Webinars

Hydrate Risk Management Informed by High-Pressure Laboratory Experiments

Prof. Zach Aman

3 April 2023

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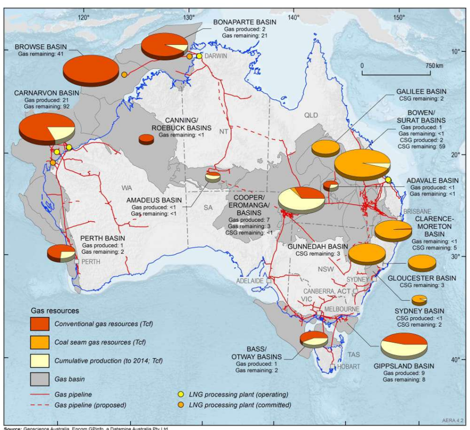
Context of Large, Remote Australian Fields



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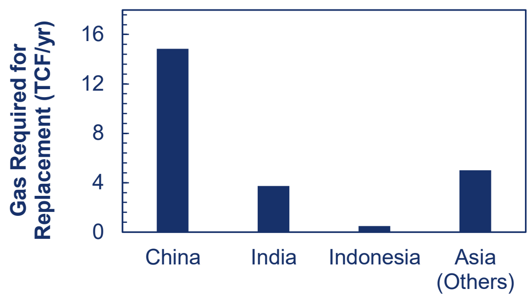

- Regional coal-to-gas switching
  - **India**: 40 years of supply, saving 500 Mt CO_2 per year; or
  - **Asia (w/o China)**: 30 years of supply, saving 800 Mt CO_2 per year
- Including prospective resources
  - Enough to supply **all** of China, India, and remaining Asia for **15 years**
  - Saving 3.5 Gt CO_2 per year

Australia’s Focus on Long Tiebacks

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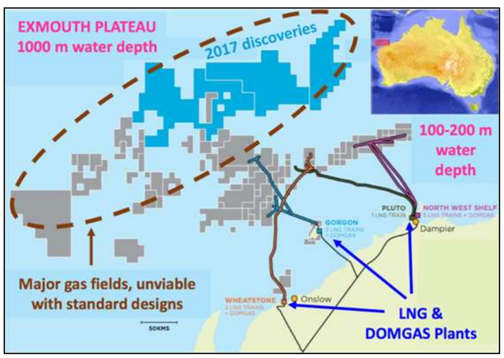
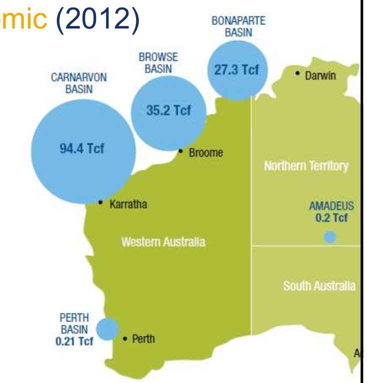


Gas transport of 100 to 300 km
- 3× definition of “long” from N. America

99 tcf of economic gas in Australia
- 57 tcf of sub-economic (2012)
- Sub-economic:
  18 tcf Browse,
  22 tcf Carnavon,
  13 tcf Bonaparte



Requirement for cost effective solutions

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World LNG Report (2018)

Hydrate Constraint in Oil-Dominant Flow

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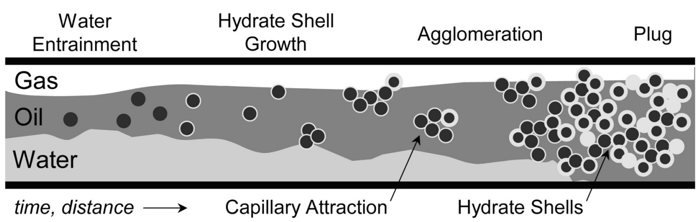
Phenomenology of Evolving Blockage



(E.D. Sloan et. al – Natural Gas Hydrates in Flow Assurance, 2011)

Model Representation in Transient Simulator

Hydrate Check → Hydrate Growth → Hydrate Dispersion → Hydrate Deposition → Fluid Rheology

