GEOCAP
Geothermal Capacity Building Program Indonesia - Netherlands

Fluid Mechanics: Two-Phase Flow in Pipes

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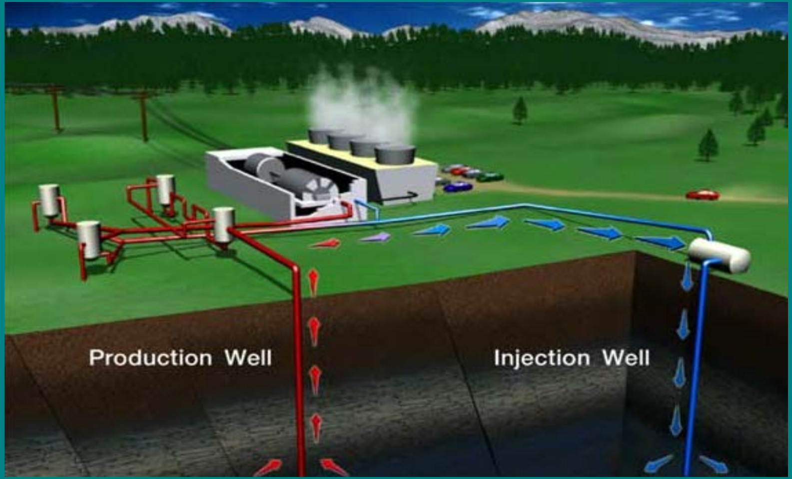
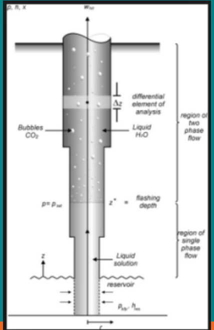
Fluid flow in geothermal

- It depends on the type of reservoir, the fluid flow may vary from liquid water single-phase, steam single-phase or steam-water two-phase flows.
- Water single-phase flow can be found in the production well, in the brine pipeline after the separator or in reinjection well.
- Steam single-phase flow presents in pipe line leaving the separator or production well.
- Steam-water two-phase flow occurs in the production well and pipe lines from the wellhead to the separator.





- Phase is a condition or a form of a substance (solid, liquid or gas).
- Multiphase flow is the simultaneous flow of several phases of a substance. Whereas if derived from a different substance called multicomponent.
- Two-phase flow is an example of a multi-phase flow involving only two forms of a substance in a stream.
- The mixture of water and water vapor is a two-phase flow, whereas a mixture of water and air flow is called two components.

- The study of two-phase flow can be divided into several types, namely: according to the combination between the phases, the two-phase flow can be divided into gas-liquid, liquid-solid, and solid-gas.
- According to the direction of the flow, the two-phase flow can be divided into two-phase flow in the upward direction, downward direction, and counterclockwise.
- While according to the position of the channel two-phase flow can be divided into horizontal, upright, and oblique flow.

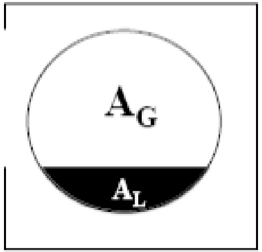
Velocity Concepts

- Velocity Concepts
  - <u>Superficial Velocity</u> - "velocity if phase had entire area of pipe available for flow"

$$v_{SL} = \frac{Q_L}{A_p} \qquad v_{SG} = \frac{Q_G}{A_p}$$

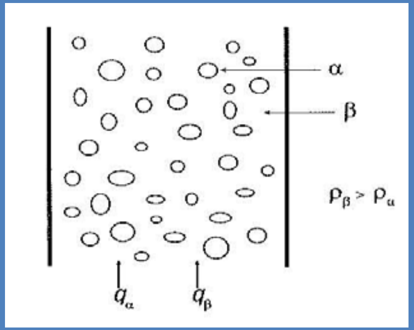
  - <u>Actual Velocity</u> - "actual flow area is reduced due to presence of other phase"

$$v_L = \frac{Q_L}{A_L} \qquad v_G = \frac{Q_G}{A_G}$$

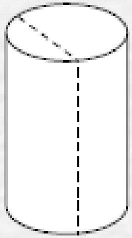


  - <u>Mixture Velocity</u> - "multiphase combined velocity, the velocity of the flow if no slip occurs between the gas and liquid"

$$v_m = \frac{Q_L + Q_G}{A_p} = v_{SL} + v_{SG}$$



α : Lighter phase β : Denser phase



- Holdup (volume ratio)

