UiO : Department of Mathematics
University of Oslo

MEK 4600
Experimental methods in Fluid Mechanics

Scope of focus

- Multiphase flow in pipes (6 March 2018)
  - Flow patterns
  - Effect on oil industry

- Measurement technology (7 Mar 2018)
  - Turbulence with HWA
  - Holdup and phase distributions with gamma/X-rays

- Hand-on experience in hydrodynamics lab
  - Stratified flow (13 Mar 2018)
  - Slug flow (14 Mar 2018)

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MEK 4600
Introduction to multiphase flow in pipes

6 Mar 2018

Goals of today

Gain necessary knowledge on

- Flow patterns
- Characteristics

- Impact on oil production

What is multiphase flow?

- Flows involving interactions of multiple fluids (or phases)

Flow

Breaking waves

- Horizontal pipe

Flow

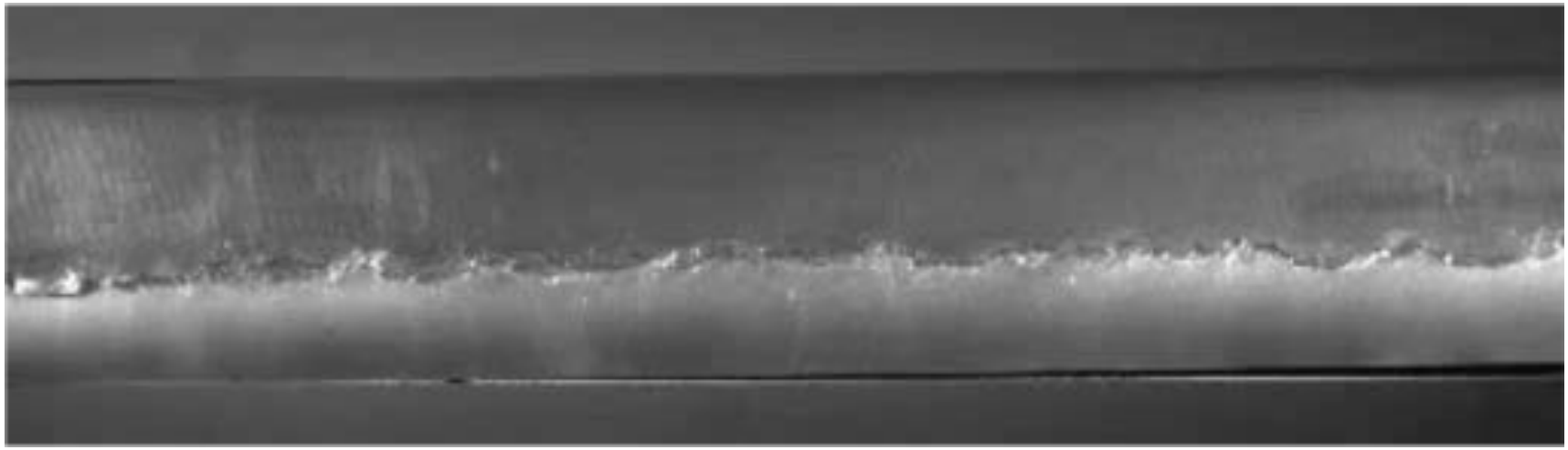
Severely braking waves

- Upward inclined pipe

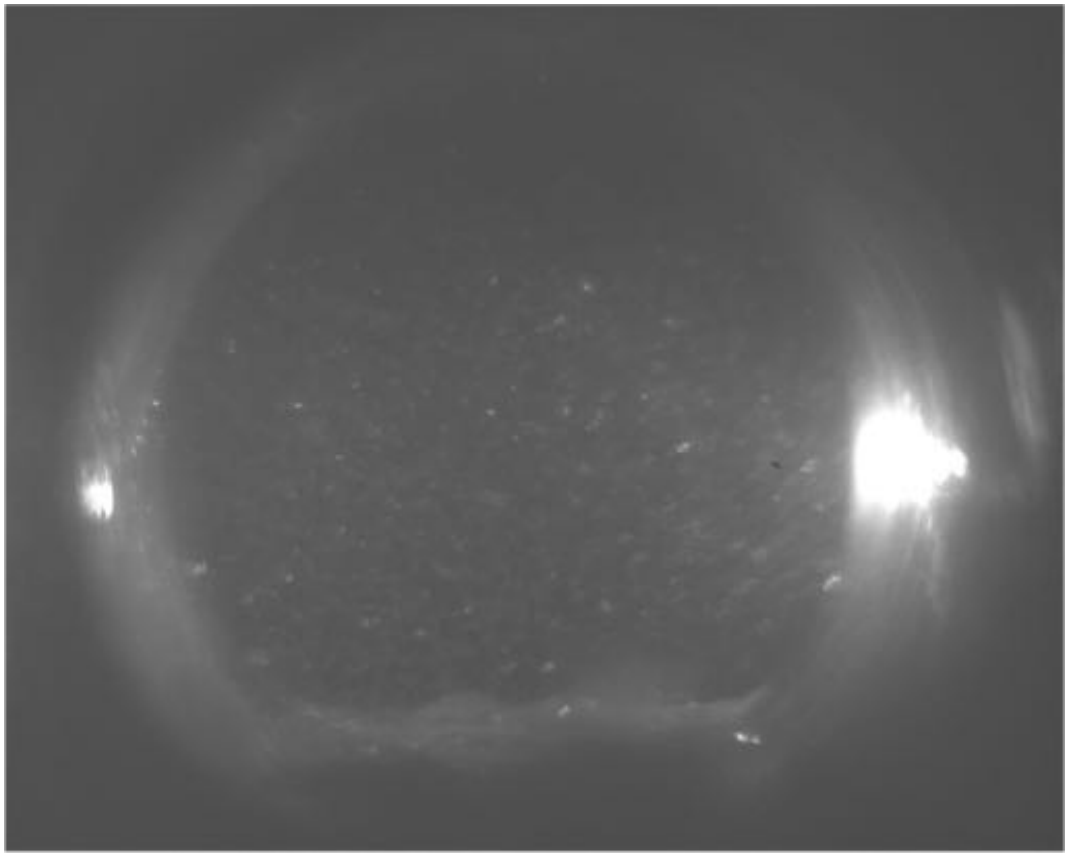
Flow

Intermittent flow

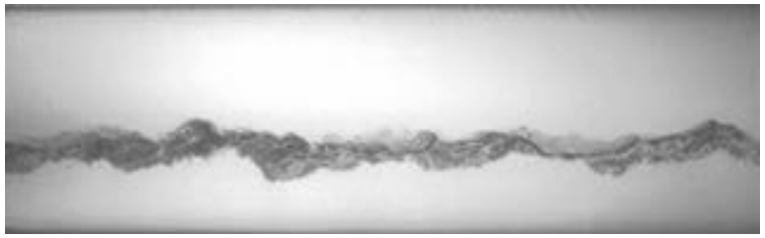
- Slug flow in horizontal pipe

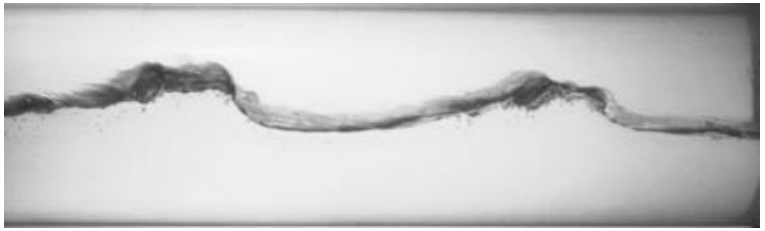