- **Hydrate Check**: Stochastic process, $T<T_{sub}$?
- **Hydrate Growth**: Kinetic, Temperature driving force
- **Hydrate Dispersion**: Homogenous dispersion in oil = viscosity increase
- **Hydrate Deposition**: Hydrate particles 'slip' with oil/water
- **Fluid Rheology**: Increasing slurry friction eventually gives rise to **plug**

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Hydrate Constraint in Gas-Dominant Flow

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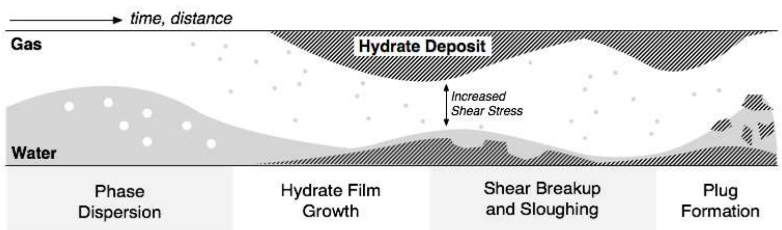
Phenomenology of Evolving Blockage



Model Representation in Transient Simulator

(based on *M.N. Lingelem et al. 1994*)

Hydrate Check	→	Hydrate Growth	→	Hydrate Dispersion	→	Hydrate Deposition	→	Fluid Rheology
Stochastic process $T<T_{sub}$?		Kinetic, Temperature driving force **Faster reaction?**		Homogenous dispersion in oil phase **No oil phase present**		Hydrate particles 'slip' with oil/water **No deposition model**		Increasing slurry friction eventually gives rise to plug. **No sloughing**

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Pilot-Scale Systems to Understand Gas-Dominant Hydrate Phenomena

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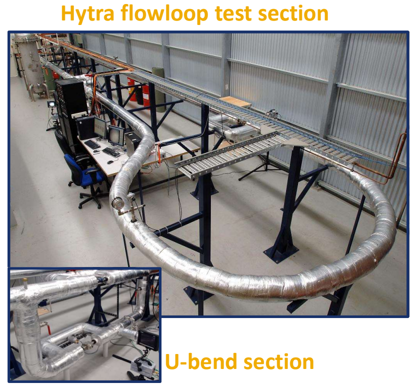
- Simulate deep-water gas field conditions
- Liquid loading below 10 vol%
- High gas velocity, wavy-annular flow regimes
- Constant-flow and transient-flow tests

TECHNICAL SPECIFICATIONS	
Test section	1 inch SS 360 pipe, 40 m long Pipe-in-pipe temperature control
Conditions	Pressure: <1750 psi (120 bar) Temperature: -8 to 30 °C
Fluids	Aqueous solutions, light oils, natural gas
Flow rates	Liquid: 1-8 Litres/min V_{SL} : 0.05-0.4 m/s Gas: 500 - 1000 scfm V_{SG} : 4.5-8.2 m/s
Instruments	7 pressure transducers, 7 RTD sensors, gas and liquid flow meters, viewing windows, high speed camera

Hytra flowloop test section



U-bend section

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Stenosis and Sloughing in Gas Lines

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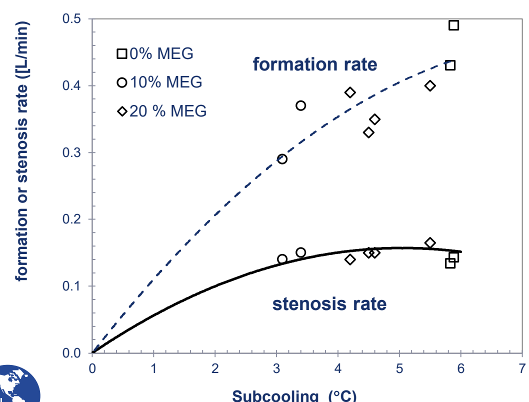
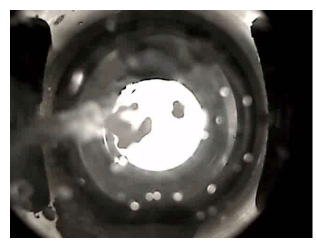
- Flowloop investigation of hydrate formation and stenosis

