Webinars

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Hydrate Flow Assurance Modeling
Predicting Hydrate Formation in Oil & Gas Pipelines

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Webinars

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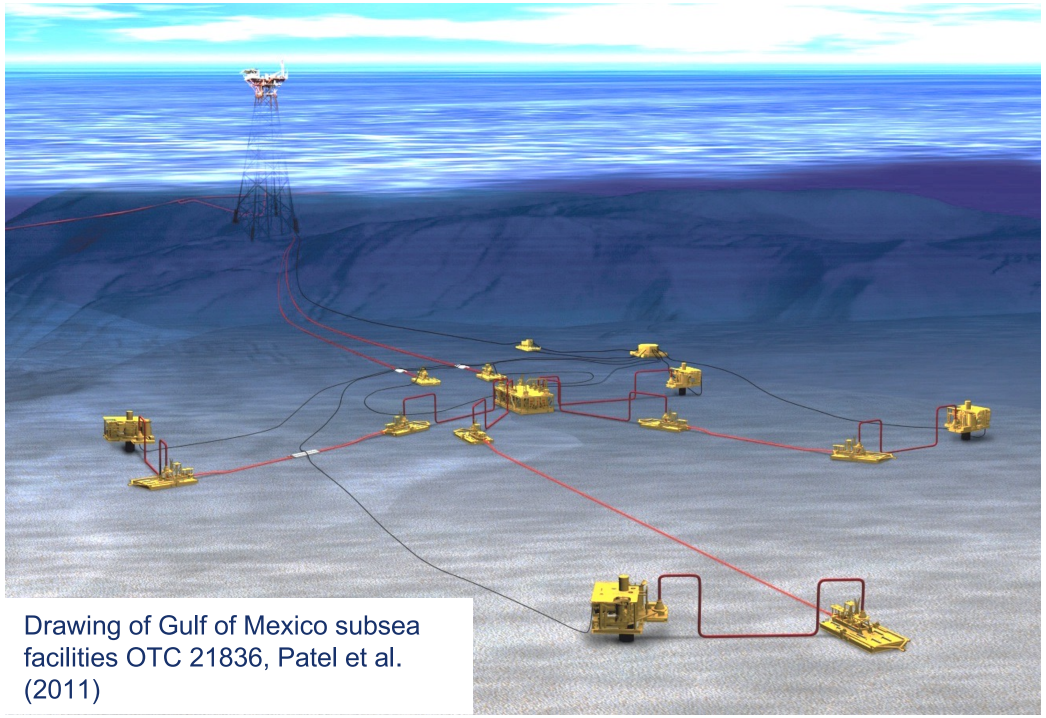
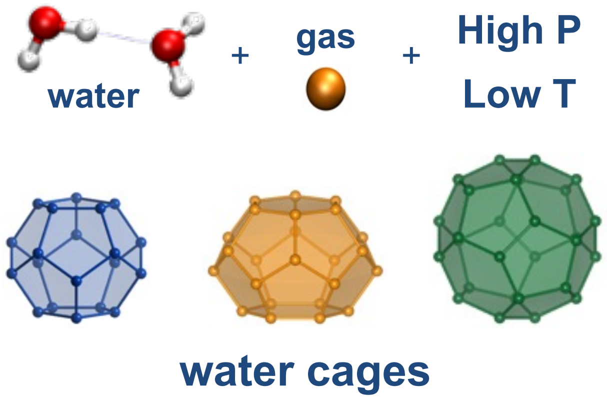
Flow Assurance: technical discipline that focuses on design of facilities and procedures for uninterrupted transport of reservoir fluids, from reservoir to point of sale



Drawing of Gulf of Mexico subsea facilities OTC 21836, Patel et al. (2011)

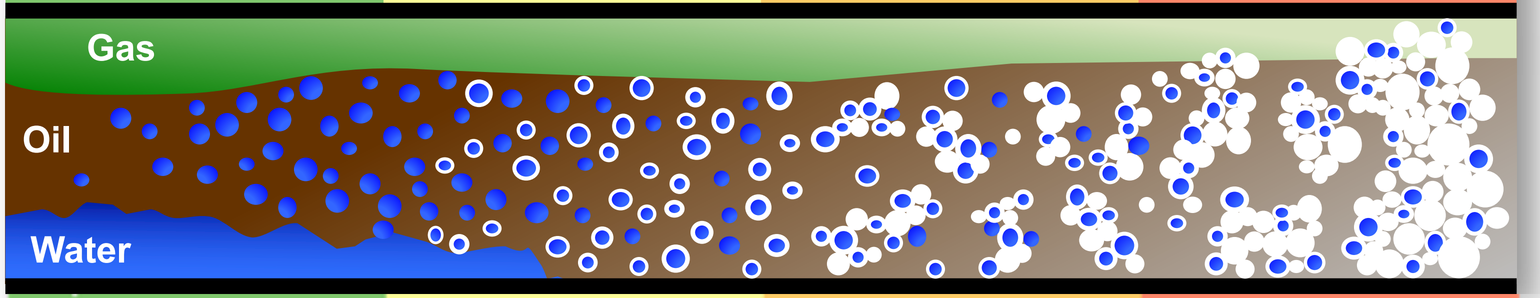
Natural Gas Hydrates



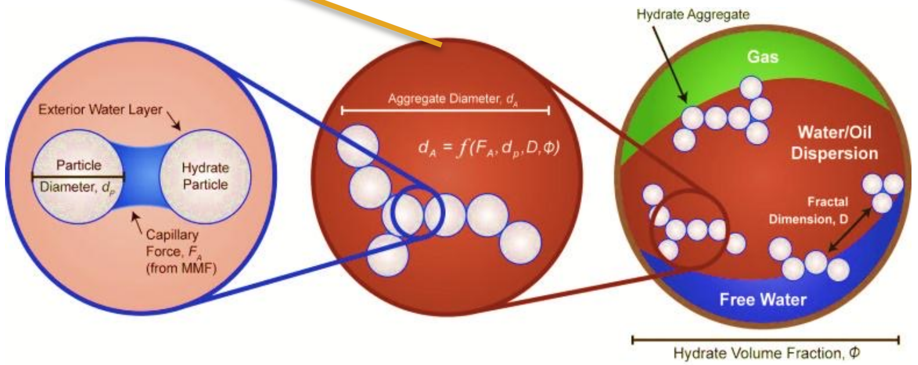
Observations from Field Cases and Experiments are Used to Develop Conceptual Pictures and then Mathematical Models

Conceptual Picture: Water/hydrocarbon interface, an ideal location for gas hydrate formation

Water Entrainment	Hydrate Growth	Agglomeration	Plugging

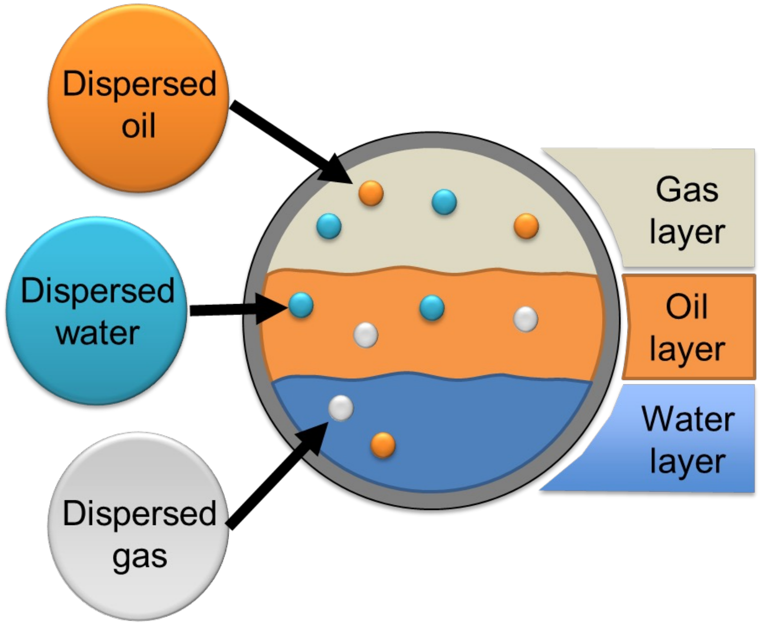


Surface area between water/hydrocarbon phases	Intrinsic kinetics or transport resistances	Particle aggregation via capillary attraction	Plugging from viscosity increase (Pressure drop increase)



A Transient Multiphase Flow in Pipe Simulator

- Unifies the treatment of liquid holdup, pressure drop and flow regimes
- Modeling approach involves the simultaneous solution of conservation equations of mass, momentum and energy for each phase
- Uses empirical correlations and simplified constitutive relationships for flow parameters:
  - Interfacial friction
  - Fraction of liquid entrained in free gas phase
  - Liquid holdup in slug body



