Challenges for Gas Hydrates in Multiphase Flow Systems

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JEM - EBECEM
Campinas, SP - BRASIL

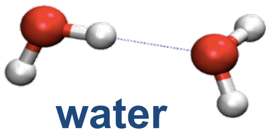
Jornadas em Escoamentos Multifásicos

COLORADO SCHOOL OF MINES
engineering the way

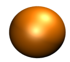
CENTER FOR HYDRATE RESEARCH

Burning Hydrate

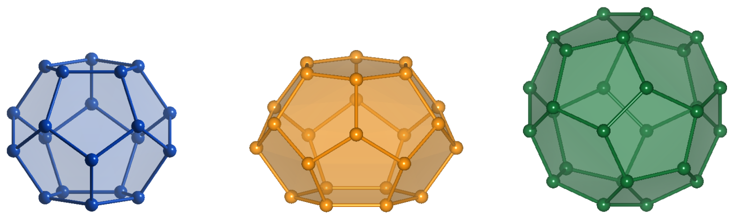
Hydrates Fundamentals



+ gas

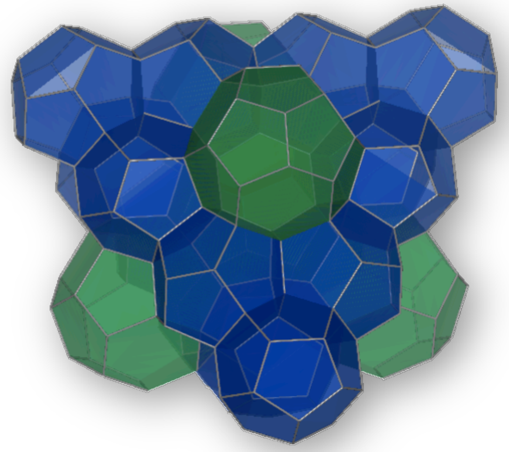


+ High *P* Low *T*

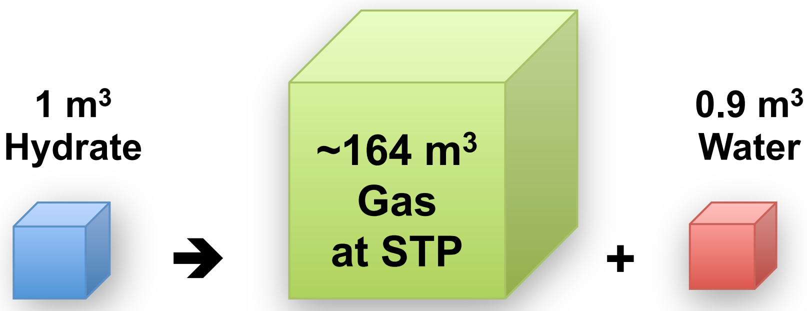


water cages

crystal structure



Burning hydrate



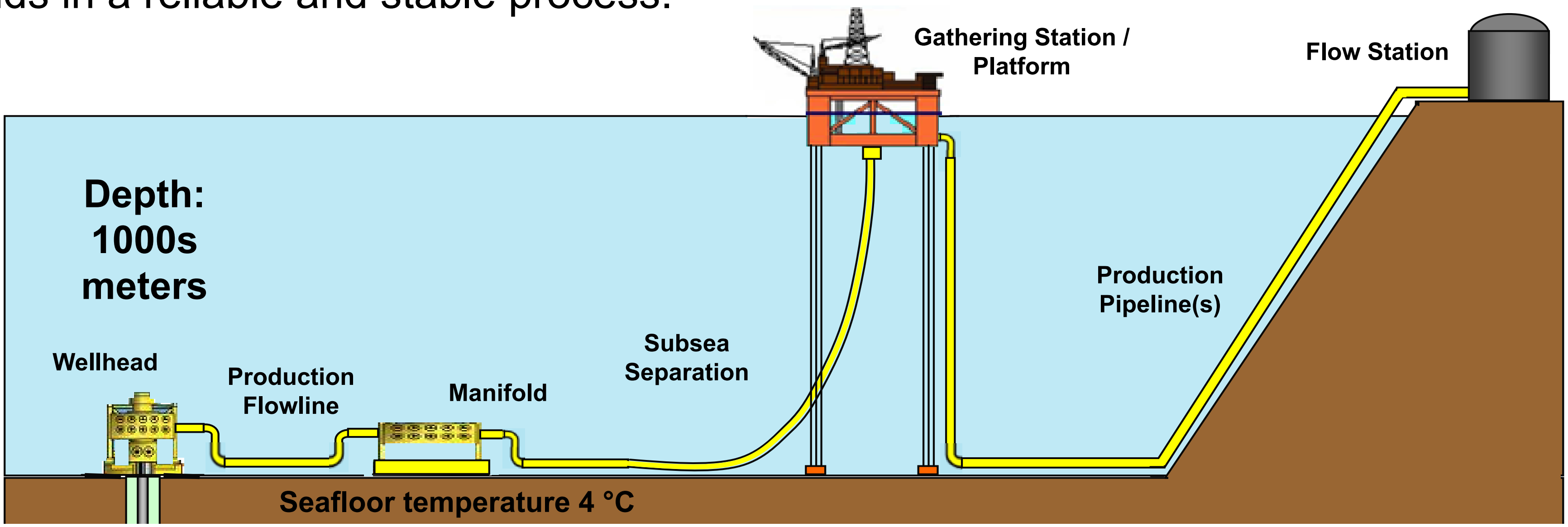
Typical hydrate forming gases:

- Methane
- Ethane
- Propane
- Carbon Dioxide
- Nitrogen
- Hydrogen
- Xenon
- Acetone

Hydrocarbon Production System

Flow Assurance*: Term used to describe the design, engineering, and management for transport of multiphase fluids in a reliable and stable process.

Separation of oil/gas/water



Produce oil/gas/water

Pipeline: 10s km
Oil: 6-8 inch
Gas: 10+ inch

*Coined by Petrobras in the early 1990s as "Garantia do Escoamento"

Hydrates in Flow Assurance

A — flowline — B

wellhead — platform

SPECIFIED

Fluid composition
and properties
Phase fractions
Thermo conditions
Flow rate

CONSTRAINTS

Field topology and conditions

NEED TO KNOW

Flow regime
Temperature/Pressure profile
Phases distribution, entrainment, emulsification
Hydrate avoidance/management
Hydrate amount, distribution
Hydrate remediation

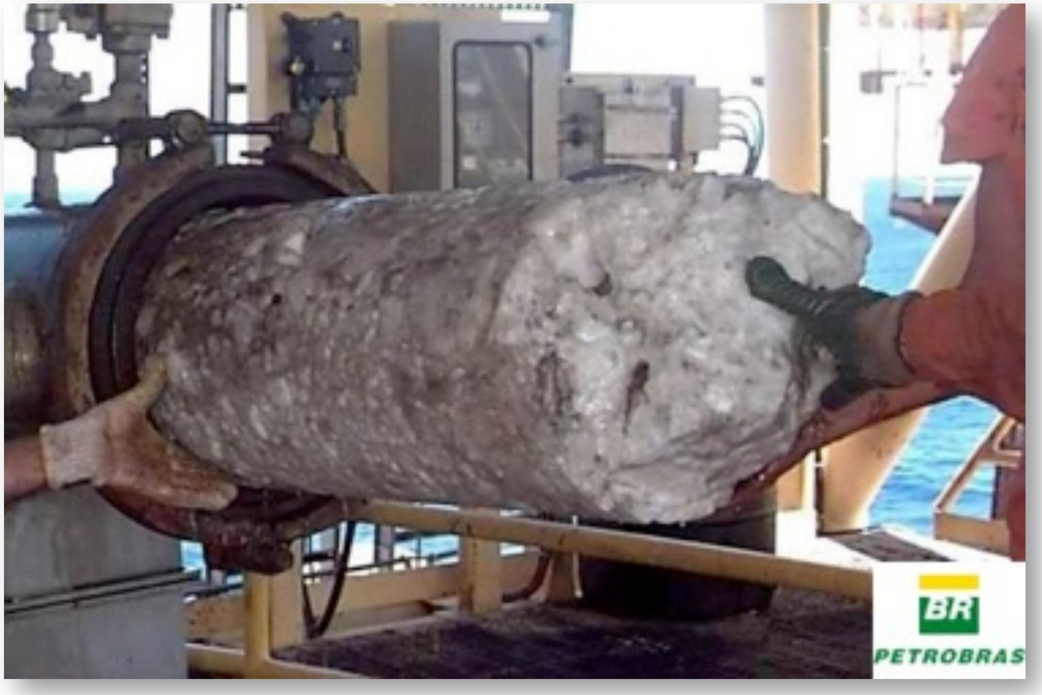
DESIRED

Producing
fluids

Maximize flow
Minimize ΔP

Hydrates in Flow Assurance

- **Hydrate formation in oil/gas flow lines**
- **#1 problem in flow assurance (more severe than wax, asphaltene, corrosion)**
- **Costly to prevent ($100sM per year)**
- **Costly to remove (lost production)**
- **Safety concern (pressure buildup)**



Hydrate plug removed from oil pipeline

Hydrate Management Strategies

- **Thermal**
  - Insulation
  - DEH
  - Bundles
  - Heat tracing
- **Chemical**
  - MeOH/EtOH
  - Glycols
  - LDHI (AA, KHI)
  - Salts
- **Hydraulic**
  - Fluid displacement
  - Gas sweep
  - Depressuriz-ation
  - Compression
  - Dense phase
- **Process**
  - Gas dehydration
  - Water cut reduction
- **No Control**
  - Operation within hydrate domain
  - Natural hydrate transport-ability
  - Natural kinetic inhibition

Modified from K. Kinnari (Statoil)

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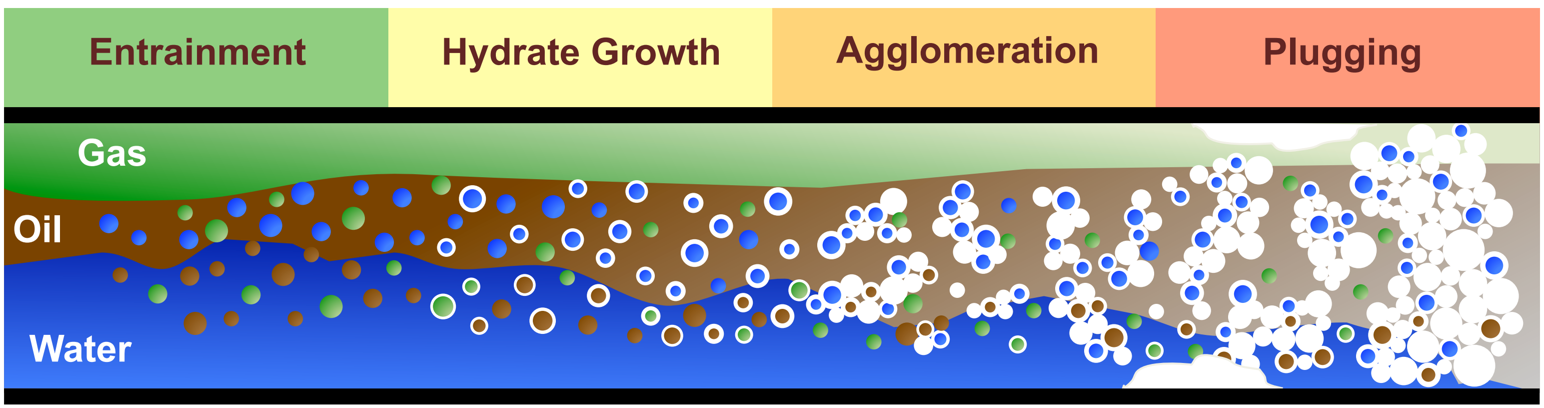
- **Risk based approach**
- **Sound engineering practice/design**
- **Understand effect of water and hydrates in production system**
- **Need to combine field experience with laboratory research**

Modified from K. Kinnari (Statoil)

Hydrate Management

Model Hydrates in Multiphase Flow

Gas, Oil, Water (free, emulsified, dispersed)



