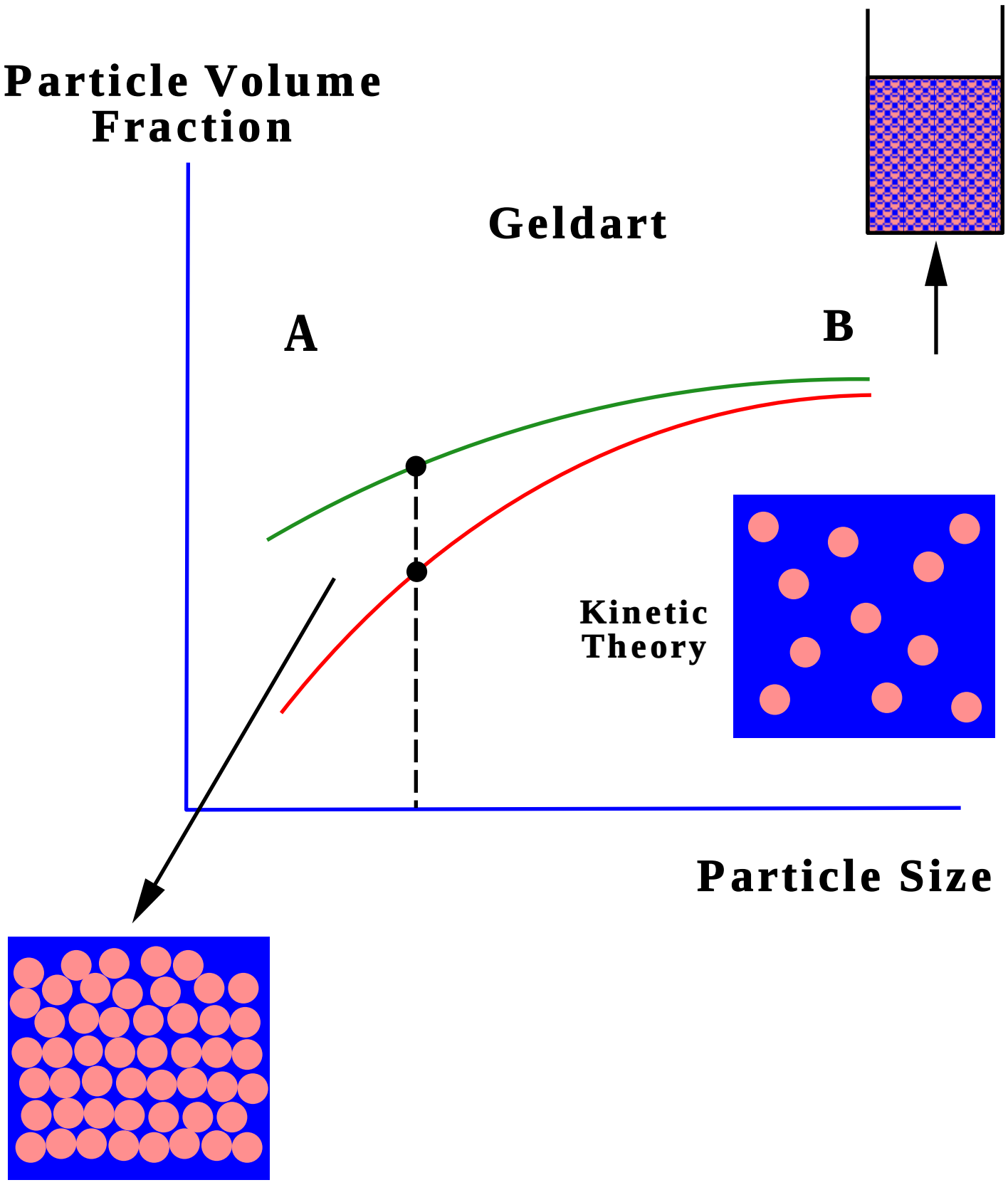
- **drag, gravity**
- **inertia vs. particle phase stress**

Glasser, Kevrekidis & Sundaresan (1996, 1997)