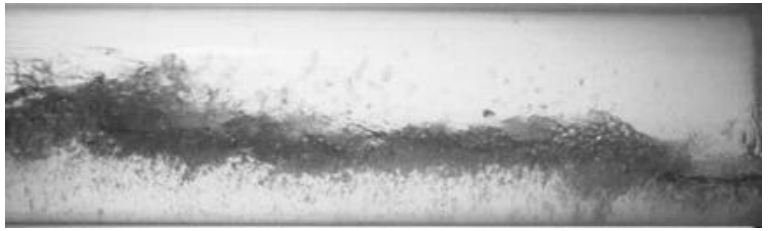
High turbulence in large diameter pipe



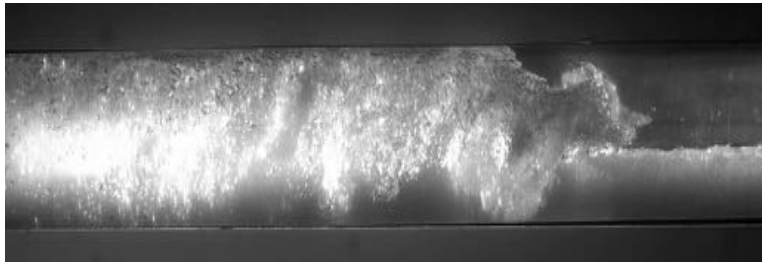
What parameters needed to define such flows?







Answer: …..

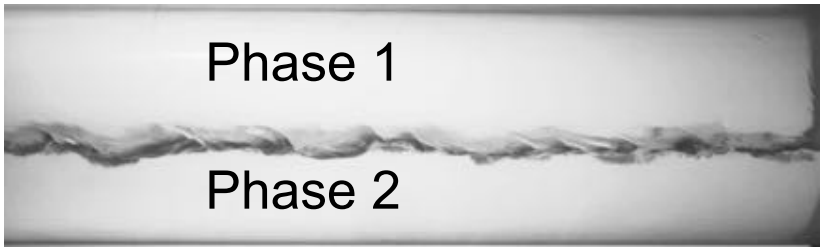


Terminology and definitions

Fluids (or phases)

- Phases can be gas, oil, water and particle

- Physical properties of phases are given by
  - **Density** (kg/m3)
  - Dynamic **viscosity** (Pa s)
  - **Surface tension** (N/m)
  - **Sizes** for particles (m)
  - …



Superficial velocity

- *A hypothetical (artificial) flow velocity calculated as if the given phase or fluid were the only one flowing or present in a given cross sectional area* – Wikipedia

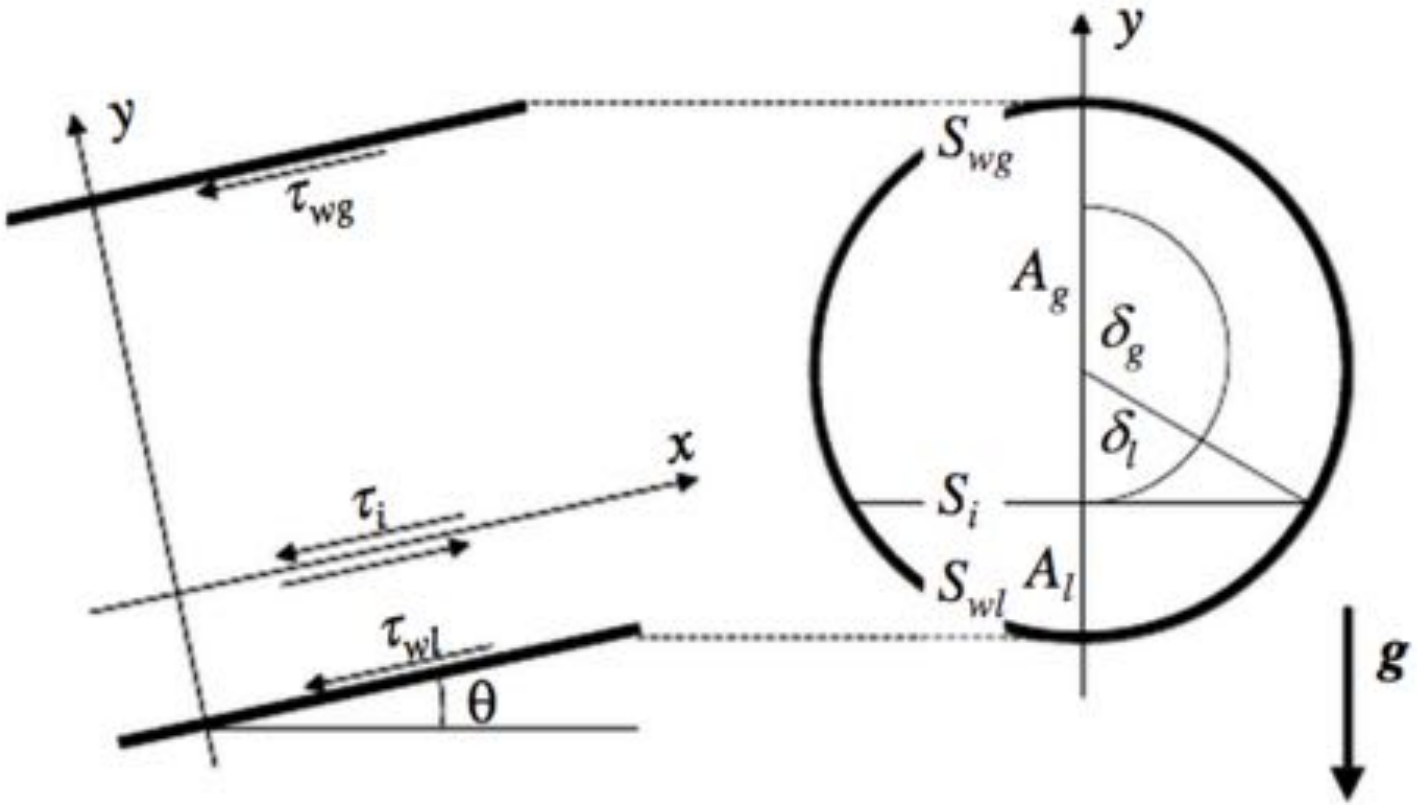
- **$U_{SL} = Q_L/A$** for liquid and USG = …
  - A is the cross-sectional area of the geometry (e.g. pipe)
  - Q is the volumetric flowrate

- **Mixture velocity** $U_{Mix} = U_{SL} + U_{SG} = U_{SO} + U_{SW} + U_{SG}$

U_{SG} ⟶

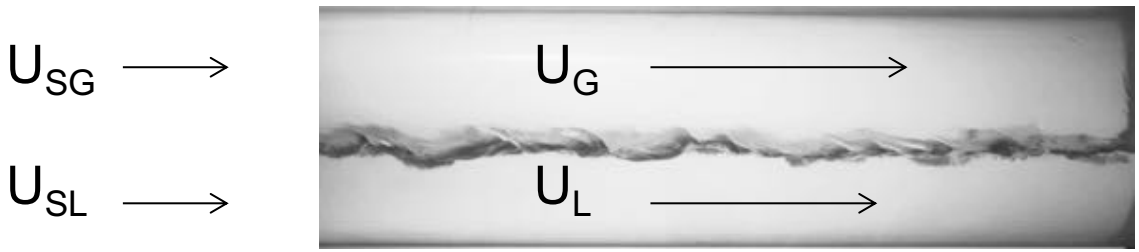
U_{SL} ⟶

Cross-section of a pipe



In-situ phase velocity (true velocity)