Emulsification/ Dispersion

Growth

Co/Ad-hesion

Deposition

Nucleation

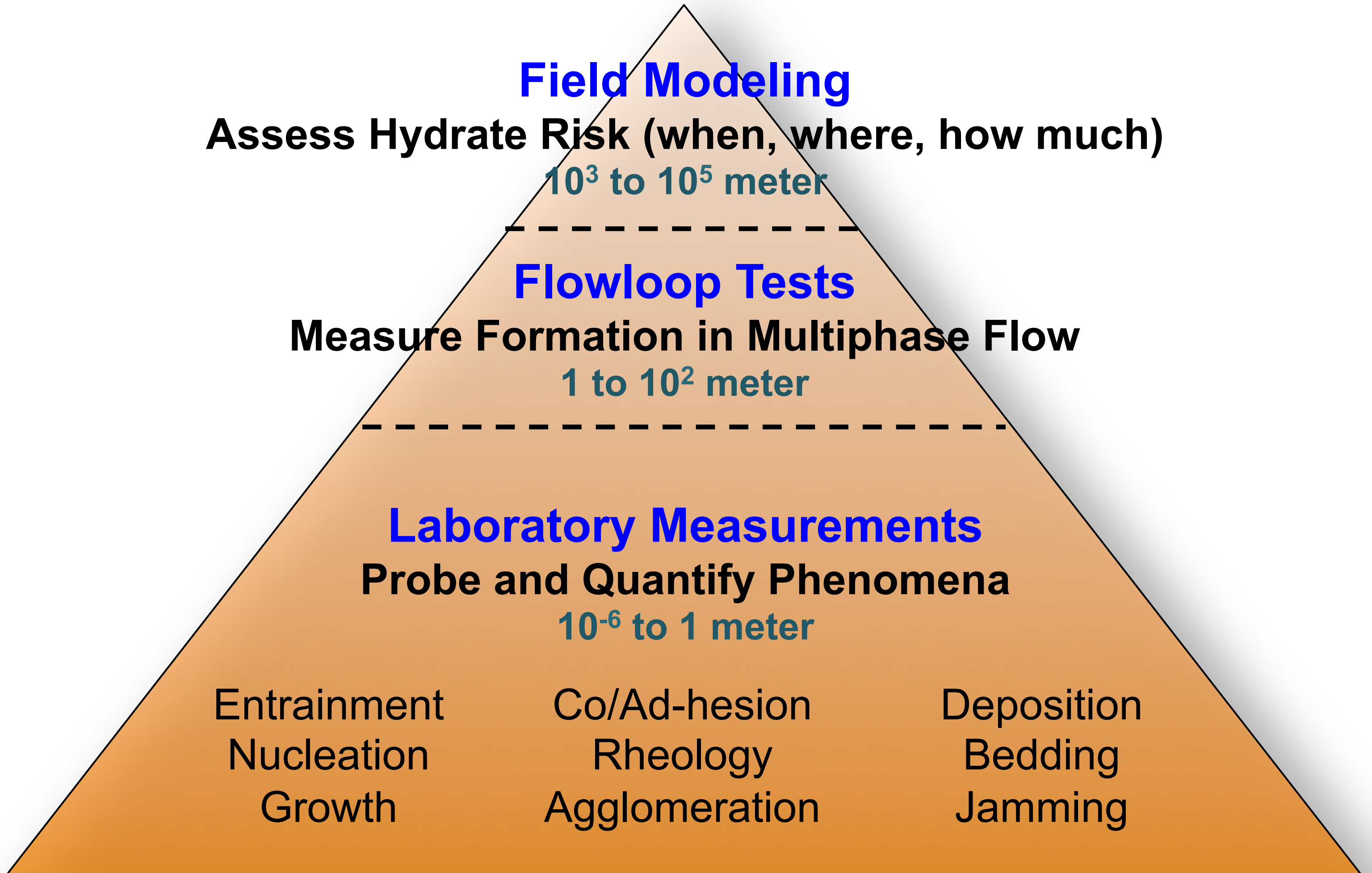
Rheology

Aggregation

Jamming/ Bedding

Must account for each phenomenon combined with multiphase flow

Multiscale Approach to Research



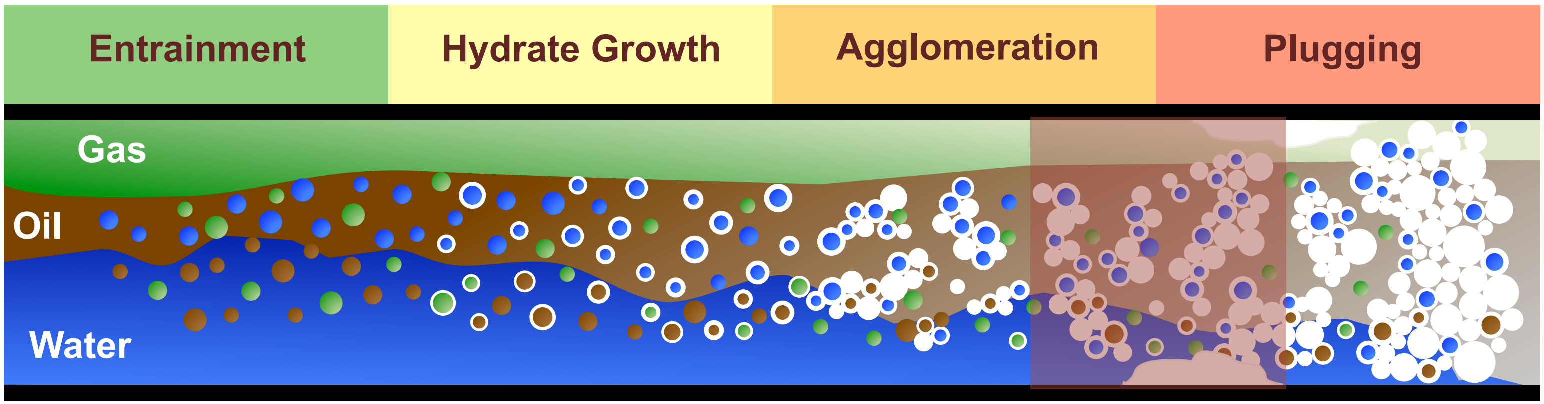
Depth and Breadth of Hydrate Research

lab scale
multiphase flow chemical inhibition
particle jamming/bedding
flowloop interfacial/surface science
heat transfer
mass transfer kinetics
simulations thermodynamics
aggregation modeling
nucleation phenomemon
rheology theory
emulsification
experiments

Hydrate Management

Model Hydrates in Multiphase Flow

Gas, Oil, Water (free, emulsified, dispersed)



Emulsification/ Dispersion

Growth

Co/Ad-hesion

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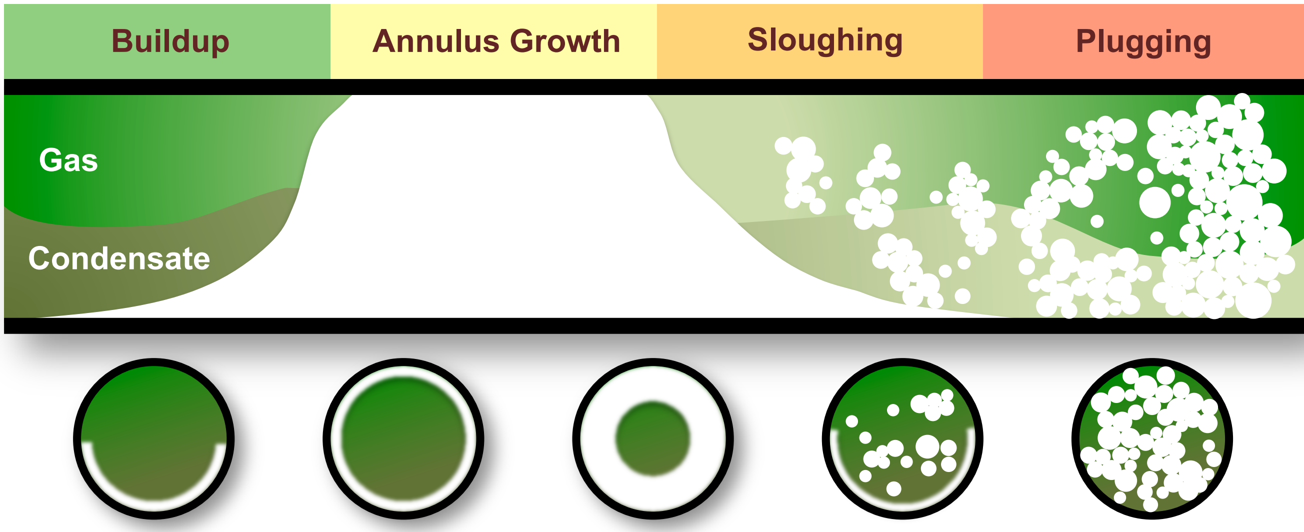
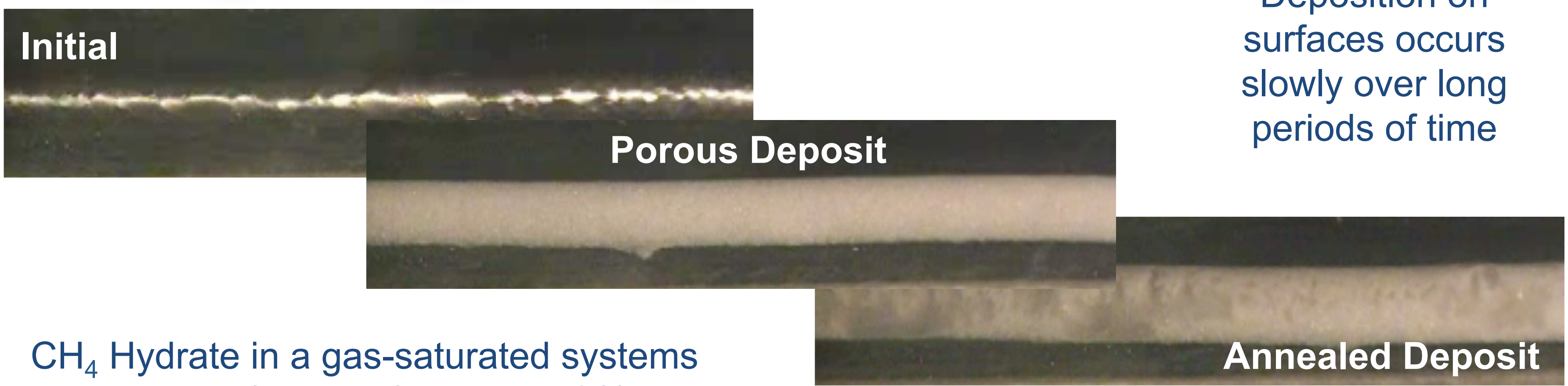
Hydrate Deposition (Gas systems)

Gas / Gas Condensate (no free water)

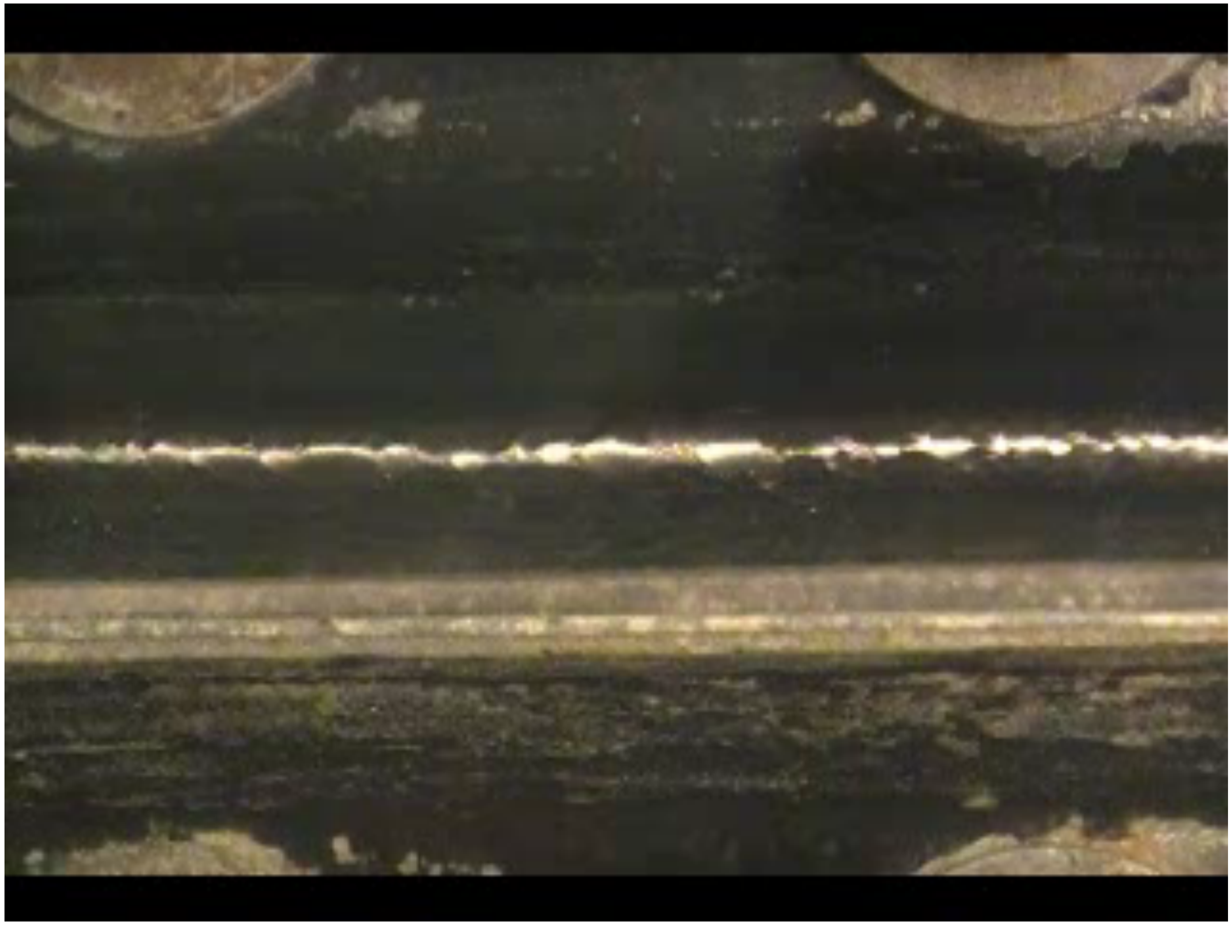




Deposition on surfaces occurs slowly over long periods of time

CH_4 Hydrate in a gas-saturated systems at 1500 psig (cold surface at 0.5 °C)

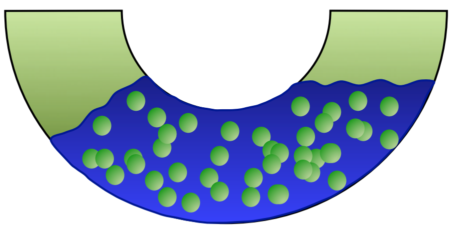
Hydrate Deposition from Gas Phase



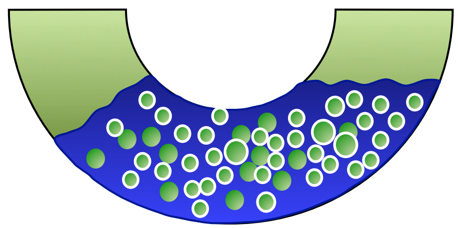
CH_4 vapor saturated with water at 30°C
P = 1300 psig, T_{cold} = 0.5°C

Gas Bubbling Through Water in Low Spots

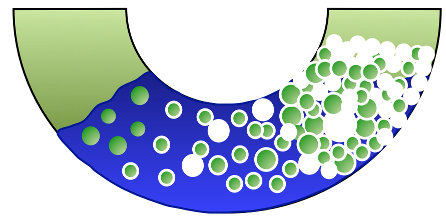
1. Early stage



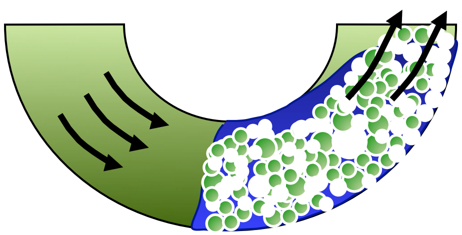
2. Early stage



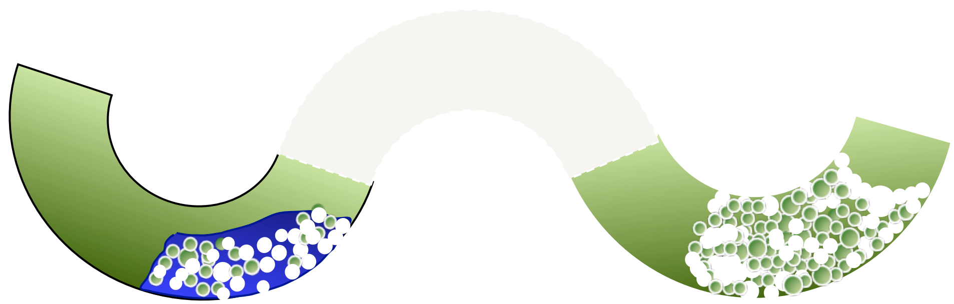
3. Build up



4. Collapse



5. Plug

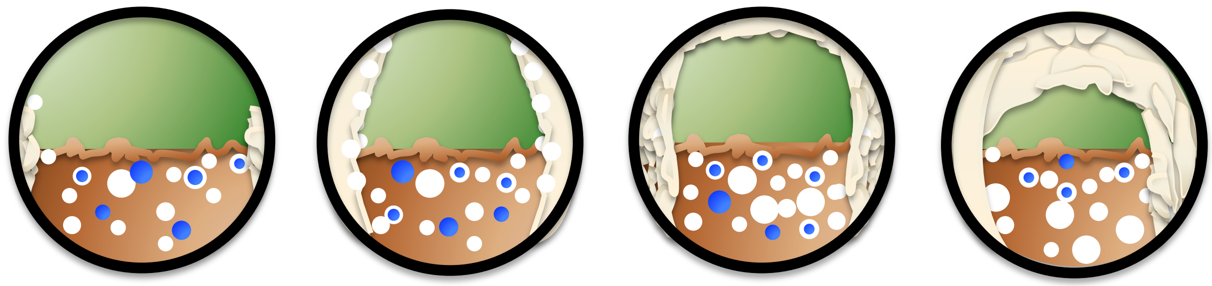


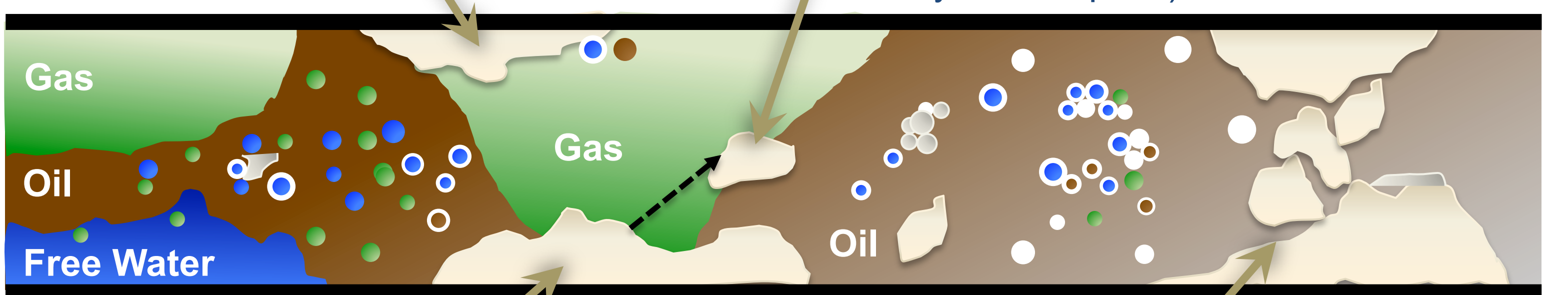
Hydrate Deposition from Accumulated Water