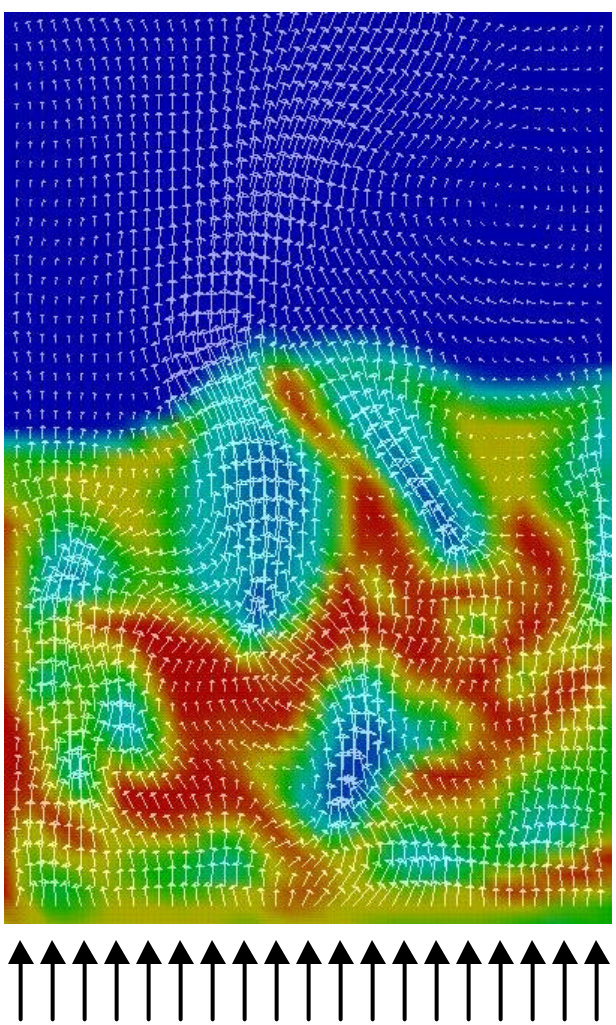


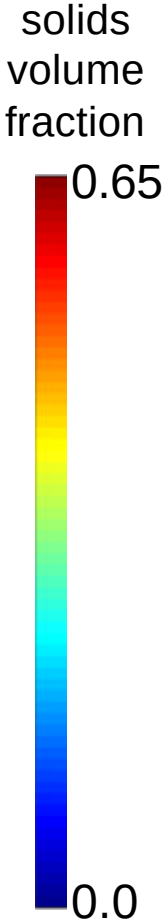
(Rowe, 1964)