Multiphase Flow Governing Equations

- Mass conservation for each mass field:

$$\frac{\partial m_f}{\partial t} = -\frac{\partial m_f v_f}{\partial x} + \sum_{\ell=1}^{NF} \psi_{f\ell} + S_f$$

Accumulation Convection Mass transfer Source

- Momentum conservation for each flowing layer:

Accumulation Convection External forces Friction terms

$$\frac{\partial}{\partial t}\sum_{f\in fj}\left(m_f v_f\right) = -\frac{\partial}{\partial x}\sum_{f\in fj}\left(m_f v_f{}^2\right) - \sum_{f\in fj} H_f \frac{\partial p}{\partial x} - \sum_{f\in fj} m_f g \sin\theta \quad - F_j^w v_j - \sum_{\ell\neq j} F_{\ell j}^i v_{\ell j}$$

$$+ \sum_{\ell\neq j}\Phi_{\ell j} + \sum_{f\in fj} S_f v_f$$

← Momentum transfer due to mass transfer

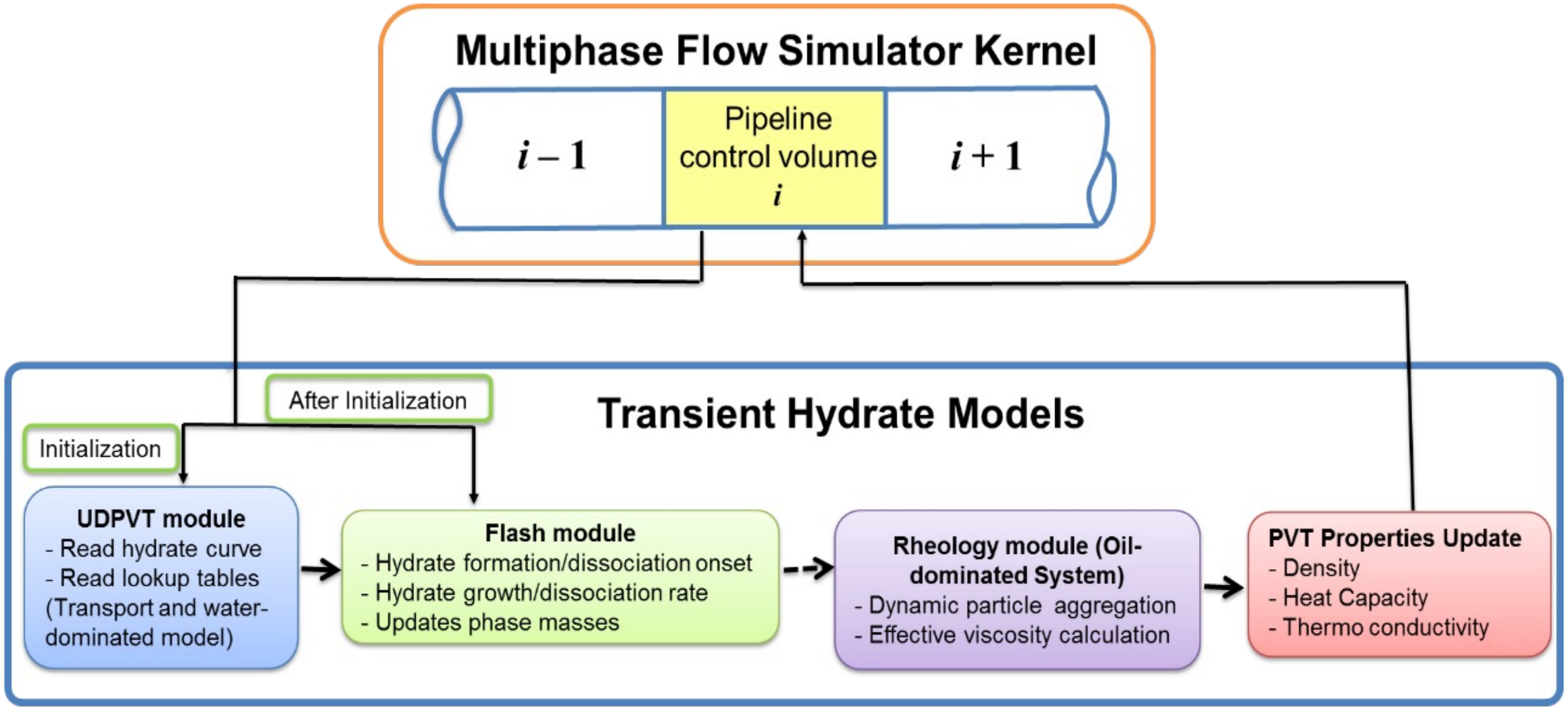
- Mixture energy balance

Accumulation Convection Source

$$\sum_{f=1}^{NF}\left[\frac{\partial\left(m_f H_f\right)}{\partial t}\right] = -\sum_{f=1}^{NF}\left[\frac{\partial\left(m_f H_f v_f\right)}{\partial x}\right] + \sum_{f=1}^{NF} H_{s,f} + q$$

Hydrate Formation Model Coupled with Transient Multiphase Flow Simulator

- A simulation tool to predict hydrate formation rate & amount, effects of hydrate on multiphase flow, and formation of hydrate blockages



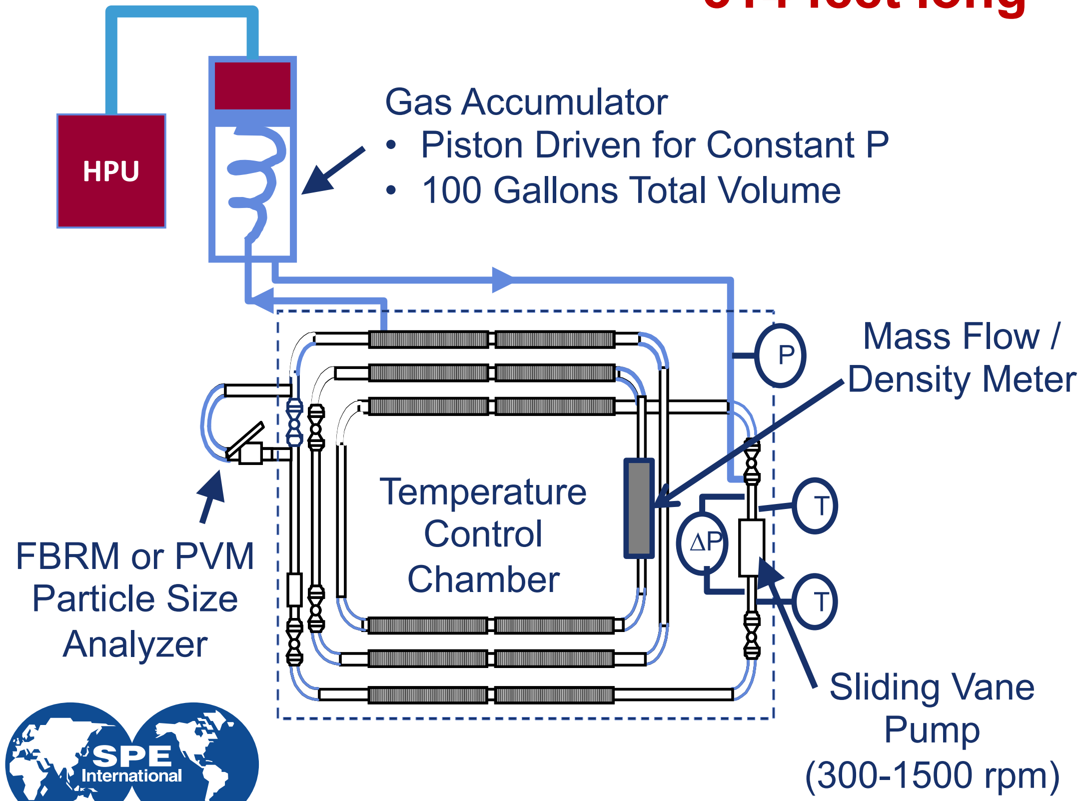
Zerpa, et al., J Pet Sci Eng, 2012

Model Verification: CSMHyK Predicts Hydrate Formation in Flow Loop Experiments (Oil-dominated Transport Model)