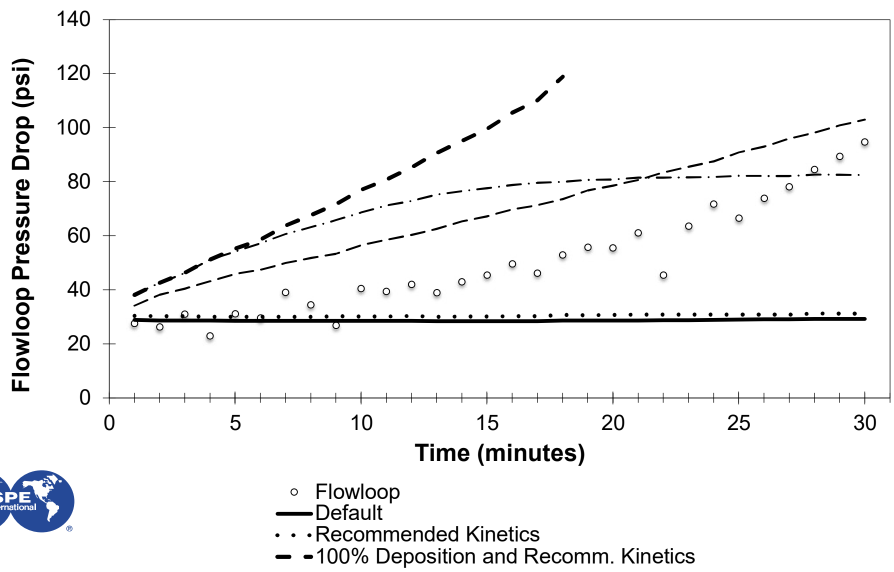


Formation rate 30-50% larger than stenosis in a subcooling range of 3-6 °C

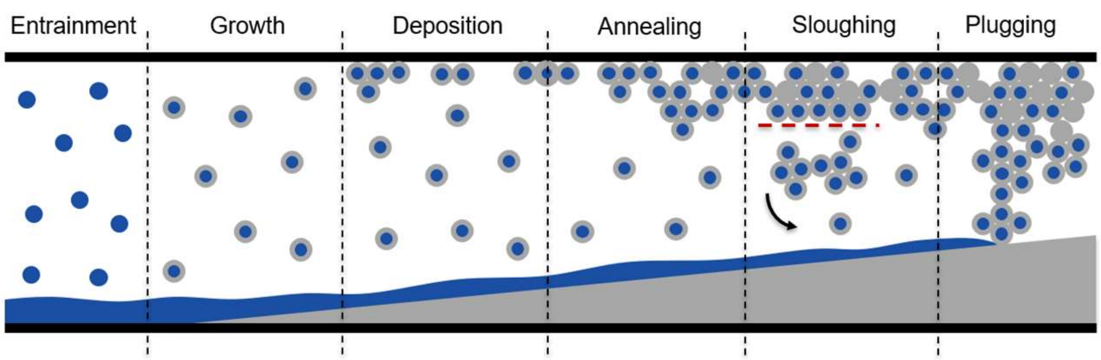


(1) Di Lorenzo, M. et al. ***Energy Fuels***, 2014, 28 (11), 7274–7284

Existing Mechanics Unable to Match ΔP



New Phenomenology for Gas-Dominant Hydrate Stenosis or Blockage



Models introduced to cover first four stages

Sloughing beyond flow simulator capability

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Early Comparison with Flowloop Data