Gas bubbling through water layer in low spot

Hydrate Wall Deposition (G-L Systems)

- Hydrate deposition initiated near gas-liquid interface
- Deposition may be localized





Hydrate deposition is especially concerning over long periods of time (ΔP increases slowly over time)

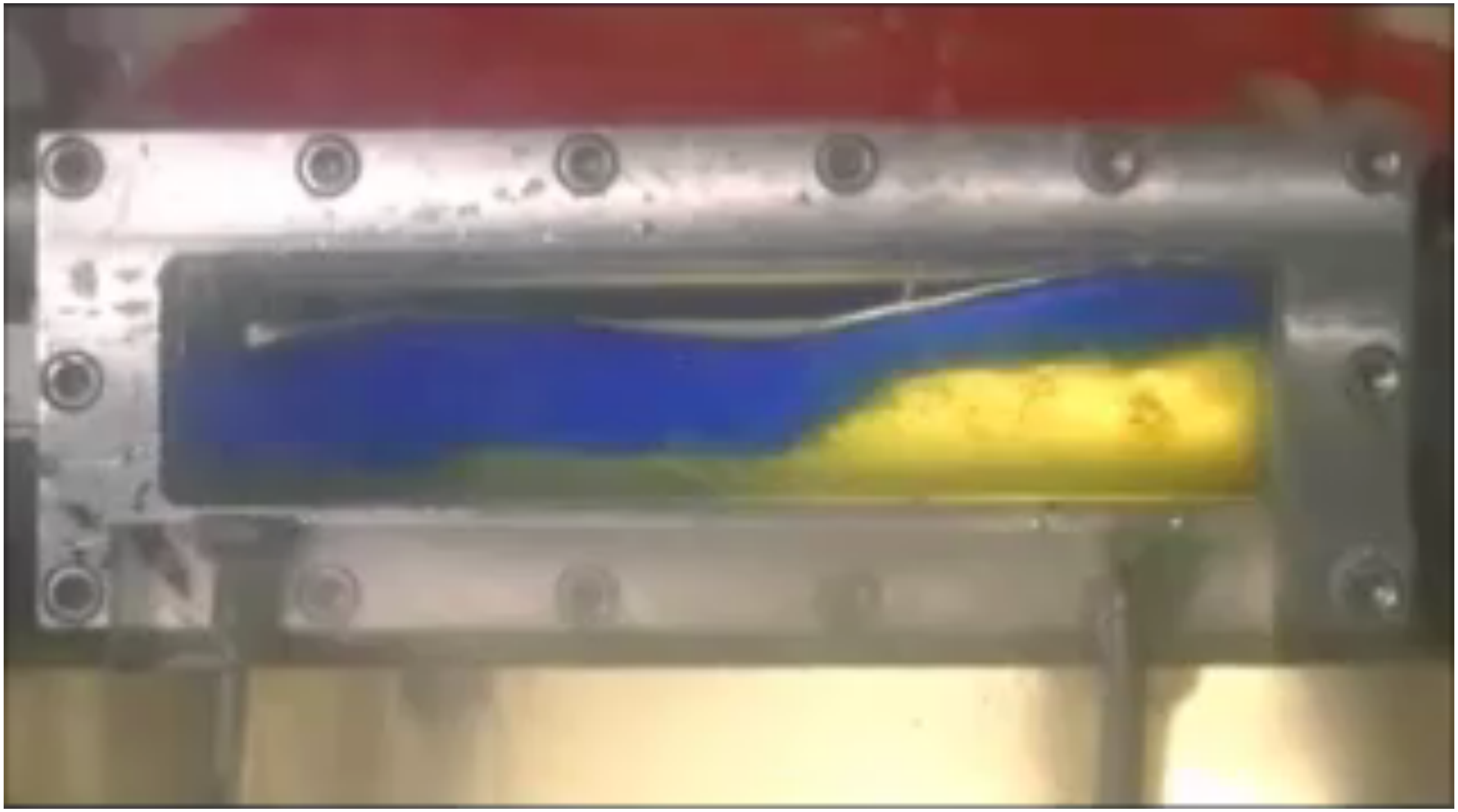
Hydrate Wall Deposition (G-L Systems)

Gas-Water, $T_{surface}$ = 1 °C, $P_{initial}$ = 550 psig, 50 vol% water

- Liquid splashes on surface; liquid also creeps up the wall
- Low porosity (~80%)
- Water conversion ~9%

Hydrate Formation in G-O-W Systems

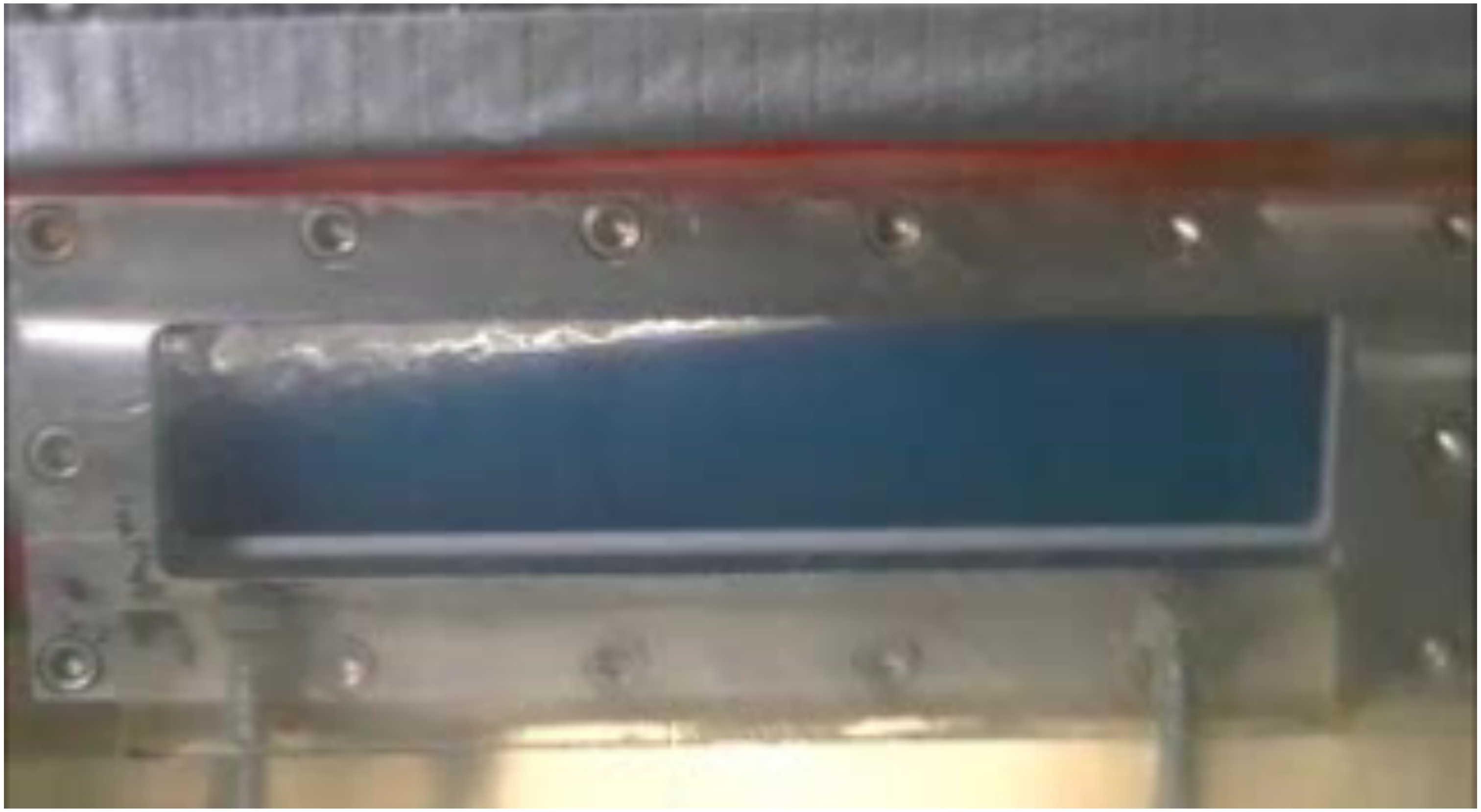
Ambient: 8 °C, Upper wall: 1 °C
Hydrate formation starts at 34 bar, 5.5 °C



Hydrate Deposition (G-O-W Systems)

C1/C2 + Mineral Oil + Water, 70 LL, 60% WC

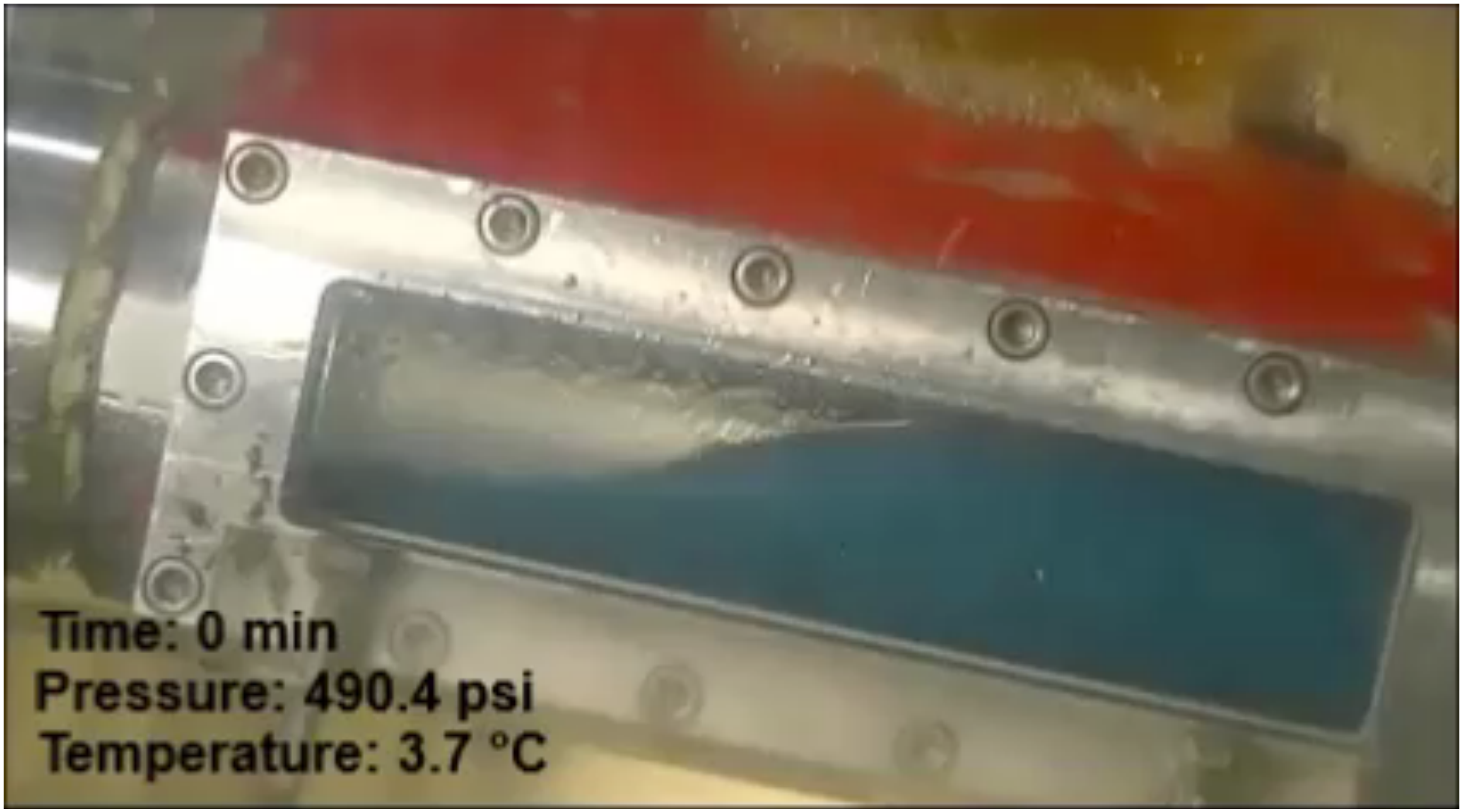
$T_{surface}$ = 1 °C, T_{bulk} = 6 °C, $P_{initial}$ = 550 psig, Const. volume