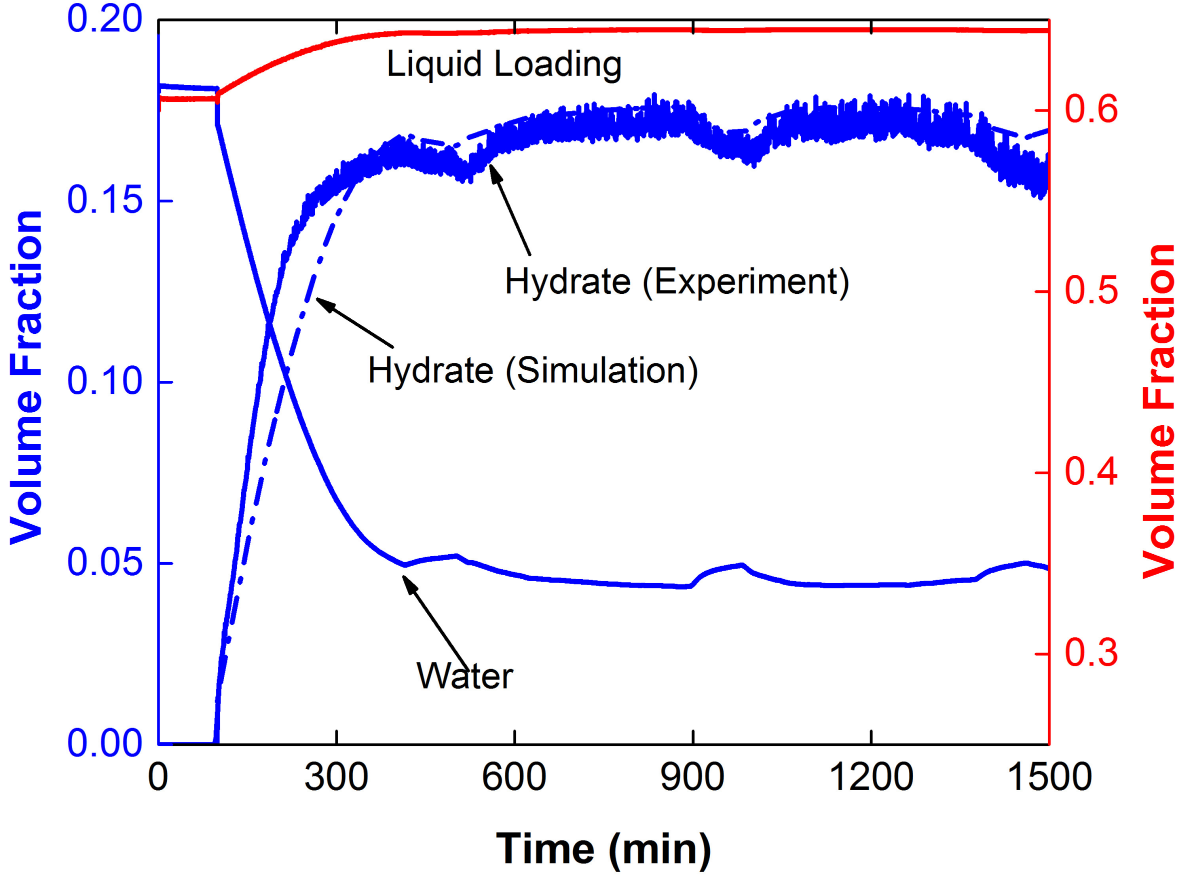
Industrial Flow Loop

3.8 inches ID

314 feet long

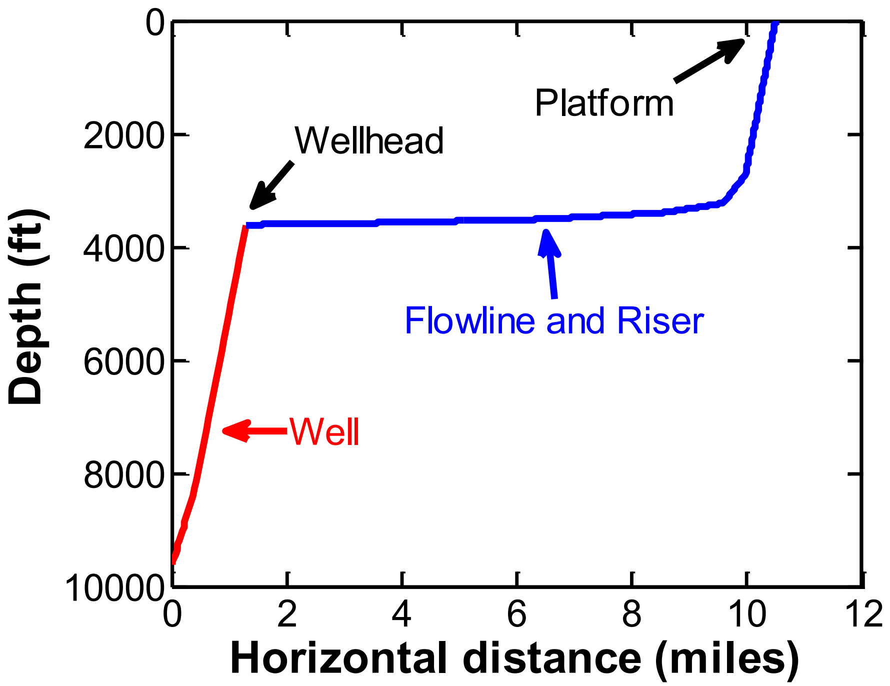


Hydrate Fraction

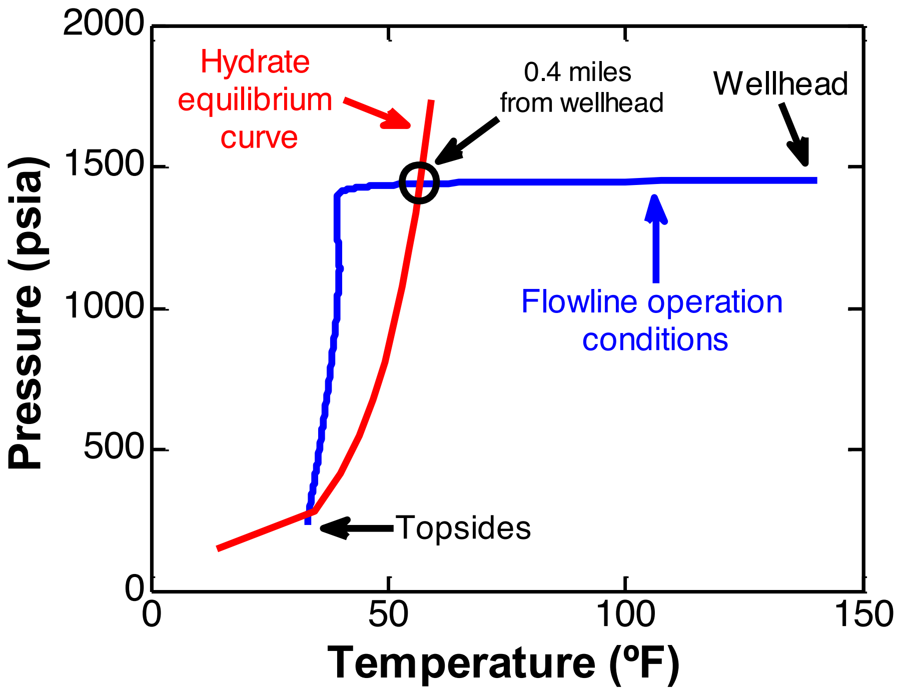


Example #1: Hydrate Formation Prediction in Subsea Well and Tieback

Geometry



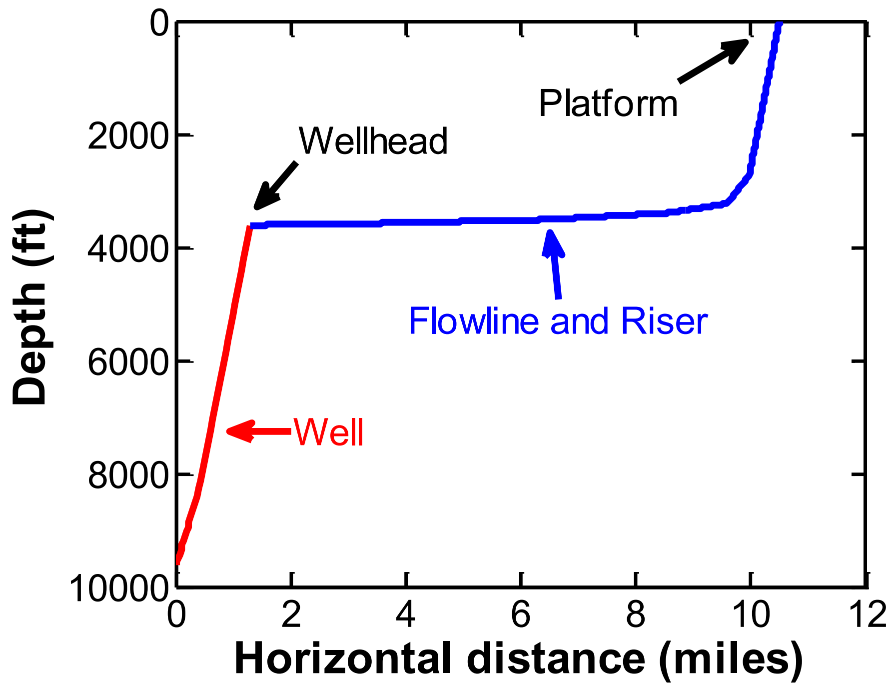
Pressure-Temperature diagram



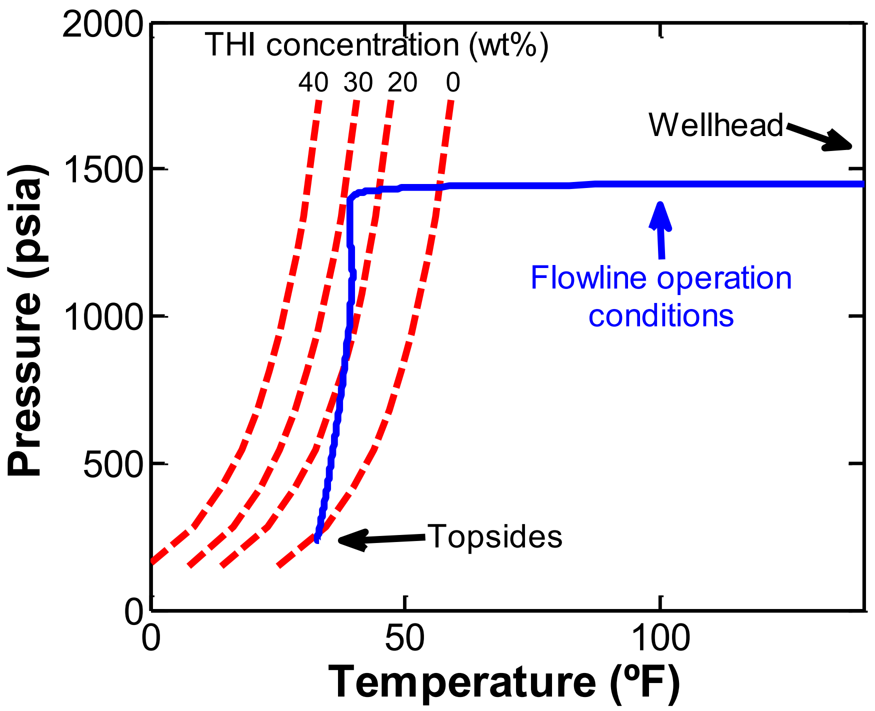
Zerpa, L.E., Sloan, E.D., Koh, C.A. and Sum, A.K., 2012. SPE 160578-PA, Oil and Gas Facilities, 1(5): 49-56.

