Multiple Phase Flow

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Lecture Notes: Flow Regime Map of Gas-Liquid Systems (Horizontal and Vertical Pipes)

Introduction

- Gas-liquid flows are encountered in various industrial processes, such as chemical reactors, pipelines, and heat exchangers.
- The flow regime depends on the pipe orientation (horizontal or vertical), gas and liquid velocities, and fluid properties.

Flow regime maps are graphical tools used to predict the distribution and behavior of gas and liquid phases under different conditions.

Gas-Liquid Flow Regimes

1. Horizontal Pipe Flow Regimes

In horizontal pipes, gravity plays a significant role in determining the flow pattern.

Bubble Flow:

- Small gas bubbles are dispersed in the liquid phase.
- Gravity causes the bubbles to move preferentially toward the top of the pipe.

Stratified Flow:

- Gas flows above the liquid, forming distinct layers (strata).
- Occurs at low liquid and gas velocities.

Slug (Plug) Flow:

- Large gas bubbles alternate with liquid slugs.
- Gas bubbles occupy nearly the full pipe diameter and are separated by liquid.

Wavy Flow:

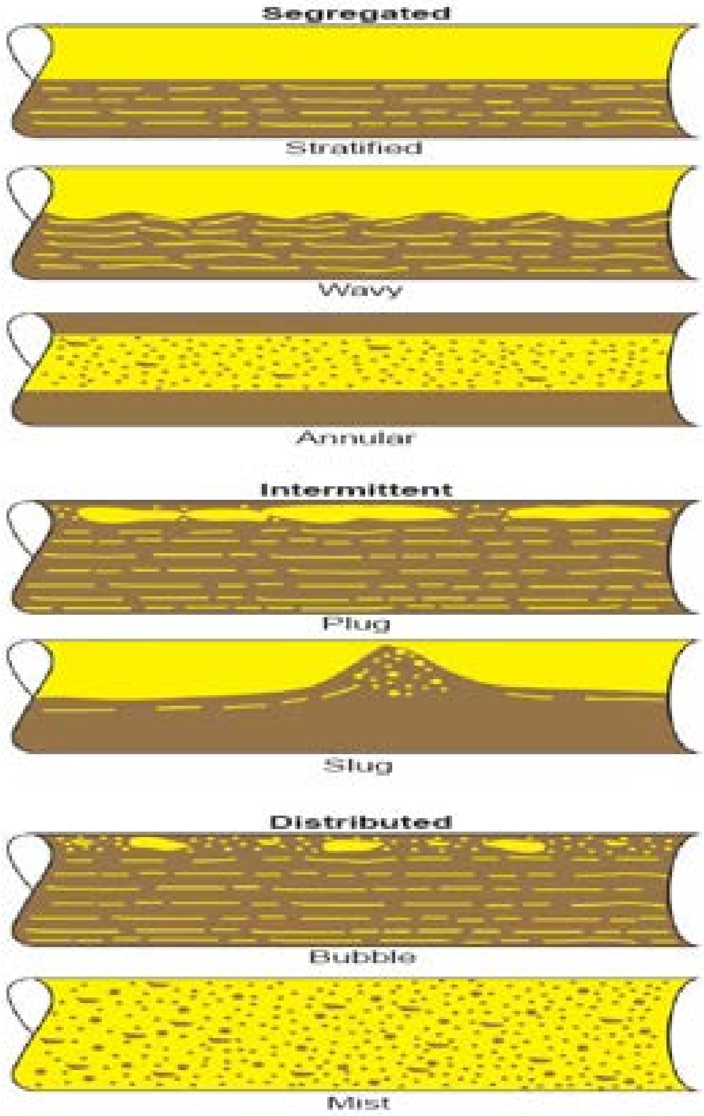
- Liquid flows as a layer along the bottom, with gas on top.
- The gas-liquid interface forms waves due to gas velocity.

Annular Flow:

- Gas flows in the center with a thin liquid film on the pipe wall.
- Occurs at high gas velocities.

Mist Flow:

- Gas phase dominates, carrying small liquid droplets.
- Seen at very high gas velocities.



2. Vertical Pipe Flow Regimes

In vertical pipes, the gravitational force acts along the pipe axis, affecting phase distribution.