Phase separation, Deposition, Sloughing, Bedding

Fully Dispersed System Phase Separates upon Hydrate Formation

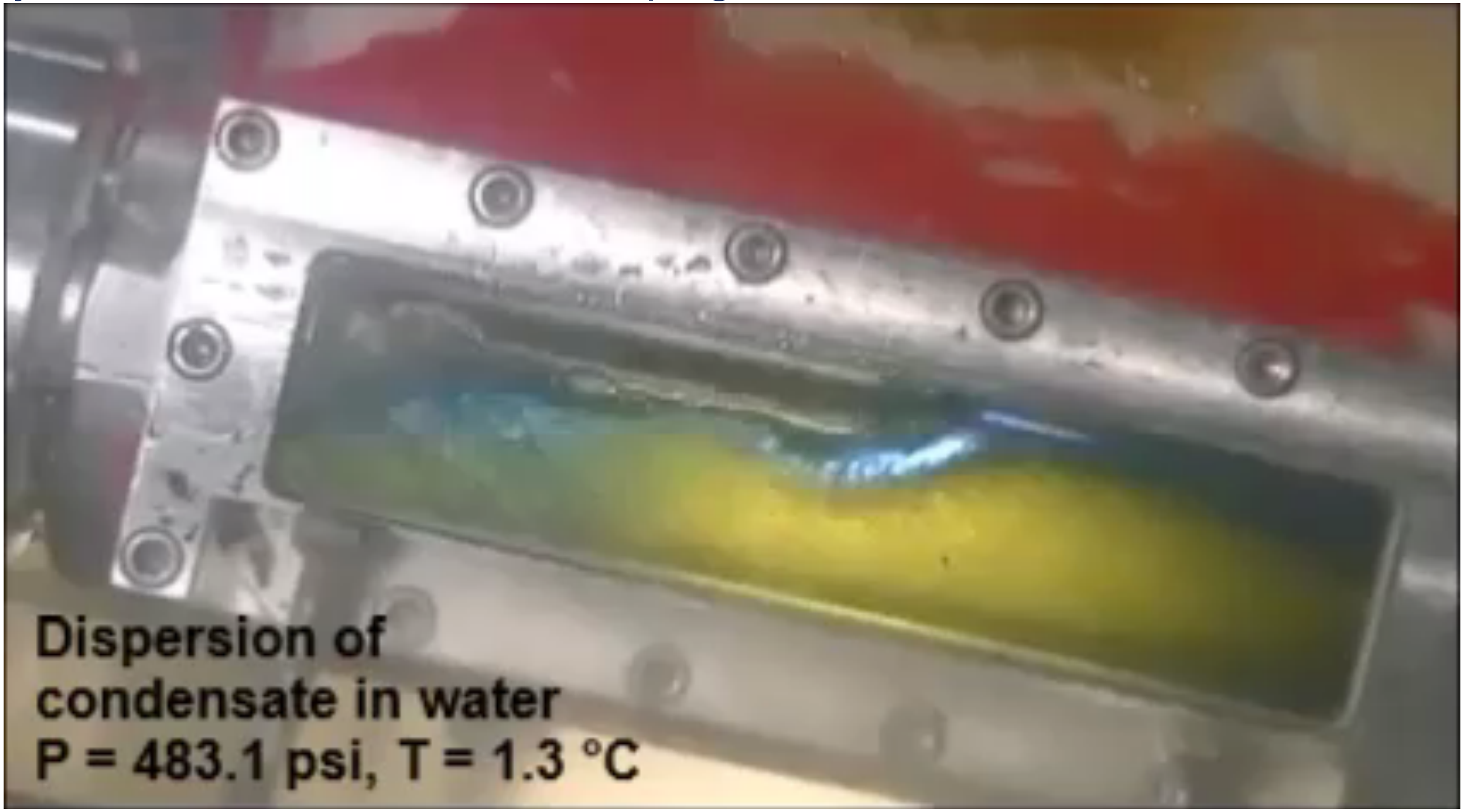
Ambient: 4 °C, Upper wall: 1 °C
Hydrate formation starts at 478 psig, 5.5 °C



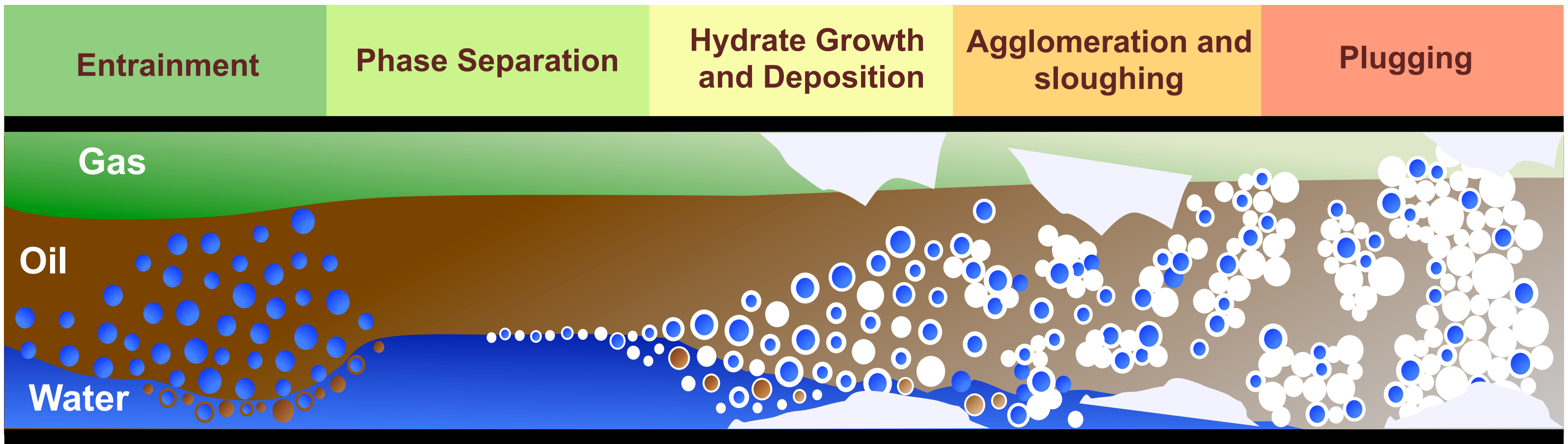
Partly Dispersed System Phase Separates upon Hydrate Formation

Ambient: 1 °C, no additional wall cooling

Hydrate formation starts at 490 psig, 3.7 °C



Proposed Model for Non-Emulsifying Systems



Water is entrained in oil and/or oil in water

Phases separates at the time of hydrate formation

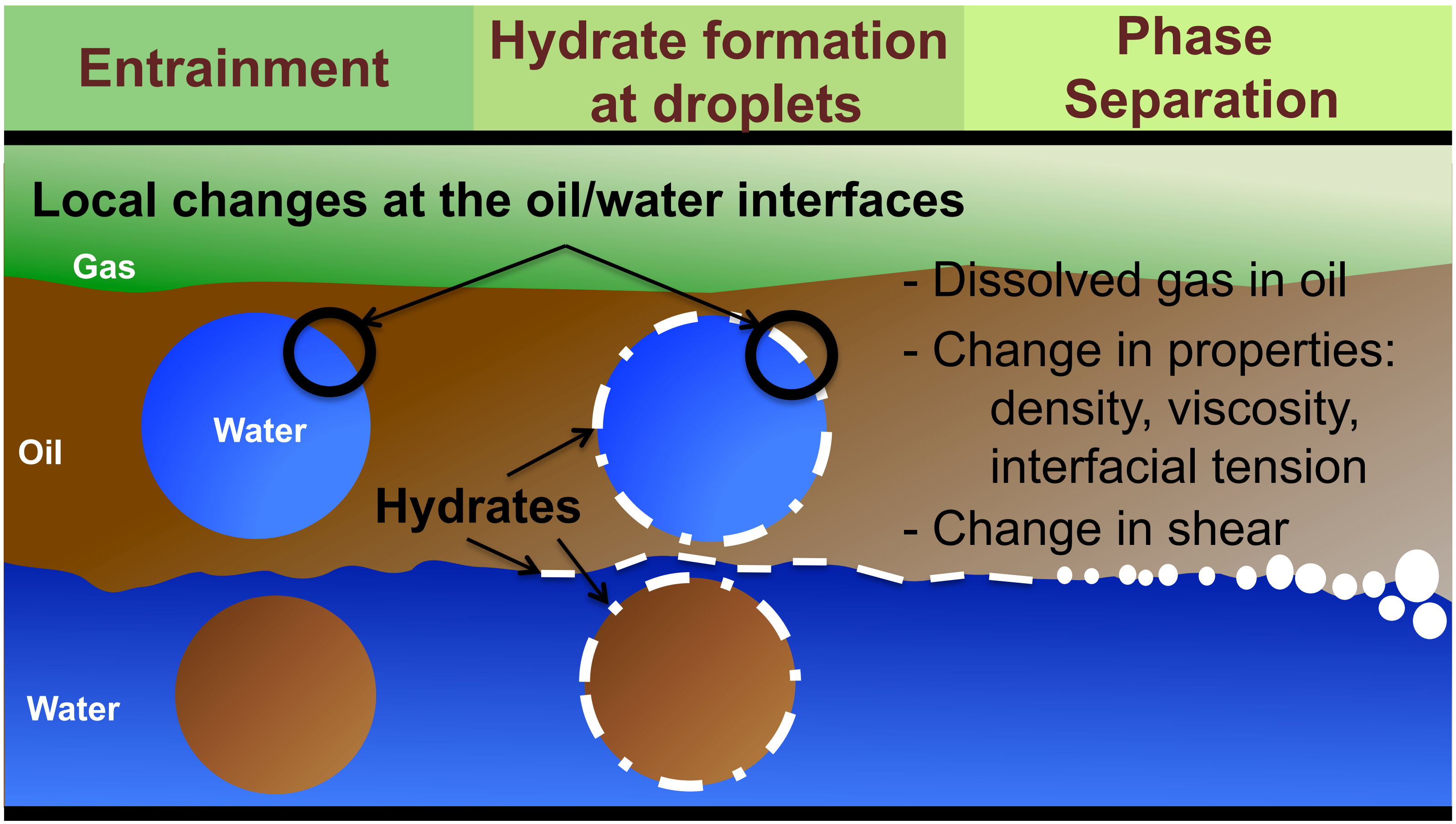
Hydrates starts appearing at interfaces between hydrocarbon and water, in the water and oil phases, and as deposits

Hydrates agglomerate and deposits slough off the pipe wall. Apparent viscosity increases and bedding may occur

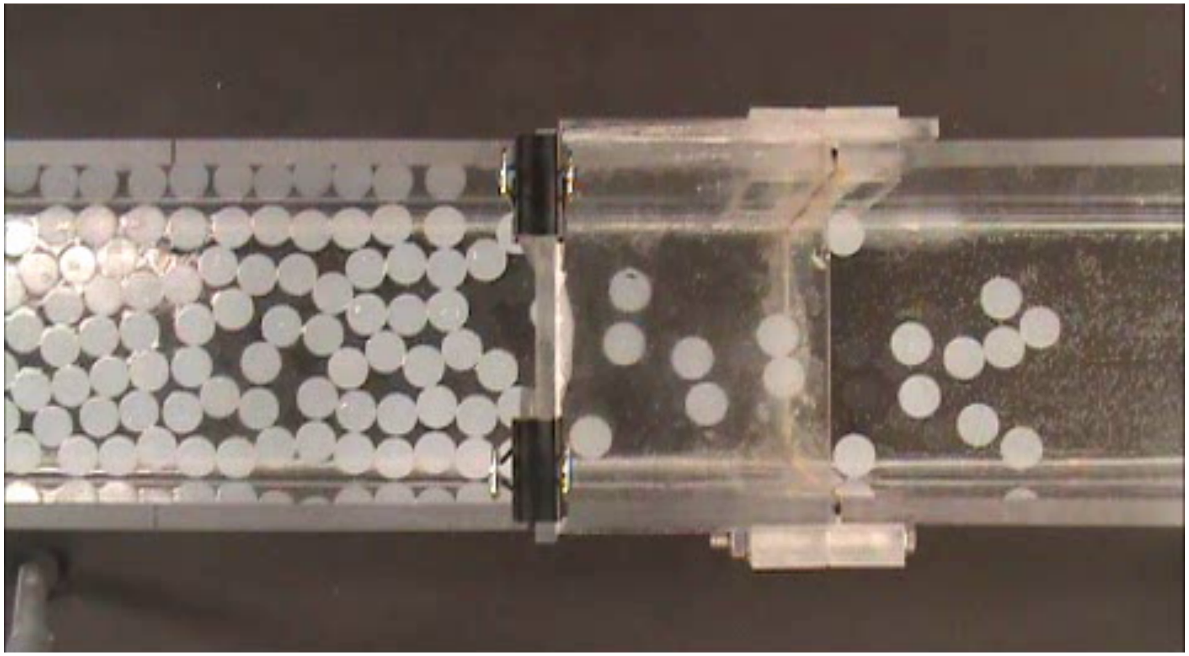
Plugging of the pipe

Possible Mechanisms for Phase Separation

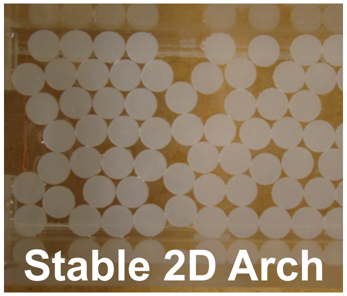
Hydrate formation destabilize droplets:



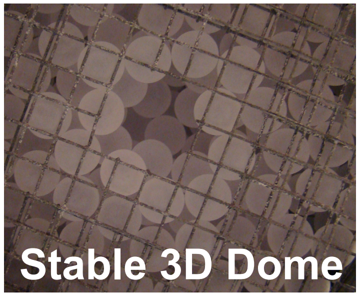
Particle Jamming in Flowing Systems



Three Ingredients:
- Dense particle flow
- Flow restriction
- $d_o/d_p = R$ is small



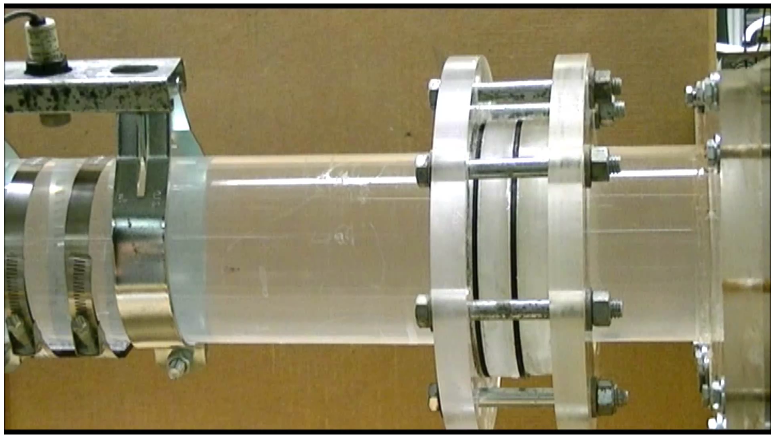
Stable 2D Arch

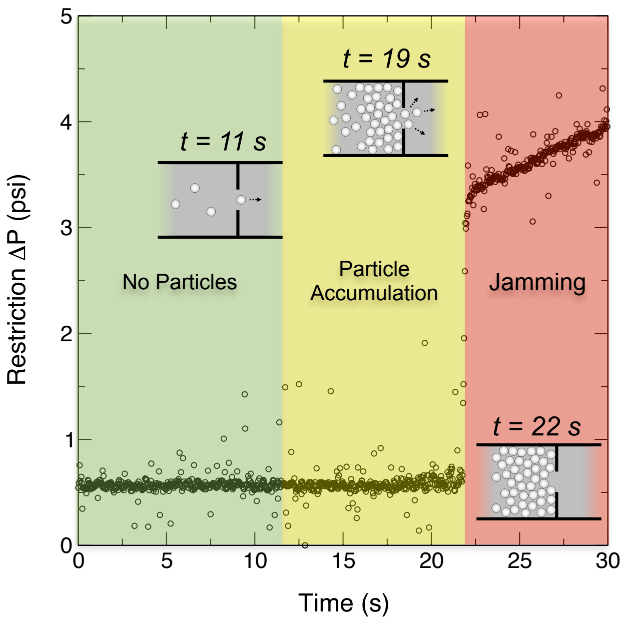


Stable 3D Dome

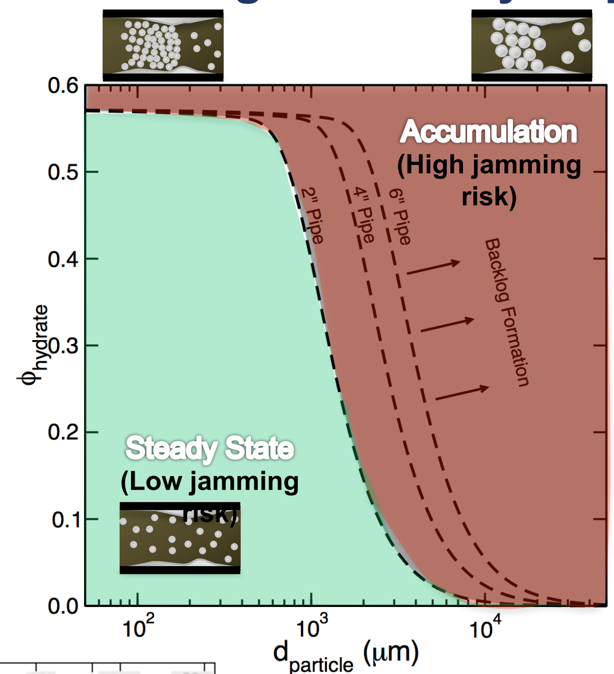
Variables:
- Particle size/shape
- Restriction size/shape
- Fluid velocity
- Particle concentration