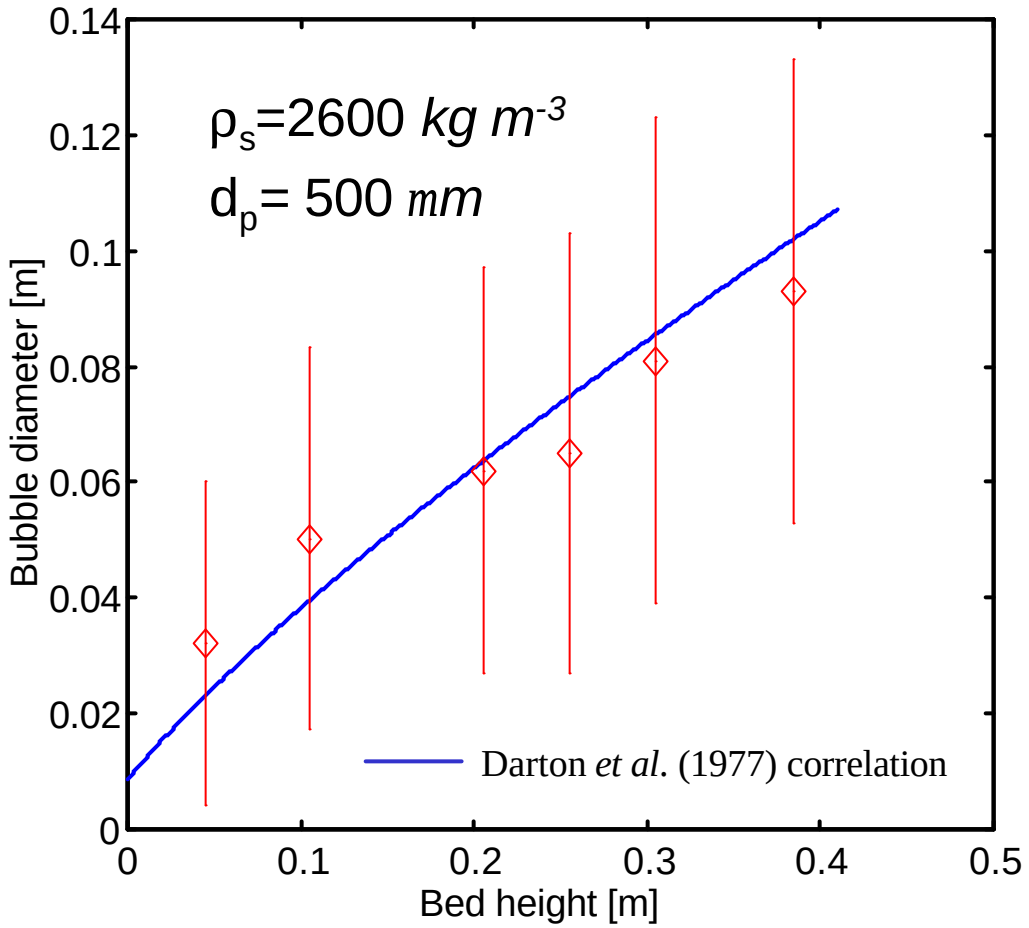
STRESS TRANSMISSION IN PARTICULATE SYSTEMS



CFD Simulation of a Gas Fluidized Bed





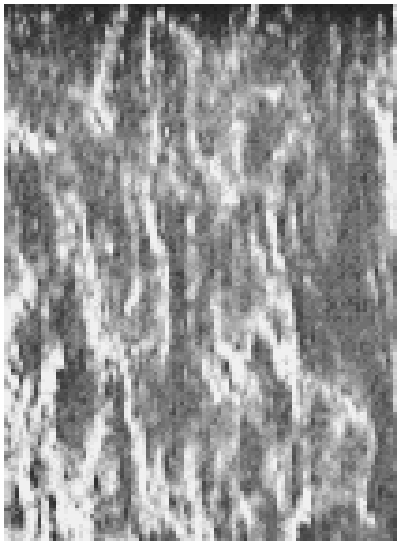


U = 0.54 *m/s* H_0=1.30 *m*

U_{mf} = 0.21 *m/s* D_T = 0.5 *m*

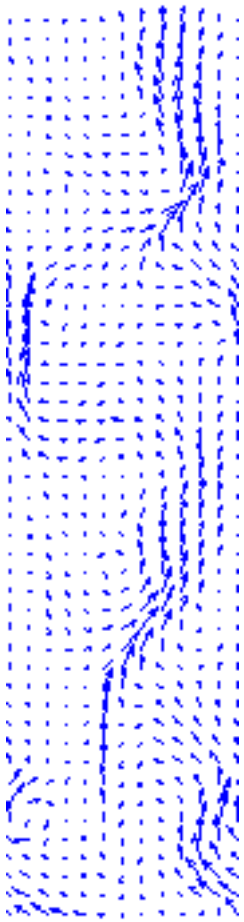
B.G.M. van Wachem, J.C. Schouten, R. Krishna, C.M. van den Bleek, and J.L. Sinclair, "*CFD Modeling of Dense Gas/Solid Systems*", 1999, submitted to *AIChE J.*

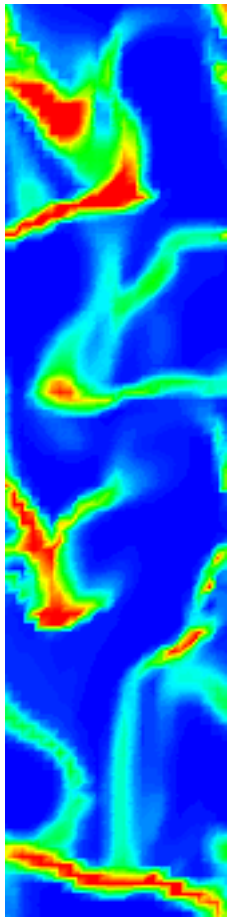
CLUSTERS AND STREAMERS IN DILUTE GAS–SOLID FLOW

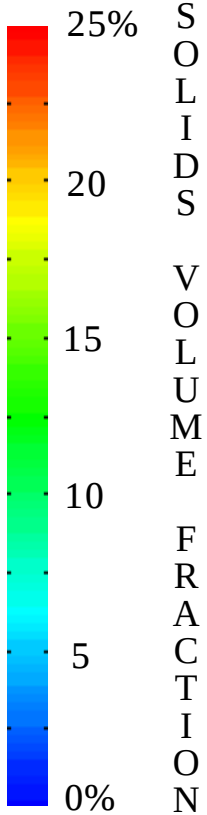


(Tsukada, 1995)