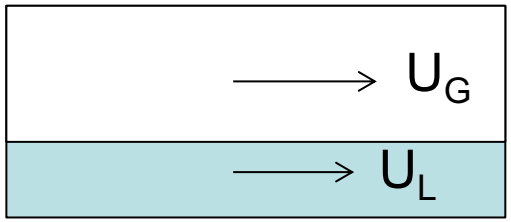
- The velocity of a phase in multiphase flow based on the area of the pipe occupied by that phase
  - Liquid velocity $\mathbf{U_L = U_{SL}/\alpha_L}$
  - Gas velocity U_G = …

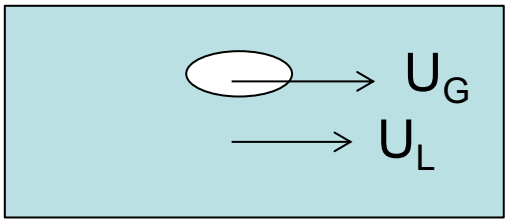


Slip velocity

- Slip velocity is the **difference** between the actual phases, e.g.
  - **$U_{slip} = U_G - U_L$**
  - Slip ratio $S = U_G/U_L$

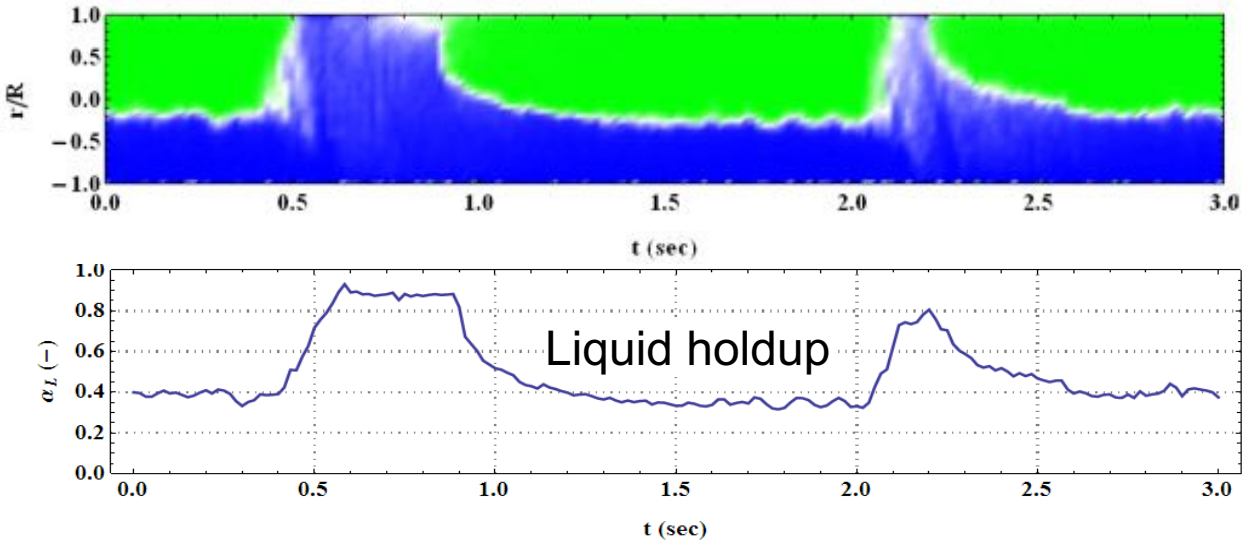
- No slip → $S = 1$ and $U_G = U_L$





Holdup of phases (α_i)

- The volume fraction of fluid in a control volume
- Sum of phase holdups equals 1
- Can be time averaged or instantaneous