$$y_\alpha = \frac{V_\alpha}{V} \qquad y_\beta = \frac{V_\beta}{V}$$

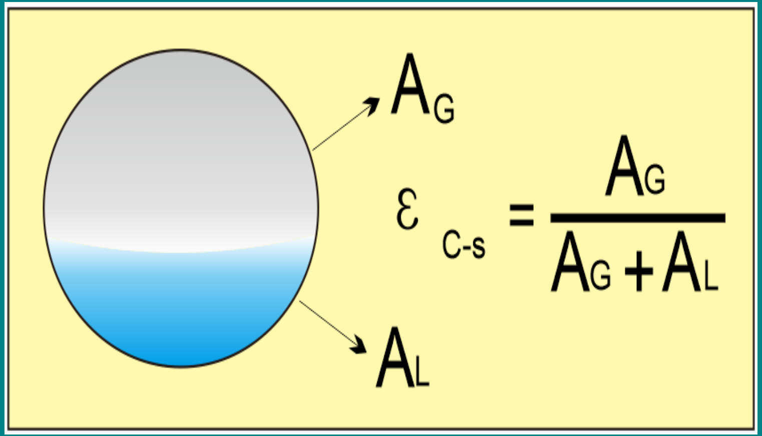
- Input Fraction (No-slip Holdup) (q is flowrate)

$$\lambda_\beta = \frac{q_\beta}{q_\alpha + q_\beta} \qquad \lambda_\alpha = 1 - \lambda_\beta$$

Void Fraction

- Void fraction is one of the parameters that is important to know the characteristics of two phase flow.
- The value of the void fraction is influenced by the superficial velocity of liquids and gases(J_L and J_G).
- The void fraction also affects the value of the two-phase flow pressure drop.

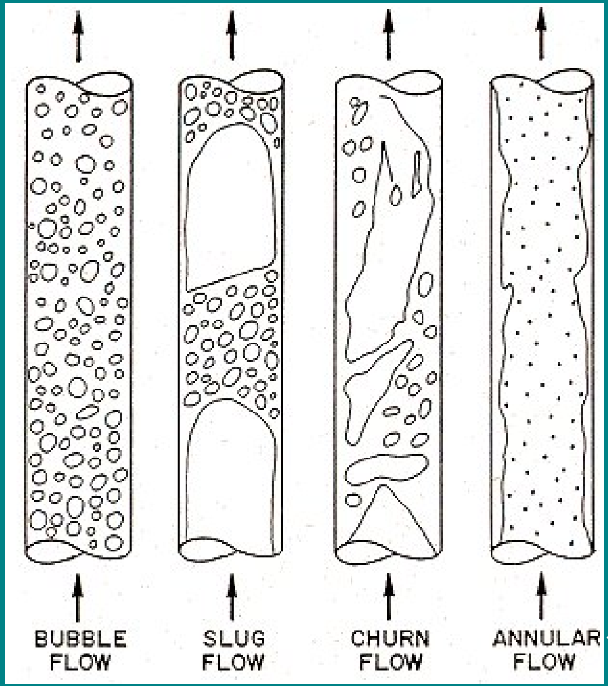
Cross-Sectional method



- Calculation of void fraction with cross-sectional method based on comparison of gas phase cross section to pipe cross section or can be formulated on the equation in the side picture.
- With A_G is the area of the gas phase cross section, while the A_L is the fluid-phase cross-section area.

Flow pattern

- The flow regime or flow pattern is a qualitative description of the phase distribution.
- For gas-liquid, upward flow, there are 4 flow regimes normally agreed in the two-phase literature
  - **Bubble, Slug, Churn,** and **Annular**
- This occurs in a process in which the gas rate increases for the given liquid rate.

