Multiple Phase Flow

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Introduction

The **drift-flux model** is a multiphase flow model that describes the relative motion between phases in systems such as gas-liquid, liquid-solid, or gas-solid flows. It bridges the gap between the **homogeneous flow model** (no slip between phases) and the **separated flow model** (full slip consideration) by incorporating the effects of relative motion (or drift) between phases.

The drift-flux model is particularly useful for analyzing phase distributions and calculating parameters like void fraction, flow rates, and velocities in practical engineering systems.

Key Assumptions

Slip Between Phases:

- Different phases can flow at different velocities ($u_g \neq u_l$), but their behavior is coupled.

Uniform Distribution:

- The phases are assumed to be uniformly distributed within the control volume or cross-sectional area.

Single Velocity Field:

- The model uses a weighted-average mixture velocity (u_m) to describe the bulk flow.

Drift Velocity:

- The relative velocity (drift velocity) between phases is explicitly modeled.

Governing Equations

1. Mixture Velocity (u_m)

The mixture velocity is the volumetric flux averaged over all phases:

$$u_m = \alpha_g u_g + \alpha_l u_l$$

Where:

- um: Mixture velocity
- ug,ul: Gas and liquid phase velocities
- αg,αl: Volume fractions of gas and liquid phases ($\alpha_g + \alpha_l = 1$)

2. Phase Velocity Relationship

The velocity of a phase (e.g., gas) can be expressed as:

$$u_g = u_m + V_{gj} (1 - \alpha_g)$$

Where:

- V_{gj}: Drift velocity of gas relative to the mixture.

Similarly, for the liquid phase:

$$u_l = u_m - V_{gj} \alpha_g$$

3. Drift Velocity (V_{gj})

The drift velocity represents the relative motion between phases and depends on:

- Gravity
- Buoyancy
- Shear forces
- Flow regime

Empirical correlations are often used to estimate V_{gj}, such as Zuber and Findlay's drift flux correlation:

$$V_{gj} = C_0 \cdot j + V_d$$

Where:

- C_0: Distribution coefficient (accounts for phase distribution and flow regime)
- j: Mixture volumetric flux ($j = u_m$)
- V_d: Drift velocity under static conditions

4. Void Fraction (α_g)

The void fraction can be related to the mixture velocity and drift velocity as:

$$\alpha_g = \frac{j_g}{C_0 j + V_d}$$

Where:

- $j_g = \alpha_g u_g$: Superficial gas velocity

Key Parameters

Void Fraction (α_g):

- The fraction of the pipe cross-sectional area occupied by the gas phase.

Drift Velocity (V_{gj}):

- Describes the relative motion of gas phase to the bulk mixture.

Distribution Coefficient (C_0):

- Depends on the flow regime and geometry.

Flow Quality (x):

- The mass fraction of the gas phase:

$$x = \frac{\dot{m}_g}{\dot{m}_g + \dot{m}_l}$$

Applications

Nuclear Reactor Safety Analysis:

- Predicts phase distribution in coolant systems of boiling water reactors.

Oil and Gas Industry:

- Used in modeling multiphase flow in pipelines and risers.

Heat Exchangers:

- Analyzes void fraction and phase velocities in evaporators and condensers.

Chemical Reactors:

- Models gas-liquid distribution in bubble column reactors.

Advantages

Realistic Phase Interaction:

- Incorporates phase slip, improving accuracy compared to the homogeneous flow model.

Computational Simplicity:

- Less complex than the separated flow model while providing reasonable accuracy.

Empirical Correlations:

- Well-supported by experimental data for common systems.

Limitations

Empirical Dependence:

- Requires correlations (e.g.,C_0, V_d) that may not generalize to all conditions.

Simplified Assumptions:

- Assumes uniform distribution and single-dimensional flow, limiting its applicability to complex flows.

Inaccuracy for Strongly Stratified Flows:

- Fails to capture phase separation in highly stratified regimes.

Example Calculation

Problem:

A vertical pipe carries a gas-liquid mixture with the following properties:

- Gas superficial velocity (j_g) = 3 m/s
- Mixture superficial velocity ($j = u_m$) = 5 m/s
- Drift velocity under static conditions (V_d) = 1 m/s
- Distribution coefficient (C_0) = 1.2

Find the void fraction (α_g).

Solution:

The void fraction is calculated using the equation:

$$\alpha_g = \frac{j_g}{C_0 j + V_d}$$

Substitute the given values:

$$\alpha_g = \frac{3}{1.2\,(5) + 1} = \frac{3}{7} = 0.4286$$

Result:

$\alpha_g \approx 0.43$ (43% of the pipe cross-sectional area is occupied by gas)}.

Conclusion

The **drift-flux model** is a versatile tool for analyzing multiphase flows where phase separation and slip are significant. By incorporating drift velocity and void fraction, it provides a realistic yet computationally efficient representation of multiphase systems. However, its reliance on empirical correlations requires careful application and validation.