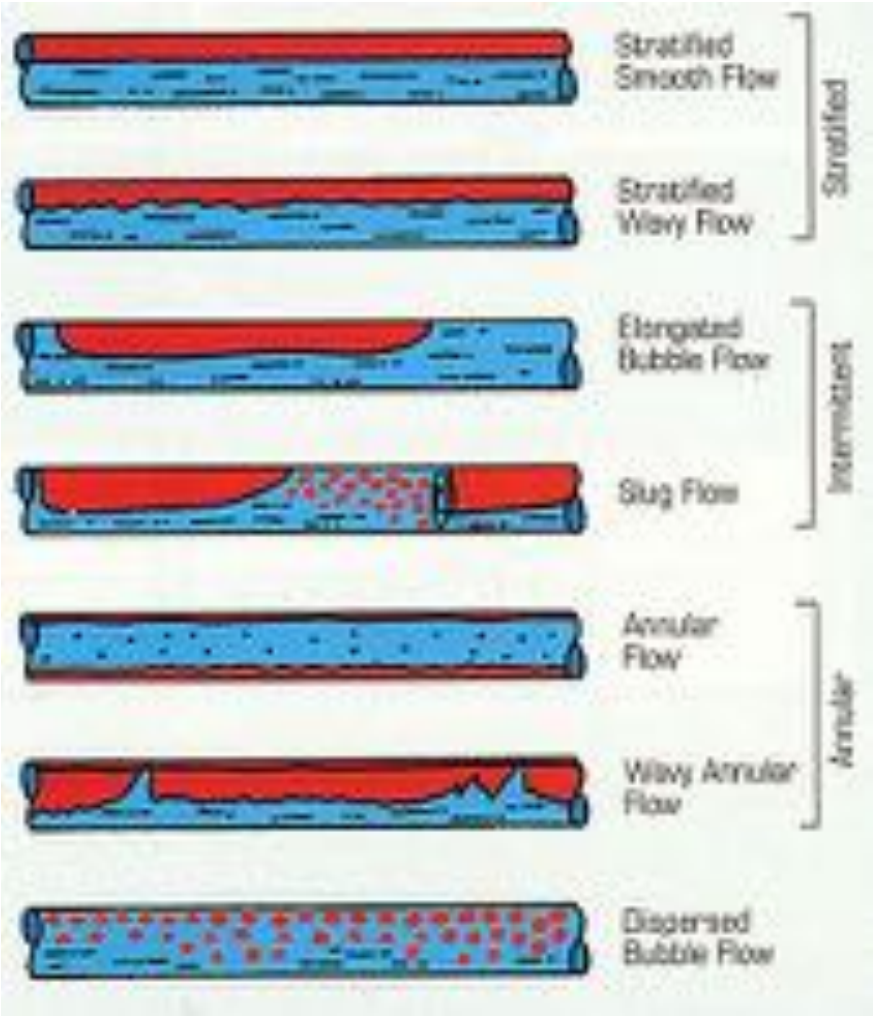


Classification of multiphase flows

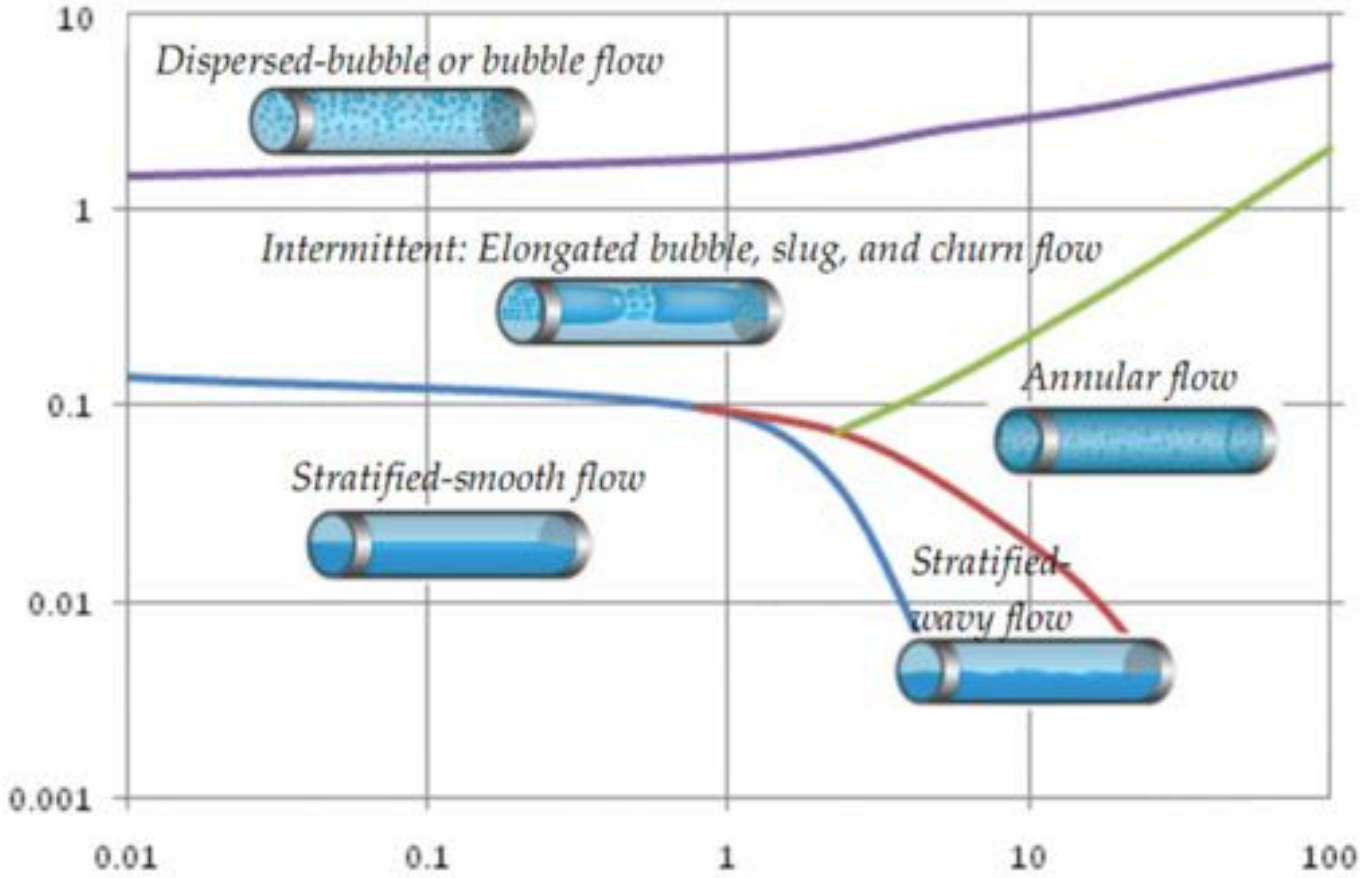
- By the number of phases present
  - Two-phase flow, Three-phase flow etc.
- By the type of phases
  - Gas-liquid, liquid-liquid, liquid-solid, gas-liquid-liquid etc
- By flow patterns or regimes
  - Stratified
  - Intermittent (slug, churn, elongated bubble)
  - Dispersed flows (with droplets, bubbles, emulsions, particles)
  - Annular flow
- By pipeline orientation
  - Horizontal, near horizontal, upward inclined, vertical flow etc.

Flow regimes (1): Gas-liquid in horizontal pipe

- Segregated flow
  - Stratified
  - Annular
  - Wavy
- Intermittent
  - Slug flow
  - Plug flow
- Distributive flow
  - Bubble/mist flow
  - Froth flow



Flow regime map (gas-liquid horizontal flow)



U_{SL}

U_{SG}

Flows in vertical pipes

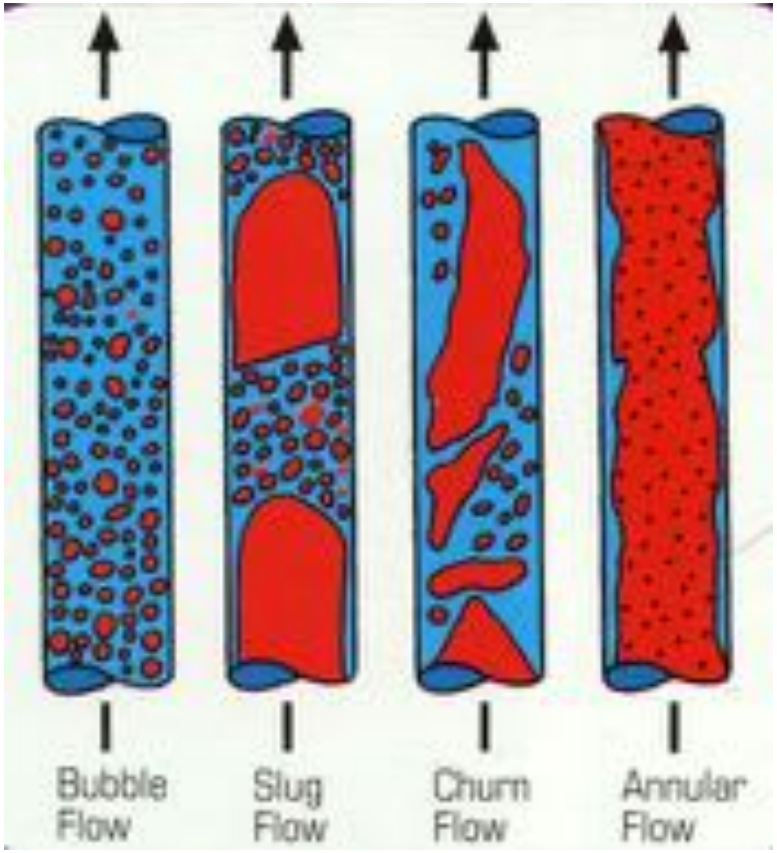
- Risers
- Nuclear reactors
- Power plant
- Process plant

