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

Vertical laser sheet image

(Rowe, 1964)

(Tsukada, 1995)
Why do particles segregate?
Trickle Bed Flow Regime Map

- **Spray**
- **Pulsing**
- **Dispersed Bubble**
- **Bubble**
- **Trickling (Uniform)**
- **Flooding**
Pulsing Flow: Scale Effect

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

Particle Size

Particle Volume
Fraction

Geldart

A

B

Kinetic Theory

Particle Size

STRESS TRANSMISSION IN PARTICULATE SYSTEMS

Particle Volume
Fraction

Geldart

A

B

Kinetic Theory

Particle Size
CFD Simulation of a Gas Fluidized Bed

\[ U = 0.54 \text{ m/s} \quad H_0 = 1.30 \text{ m} \]
\[ U_{mf} = 0.21 \text{ m/s} \quad D_T = 0.5 \text{ m} \]

CLUSTERS AND STREAMERS IN DILUTE GAS–SOLID FLOW

(Tsukada, 1995)

- drag, gravity
- inertia, inelastic collisions

Agrawal (1999)
PHYSICS BEHIND LATERAL SEGREGATION IN RISERS

- **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
    - capillary pressure
    - effective viscosities
  (Saez & Carbonell, 1985)

- 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