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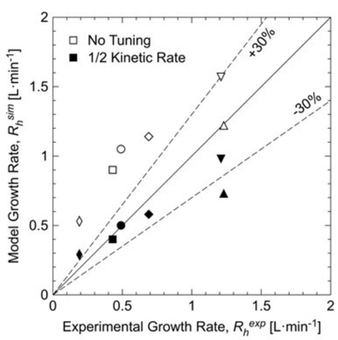
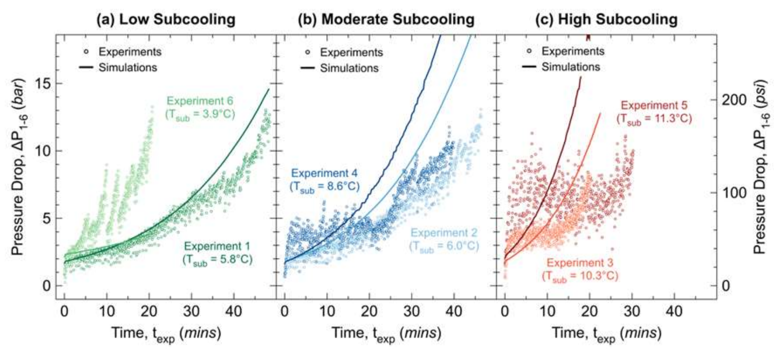
Growth



Deposition (without tuning)



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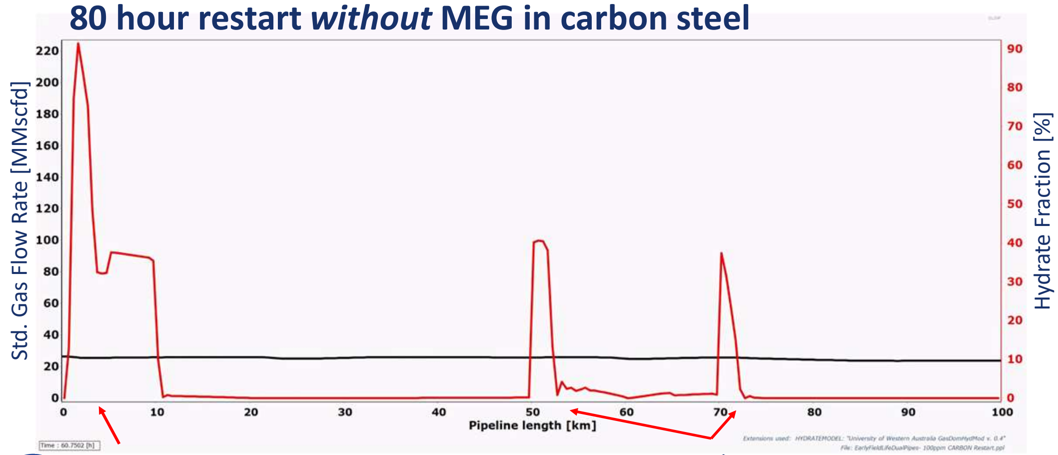
Example: Blockage in Uninhibited System

80 hour restart *without* MEG in carbon steel



Severe deposit in < 8 hrs

Secondary deposits at ≈ 18 hrs

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Expanding to Jumper and JT Loops

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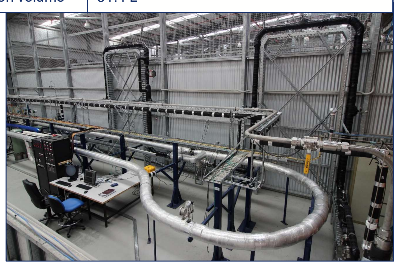
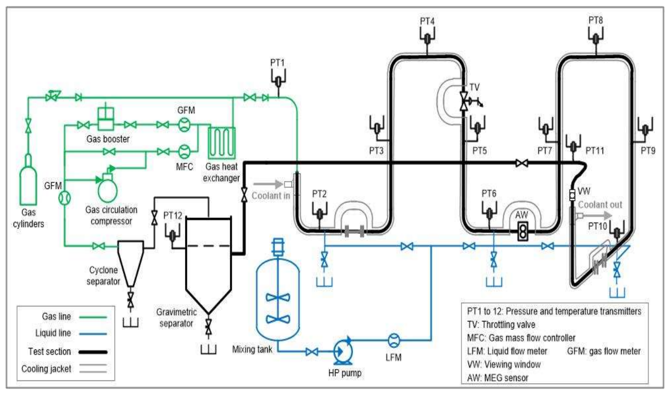
TECHNICAL SPECIFICATIONS	
Geometry	2 inch OD SS 360 pipe 2 high points, height: 4 m 3 low points Total length: 35 m Cooling jacket
Conditions	P: <120 bar (1700 psi) T: -4 to 30 °C
Gas velocity	V_{SG}: 0.02 to 2 m/s
Instruments	11 Pressure, RTD sensors Gas flow meter, MEG sensor
Test section volume	51.4 L