Vertical bubbly flow

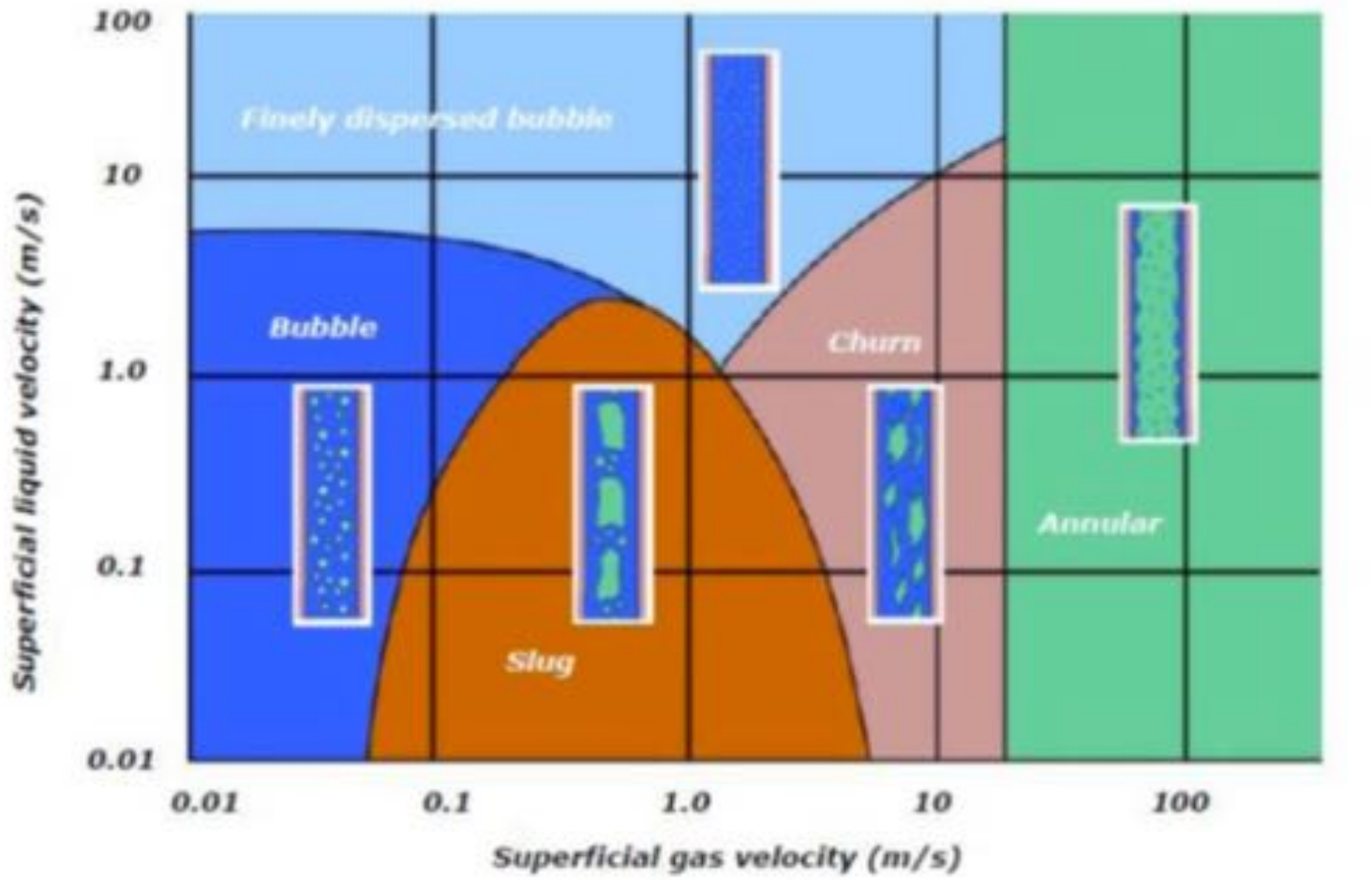
Slug flow in vertical pipe

Flow regimes (2): Gas-liquid in vertical pipe

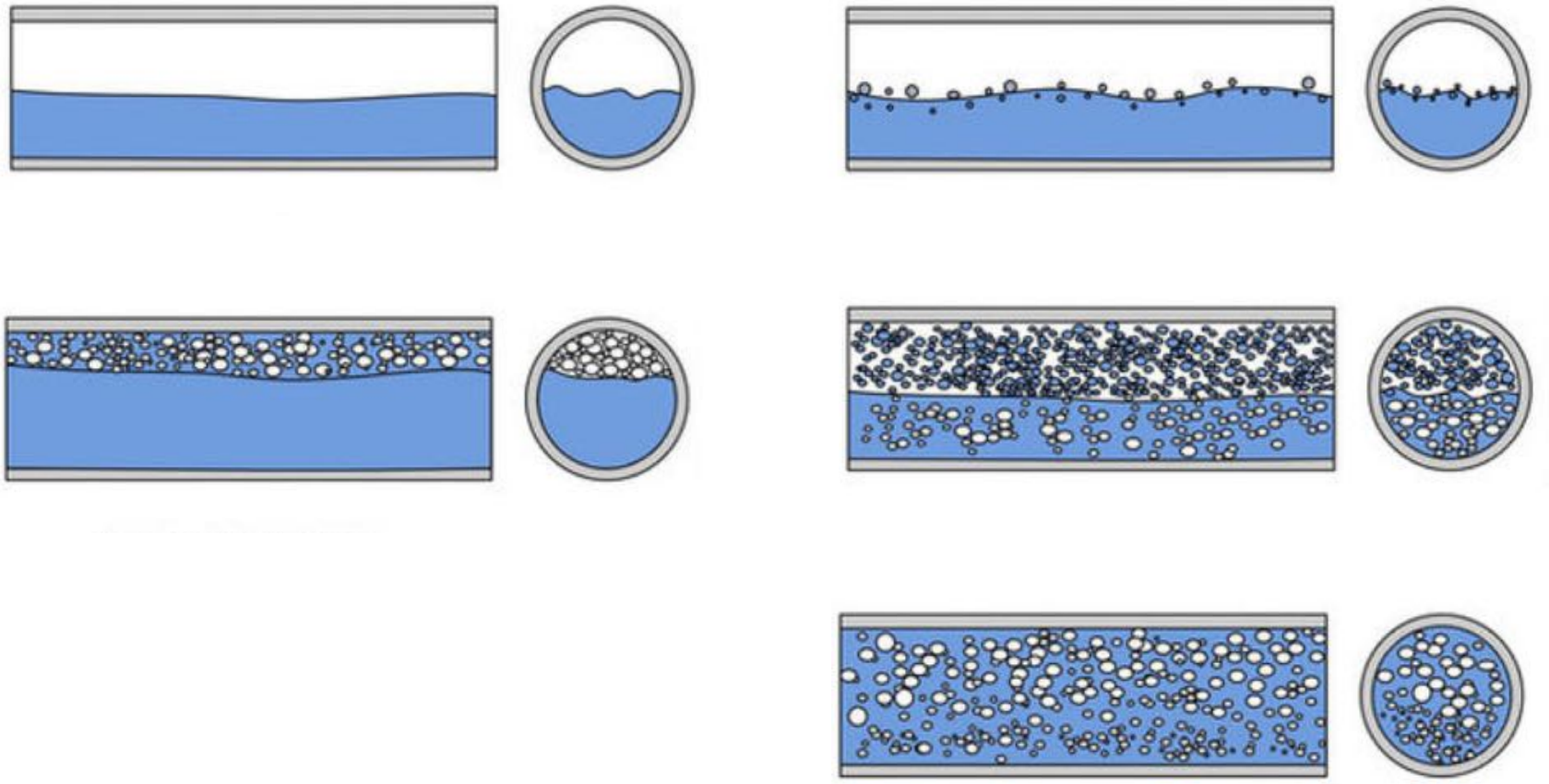
- Bubble flow
  - Continuous liquid phase with dispersed bubbles of gas
- Slug flow
  - Large gas bubbles
  - Slugs of liquid (with small bubbles) in between
- Churn flow
  - Bubbles start to coalesce
  - Up and down motion of liquid
- Annular flow
  - Gas becomes the continuous phase
  - Droplets in the gas phase