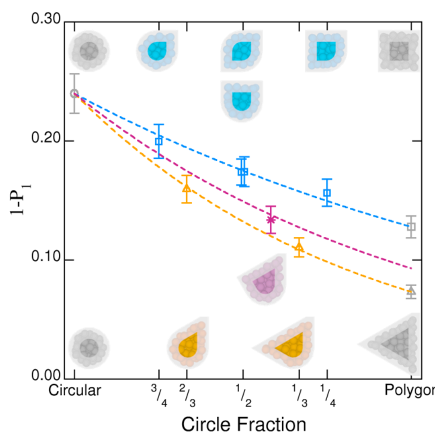
Particle Jamming in Flowing Systems





Jamming Probability Map





Survival Probability

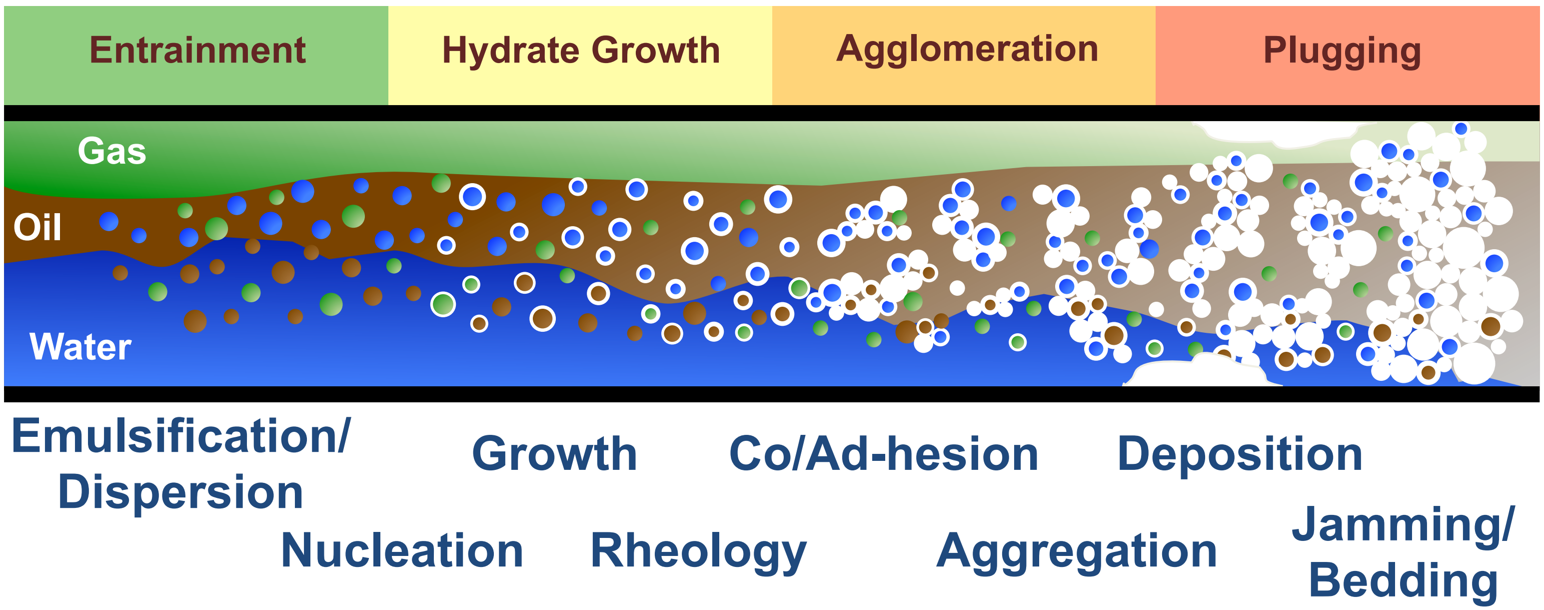
$$\ln\left[S(\tau)\right] = -\int_0^{\tau} \Lambda d\tau$$

Jamming in any geometry

Hydrate Management

Model Hydrates in Multiphase Flow

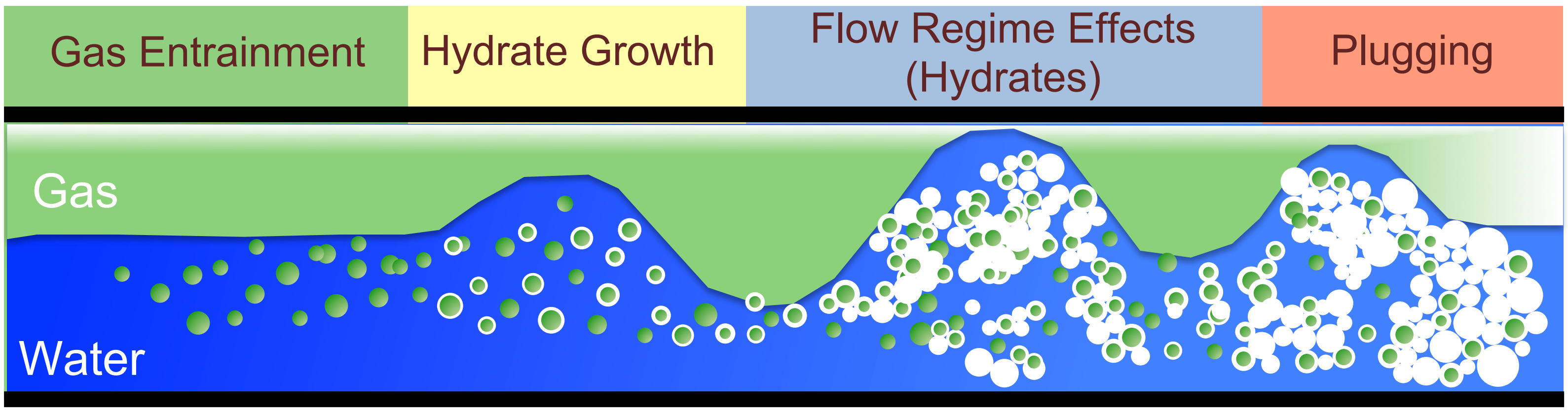
Gas, Oil, Water (free, emulsified, dispersed)



Each phenomenon studied separately

Multiphase flow & hydrate formation are interdependent

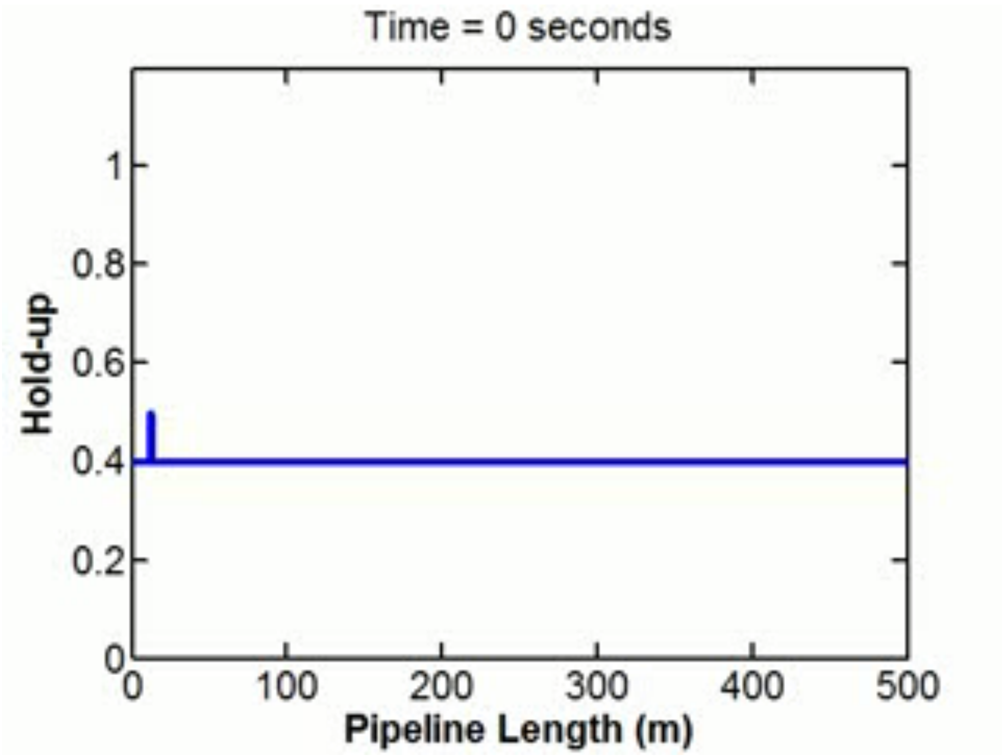
Multiphase Flow & Hydrate Interdependence



- Hydrate formation = f(LL, WC, mixture velocity, T, P)
- **CSMFlow:** incorporates flow regime in calculations
- Effort to understand multiphase flow and **its effect on hydrate formation (and vice-versa)**

Capabilities of **CSMFlow**

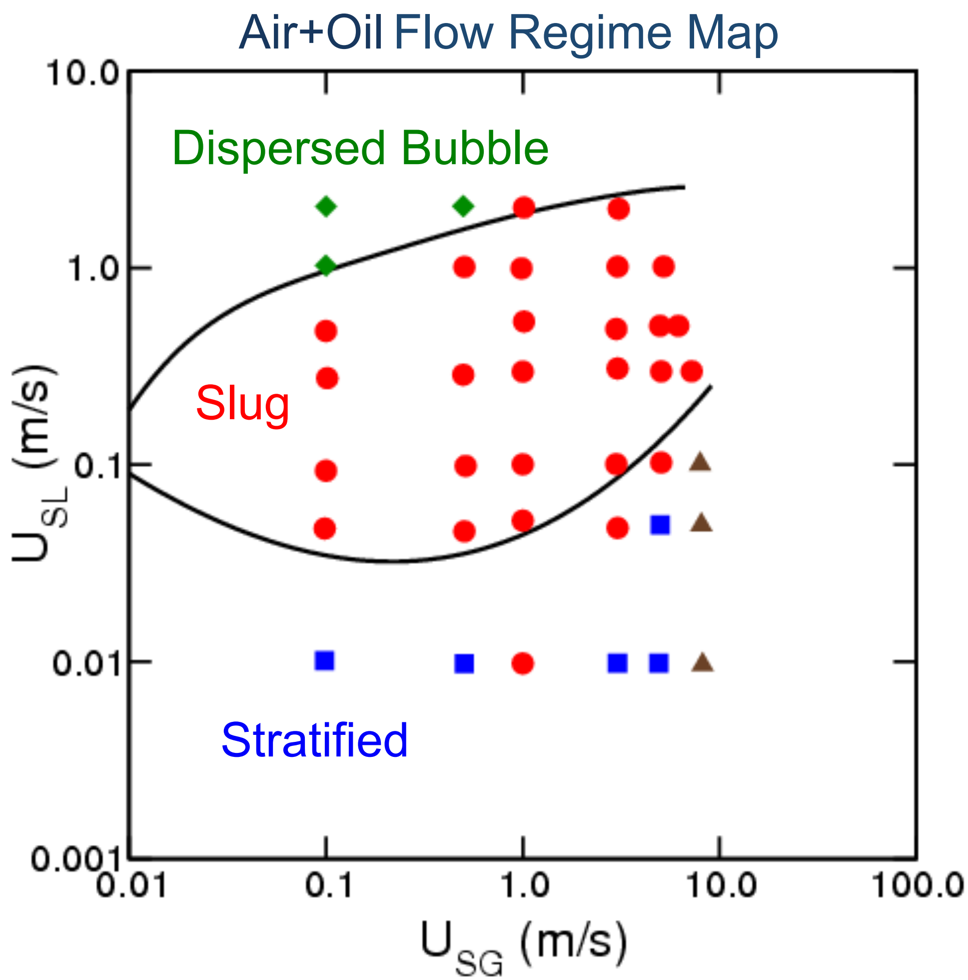
- Two-phase (G-L) flow



- Based on fundamental concepts of multiphase flow
- Uses Drift-Flux model
- Predicts slug formation