Example #1: Evaluation of Thermodynamic Hydrate Inhibition (THI) Concentration Required to Prevent Hydrate Formation

Geometry



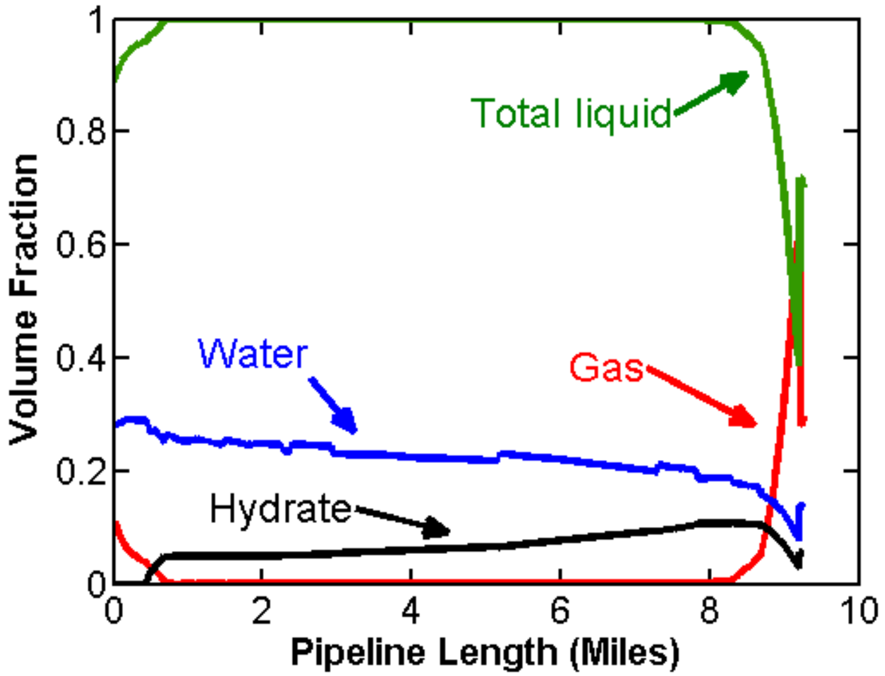
Pressure-Temperature diagram



Zerpa, L.E., Sloan, E.D., Koh, C.A. and Sum, A.K., 2012. SPE 160578-PA, Oil and Gas Facilities, 1(5): 49-56.

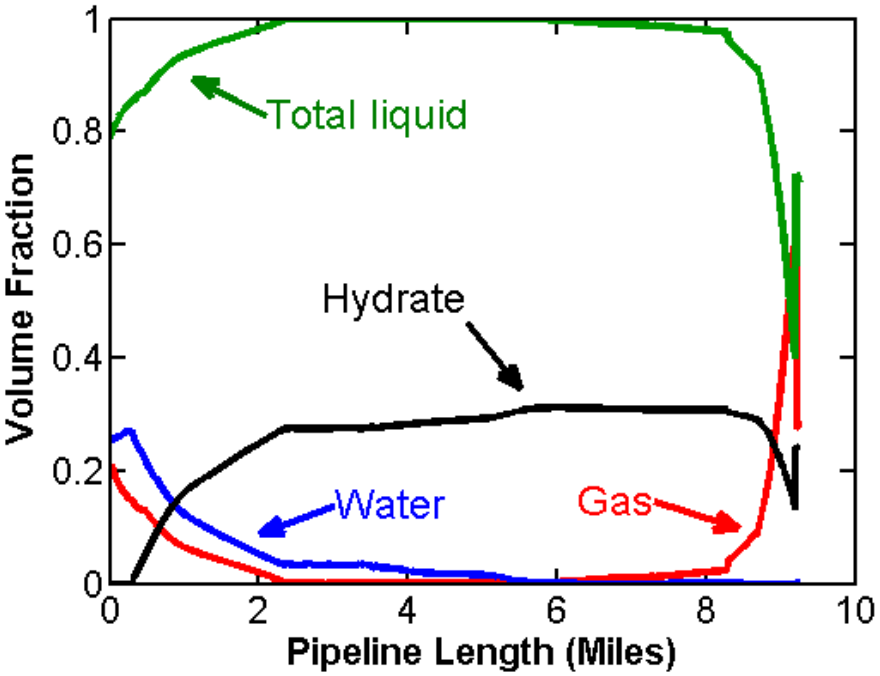
Example #1: Prediction of Fluids Distribution and Hydrate Formation at Different Conditions

