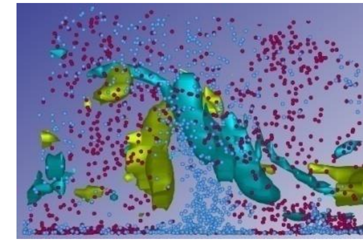
Università degli Studi di Udine
Dip. Politecnico Ingegneria & Architettura

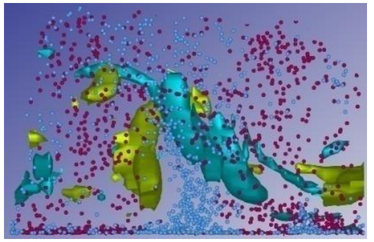


Gas liquid multiphase flows: flow regimes and pressure drops

M.Campolo

Design of Industrial Plants 2018

Multiphase flow in everyday life

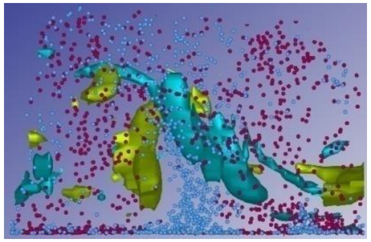


Liquid spray in a gas stream

Sea waves generated by wind shear

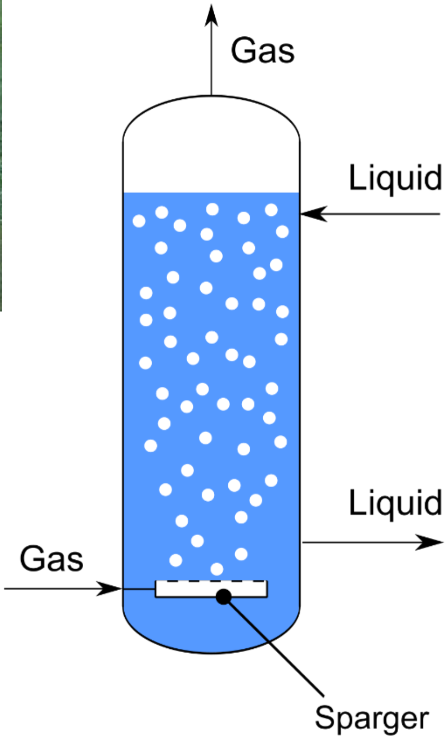
Gas bubbles in liquid

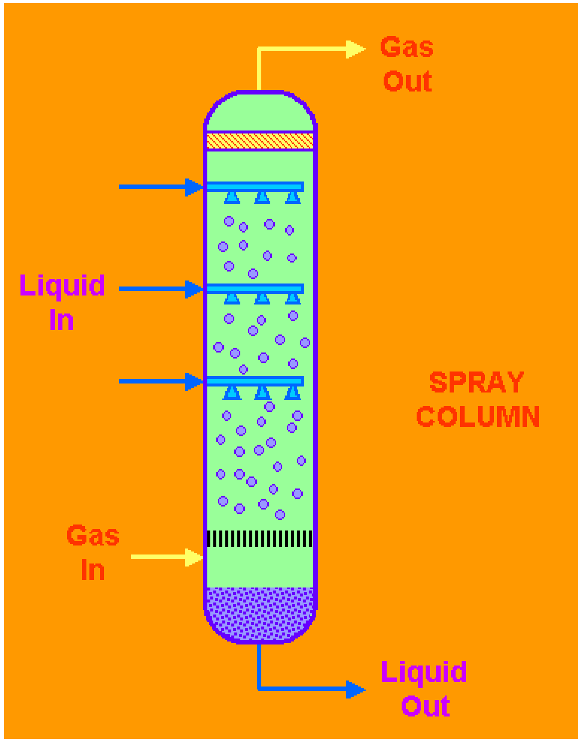
Multiphase flow in industrial application



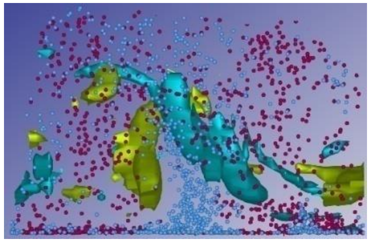
Oil/gas transportation pipeline

Multiphase reacting systems (e.g. absorption and stripping columns)





Problem & Objective



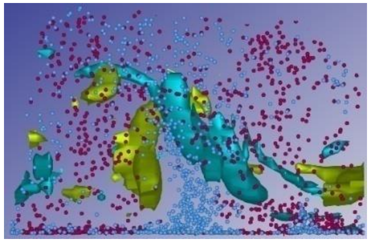
Many different gas/liquid configurations are possible when gas and liquid move together

How to predict the spatial distribution of gas/liquid phases based on system characteristics and working conditions?