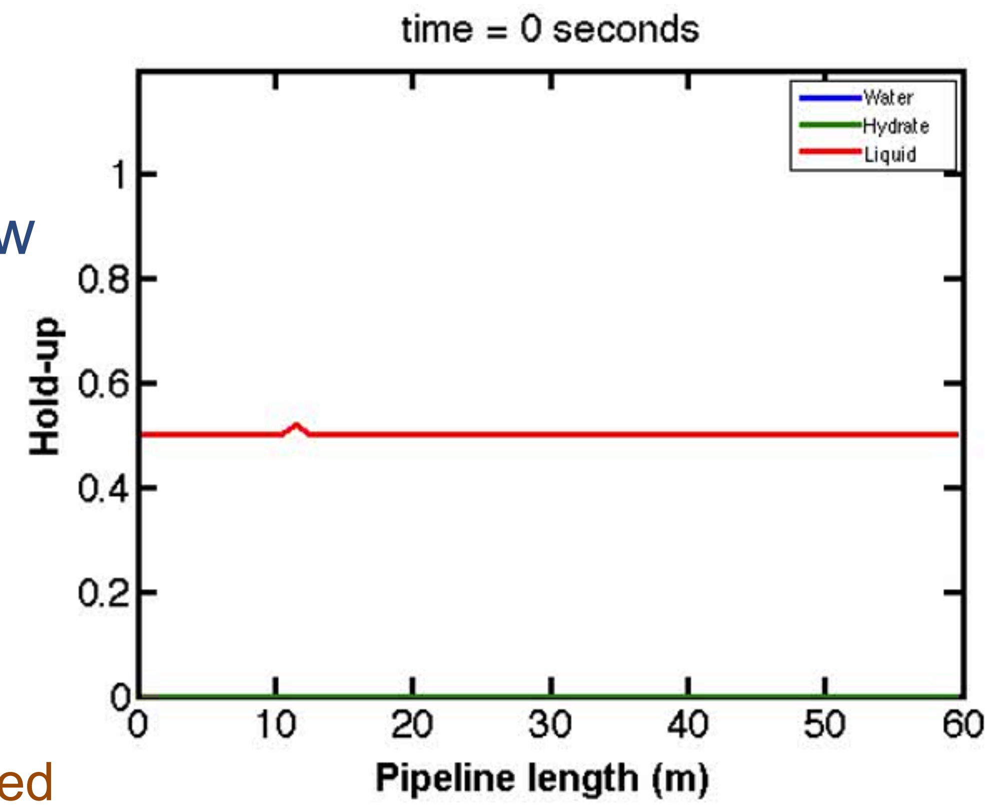
Capabilities of **CSMFlow**

- Two-phase (G-L) flow
- Flow regime maps



Capabilities of **CSMFlow**

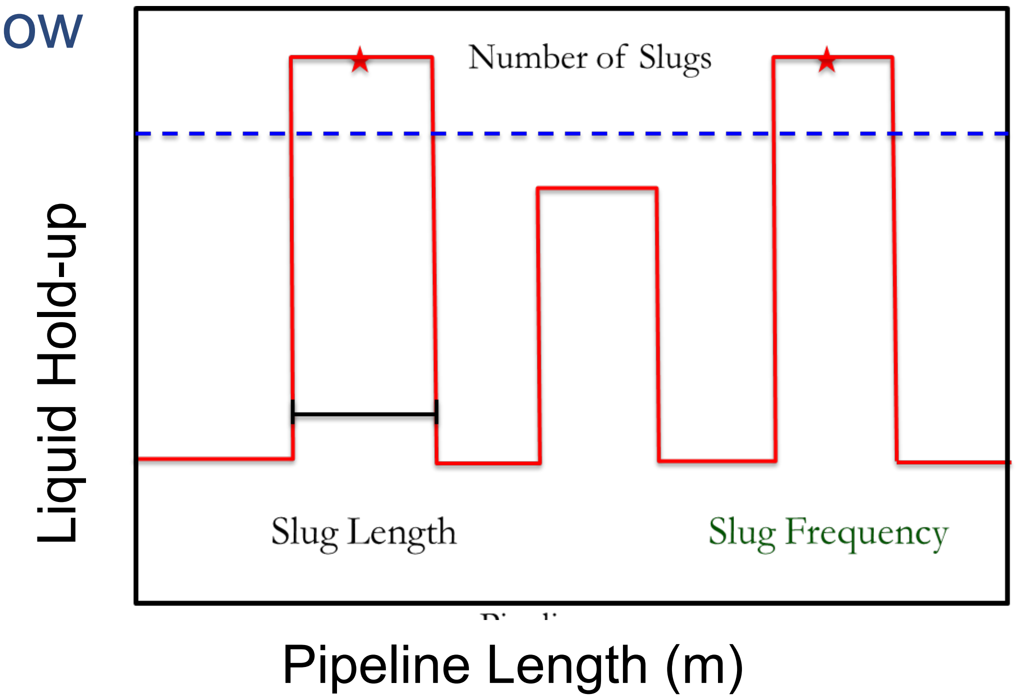
- Two-phase (G-L) flow
- Flow regime maps
- Three-phase (G-L-H) flow
  (with hydrate formation and growth models)



- Extended model for hydrates
- Flow regime transition predicted from stratified/wavy to slug

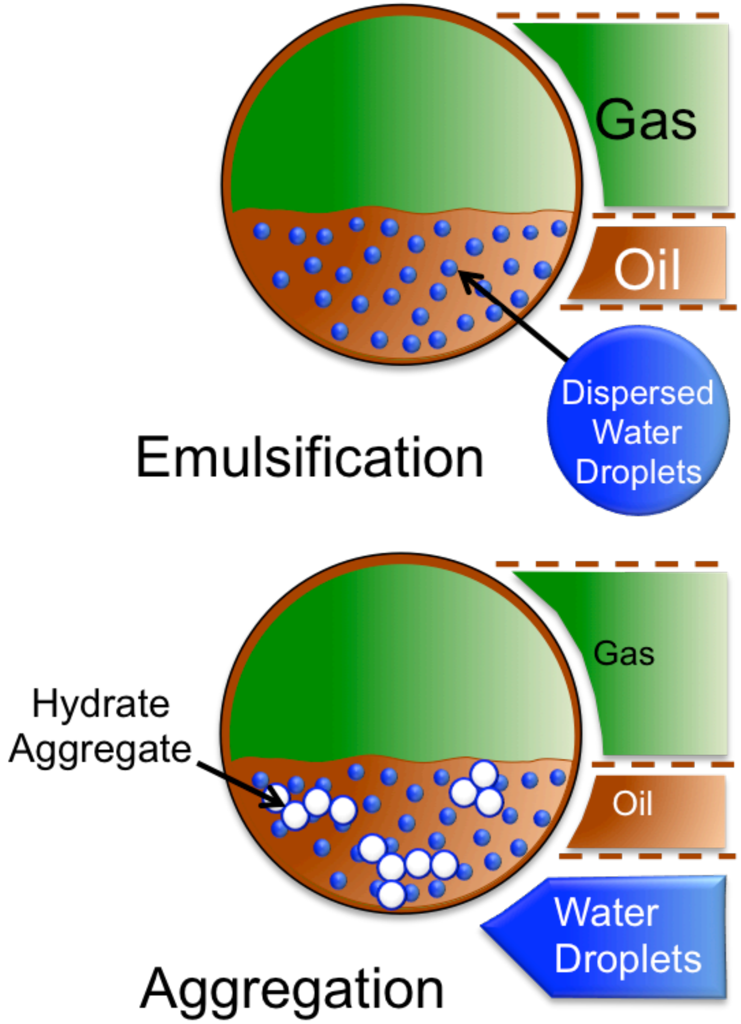
Capabilities of **CSMFlow**

- Two-phase (G-L) flow
- Flow regime maps
- Three-phase (G-L-H) flow
  (with hydrate formation and growth models)
- Slug quantification

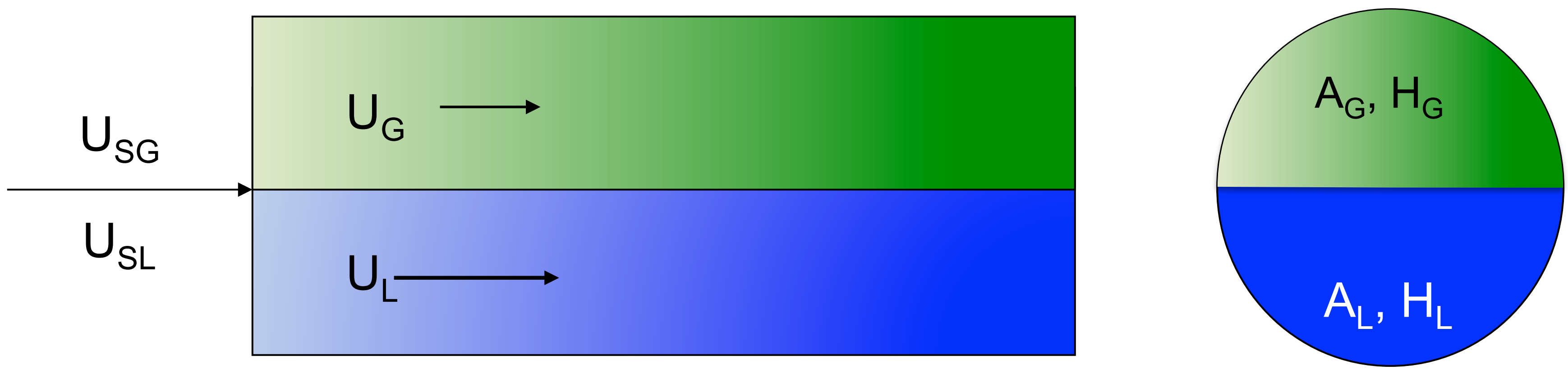


Capabilities of **CSMFlow**

- Two-phase (G-L) flow
- Flow regime maps
- Three-phase (G-L-H) flow (with hydrate formation and growth models)
- Slug quantification
- Water-in-oil emulsion
- Aggregation of hydrates



Fundamental Multiphase Flow Concepts



Hold-up:

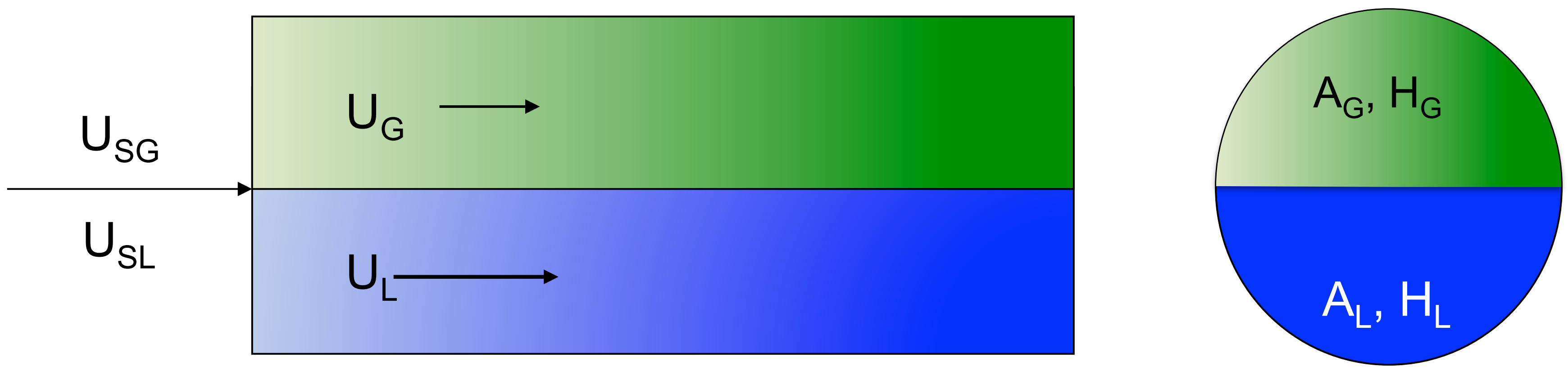
$$H_i = \frac{A_i}{A_{\text{pipe}}}$$

Superficial Velocity: $$U_{Si} = \frac{Q_i}{A_{\text{pipe}}}$$

Linear Velocity: $$U_i = \frac{U_{Si}}{H_i}$$

where 'i' stands for phase (L, G or Hyd)

Fundamental Multiphase Flow Concepts

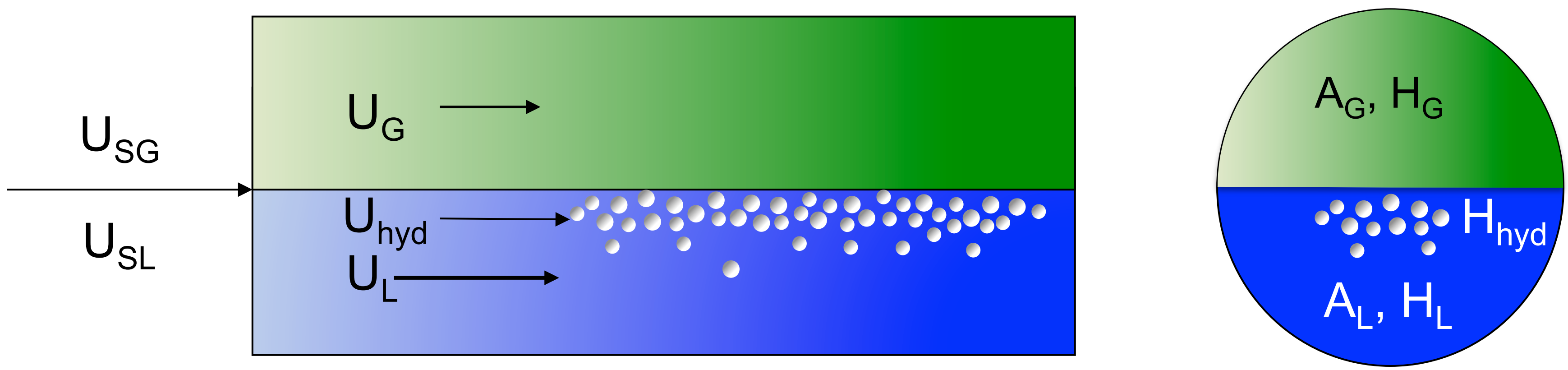


Phases hold-up: $H_G + H_L = 1$

Mixture velocity: $U_M = U_{SG} + U_{SL}$

Slip Velocity: $U_{S\ (G\text{-}L)} = U_G - U_L$

Fundamental Multiphase Flow Concepts



Phases hold-up: $H_G + H_L$ **$+ H_{hyd} = 1$**

Mixture velocity: $U_M = U_{SG} + U_{SL}$ **$+ U_{Shyd}$**

Slip Velocity: $U_{S\ (G\text{-}L)} = U_G - U_L$

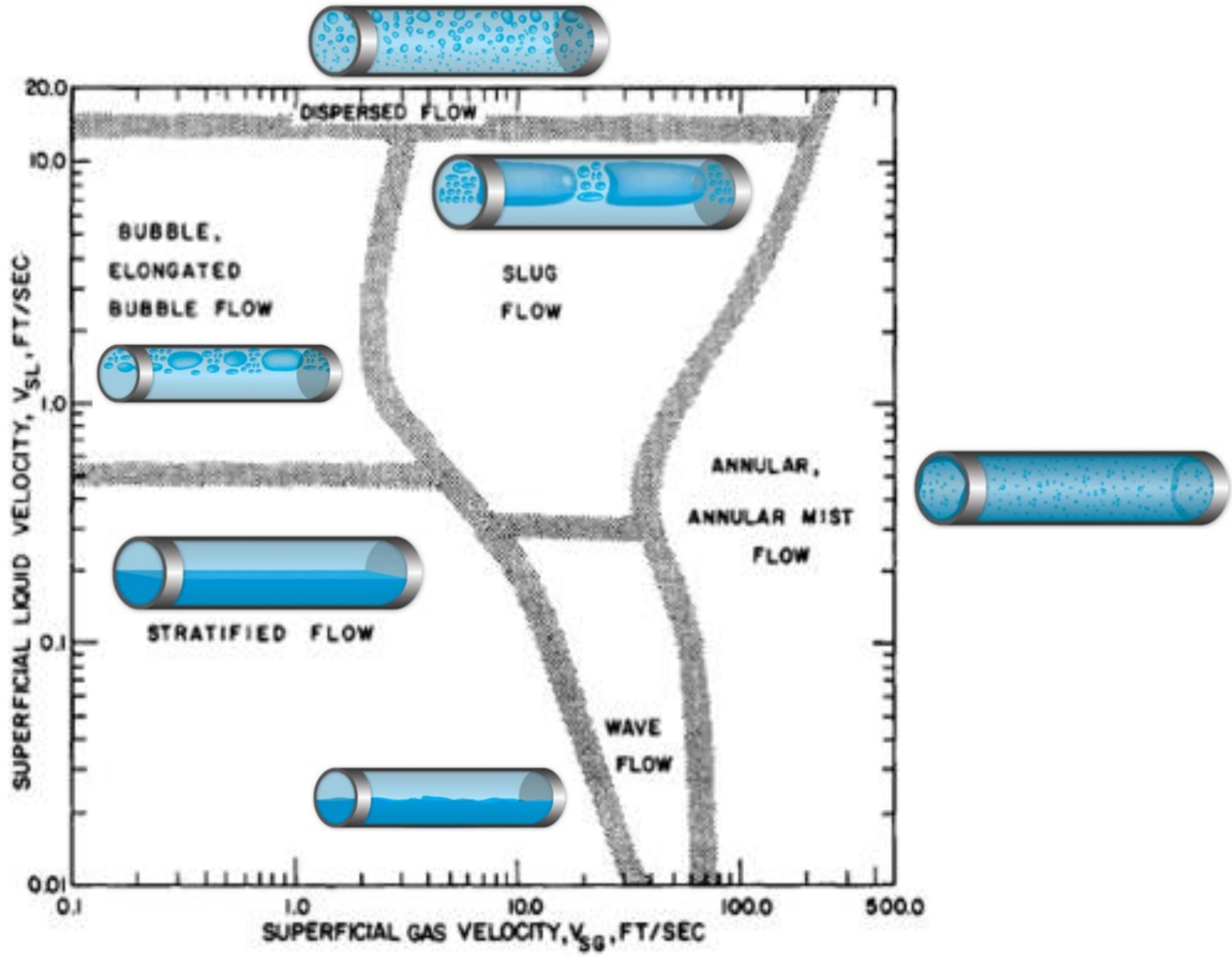
$U_{S\ (L\text{-}hyd)} = U_L - U_{hyd}$

Overall Prediction of CSMFlow

Method	Prediction Efficiency (%)	
	All data	Liquid (oil) data
Beggs & Brill*	57	60
Taitel & Dukler*	75	73
Mukherjee & Brill*	29	19
Unified Theory*	78	79
CSMFlow	84	88

