Multiple Phase Flow

Burhan S Abdulrazak, Ph.D.
Chemical Engineering Department

Lecture Notes: Flow Regime Maps for Gas-Solid Systems

Introduction

Gas-solid systems involve the flow of gas and solid particles in a variety of configurations, including pipelines, fluidized beds, and pneumatic conveying systems. **Flow regime maps** for gas-solid systems categorize the patterns of interaction between the gas phase and solid particles under different operating conditions. These maps are crucial for understanding flow dynamics, optimizing industrial processes, and ensuring operational safety.

Key Flow Regimes in Gas-Solid Systems

1. **Packed Bed**:
    - Particles are stationary and tightly packed.
    - Gas flows through voids in the packed structure.
    - Low gas velocities prevent particle movement.
2. **Fixed Bed**:
    - Similar to a packed bed but with slight particle rearrangement under higher gas flow.
    - Particle movement is negligible.

3. **Minimum Fluidization**:
   - The gas velocity reaches the **minimum fluidization velocity (U_{mf})**, at which the drag force balances the weight of the particles.
   - Particles are suspended, and the bed behaves like a fluid.
4. **Fluidized Bed**:
   - Gas velocity exceeds U_{mf}, causing vigorous particle movement.
   - Particles are fully suspended, enhancing mixing and heat/mass transfer.
5. **Bubbling Fluidized Bed**:
   - At moderate gas velocities, gas bubbles form and rise through the particle bed.
   - Localized regions of particle movement are created by gas bubbles.
6. **Slugging**:
   - At higher gas velocities, large gas slugs form, displacing large groups of particles.
   - Causes pressure fluctuations and uneven flow.

7. **Turbulent Fluidization**:
   - At even higher velocities, particle movement becomes chaotic and turbulent.
   - Characterized by intense mixing and irregular particle clusters.
8. **Fast Fluidization**:
   - Gas velocity is high enough to create significant particle entrainment.
   - The solid phase is partially carried out of the system unless recirculated.
9. **Pneumatic Transport**:
   - Gas velocities are so high that particles are fully entrained and transported as a dispersed phase.
   - Typical in conveying systems for powders and granules.

Flow Regime Map for Gas-Solid Systems

Axes

- **x-axis**: Gas velocity (U_g), representing the flow rate of the gas phase.
- **y-axis**: Particle-related parameter (e.g., particle size, particle density, or particle Reynolds number, Re_p).

Alternatively:

- The particle Froude number $\left(Fr_p = \frac{U_g^2}{g\,D_p}\right)$ can be used to represent the balance of inertial and gravitational forces.

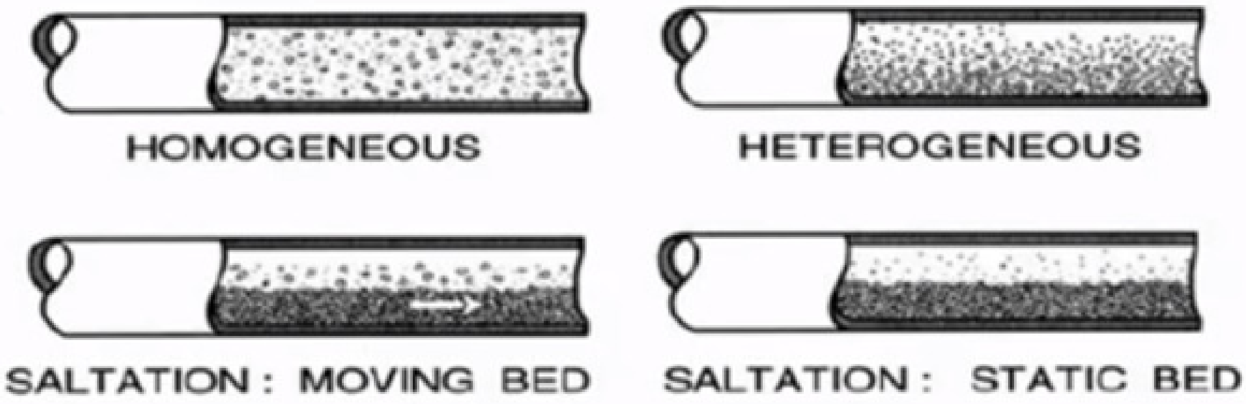
Different Flow Regimes in a Horizontal Pipe for Liquid-Solid System (hydraulic conveying)