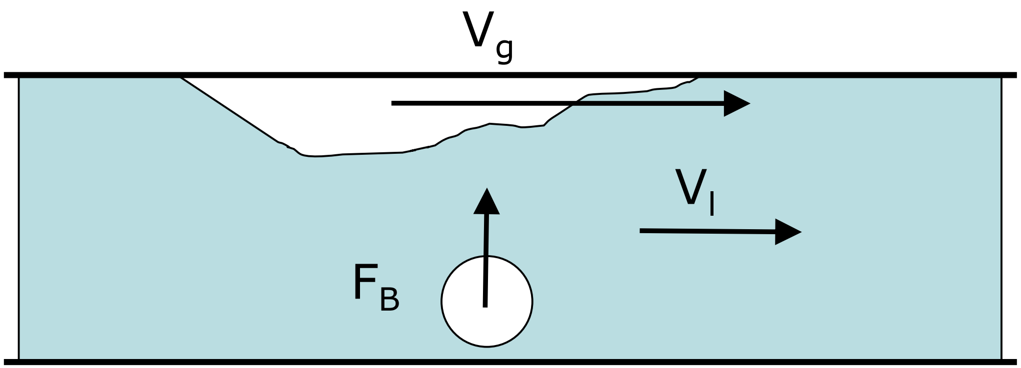
Liquid/gas momentum exchange depends on phase configuration

How much energy is required to generate/maintain that flow?

How can we calculate the pressure drop in multiphase flow transport system?



Gas-liquid interaction

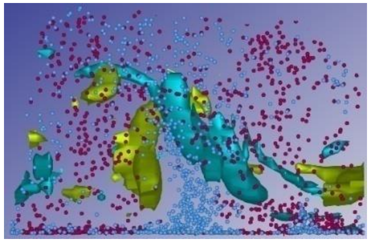


Gas is lighter than liquid → Buoyancy force accumulate the gas at top

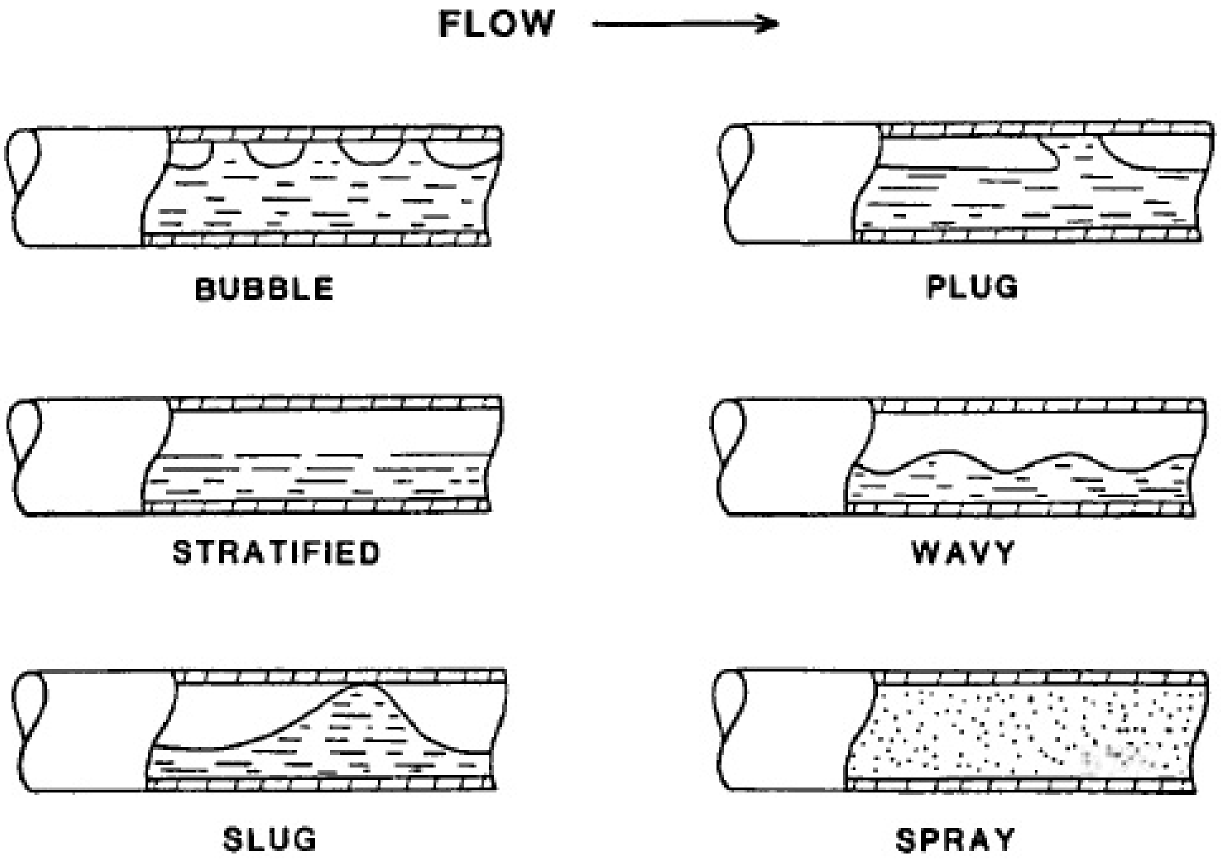
Gas is less inertial than liquid → May be transported by the liquid