Gas velocity field



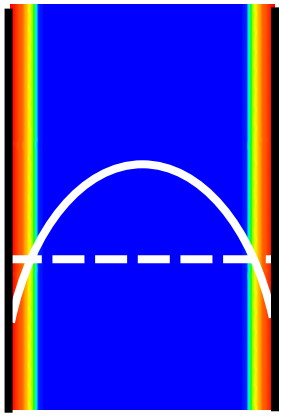




- drag, gravity
- inertia, inelastic collisions

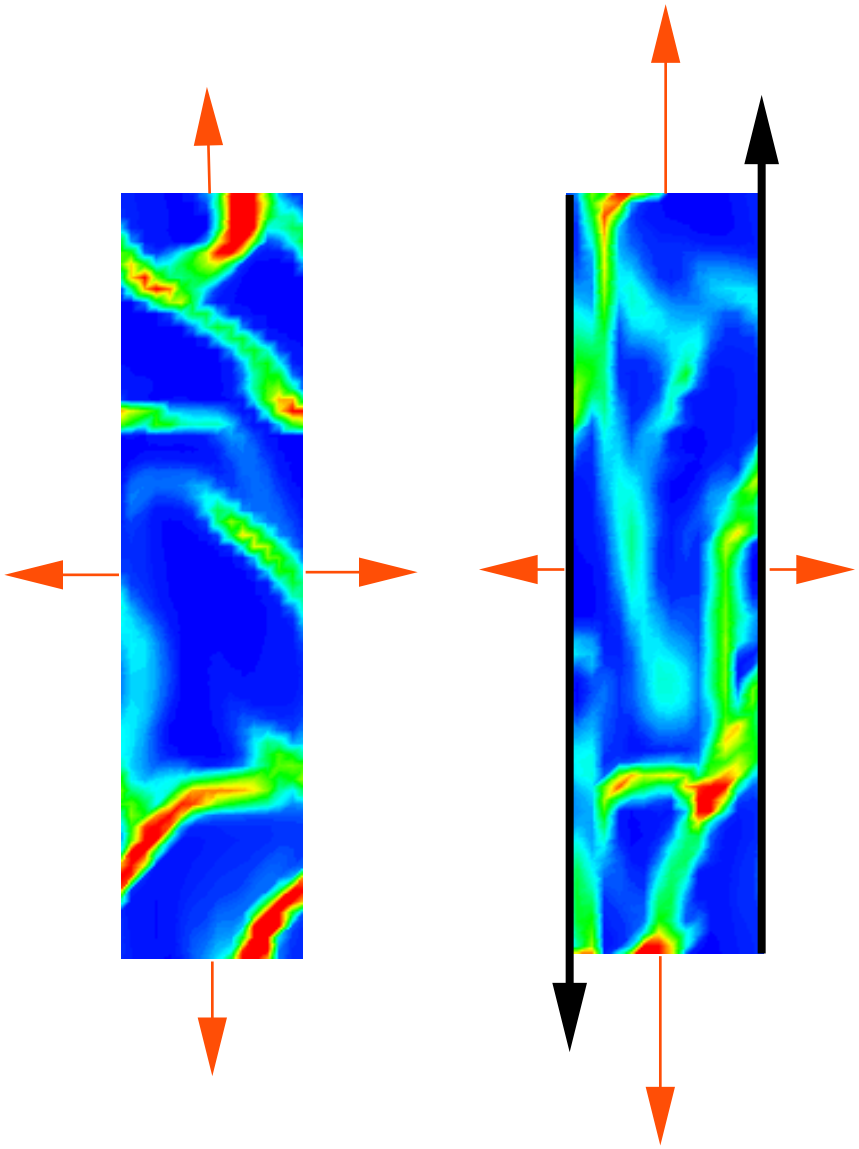
Agrawal (1999)

PHYSICS BEHIND LATERAL SEGREGATION IN RISERS



Gas

Particles



- **EFFECTS OF SHEAR**
  - orients streamers
  - shear thinning
  - normal stress anisotropy
  - lowers horizontal normal stress

Loezos (1999)

Gas-liquid Flow in Packed Columns

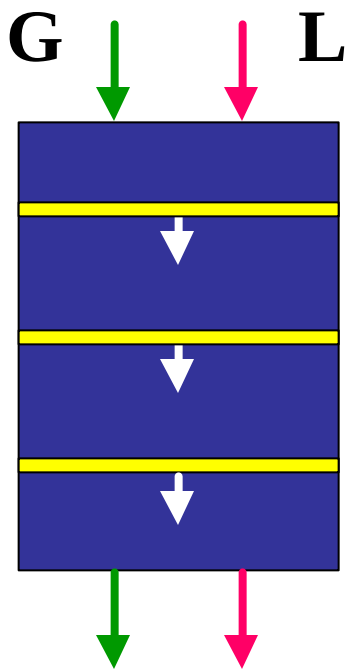
- **Continuum two-fluid model**
  - **inertia** **gravity** **drag**
  - **effective stresses** **(Saez & Carbonell, 1985)**
    - **capillary pressure**
    - **effective viscosities**
- **Trickling-to-pulsing**
  - **inertia overwhelms capillary force**

