Multiple Phase Flow

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Introduction

The **Lockhart-Martinelli correlation** is a widely used empirical approach for analyzing **two-phase flows** in pipes. It provides a method to estimate the pressure drop in a gas-liquid system by relating it to the pressure drop of a single-phase flow. This correlation is especially useful in horizontal and near-horizontal pipelines for predicting the effects of multiphase flow on system performance.

Key Concepts

1. Pressure Drop in Two-Phase Flow

The pressure drop in a two-phase system is influenced by the interaction between gas and liquid phases. The Lockhart-Martinelli correlation simplifies this calculation by introducing a correction factor based on single-phase flow characteristics.

2. Parameters of Interest

- **Two-Phase Pressure Drop (ΔP_{TP})**: The actual pressure drop in the gas-liquid flow.
- **Single-Phase Pressure Drops**:
  - ΔP_L: Pressure drop if the liquid were flowing alone.
  - ΔP_G: Pressure drop if the gas were flowing alone.
- **Lockhart-Martinelli Parameter (X)**: Represents the ratio of liquid-to-gas frictional pressure drops in single-phase flow.

Lockhart-Martinelli Parameter (X)

The dimensionless parameter X is defined as:

$$X^2 = \frac{\Delta P_L}{\Delta P_G}$$

Where:

- ΔP_L: Frictional pressure drop of liquid alone.
- ΔP_G: Frictional pressure drop of gas alone.

In terms of flow properties:

$$X^2 = \frac{\dot{m}_l^2 \rho_g}{\dot{m}_g^2 \rho_l}$$

Where:

- $\dot{m}_l, \dot{m}_g$: Mass flow rates of liquid and gas.
- ρ_l, ρ_g: Densities of liquid and gas.

Two-Phase Pressure Drop Calculation

The two-phase frictional pressure drop is expressed as:

$$\Delta P_{TP} = \phi^2 \Delta P_L$$

Where:

- ϕ^2: Two-phase multiplier for the liquid phase.
- ϕ^2 is a function of X, determined empirically.

Two-Phase Multiplier (ϕ^2) Relationships:

The relationship between ϕ^2 and X depends on the flow regime. Typical empirical equations are:

For liquid-dominated flow ($X > 1$):

$$\phi^2 = 1 + CX + X^2$$

For gas-dominated flow ($X < 1$):

$$\phi^2 = 1 + C\frac{1}{X} + \frac{1}{X^2}$$

Where C is an empirical constant determined by flow characteristics and pipe geometry.

Typical C Values:

- $C = 20$ for smooth pipes.
- $C = 12$ for rough pipes.

Advantages

Simple Implementation:

- Based on readily measurable parameters (mass flow rates, densities).

Broad Applicability:

- Can be applied to a wide range of two-phase flow scenarios.

Validated Framework:

- Widely used and validated for horizontal and near-horizontal pipes.

Limitations

Empirical Basis:

- Requires empirical constants (C) that may not generalize across all systems.

Limited to Two-Phase Flow:

- Cannot be extended to three-phase or highly transient flows.

Accuracy:

- Assumes steady-state conditions and may not account for dynamic effects.

Applications

Oil and Gas Pipelines:

- Predicts pressure drop in gas-liquid transport systems.

Chemical Engineering:

- Designs multiphase reactors and flow systems.

Power Generation:

- Analyzes two-phase flow in condensers and boilers.

Example Calculation

Problem:

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

- Liquid mass flow rate ($\dot{m}_l$) = 5 kg/s
- Gas mass flow rate ($\dot{m}_g$)= 2 kg/s
- Liquid density (ρ_l) = 1000 kg/m^3
- Gas density (ρ_g) = 5 kg/m^3
- Frictional pressure drop for liquid (ΔP_L) = 200 Pa/m

Find the two-phase pressure drop (ΔP_{TP}) assuming C = 20.

Solution:

Calculate X²:

$$X^2 = \frac{\dot{m}_l^2 \rho_g}{\dot{m}_g^2 \rho_l}$$

Substituting the values:

$$X^2 = \frac{5^2.5}{2^2.1000} = \frac{125}{4000} = 0.03125$$

Determine Flow Type:

- $X^2 < 1$: Gas-dominated flow.

Calculate ϕ^2: For gas-dominated flow:

$$\phi^2 = 1 + C\frac{1}{X} + \frac{1}{X^2}$$

Substitute C = 20 and $X = \sqrt{0.03125} \approx 0.1768$:

$$\phi^2 = 1 + 20 \cdot \frac{1}{0.1768} + \frac{1}{(0.1768)^2}$$

$$\phi^2 = 1 + 20 \cdot 5.655 + 31.887$$

$$\phi^2 = 1 + 113.1 + 31.887 = 145.987$$

Calculate Two-Phase Pressure Drop:

$$\Delta P_{TP} = \phi^2 \Delta P_L$$

Substituting the values:

$$\Delta P_{TP} = 145.987 \cdot 200 = 29197.4\,\mathrm{Pa/m}$$