→ May accelerate quicker than the liquid under a given pressure gradient

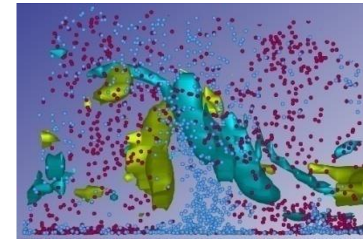
Flow regimes: horizontal pipe



Increasing the gas flow rate

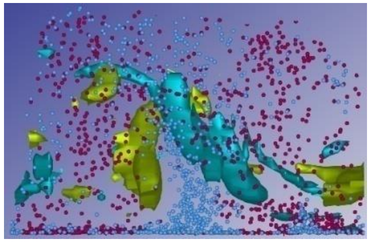


Flow regimes: horizontal pipe

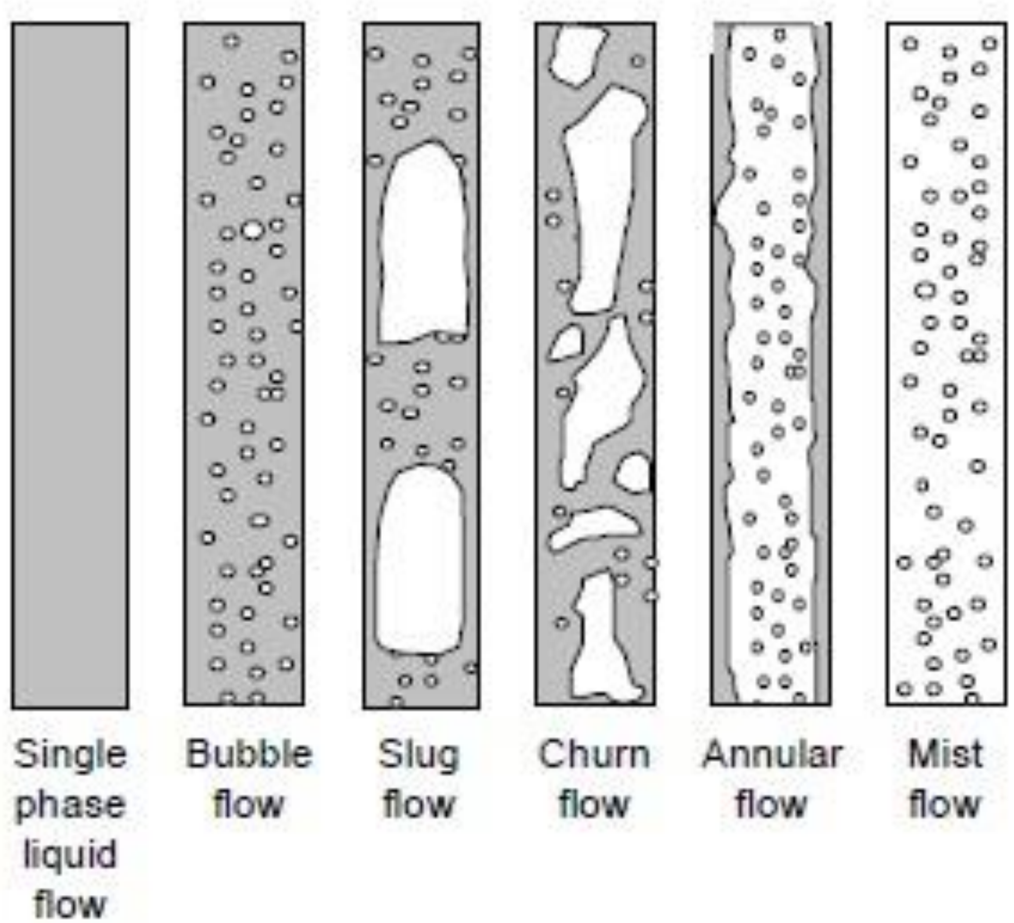


https://youtu.be/kjOSxOAQIF4

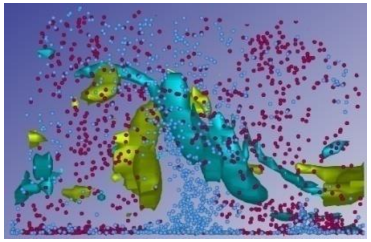
Flow regimes: vertical pipe