*Model predictions using PIPESIM®

Two-Phase Flow Regime Map



Air-Water Flow Regime Map (Mandhane, 1974)

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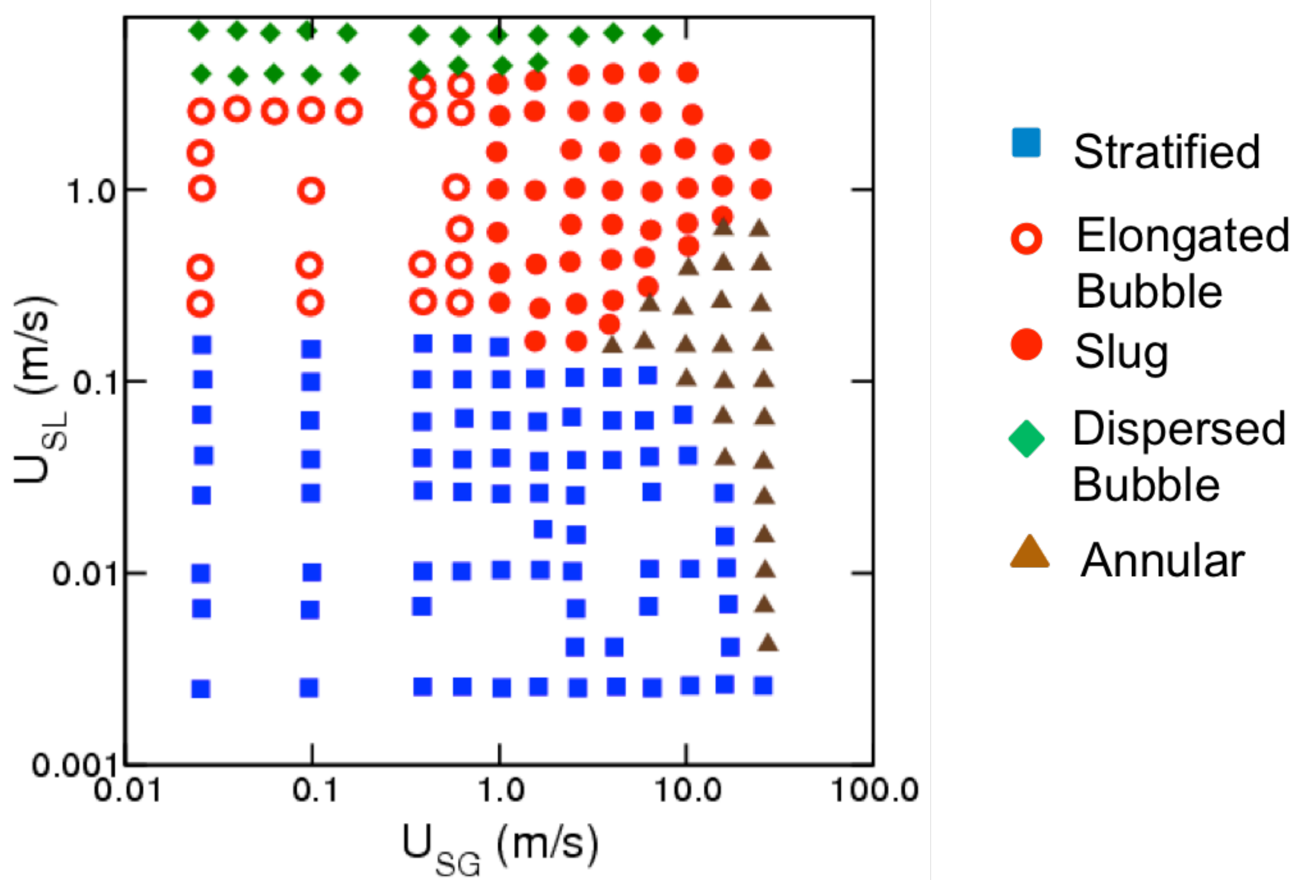
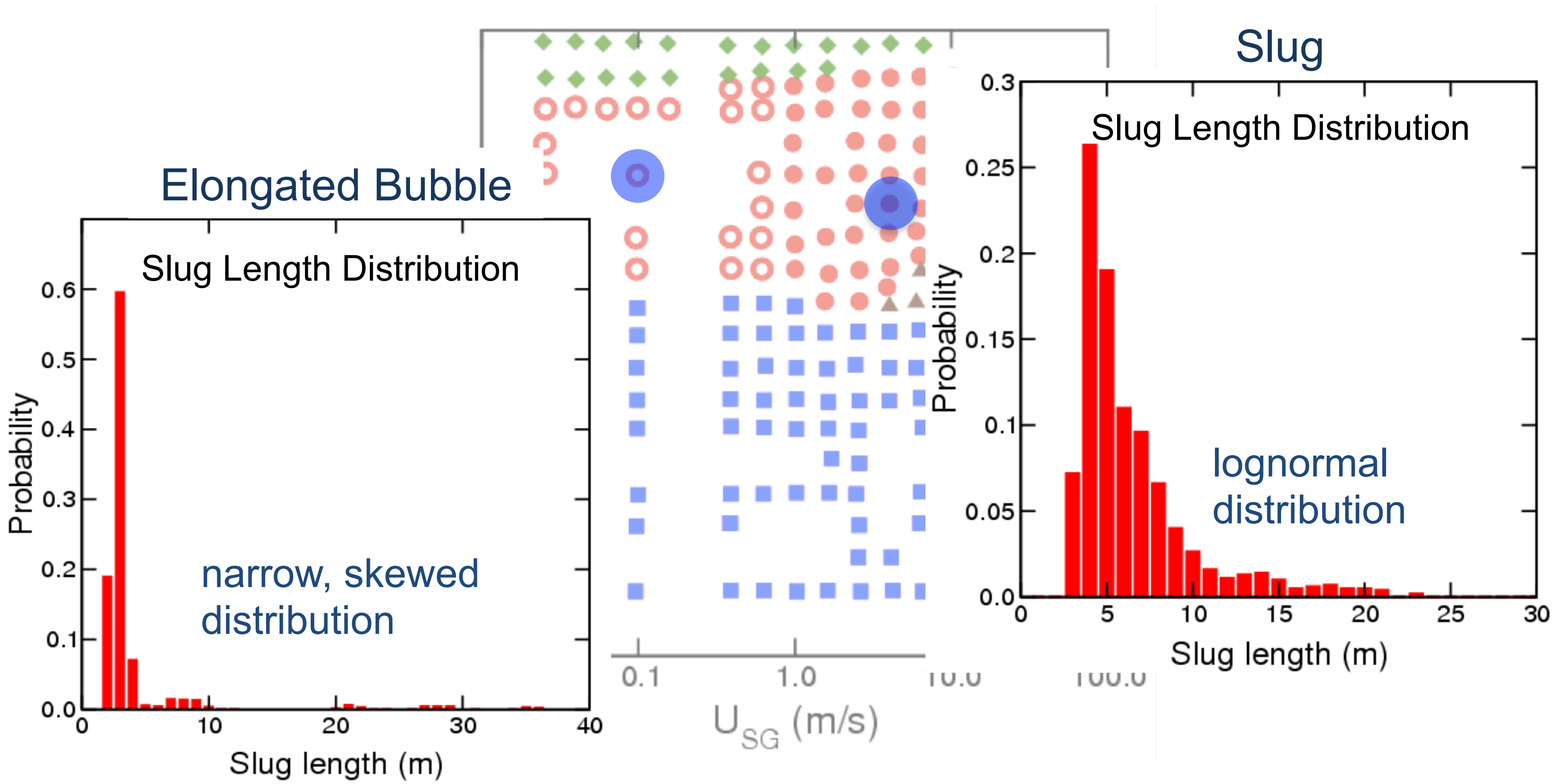
CSMFlow: Unique Tool for Multiphase Flow

Air-Water system (Shoham, 1984)



CSMFlow: Unique Tool for Multiphase Flow

Air-Water system (Shoham, 1984)



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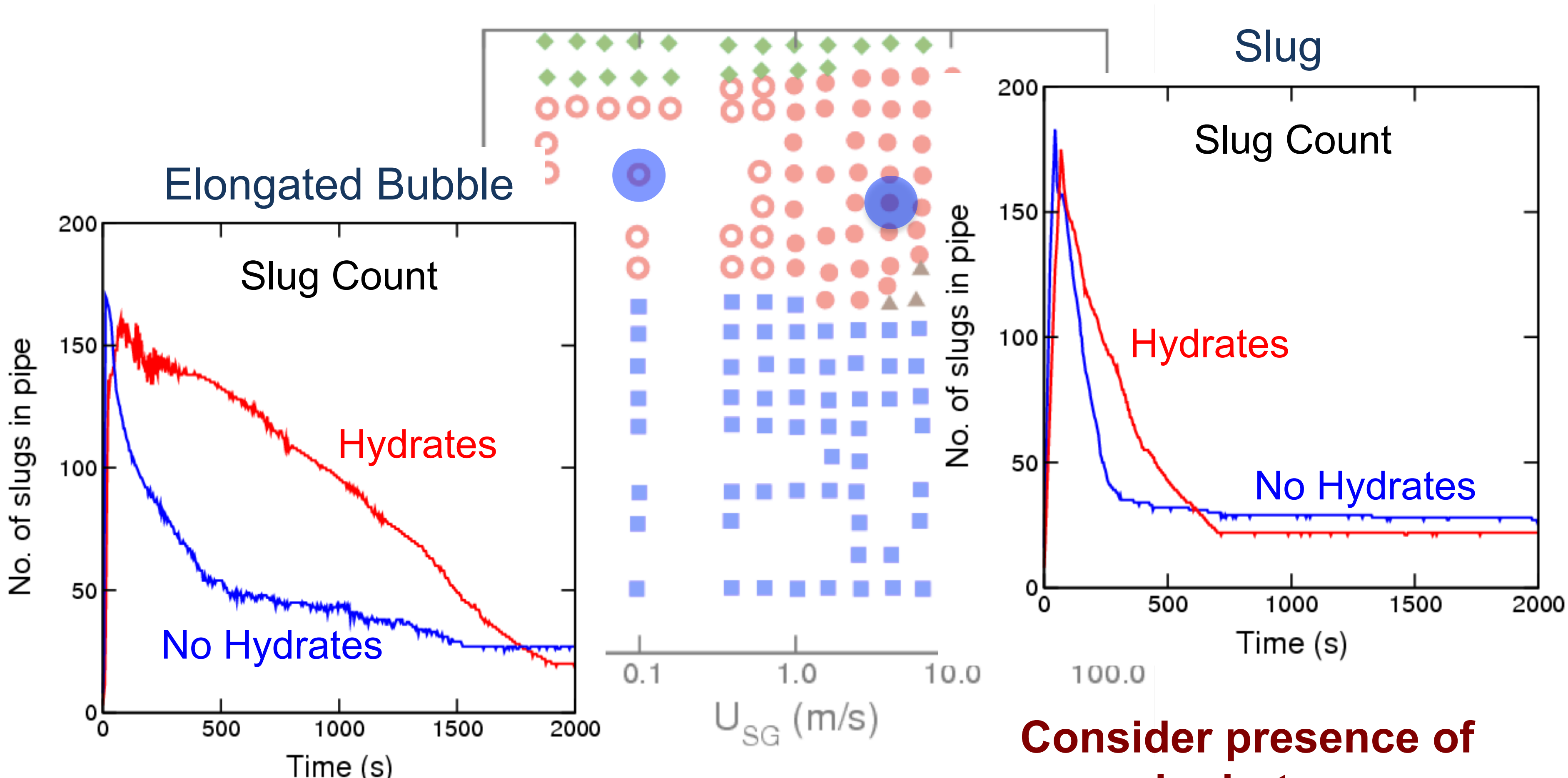
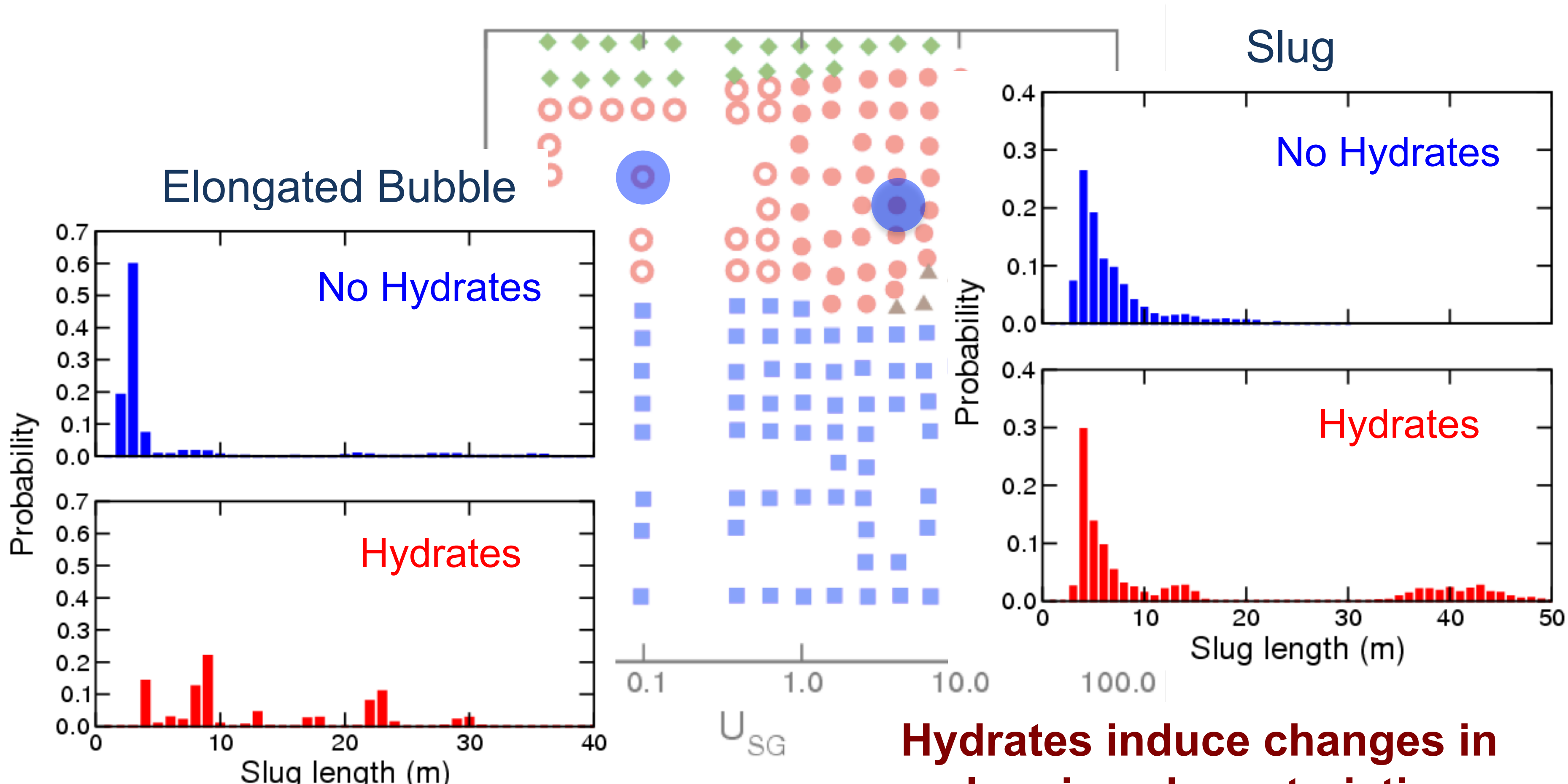