Flowloop is owned by CSIRO and co-operated by CSIRO and UWA

HyJump (black) and Hytra (silver) flowloop test sections

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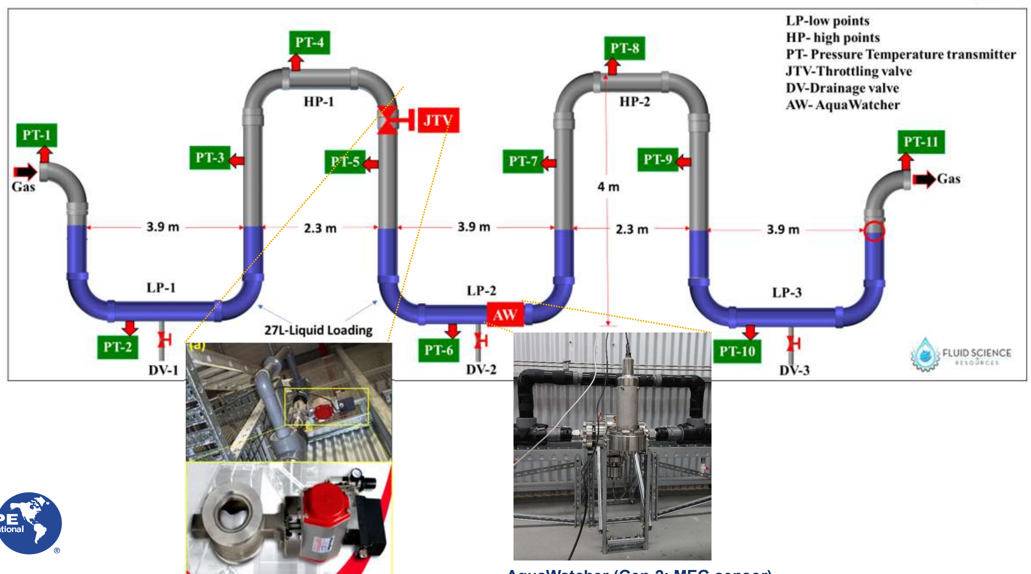
Expanding Effort to Jumper Flowloop



Throttling valve

AquaWatcher (Gen-2; MEG sensor)

Sweep Efficiency on Restart (Jumper)

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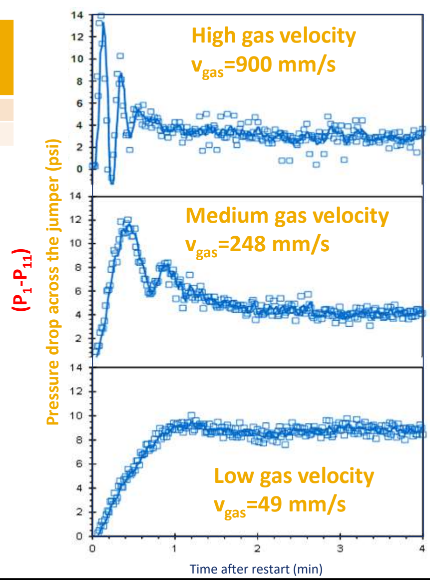
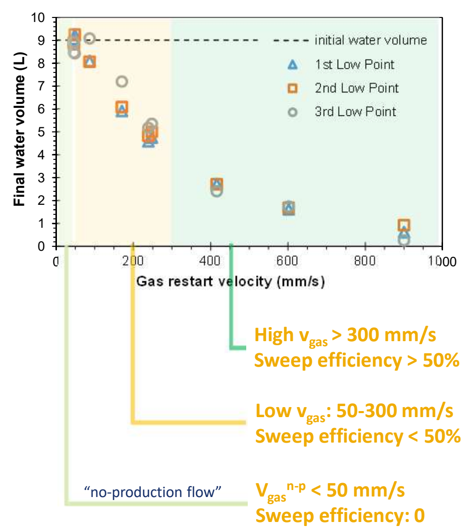
Shut-in pressure	Shut-in temperature
(psi)	(°C)
1189	17.8