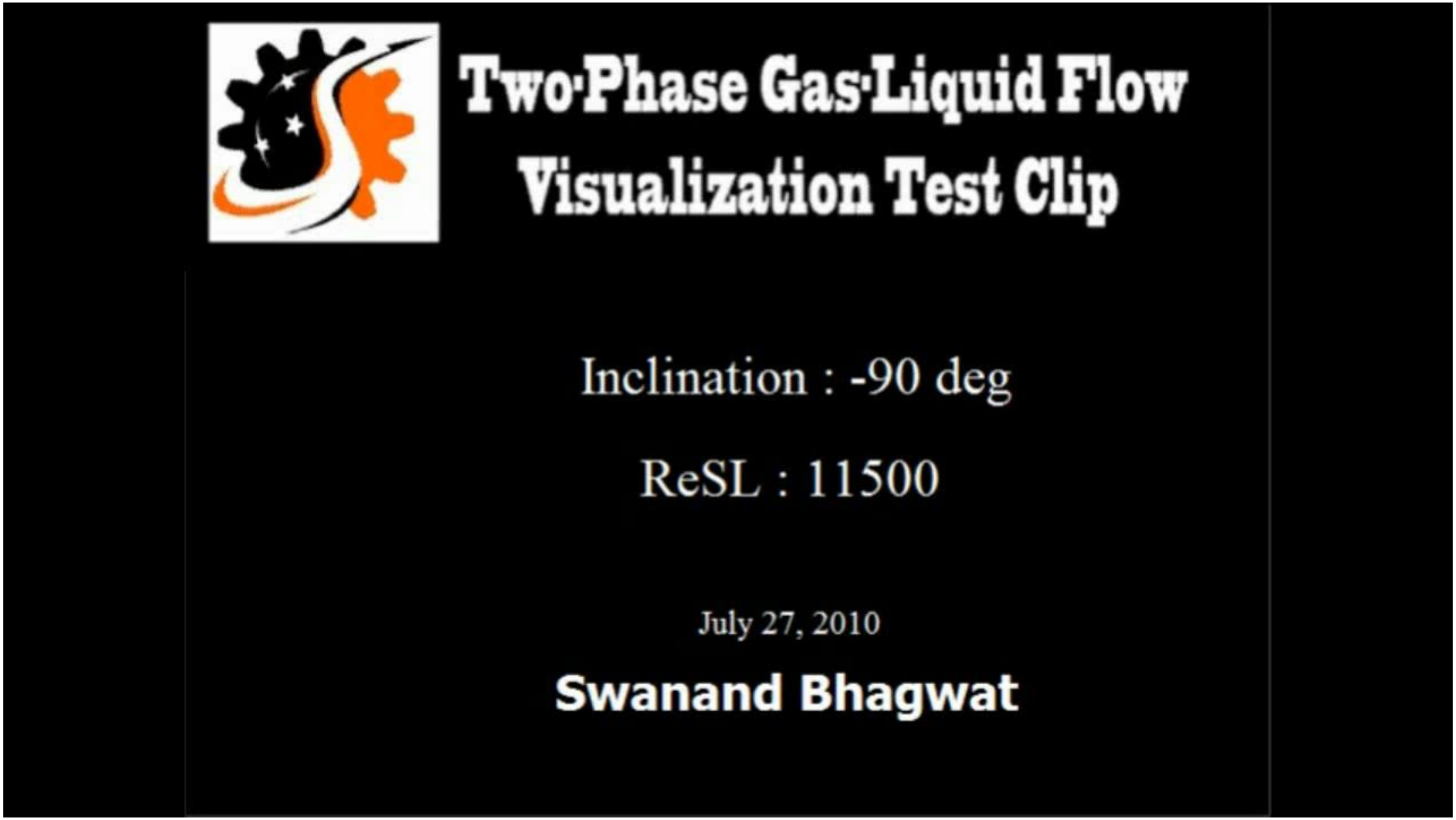


Increasing the gas flow rate



Flow regimes: vertical pipe





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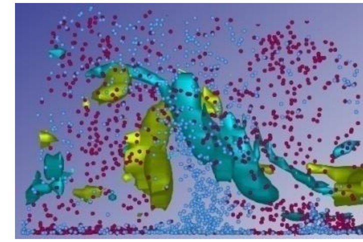
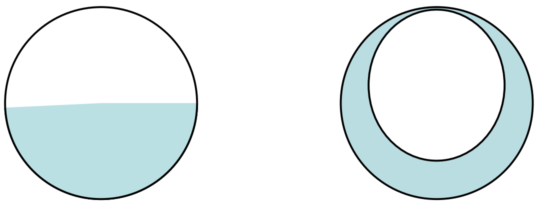
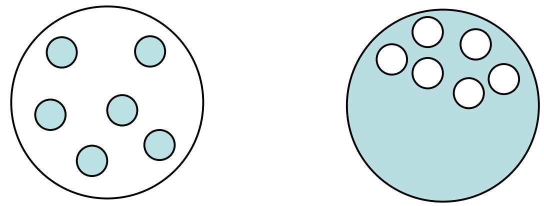
How to classify multiphase flow



How are phases distributed in the cross section of the pipe?