Consider presence of hydrates

CSMFlow: Unique Tool for Multiphase Flow

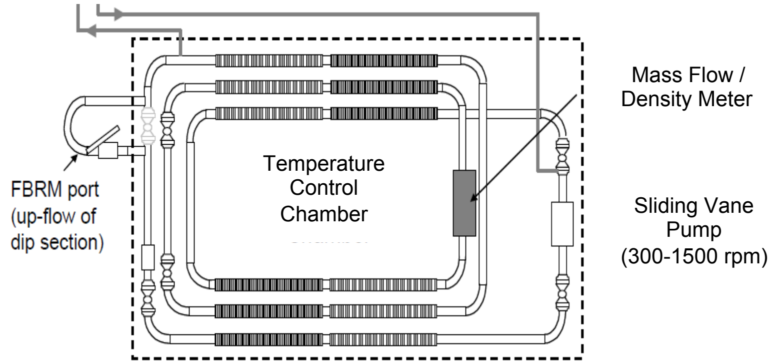
Air-Water system (Shoham, 1984)



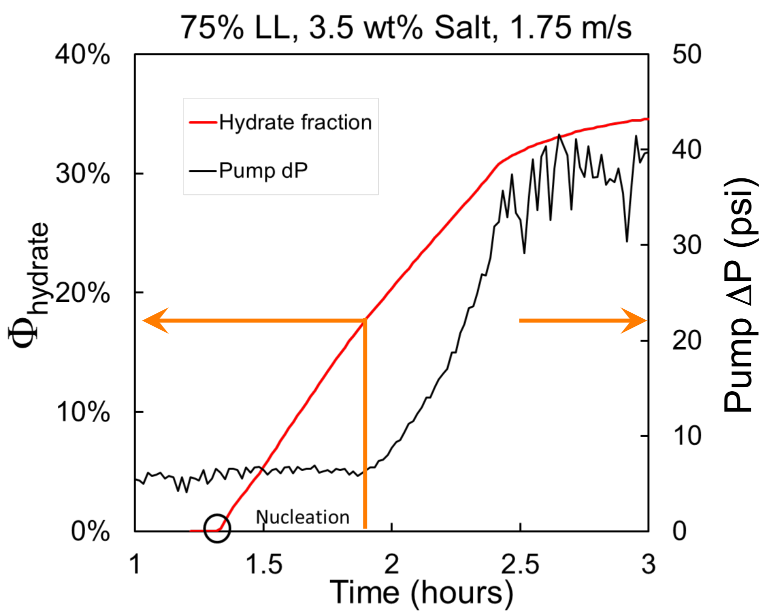
Hydrates induce changes in slugging characteristics

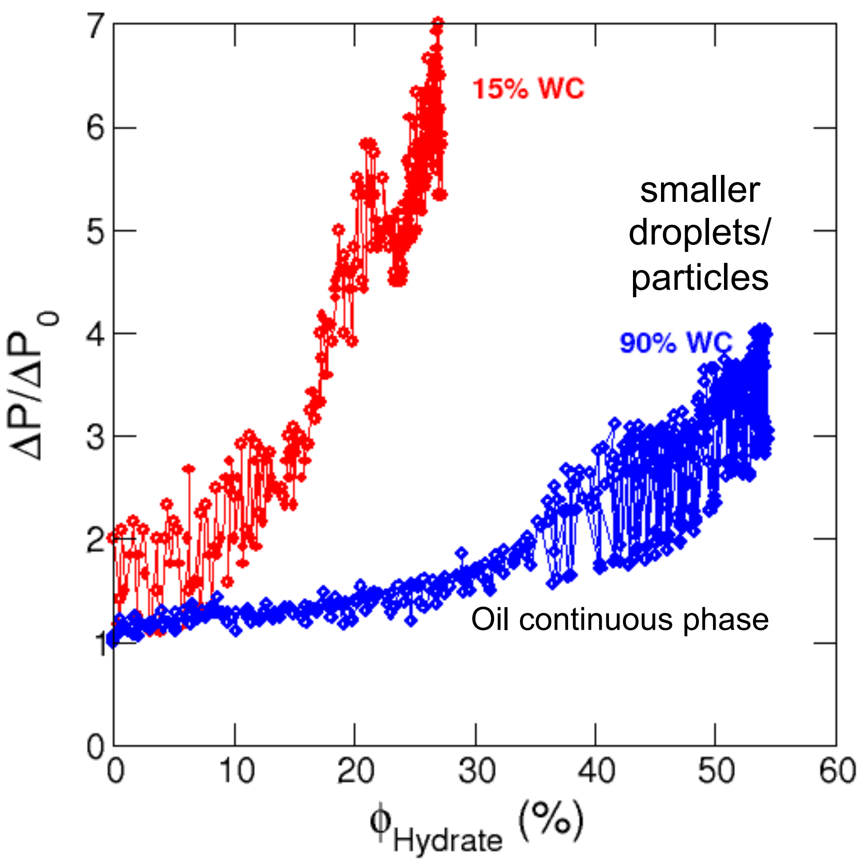
Hydrate Formation in Multiphase Flow

Flowloop tests considering live fluids



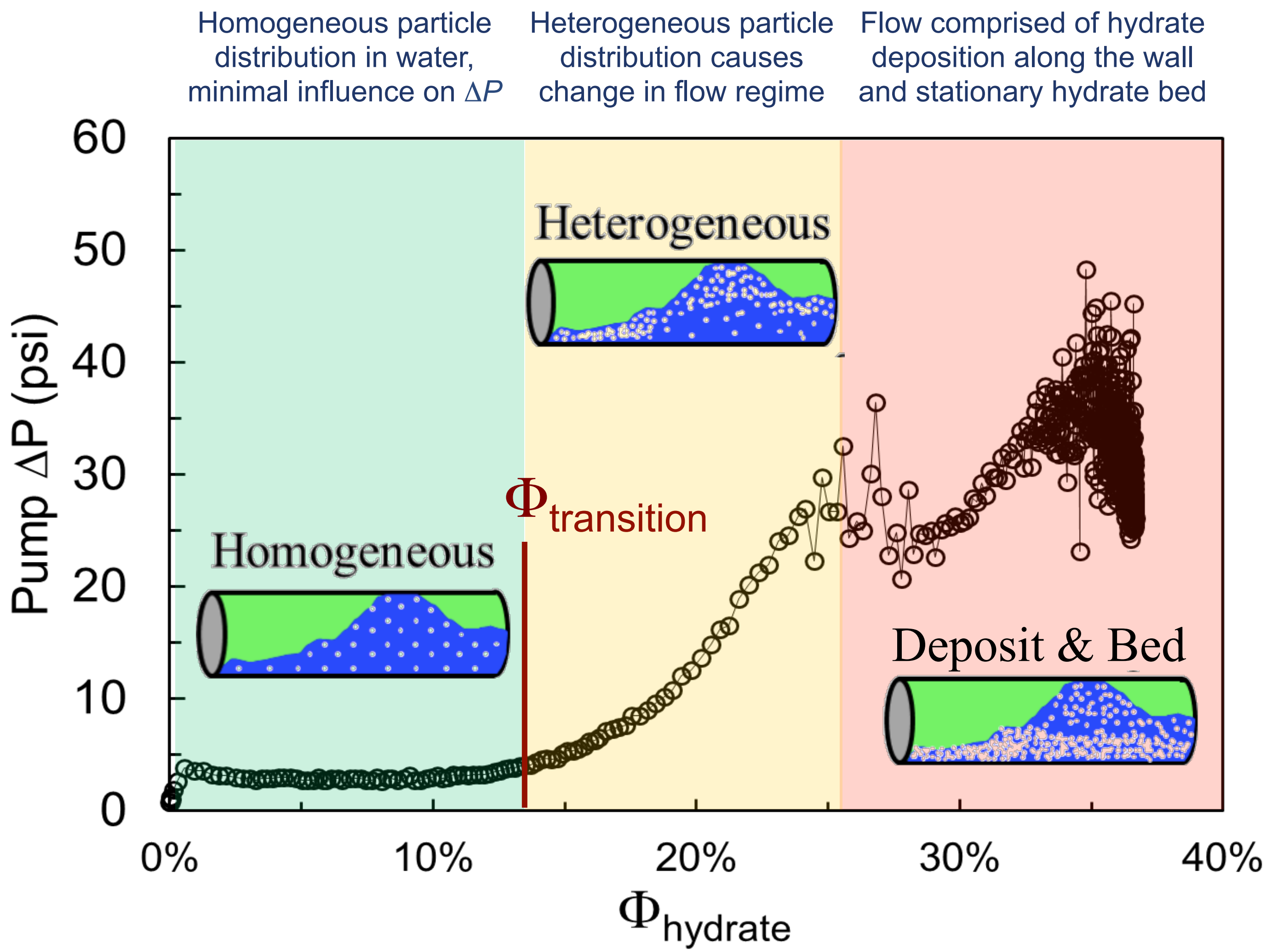
Conroe Oil, 3.5 wt% salt, 50% LL, 1.75 m/s, 1000 psig, 34 °F (set point)





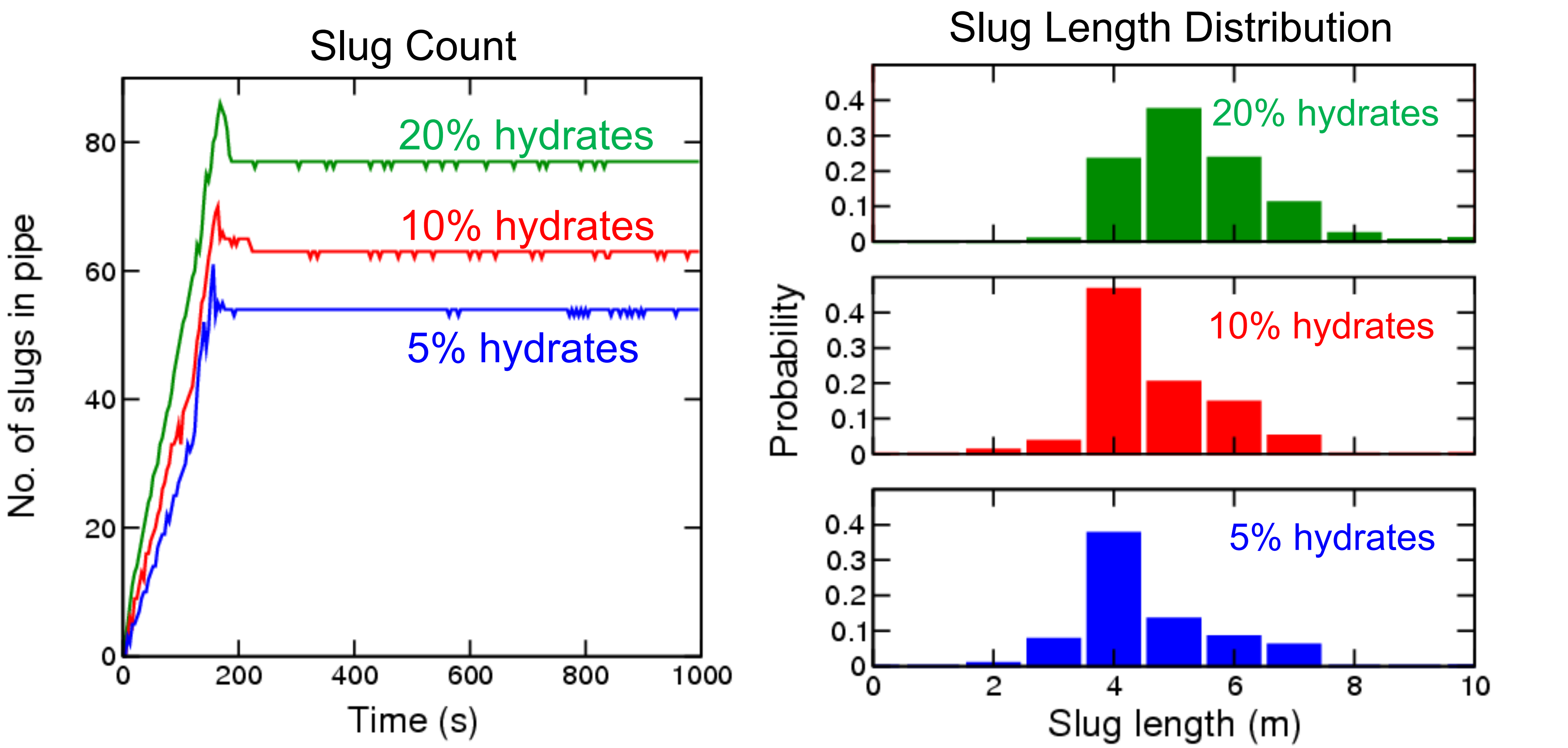
Hydrate Plug Formation in Gas-Water Systems

Flowloop tests: hydrate formation in multiphase flow



CSMFlow: Unique Tool for Multiphase Flow

Hydrate Fraction Plays Important Role in Flow Behavior



Can we infer hydrate formation from slugging characteristics?

Hydrates in Flow Assurance: Challenges

More challenging production conditions:

- **Ultra-high pressure (>10,000 psi):** need hydrate phase equilibria
- **High salinity systems (near solubility limit):** need hydrate phase equilibria, formation kinetics, rheology
- **High sour gas (H_2S and CO_2) content:** need phase equilibrium data, model validation, formation kinetics, inhibition
- **High water content systems:** need formation kinetics, chemical treatment

Hydrates in Flow Assurance: Challenges

AREAS OF NEED:

- **Improve development and deployment of LDHIs (AA/KHI):** need to understand mechanism
- **Hydrate risk during shut-in/restart:** need to determine formation rate, distribution of phases, chemical treatment
- **Hydrates with other solids/chemicals:** interaction of hydrates with production chemicals (e.g., corrosion inhibitors) and solids (e.g., sand, wax, asphaltenes)
- **Hydrates and multiphase flow:** need to know flow regime and distribution of phases

Summary

- **Hydrate avoidance works!** Past, Present and Future
- Hydrate management: **live with hydrates**
- Must know the **risk of hydrate** formation and plugging
- More challenging production conditions: **much to learn about hydrates**

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An Ecolab Company
multi-chem
A HALLIBURTON SERVICE
BR PETROBRAS
Shell
Schlumberger
SPT GROUP
A Schlumberger Company
Statoil
TOTAL

DeepStar Energy Consortium

RPSEA
Research Partnership to Secure Energy for America

U.S. DEPARTMENT OF ENERGY

NSF

THANK YOU!

Questions???