Liquid velocity high or

Low solid loading

Increase solid loading or

Decrease the Liquid velocity



Further Increase solid loading or

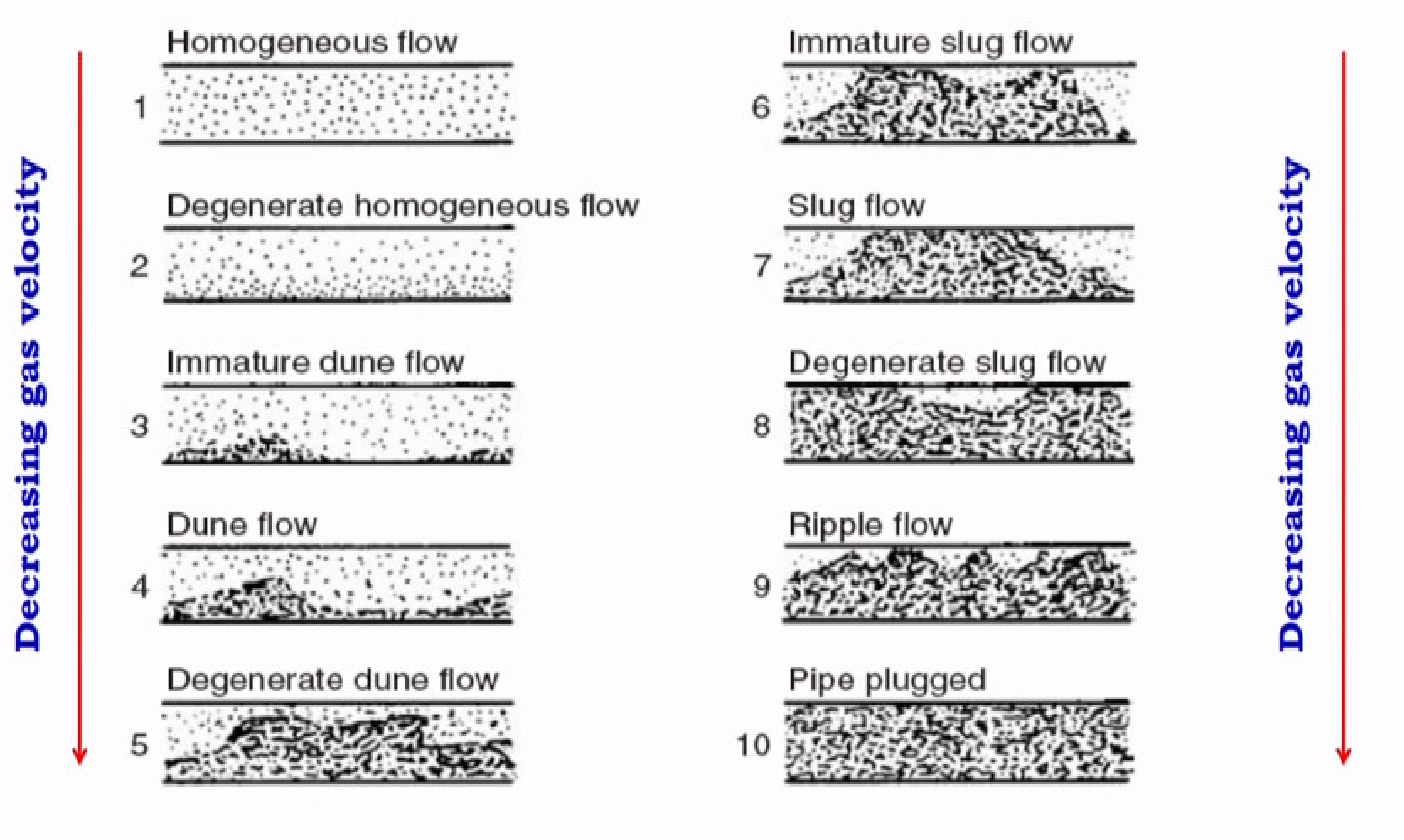
Decrease the Liquid velocity

Further Increase solid loading or

Decrease the Liquid velocity

Flow regimes for liquid-Solid slurry flow in a horizontal pipe

Different Flow Regimes in a Horizontal Pipe for Gas-Solid System (Pneumatic Conveying)



Typical Flow Regime Maps

1. **Geldart Classification (1973)**:
   - Groups particles into four categories (A, B, C, D) based on density and size.
     - **Group A**: Easily fluidized (e.g., fine powders).
     - **Group B**: Sand-like particles with higher densities.
     - **Group C**: Cohesive particles that are difficult to fluidize.
     - **Group D**: Large, heavy particles prone to spouting.
2. **Kunii and Levenspiel Map**:
   - Uses superficial gas velocity and particle properties to delineate regimes.
   - Identifies transitions from bubbling to turbulent and fast fluidization.
3. **Zenz and Othmer Diagram**:
   - Describes flow behavior in pneumatic conveying systems.
   - Identifies dilute-phase and dense-phase transport.

Key Parameters Affecting Flow Regimes

1. **Gas Velocity (U_g)**:
   - Increasing U_g transitions the system from packed beds to fluidized and pneumatic transport regimes.
2. **Particle Properties**:
   - **Density (ρ_s)**: Heavier particles require higher velocities for fluidization.
   - **Size (D_p)**: Smaller particles are more easily fluidized due to lower inertial forces.
3. **Bed Properties**:
   - **Bed Height (H)**: Affects the stability of fluidization.
   - **Void Fraction (ϵ)**: Determines the space available for gas flow.
4. **System Geometry**:

Pipe or reactor diameter influences flow patterns, especially in turbulent and fast fluidization.

Applications of Flow Regime Maps for Gas-Solid Systems

1. **Fluidized Beds**:
   - Used in catalytic cracking, coal gasification, and drying operations.
   - Flow regime maps help optimize mixing and reaction rates.
2. **Pneumatic Conveying**:
   - Critical for transporting powders and granular materials.
   - Maps guide the selection of gas velocity to avoid blockages or excessive wear.
3. **Combustion Systems**:
   - Ensure proper air-fuel mixing in fluidized-bed combustion systems.
4. **Granular Flow Studies**:
   - Helps in studying erosion, sediment transport, and pharmaceutical tablet coating.

Challenges and Limitations

1. **Complex Transitions**:
   - Regime boundaries are often not sharp, requiring experimental validation.
2. **Cohesive Particles**:
   - Fine particles (Geldart Group C) pose challenges due to agglomeration.
3. **Scale-Up Issues**:
   - Laboratory-based maps may not directly apply to industrial-scale systems.
4. **Dynamic Behavior**:
   - Transient flows (e.g., slugging) are difficult to predict accurately.

Example Flow Regime Map

Flow Regime	Superficial Gas Velocity (U_g)
Packed Bed	$U_g < U_{mf}$
Bubbling Fluidized Bed	$U_{mf} < U_g < U_{churn}$
Slugging	$U_{churn} < U_g < U_{turbulent}$
Turbulent Fluidization	$U_{turbulent} < U_g < U_{fast}$
Fast Fluidization	$U_{fast} < U_g < U_{transport}$
Pneumatic Transport	$U_g > U_{transport}$

Conclusion

Flow regime maps for gas-solid systems are indispensable for understanding and optimizing industrial processes. They provide insights into the behavior of gas-solid mixtures across various conditions, enabling better design and control of equipment such as fluidized beds and pneumatic conveyors.