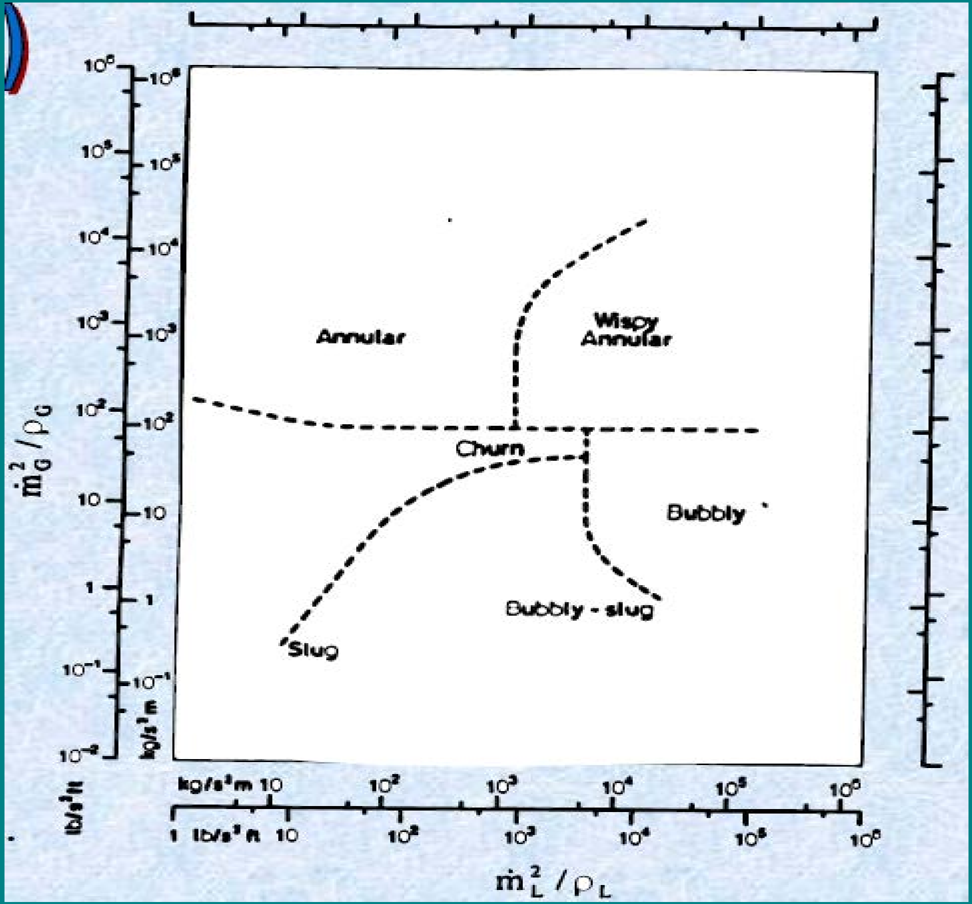


Gas in the center and liquid “hugging” or “climbing” the walls

Mist Flow

Intermittent Flow

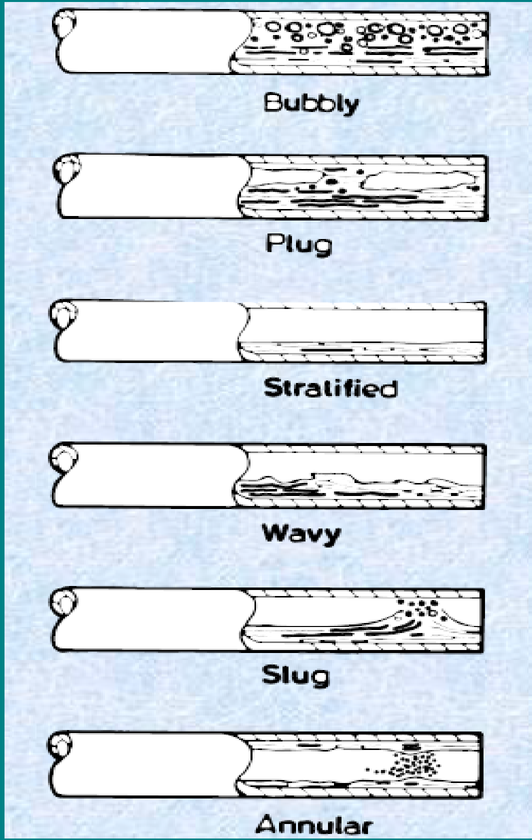
Increasing Gas-Liquid Ratio



Flow pattern maps

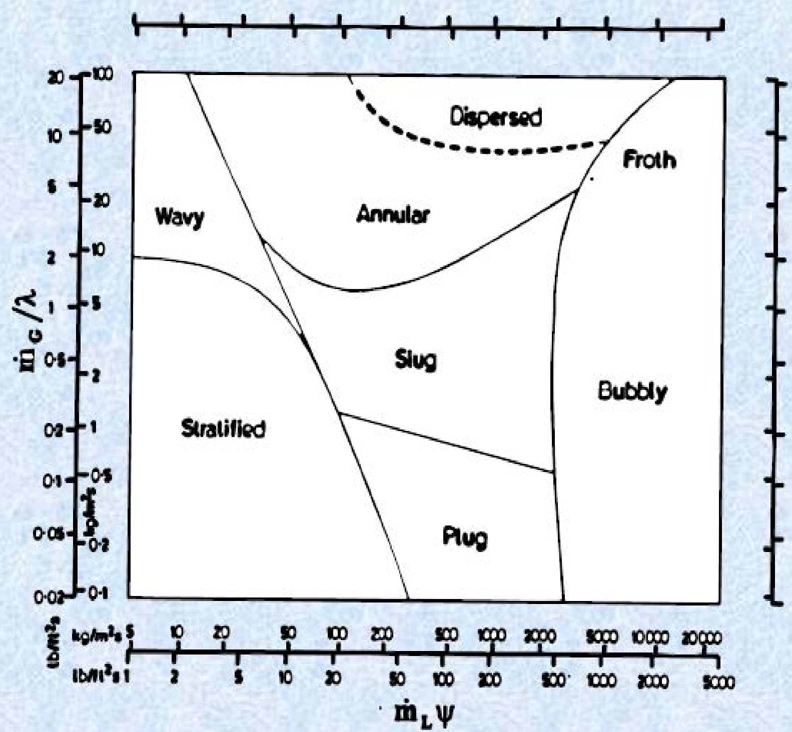
Hewitt-Roberts (1969)