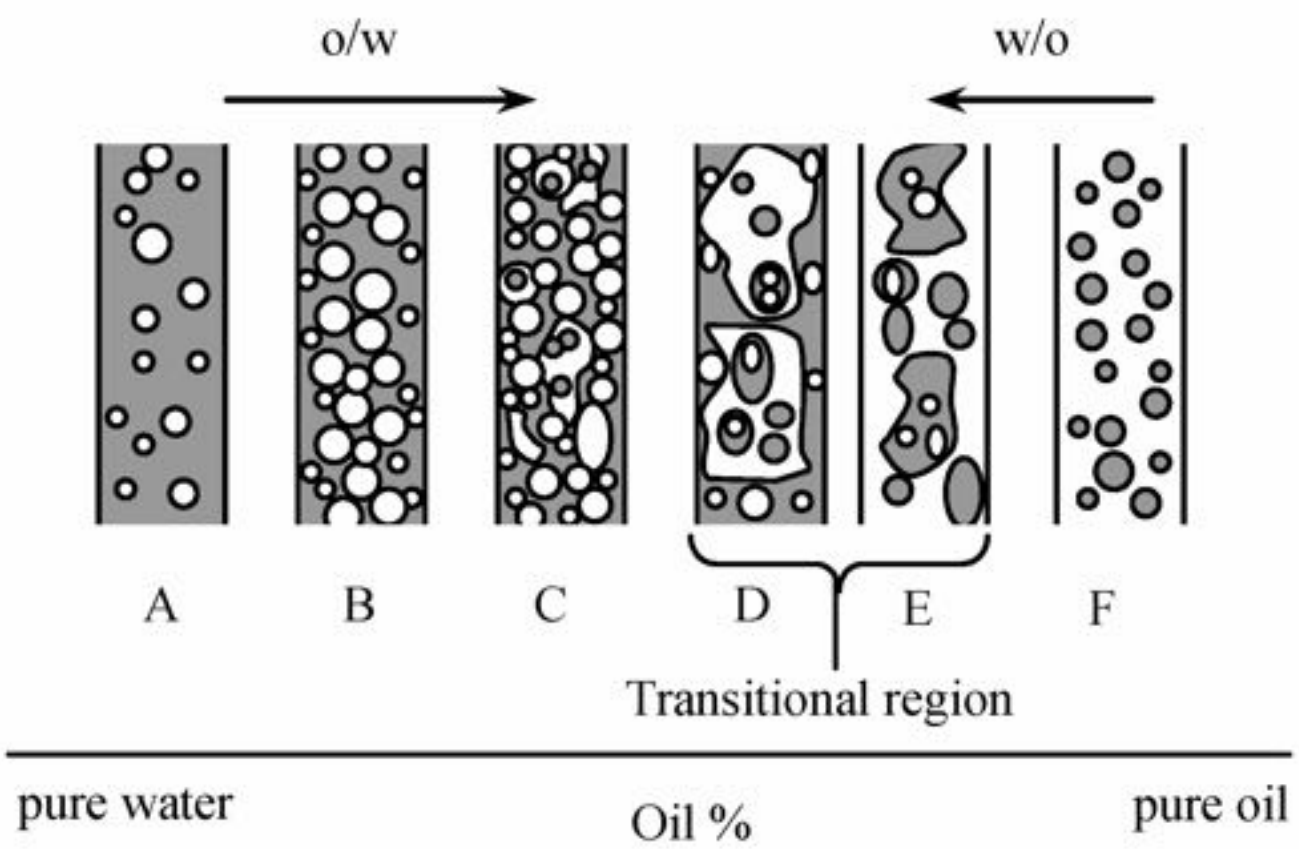
Flow regime map (vertical upwards)



Oil-water horizontal flows

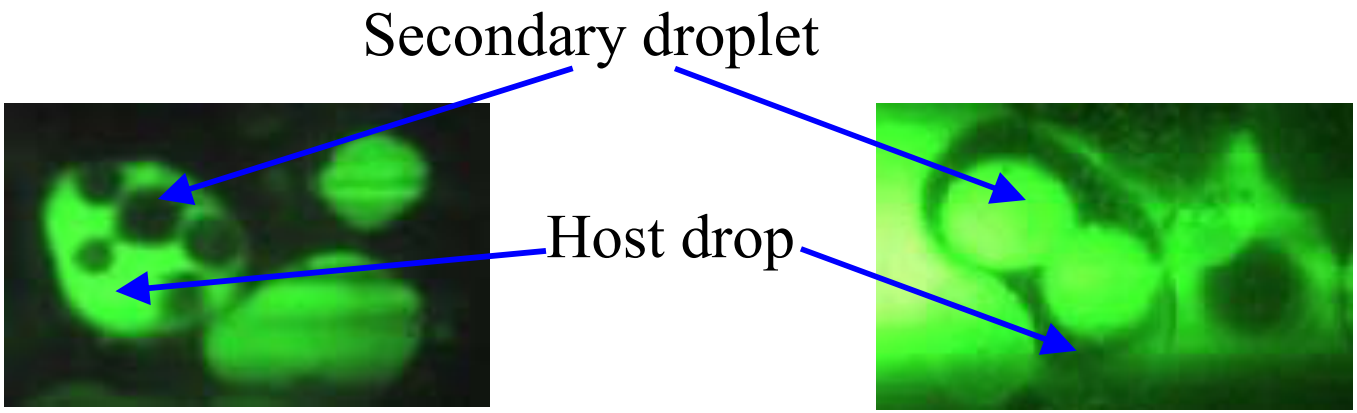


Oil-water vertical flows



Phase inversion: O/W ← → W/O

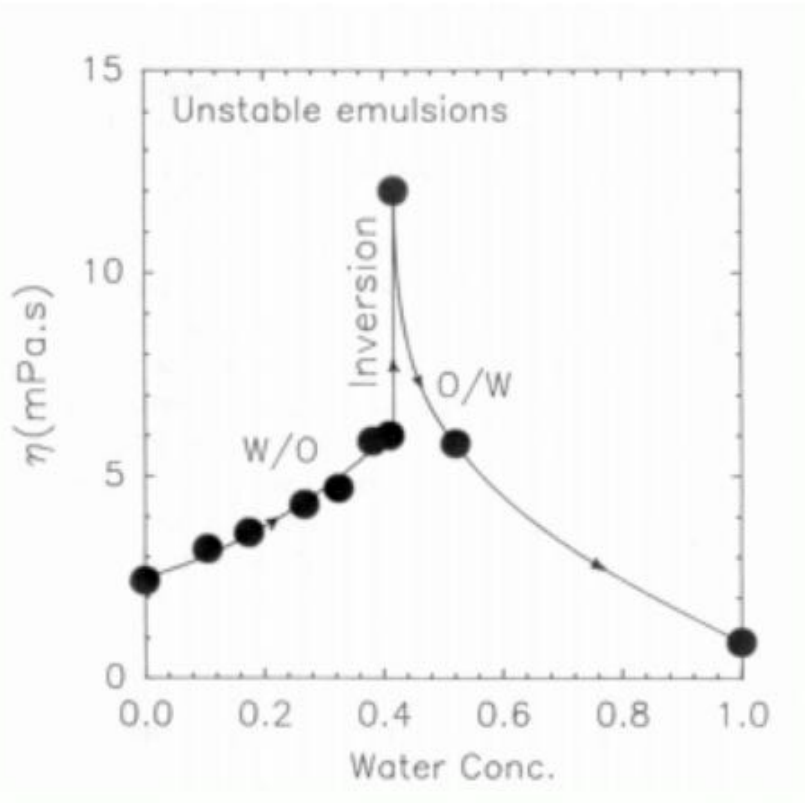
During phase inversion, complex droplet structures formed