Low hydrate plugging risk



- Liquid Holdup = 90 vol. %
- Water cut = 30 %
- GOR = 570 scf/STB

High hydrate plugging risk

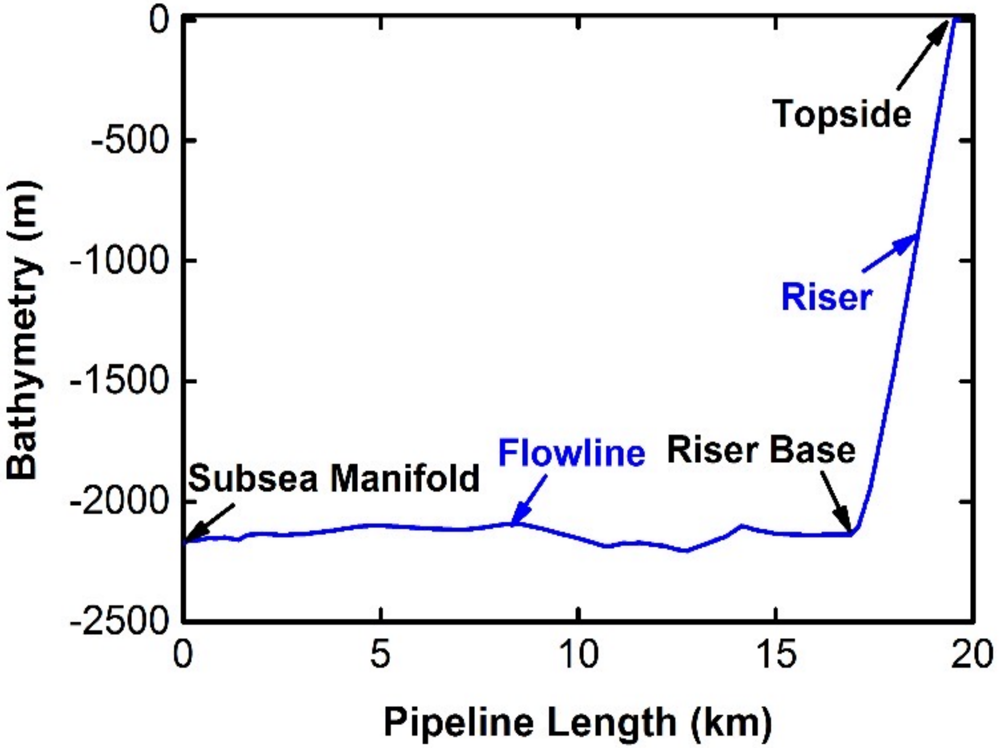


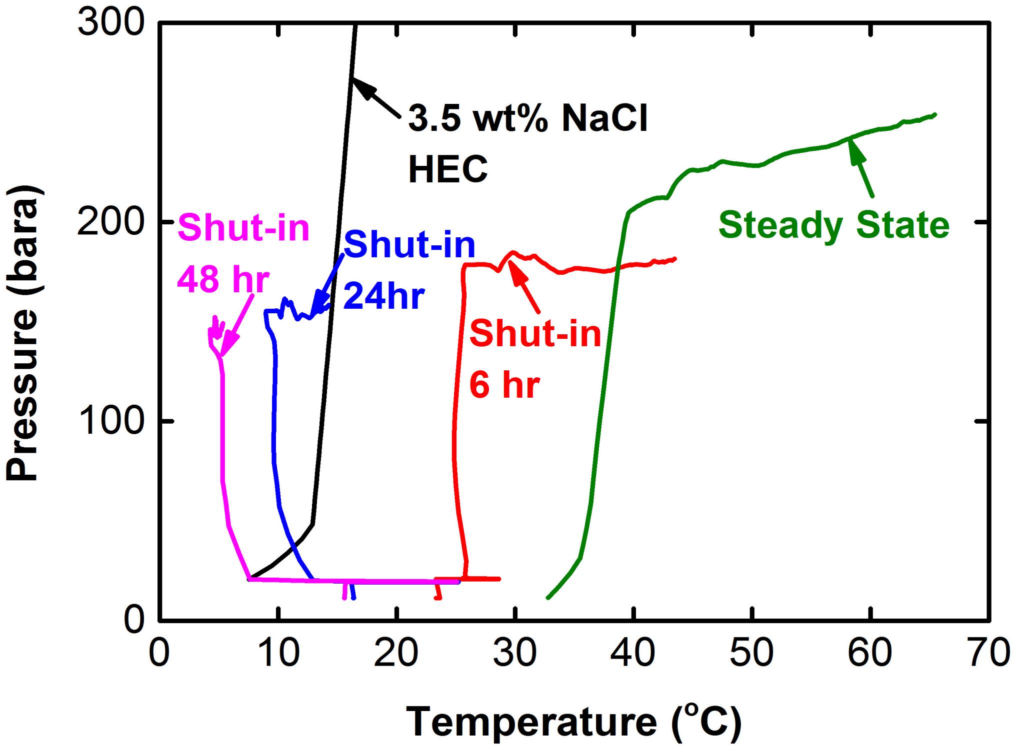
- Liquid Holdup = 79 vol. %
- Water cut = 32 %
- GOR = 894 scf/STB

Zerpa, L.E., Sloan, E.D., Koh, C.A. and Sum, A.K., 2012. SPE 160578-PA, Oil and Gas Facilities, 1(5): 49-56.

Example #2: Subsea Tieback

Hydrate may form during transient operations (shut-in/restart)

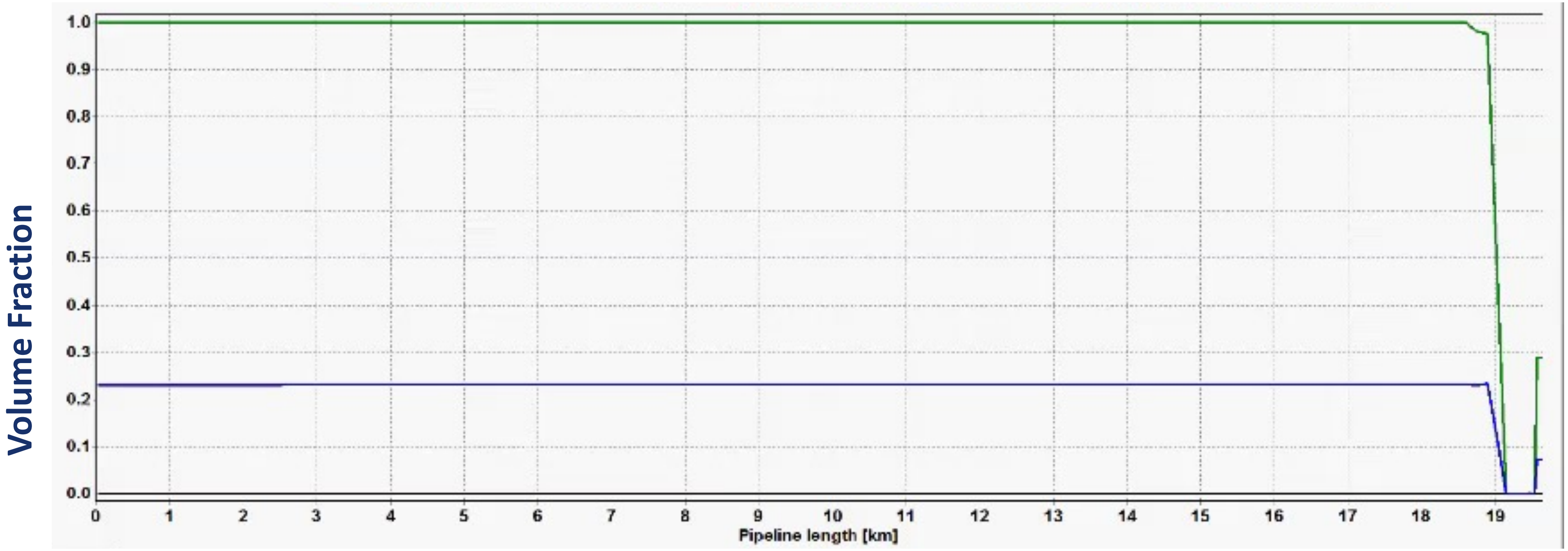




- Normal operation conditions (P & T) outside hydrate stability
- System cools down upon shut-in of production, entering hydrate formation conditions

Example #2: Hydrate starts to form after 8 hrs of shut-in at 25 vol.% wc (stable emulsion)

Liquid Water Restart after: 8 hrs; 9 hrs; 24 hrs; 48 hrs (Hydrate)



Manifold

Topside

Thermodynamic limit:

25 vol.% WC:

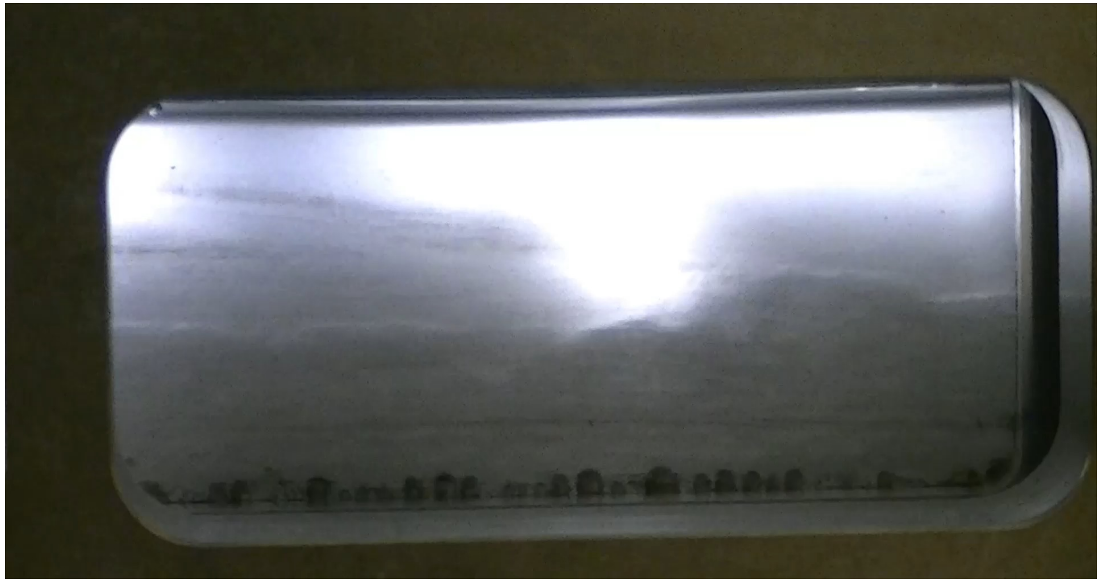
14 vol.% hydrates

- Long shut-ins result in more and faster hydrate formation
- Hydrate formation: riser base first --> flowline
- **If hydrates slip from the oil → more hydrate accumulation locally**