Bubble Flow:

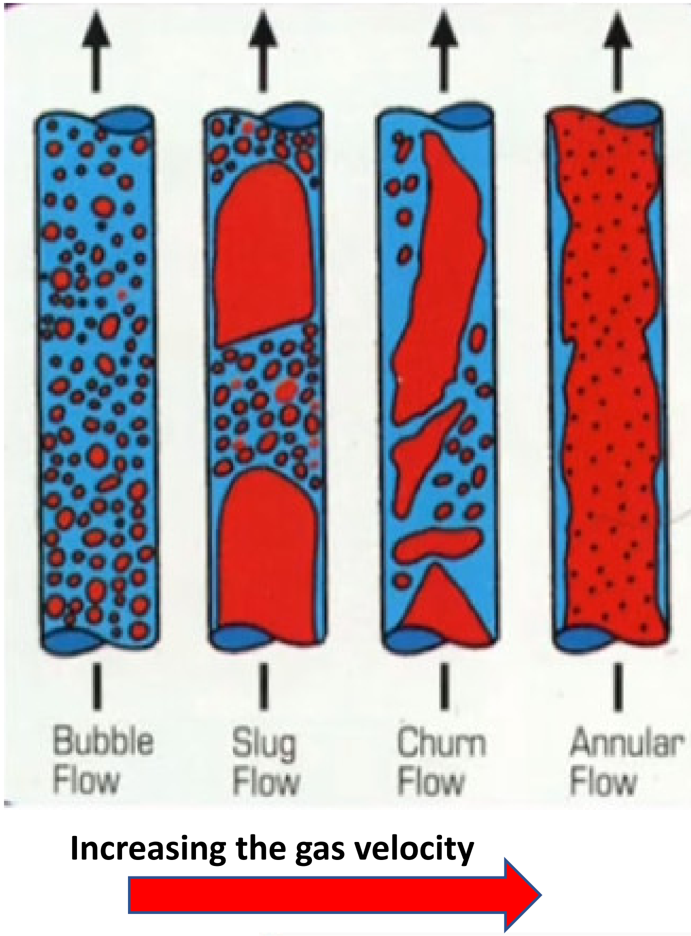
- Similar to horizontal bubble flow but more symmetrical due to gravity alignment.
- Gas bubbles rise through the liquid phase.

Slug Flow:

- Large gas bubbles (Taylor bubbles) form and move upward.
- These bubbles are separated by liquid slugs.

Churn Flow:

- A chaotic and highly turbulent flow regime.
- Transition between slug and annular flow.

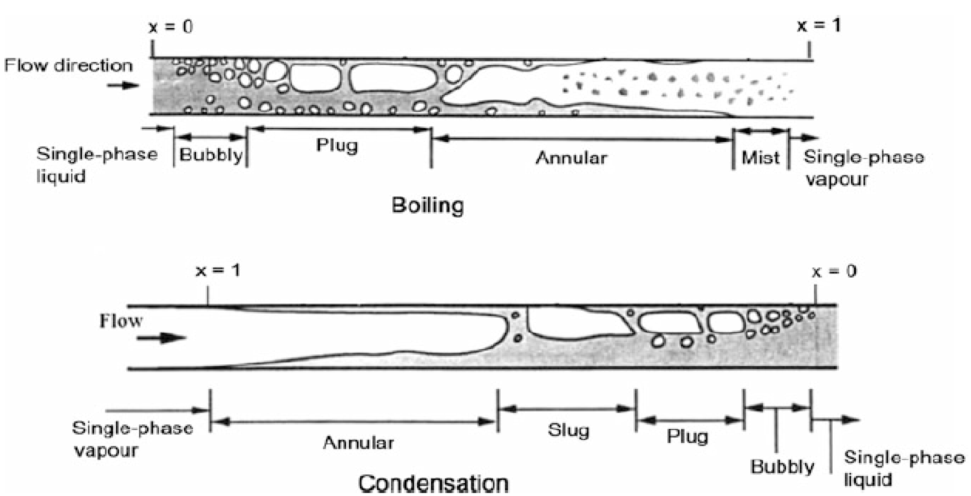


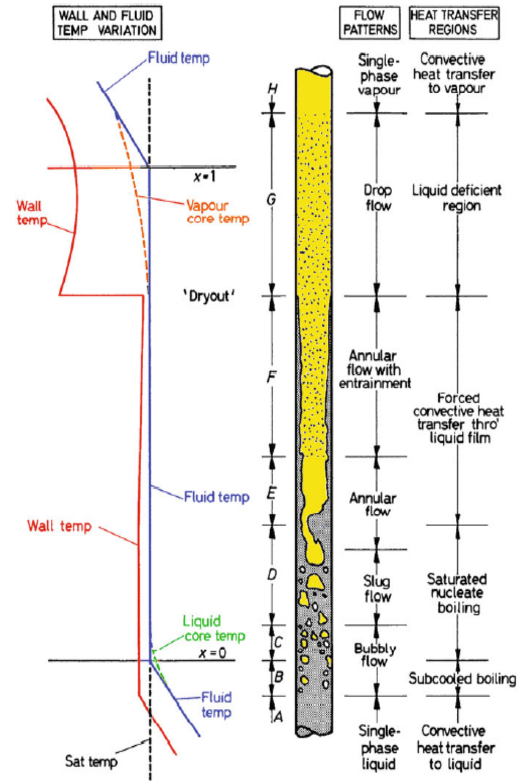
Annular Flow:

- Gas flows up the center, with a liquid film on the pipe walls.
- Liquid film may be thinner at higher gas velocities.