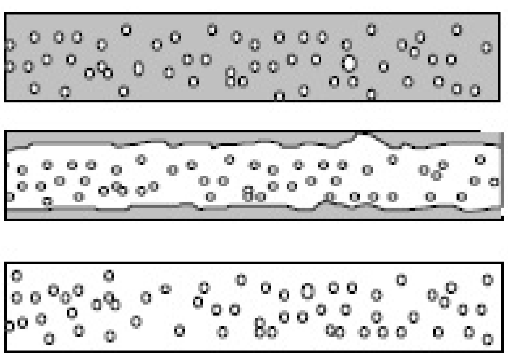
Separated/stratified flow



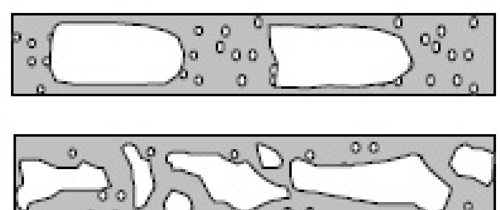
Dispersed flow

How are the phases distributed in the streamwise direction? Is the phase distribution observed in the cross section stable in time?

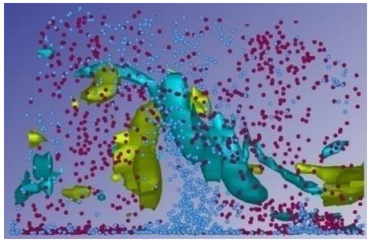
Continuous flow



Intermittent flow



Real multiphase transport



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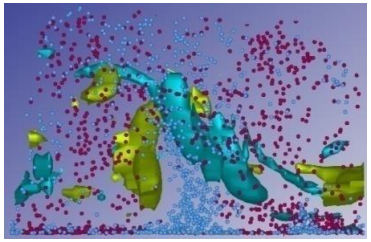
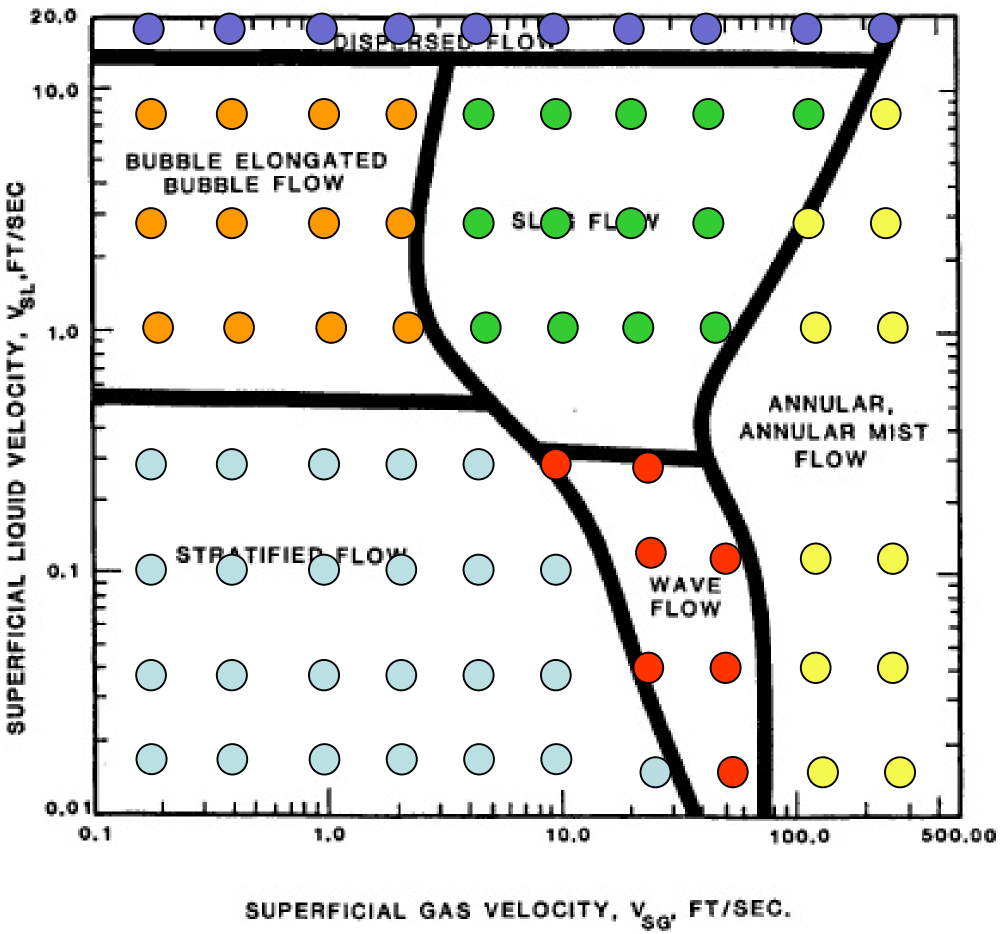