INTRODUCING NEW PHYSICS TO IMPROVE PREDICTIONS

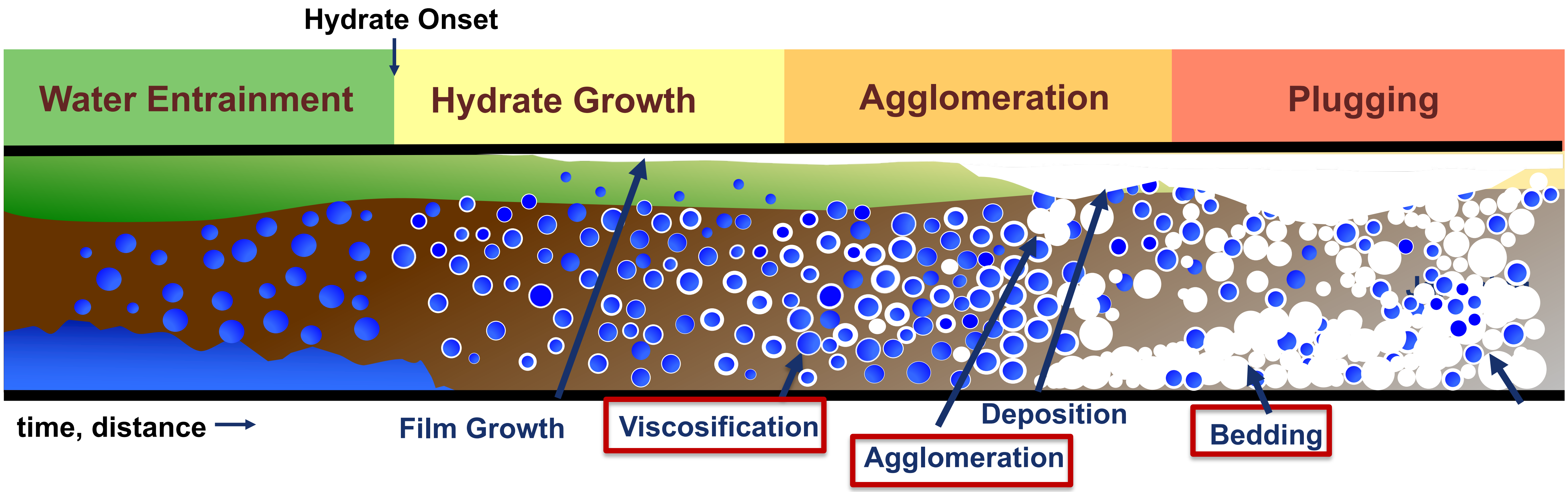
Physical Mechanisms Involved in Formation of Hydrate Blockages

Hydrate particle bedding



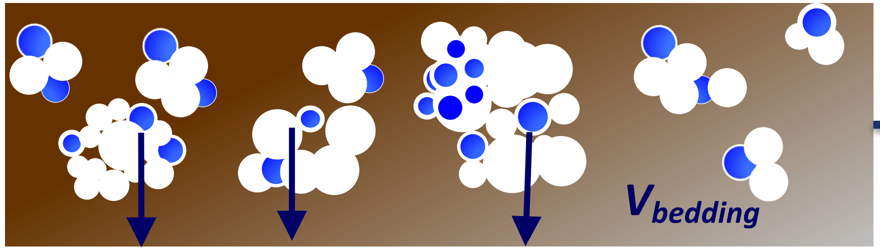
Hydrate deposition on pipe wall

Updated Conceptual Picture: Physical mechanisms involved in formation of hydrate blockages

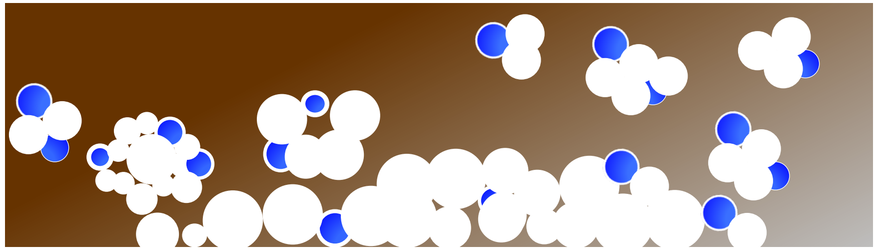


Bedding Model Hypothesis

Hypothesis: agglomeration controls bedding. Bedding increases ΔP and decreases hydrate transportability.



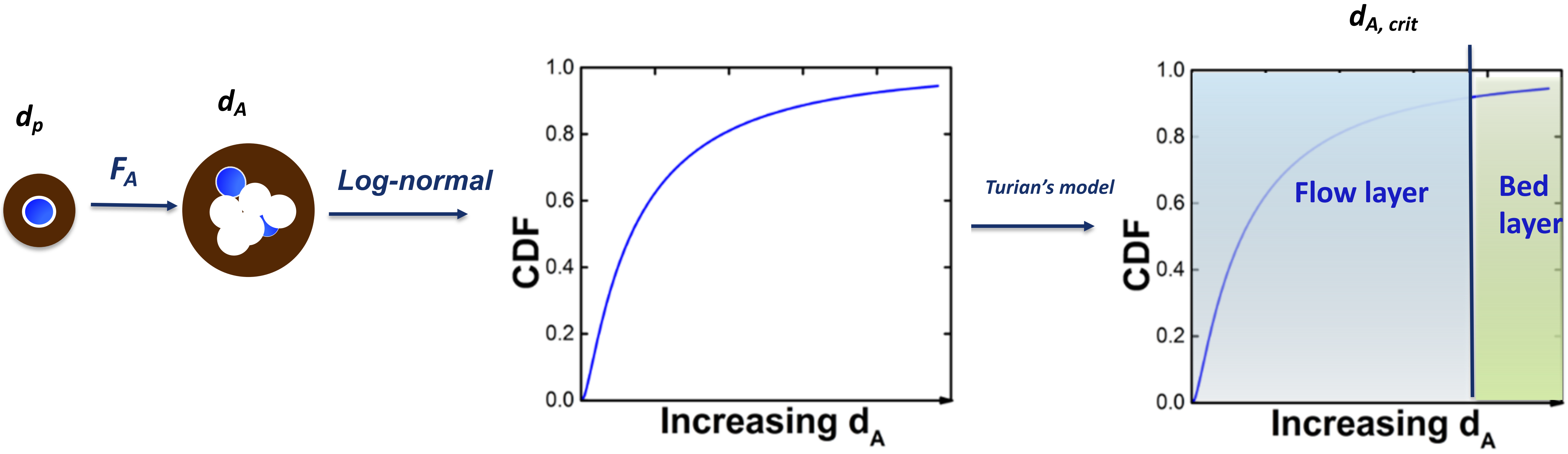
Bedding (Large Agglomerates)



Bedded Agglomerates

Y. Wang, PhD Thesis, 2019

Agglomerate size distribution calculated to determine bedding occurrence



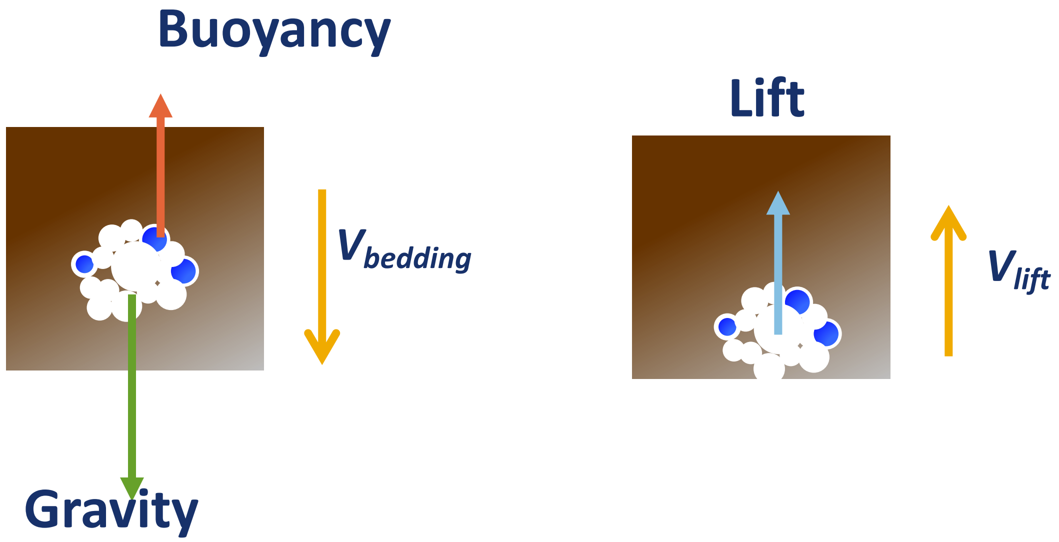
$$d_{A,crit} = f(U_l, \varphi_h, D_P, \rho_{oil}, \mu_{oil}, \rho_{hyd})$$