Phase inversion: O/W ← → W/O

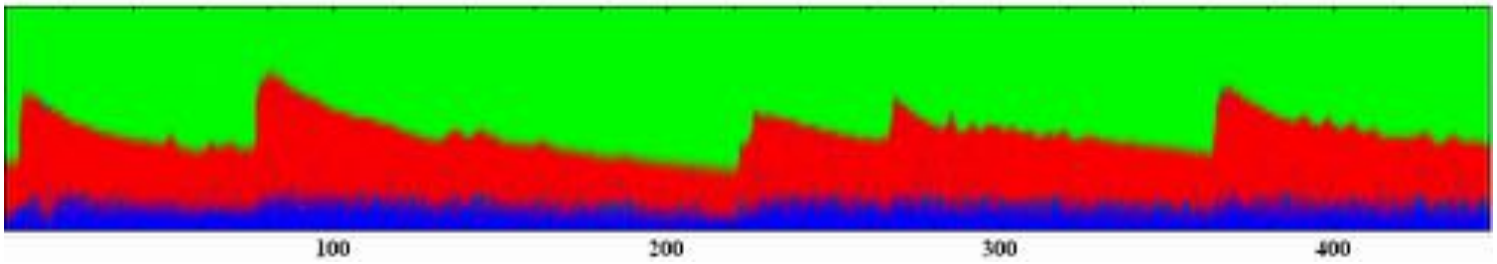
When phase inversion occurs

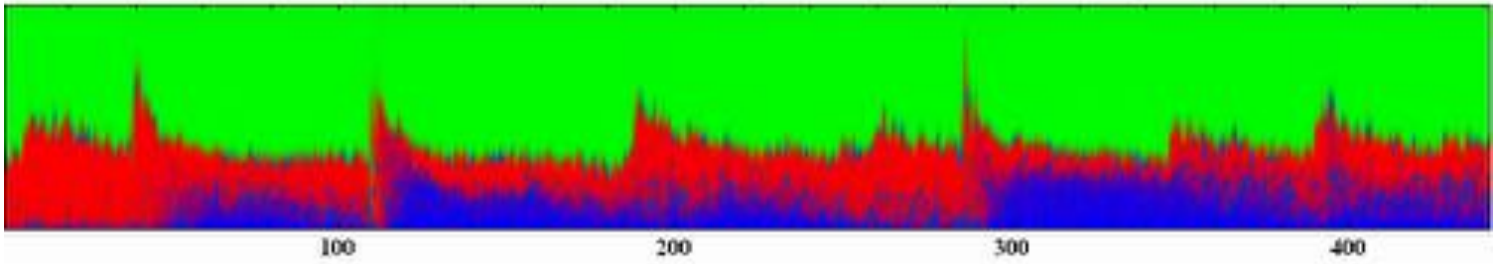
- Emulsion viscosity increases dramatically
- Pressure drop increases
- Catastrophic change of emulsion properties



Three-phase flow

Three-phase large wave flow



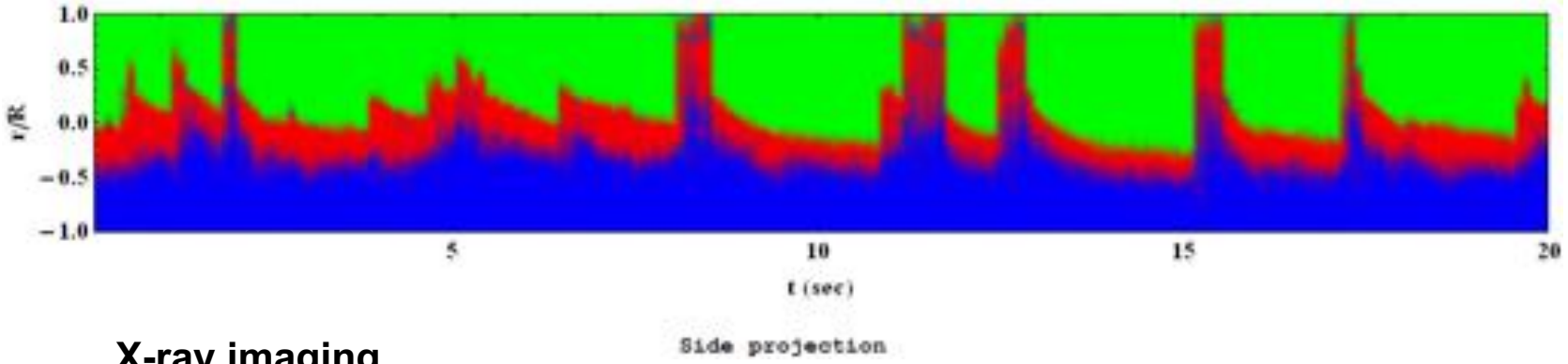


Flow

X-ray imaging

Three-phase slug flow

Flow



X-ray imaging

Summary

- Flow patterns
  - Gas-liquid
  - Oil-water
  - Gas-oil-water
- Horizontal and vertical
- Characteristics of each flow pattern

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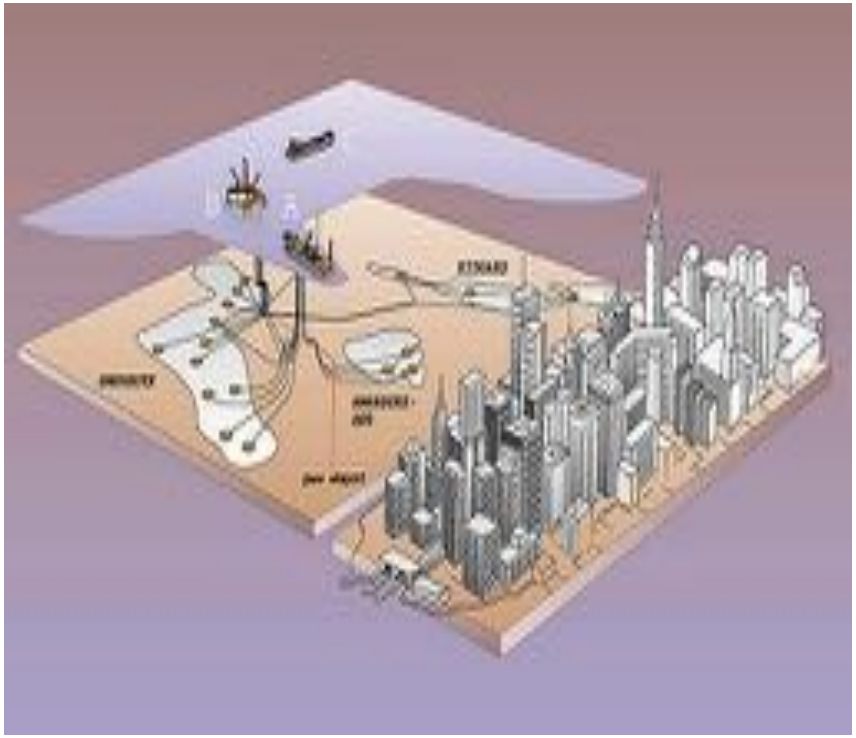
Multiphase flow and flow assurance in oil production