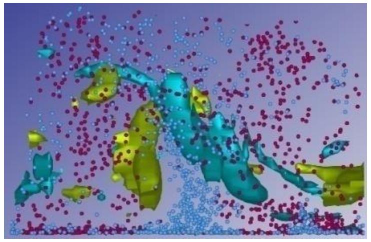
Flow maps: horizontal flow

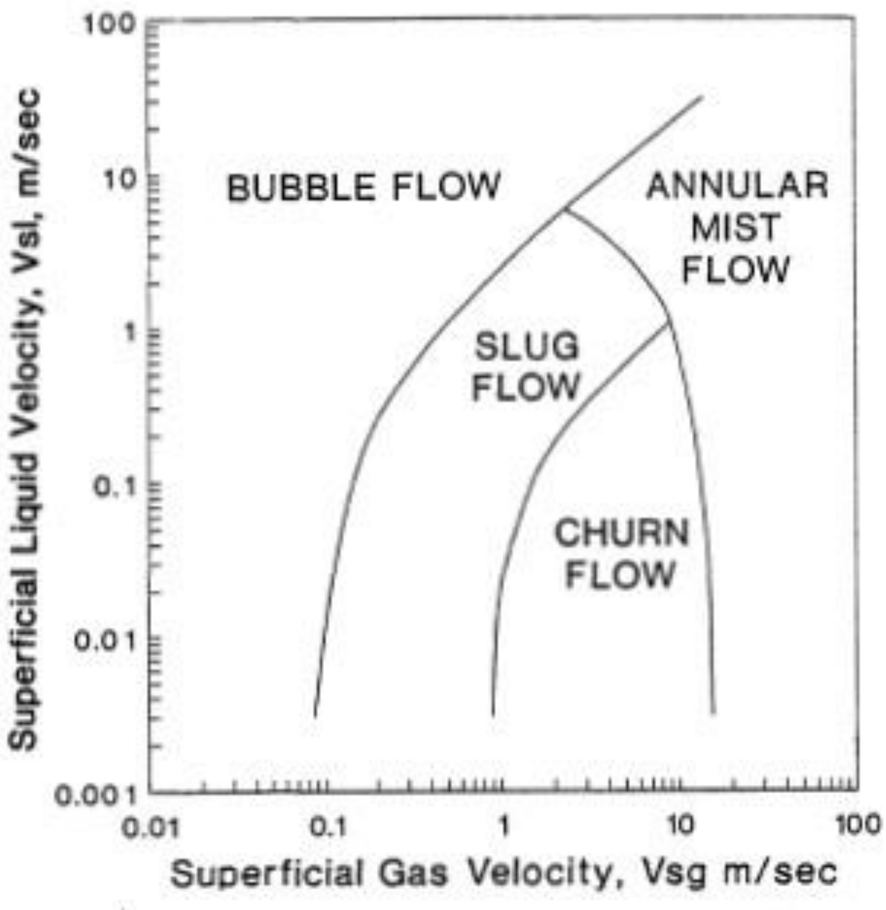
Systematic observation of flow regimes: $(Q_g, Q_L) \rightarrow$ flow pattern

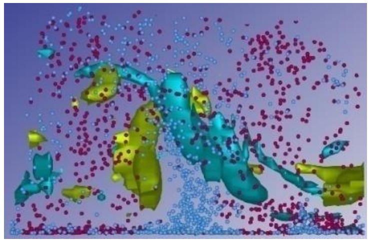


- Stratified flow
- Bubble flow
- Slug flow
- Wave flow
- Annular mist flow
- Dispersed flow

Flow maps: vertical flow







Flow variables

Flow rates: Q_g, Q_L

Volumetric fraction: gas (liquid) volumetric flow rate/overall volumetric flow rate

$$\alpha_g = \frac{Q_g}{Q_g + Q_L} \qquad \alpha_L = \frac{Q_L}{Q_g + Q_L}$$

Superficial flow velocities: velocity of gas/liquid phase if flowing through the whole pipe section

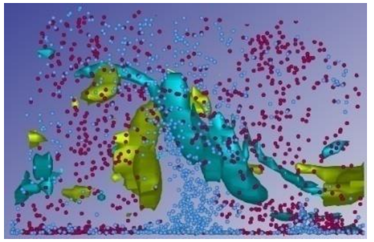
$$u_{s,g} = \frac{Q_g}{A_{TOT}} \qquad u_{s,L} = \frac{Q_L}{A_{TOT}}$$