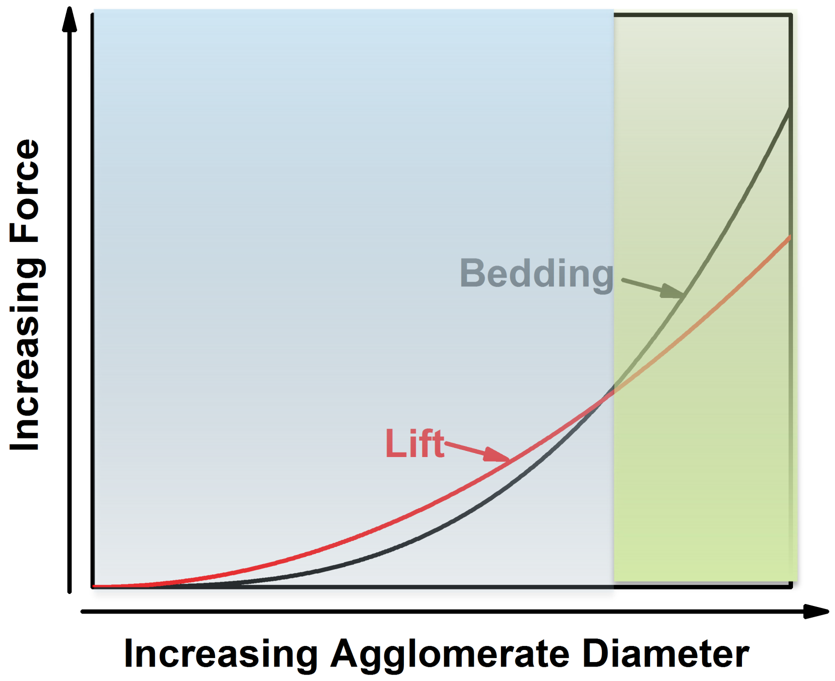
CDF: cumulative distribution function

$d_{A,crit}$: critical agglomerate size
U_l: liquid velocity D_P: pipe diameter
φ_h: hydrate volume fraction

Turian, AIChE Journal, 1980

Bedding force dominates at large agglomerate diameters

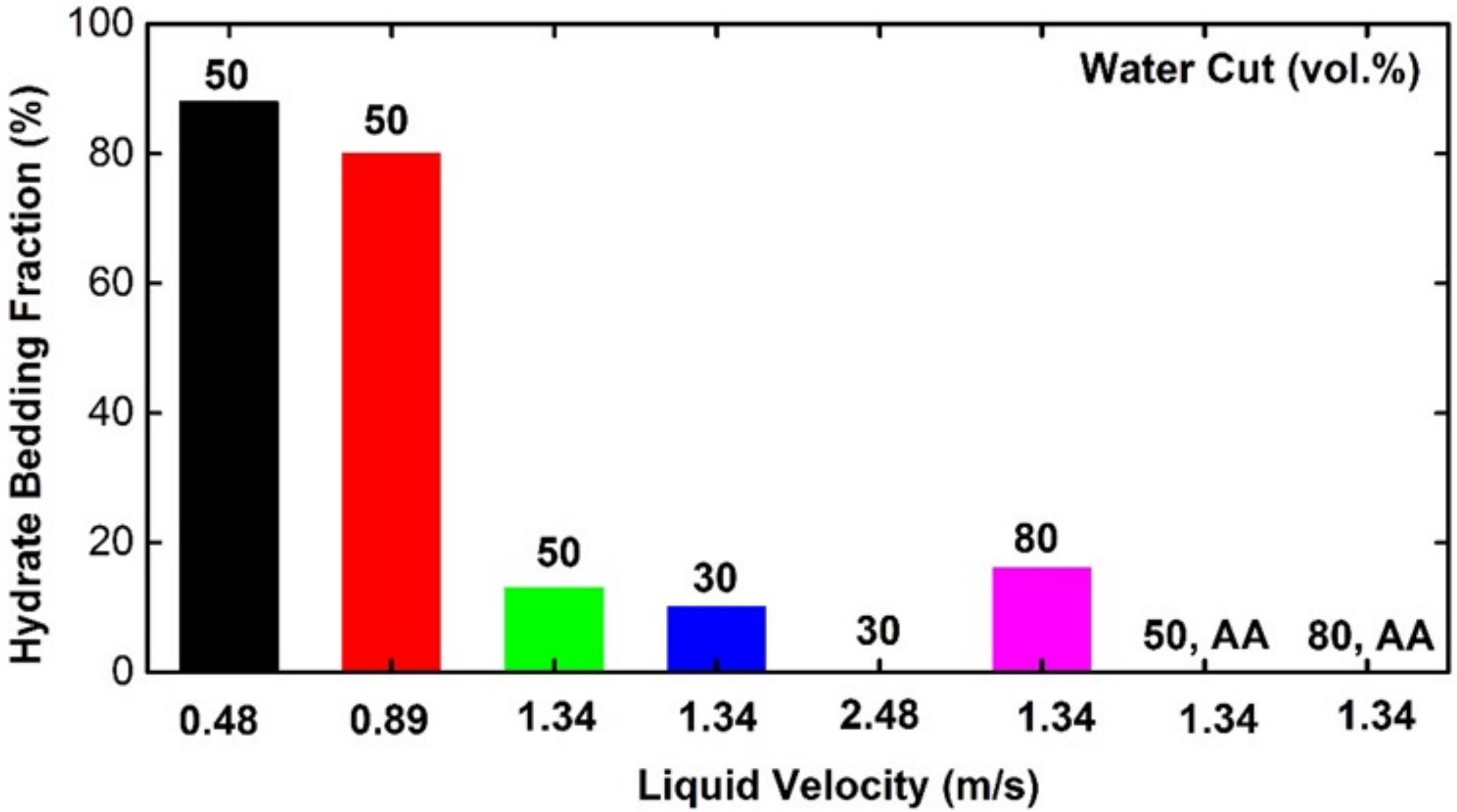




$$F_{lift} = f(\rho_{oil}, \mu_{oil}, v_{slip}, d_A, \gamma)$$

F_{lift}: lift force
ρ_{oil}: oil density
μ_{oil}: oil viscosity
v_{slip}: slip velocity
d_A: agglomerate diameter
γ: shear rate

Flowloop Simulations: Increasing U_l decreases bedding



Dominant plugging mechanism:

- 0.48 – 0.89 m/s: bedding
- 1.34 – 2.48 m/s: agglomeration

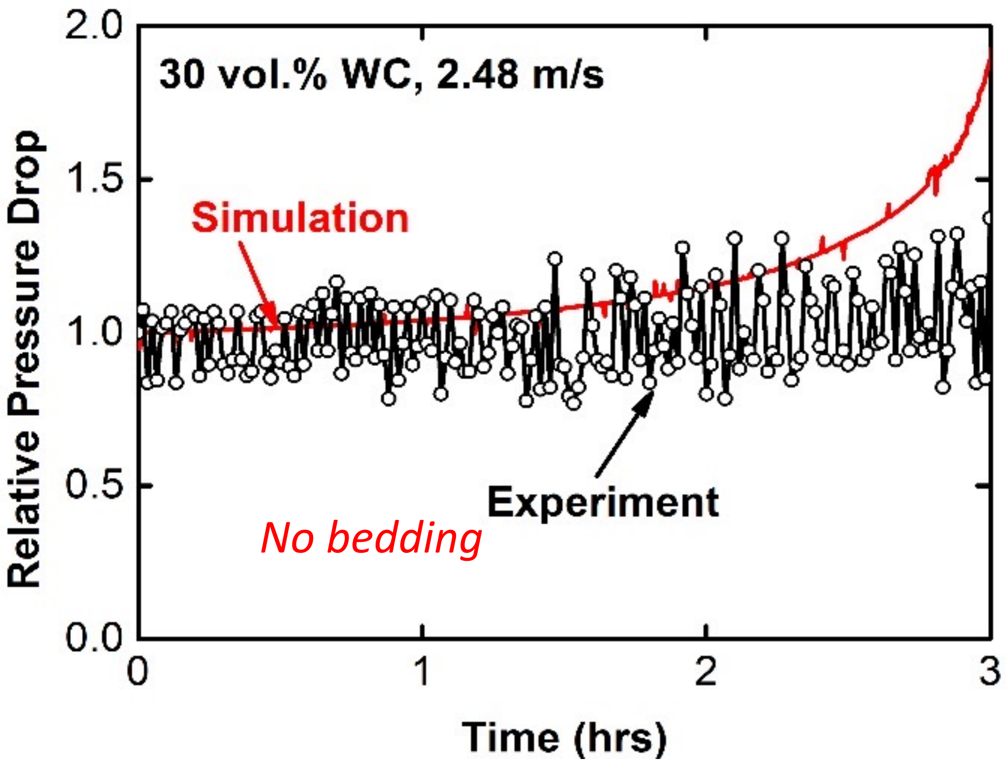
- Bedding occurs when $U_l \leq 1.34$ m/s (corresponds to experiments)
- Adding AA prevents bedding