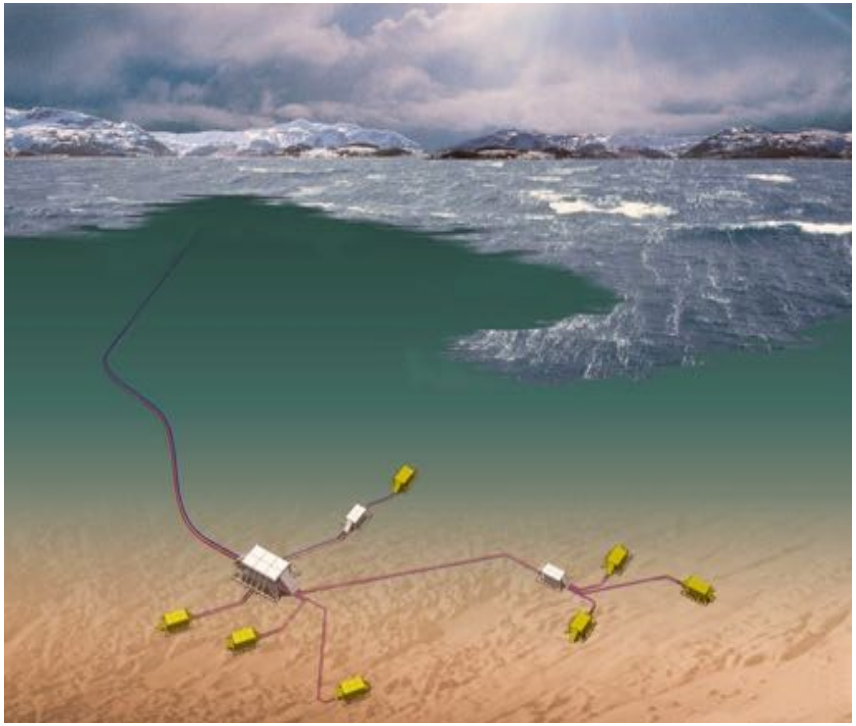
6 Mar 2018

Multiphase Transport Solutions

The Åsgard field:
Floating production platform



The Snøhvit solution:
Transport directly via subsea pipe



(www.statoil.com)

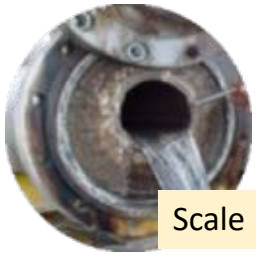
Sea depth

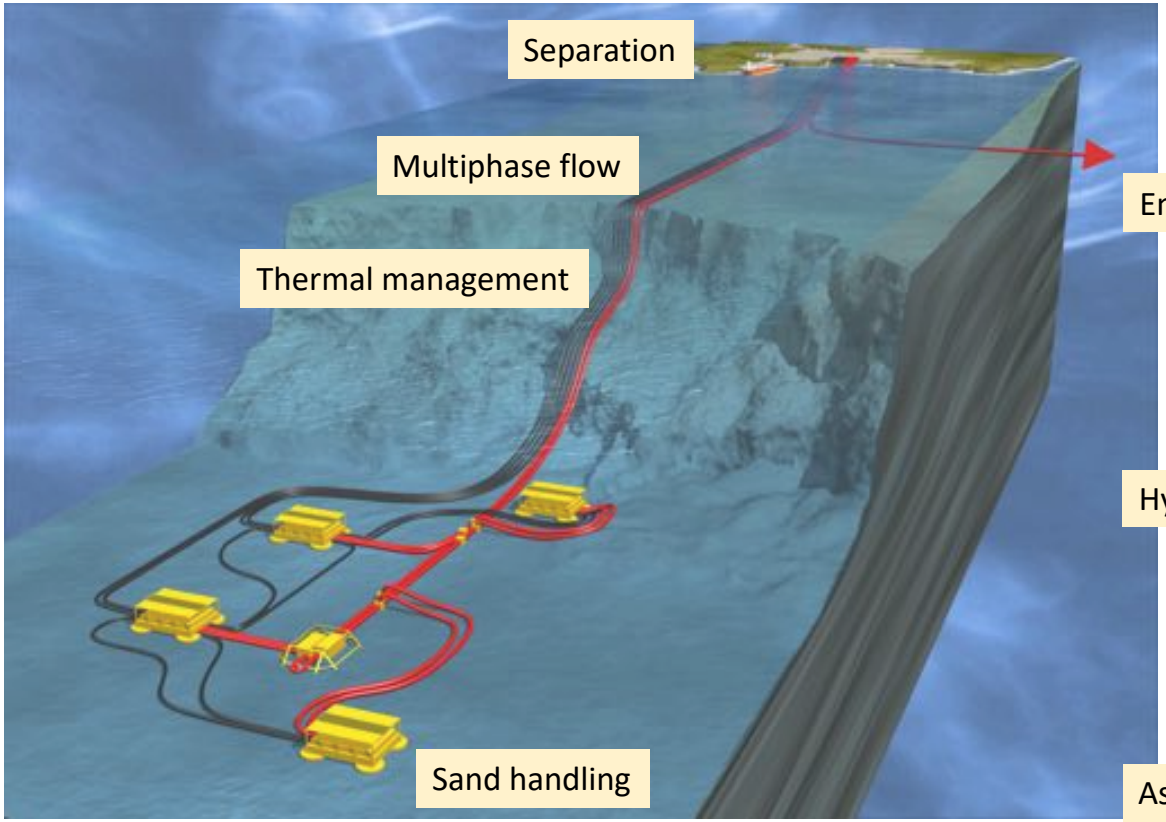
- Norwegian Sea **1500** meter
- Gulf of Mexico **2500** meter
- West Africa 1500 meter
- Brazil 300 meter
- Caspian Sea 600 meter
- Venezuela 300 meter

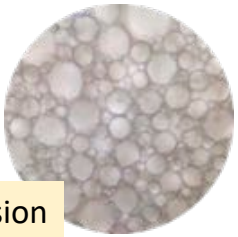
Typical flow assurance challenges


Wax


Corrosion


Scale




Emulsion


Hydrate

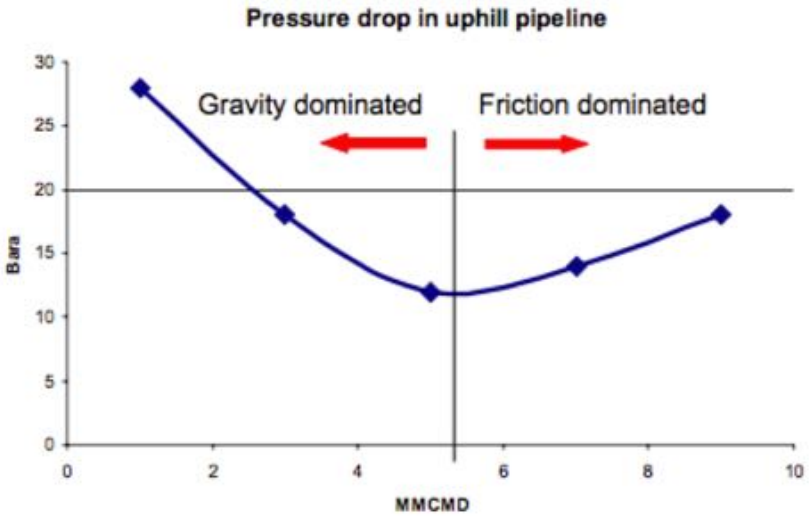

Asphaltenes

Fluid and flow control

- Fluids
  - Hydrate, sand, wax/paraffin, scale
  - Viscosity
- Flow control
  - Emulsion, separation
  - Slugging
  - Water accumulation
  - Sand

Gas condensate pipeline

- Hydrate control
- MEG injection
- Corrosion inhibitor
- Liquid management
- Ramp up/down



Summary

- Long distance, deep water subsea pipeline is of importance in oil production
- Know-how and reliable measurement of multiphase flows are crucial to ensure safe and smooth transportations
- Laboratory work and experimental studies are invaluable!