Flow patterns in horizontal pipe



- The plug and slug flow are sometimes grouped into one category: intermittent.
- The two-phase flow pattern in a horizontal pipe is similar to the flow in the vertical pipe but the fluid distribution is affected by the gravity that forms the fluid stratification to the bottom of the pipe and gas upward.
- The flow pattern for the co-current gas and liquid in the horizontal pipe is shown in the side picture.

Flow pattern maps

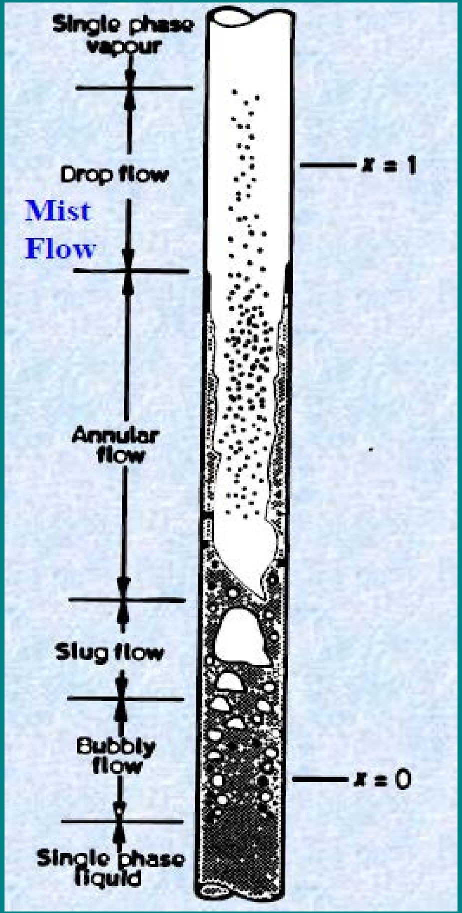


$$\lambda = \left(\frac{\rho_G}{\rho_{air}}\frac{\rho_L}{\rho_{water}}\right)^{1/2}$$

$$\psi = \left(\frac{\sigma_{water}}{\sigma}\right)\left[\left(\frac{\mu_L}{\mu_{water}}\right)\left(\frac{\rho_{water}}{\rho_L}\right)^2\right]^{1/3}$$

$$\rho_{water} = 1000\ \text{kg/m}^3;$$
$$\rho_{air} = 1.23\ \text{kg/m}^3;$$
$$\mu_{water} = 0.001\ \text{Ns/m}^2;$$
$$\sigma_{water} = 0.072\ \text{N/m}.$$

Baker (1954)



Two–phase flow correlations in vertical flow

Not necessarily all flow patterns appear in the flow, depending on flow conditions.

- General equation of pressure gradient :

$$\frac{dp}{dL} = \frac{g}{g_c} \rho_s \sin \phi + \frac{f \rho_f v_m^2}{2 g_c d} + \frac{\rho v_m dv_m}{g_c dL}$$

$$\rho_s = \rho_L H_L + \rho_g H_g$$

- For vertical pipe, $\phi=90^o$, dL=dz

$$\frac{dp}{dZ} = \left(\frac{dp}{dZ}\right)_{el} + \left(\frac{dp}{dZ}\right)_{f} + \left(\frac{dp}{dZ}\right)_{acc}$$

- Pressure drops caused by elevation changes depend on the density of the two phase mix and are usually calculated using holdup.
- Except for high-speed conditions, the pressure drop on the vertical pipe is caused by this component.
- Pressure drop due to friction loss requires evaluation of two phase friction factor.
- Pressure drop due to acceleration is generally ignored except for high speed conditions.
- Many correlations are developed to estimate pressure gradient of two phase flow by using empirical formulas based on flow patterns that occur.