$$Bedding\ Fraction = \frac{HVF\ in\ bed}{Total\ HVF}$$

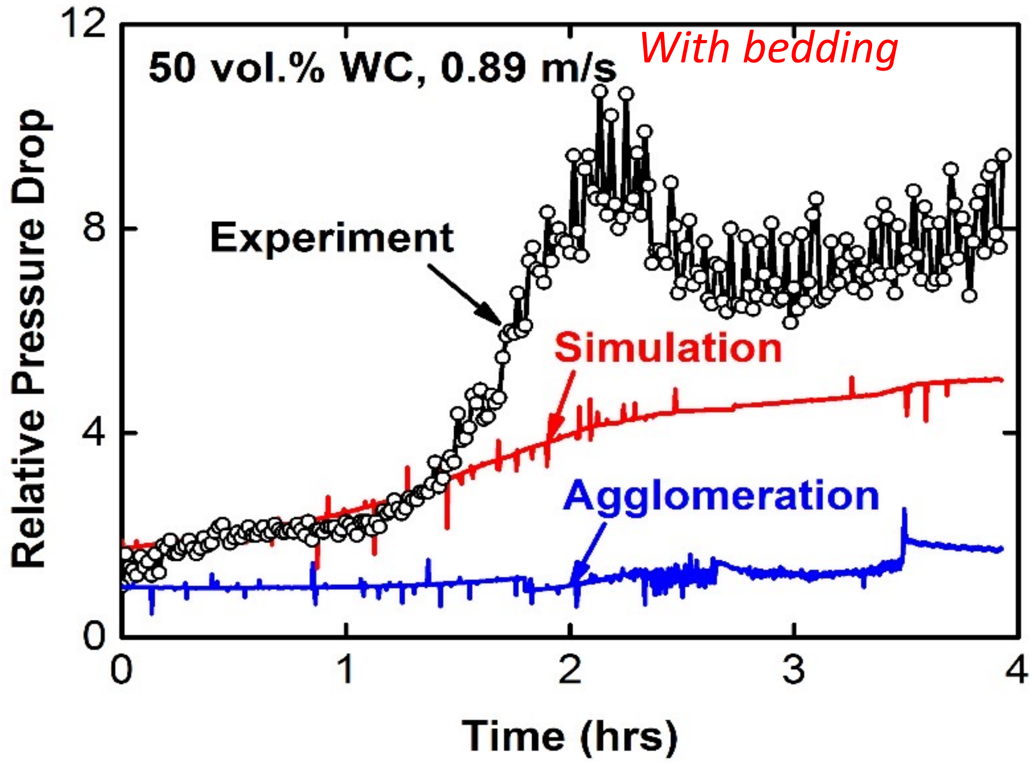
ΔP Prediction Improved with Bedding Model

Φ: porosity

*Φ = 0.65



Φ = 0.65



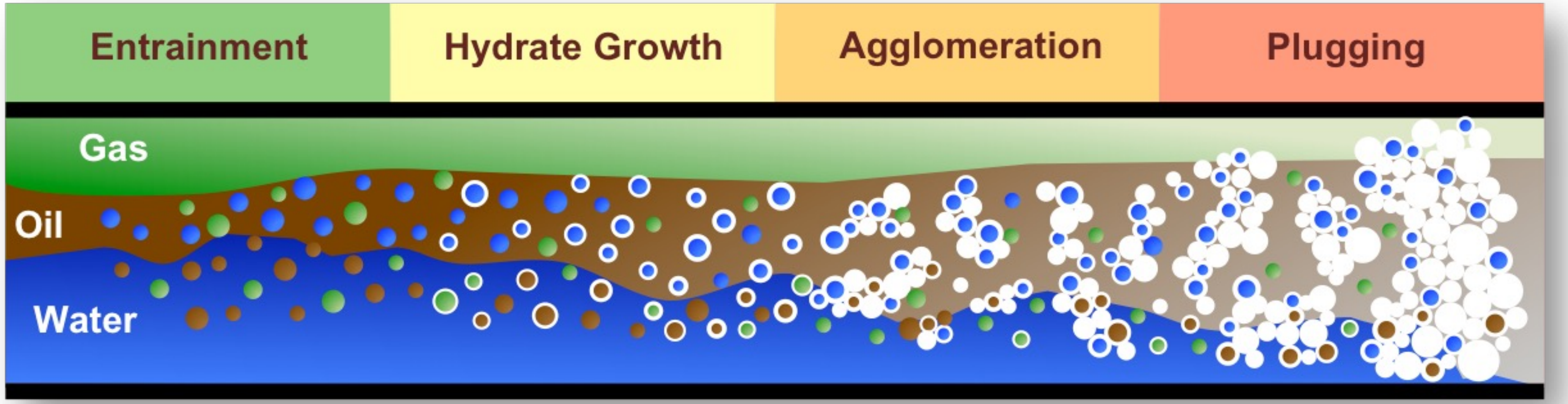
- ΔP is a complicated result of multiple phenomena
- Bedding may lead to larger ΔP compared to agglomeration

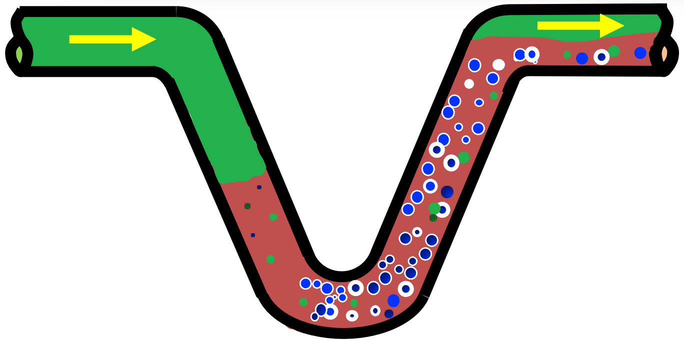
$$Relative\ \Delta P = \frac{\Delta P(t)}{\Delta P(t_{onset})}$$

Y. Wang, PhD Thesis, 2019

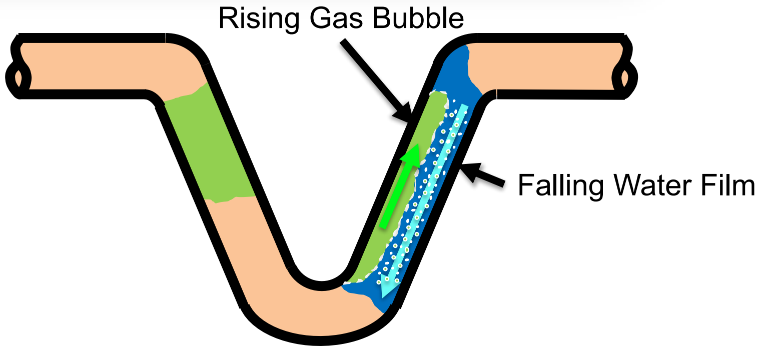
Hydrate Formation and Transportability Models for Transient Operations

General Conceptual Picture for Continuous Flow





Fully Dispersed Systems



Segregated/Partially Dispersed Systems

Conclusions

- Introduction of new hydrate related physics improve CSMHyK predictions
  - In terms of pressure drop along pipeline
- Hydrate formation models may be applied to generate cost-effective hydrate management guidelines for field operations
- Water (hydrate) interfaces with hydrocarbons are key for design of hydrate management strategies that prevent pipeline blockages

Acknowledgement

- Support from CSM Hydrate Consortium, which currently includes Chevron, ExxonMobil, Petrobras, Phillips66, Total, and Wintershall DEA

- Hydrate busters