Grosser, Carbonell, Sundaresan (1988)

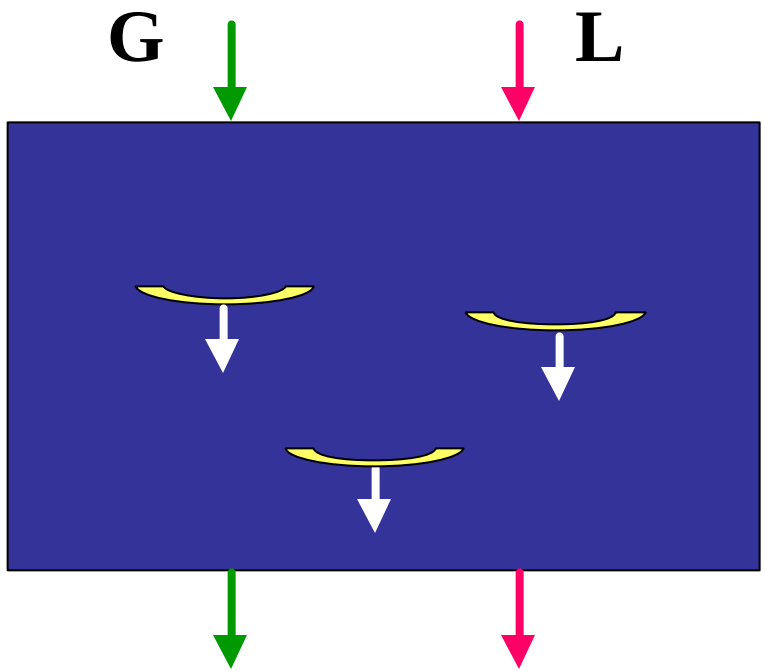
Dankworth, Kevrekidis, Sundaresan (1990)

Attou, Ferschneider (1999)

Pulsing Flow: Scale Effect



Small diameter column

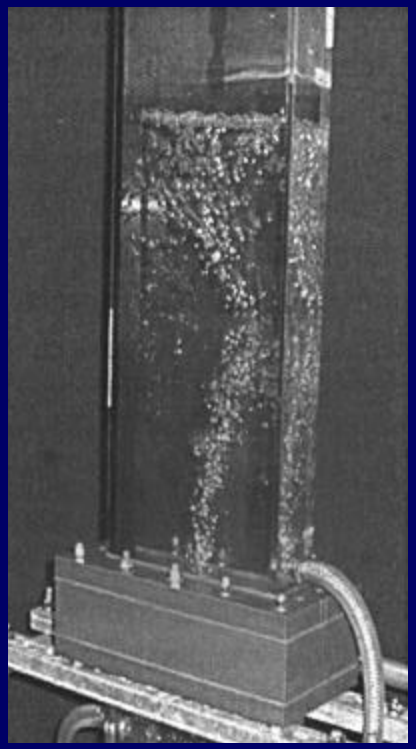


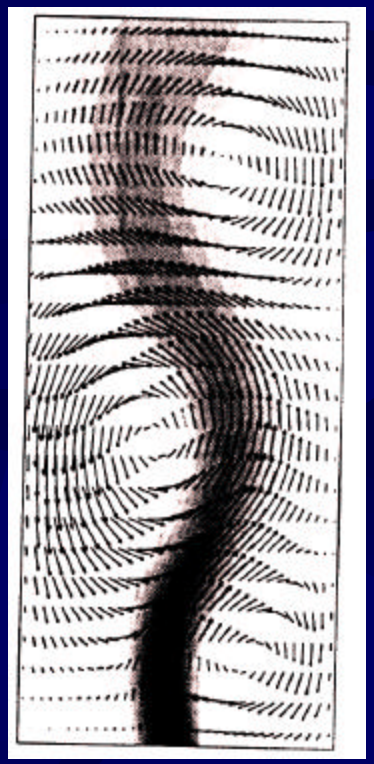
Large diameter column

Christensen, McGovern & Sundaresan (1986)

Dankworth & Sundaresan (1994)

Meandering swarm of bubbles





- **Inertial instability**
  - drag
  - added mass
  - inertia
  - gravity
- **Length and time scales**
  - viscosity

Pfleger *et al.*, 1999
BASF

HYDRODYNAMICS OF MULTIPHASE REACTORS

Where are we now:

- Qualitative understanding of the meso–scale and macro–scale structures
- CFD tools to perform computational experiments

What is ahead:

- Quantitative closure models
  - Microhydrodynamics computations
- Quantitative comparisons with data
  - Experimental data of high quality