No hydrates in the system





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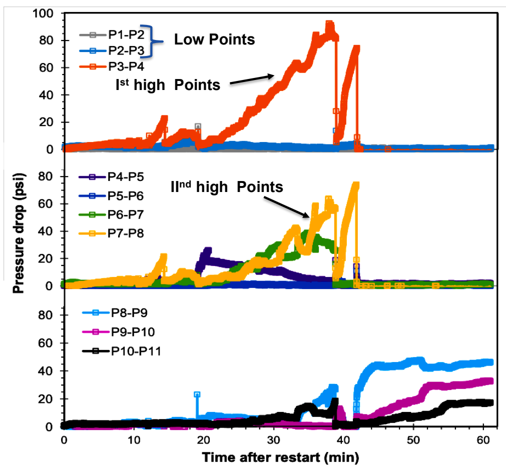
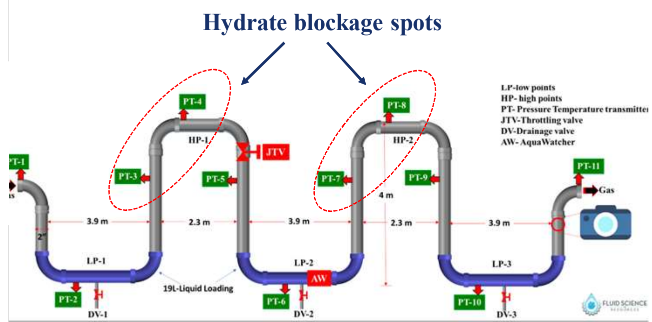
Accumulation in Bends, High Points





Incorporating a Dedicated JT Loop

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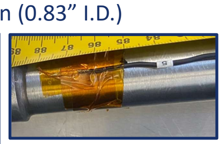
Post-experiment gas storage

Moisture removal stage

Gas compressor

Controllable JT Valve

Detachable test section (0.83” I.D.)



Post-experiment visual observation

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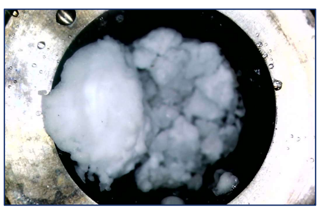
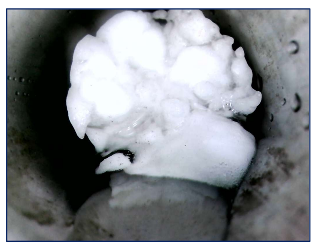
Rapid Plug Onset in Severe JT Expansion

Test section inlet

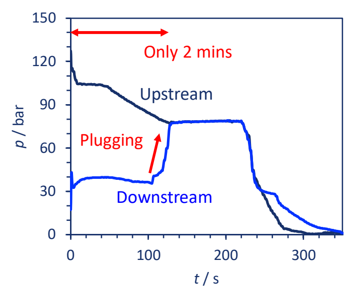


Test section outlet



Variables affecting Hydrate formation

- *Pressure drop*
- *Fluid temperature*
- *Water droplet size (entrainment)*
- *Working fluid*



CH_4 + Water
P_{feed}= 115 bar, T_{feed}= 8°C
Back Pressure regulator = 30 bar
Total water loading= 533 ml