Correlation classification

a. No slippage, do not consider flow regime. Mixed density is calculated based on the gas-liquid ratio (GLR) input. Gas and liquid are assumed to flow at the same speed in the pipeline. What is needed is a two-phase friction factor and applies to all flow regimes.

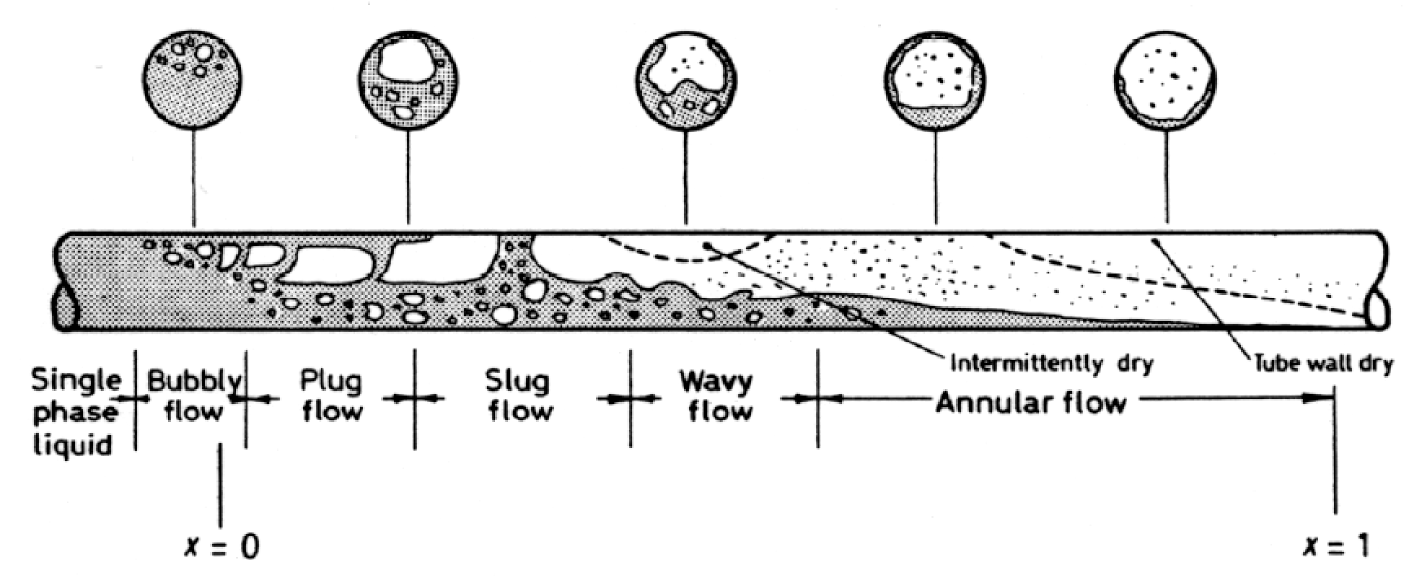
b. Consider slippage, do not consider flow regime. Requires correlation of liquid holdup and friction factor. Since liquids and gases flow at different speeds, a method is needed to estimate the portion of the pipe filled by the liquid in any location. The same correlation for liquid holdup and friction factor applies to all regimes.

c. Slips considered, flow regimes considered. It is not only the correlation to predict the required holdup and friction factor, but also the method for predicting what the flow regime is going on. The correlations for each flow regime are different as well as the method of calculating the acceleration pressure gradient.

Some of Correlations

- Poettmann and Carpenter
- Hagedorn and Brown
- Duns & Ros
- Orkiszewski

Two–phase flow correlations in horizontal flow



- If the pipe is in a horizontal position, then the sinus angle is zero. Thus there is no pressure drop due to elevation so that the pressure gradient equation :

$$\frac{dp}{dX} = \frac{f \rho_f v_m^2}{2 g_c d} + \frac{\rho v_m d v_m}{g_c dX}$$

$$\frac{dp}{dX} = \left(\frac{dp}{dX}\right)_f + \left(\frac{dp}{dX}\right)_{acc}$$

- The liquid holdup prediction is not very critical for the calculation of pressure loss versus oblique or vertical pipes, but some holdup correlations are still required to calculate the density in the friction and acceleration components.
- Pressure drop because acceleration is usually minor and often ignored in design calculations.

Some of Correlations

- Eaton et al
- Dukler et al
- Lockhart & Martinelli
- Beggs & Brill

Thank You