Mist Flow:

- Gas carries small liquid droplets upward.
- Dominates at high gas velocities.





Flow Regime Map for Horizontal Pipes

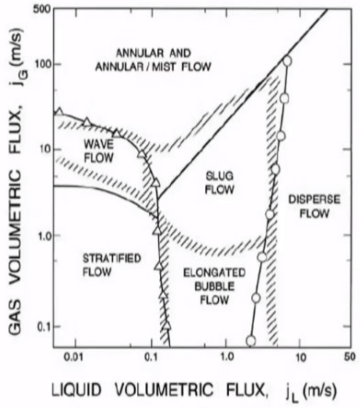
Flow regimes in horizontal pipes are influenced by:

- **Gravity**: Causes phase separation.
- **Interfacial forces**: Control bubble and wave dynamics.

Key examples:

- **Taitel and Dukler Map (1976)**: Predicts transitions between stratified, slug, and annular regimes.
- **Mandhane Map (1974)**: Simplified representation based on experimental data.

Flow Regimes Map for a Horizontal Pipe (2.5 cm)



Flow regimes map for flow of air/water mixtures in a horizontal, **2.5** ***cm*** *diameter pipe. Adapted from Weisman (1983).*

Flow Regime Map for Vertical Pipes

Flow regimes in vertical pipes are influenced by:

- **Gravity**: Promotes phase separation but causes distinct flow behavior compared to horizontal pipes.
- **Interphase Momentum Transfer**: Affects bubble dynamics and liquid entrainment.

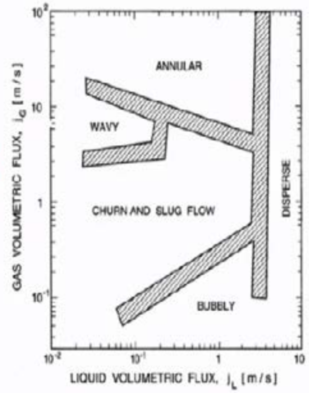
Key examples:

- **Hewitt and Roberts Map (1969)**: Widely used for vertical flows.
- **Wallis Map (1969)**: Focuses on transitions to mist flow.

Mishima and Ishii Map (1984): Incorporates experimental data for small-diameter pipes.

Flow Regimes Map for a Vertical Pipe (2.5 cm)

Generally in gas-liquid vertical flow system :
Liquid volumetric flux << Gas volumetric flux



A flow regime map for the flow of an air/water mixture in a vertical, **2.5 cm** *diameter pipe showing the experimentally observed transition* regions hatched;

Comparison: Horizontal vs. Vertical Pipe Flow Regimes

Aspect	Horizontal Pipes	Vertical Pipes
Key Flow Regimes	Stratified, bubbly, slug, annular, dispersed	Bubbly, slug, churn, annular, dispersed
Effect of Gravity	Promotes stratification and phase separation	Affects rise of gas bubbles and droplet motion
Flow Pattern	Strong phase layering	Axisymmetric distribution (for many regimes)
Key Transitions	Stratified → Wavy → Slug → Annular → Dispersed	Bubbly → Slug → Churn → Annular → Dispersed
Dominant Tools	Taitel & Dukler, Mandhane maps	Hewitt & Roberts, Wallis maps

Factors Influencing Flow Regimes

Superficial Velocities:

- $v_{sL} = \frac{Q_L}{A}$: Liquid superficial velocity.
- $\mathrm{v_{sG}} = \frac{\mathrm{Q_G}}{\mathrm{A}}$: Gas superficial velocity.

Pipe Diameter:

- Larger diameters favor stratified flow in horizontal pipes.

Fluid Properties:

- Surface tension, viscosity, and density impact the flow regime.

Orientation:

- Horizontal pipes experience gravity-driven stratification.
- Vertical pipes show more symmetric phase distribution.

Applications

Oil and Gas Pipelines:

- To manage multiphase transport in horizontal and vertical wells.

Chemical Reactors:

- Ensure proper gas-liquid mixing.

Heat Exchangers:

Optimize phase interaction for heat transfer.

Conclusion

Flow regime maps are essential tools for understanding gas-liquid behavior in horizontal and vertical pipes. Engineers use maps like the Mandhane, Taitel-Dukler, and Baker charts to design and optimize multiphase flow systems.