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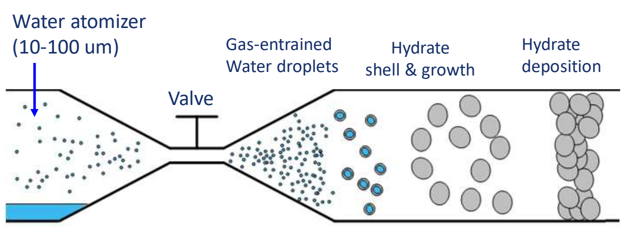
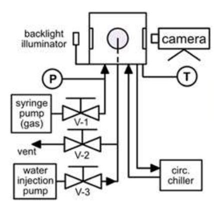
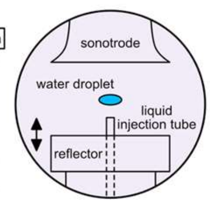
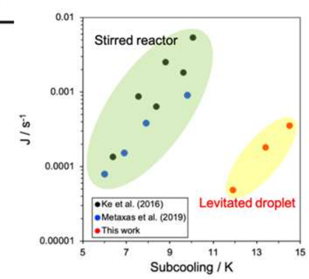
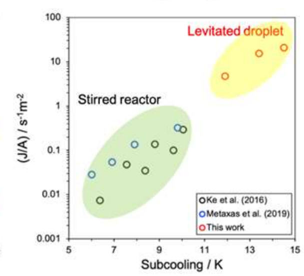
Entrained Surface Area Dominates Growth











- Total interfacial area of atomized water droplet is **4 orders of magnitude larger** than bulk water

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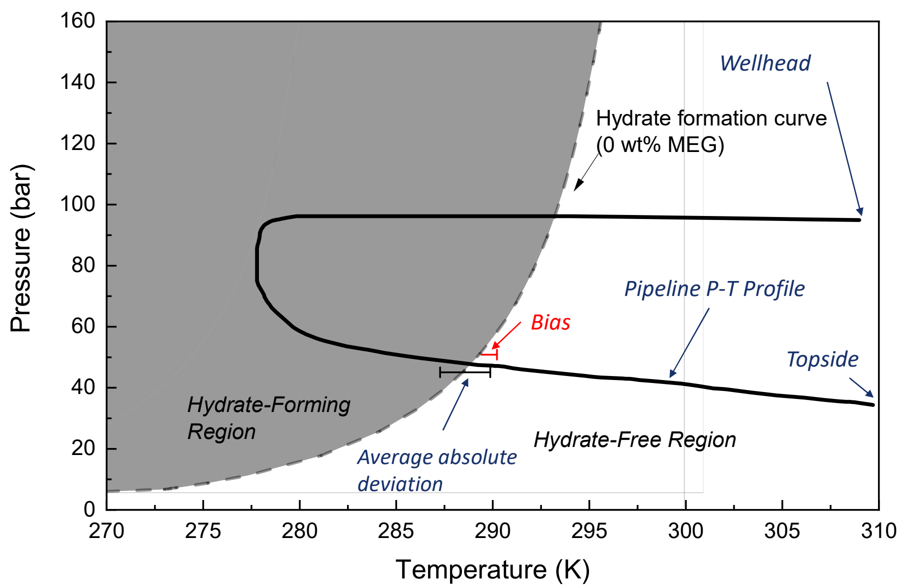
Uncertainty is the Key to Cost

- Bias highlights conservativeness of hydrate model prediction
- Uncertainty bounds change with **system fluid composition**
- **Paucity of data >50 wt% MEG → larger uncertainty (as shown)**



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Establishing Nucleation Probability

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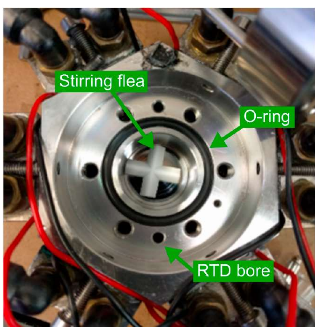
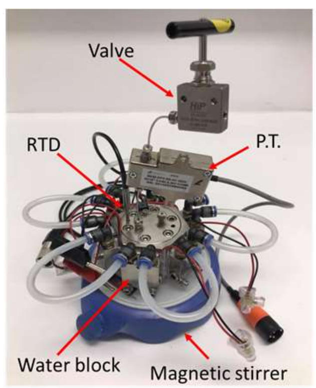
Stirred system
Small thermal mass (11 mL)





Peltier driven cooling system
(up to 5 K/min)

Thermal enclosure for
ambient temperature control

Metaxas, Lim et. al., *Fuel*, 252, 448-457, **2019**
Lim et. al., *CEJ*, 124177, **2020**