Flow regime: Reynolds number based on superficial flow velocity

$$Re_{s,g} = \frac{u_{s,g} D \rho_g}{\mu_g} \qquad Re_{s,L} = \frac{u_{s,L} D \rho_L}{\mu_L}$$

<2100 viscous

>2100 turbulent



Flow variables

Effective flow velocities: real velocity of gas/liquid phase flowing in a portion of pipe section only

$$u_{eff,g} = \frac{Q_g}{A_g} \qquad u_{eff,L} = \frac{Q_L}{A_L} \qquad A_{TOT} = A_g + A_L$$

Effective vs Superficial flow velocities:

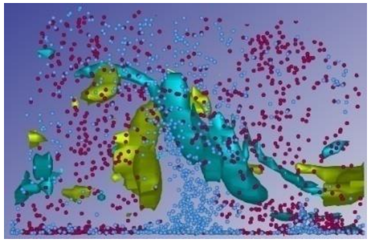
$$u_{s,g} = \frac{Q_g A_g}{A_g A_{TOT}} = \frac{u_{eff,g}}{\lambda_g} \qquad u_{s,L} = \frac{Q_L A_L}{A_L A_{TOT}} = \frac{u_{eff,L}}{\lambda_L}$$

Hold up: fraction of pipe area occupied by the gas/liquid

$$\lambda_g = \frac{A_g}{A_{TOT}} \qquad \lambda_L = 1 - \lambda_G = \frac{A_L}{A_{TOT}} \qquad \lambda_L + \lambda_G = 1$$

λ_g, λ_L are difficult to measure (by gamma-densitometry or impedence techniques)
→ rely on the simplest variables for calculations!

Calculation of pressure loss



Design data:

Gas and liquid mass flow rates $\dot{m}_g, \dot{m}_L$

Fluid properties(density, viscosity) $\rho_g, \mu_g, \rho_L, \mu_L$

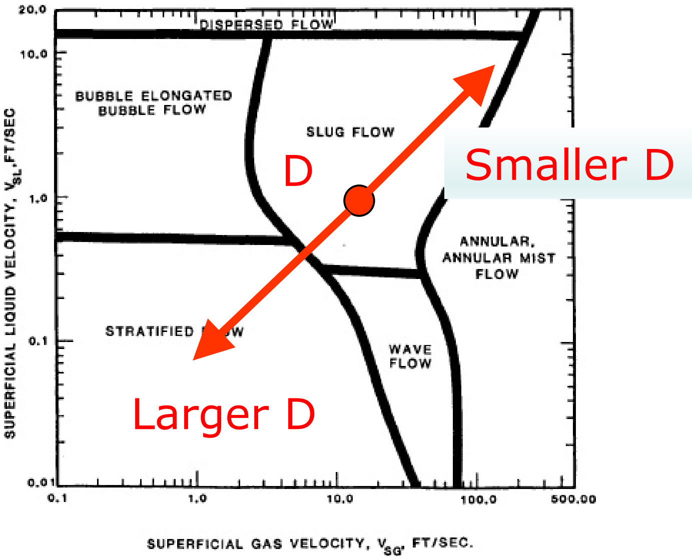
Lenght of pipe L

→ select pipe diameter D

→ Calculate gas/liquid superficial velocities

→ Identify the flow regime from the map (suitable for continuous operations?)

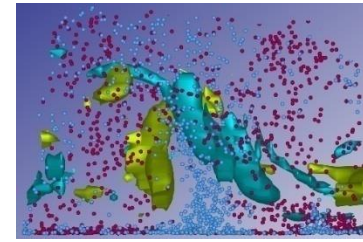
→ Modify the pipe diameter if it is the case



→ Calculate the pressure drop (single phase gas/liquid)

$$\Delta p_g = 2 f_g \frac{L}{D} \rho_g u_{s,g}^2 \qquad \Delta p_L = 2 f_L \frac{L}{D} \rho_L u_{s,L}^2$$