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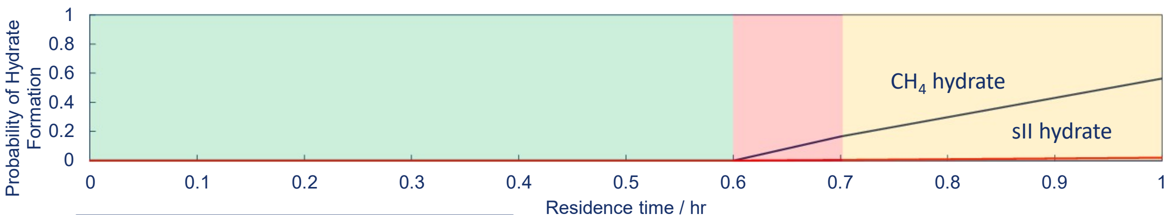
Nucleation Model in Transient Tool(s)

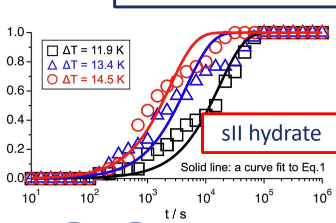


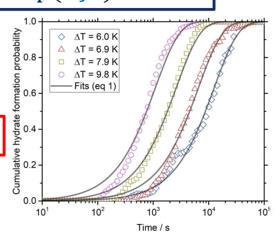
$$F(t) = 1 - \exp(-Jt)$$

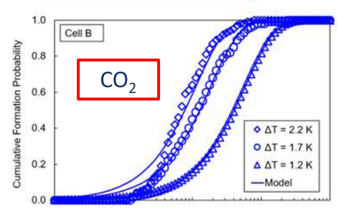
$$J = A \exp\left(\frac{\Delta s_e \Delta T}{k_B T}\right) \exp\left(\frac{-B'}{T \Delta T^2}\right)$$

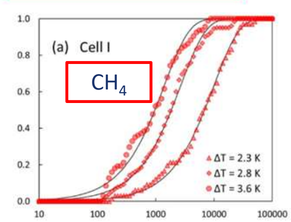
∝ Number of sites

Energy barrier at sites









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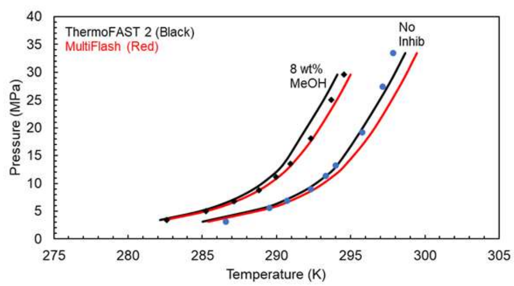
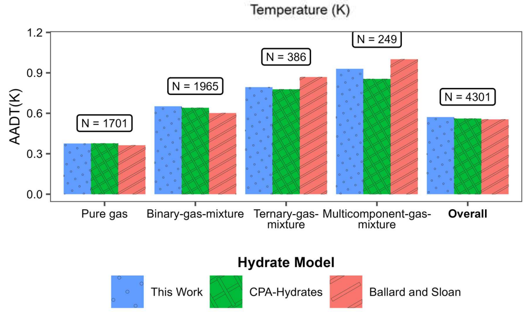
A New Hydrate Phase Boundary Model





Hydrate Equilibrium Model	Parameters
Ballard and Sloan (2002)	103
Hielscher et al. (2019)	92
Zhu et al. (2022) – THIS WORK	**64**

Component	Mole Fraction
CO2	0.0134
Methane	0.7724
Ethane	0.0761
Propane	0.0369
Isobutane	0.0056
N-butane	0.014
Isopentane	0.0003
N-pentane	0.0089
Hexanes	0.0067
C_{7+}	0.0657

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Summary

- Pilot-scale flowloop systems to establish phenomenology
  - Hytra (horizontal) system: entrainment > subcooling
  - HyJump (jumper-based) system: bends, high points
  - JT expansion loop: entrained droplet size, pressure drop
- Interfacial efforts to improve transient model prediction
  - HP levitation and HPS-ALTA: establishing nucleation probability
  - Phase boundary, integrated compositional tracking

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