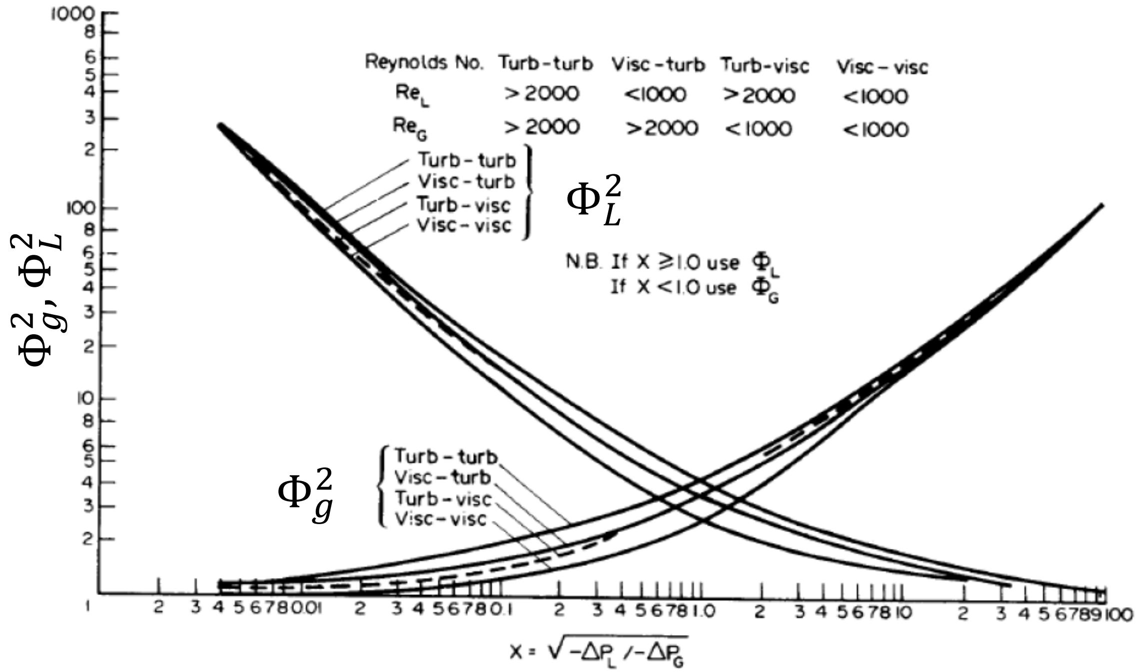
→ Correct the pressure drop to account for the second phase



Pressure drop correction (Lockhart-Martinelli)

$\Delta p_{TP} = \Phi_g^2 \Delta p_g = \Phi_L^2 \Delta p_L$

$\Phi_g^2, \Phi_L^2 = f(X)$ correction coefficients

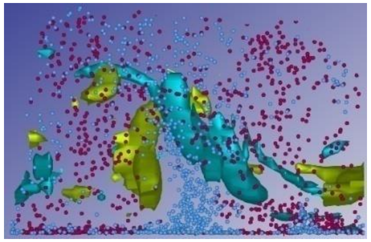


Lockhart-Martinelli parameter

$$X = \sqrt{\frac{\Delta p_L}{\Delta p_g}}$$

$$\Phi_L^2(X) = 1 + \frac{C}{X} + \frac{1}{X^2} \qquad \Phi_g^2(X) = \Phi_L^2(X) \cdot X^2$$

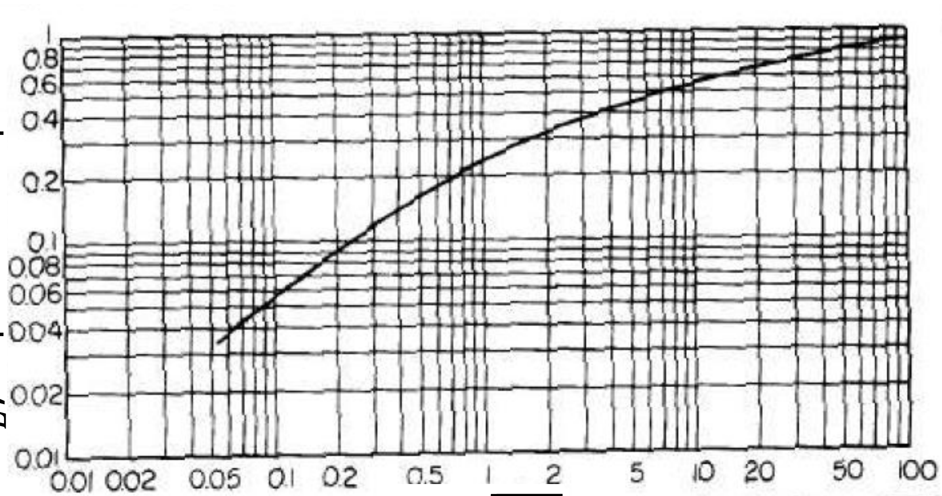
C	L	G
20	T	T
10	T	V
12	V	T
5	V	V



Additional pressure drop in vertical pipe

Extra energy is required to lift the fluid at the height H

$$\Delta p'_{TP} = \Delta p_{TP} + \rho_g g H \lambda_g + \rho_L g H \lambda_L \sim \Delta p_{TP} + \rho_L g H \lambda_L$$



λ_L, liquid hold-up

$$X = \sqrt{\frac{\Delta p_L}{\Delta p_g}}$$

$$\lambda_L(X) = 0.186 + 0.0191X \quad 1 < X < 5$$

$$= 0.143X^{0.42} \quad 5 < X < 50$$

$$= \frac{1}{0.97 + {}^{19}/_{X}} \quad 50 < X < 500$$