Managing and Mitigating Hydrate Risks Associated with Geological CO_2 Storage

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Introduction

CCUS is a critical component among several others to deliver Paris Agreement goals

Understanding key operational challenges related to CO_2 injection is critical

Main issues associated with this are:

- **Corrosion**
- **Injection well integrity (cement)**
- **CO_2 injectivity**

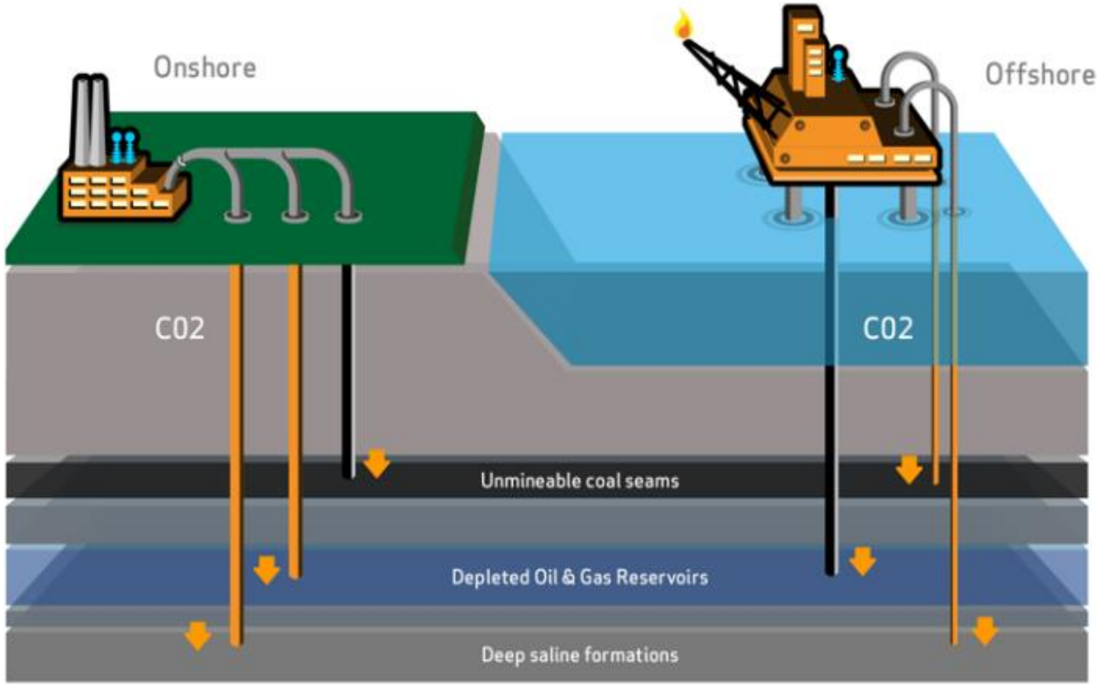
Whilst CO_2 injection is not new, conditions differ significantly for geological carbon storage e.g., lower temps and pressures than O&G Production

Effective & reliable lab assessment methods are crucial to determine under which conditions CO_2 injectivity impairment begins and how this can be effectively mitigated and controlled

Geological Carbon Storage - Issues

Risks associated with CO_2 injection into GCS targets

- Injection under matrix conditions
- Dry CO_2 injection strips water
- Suspended solids
- CO_2 hydrates formation in the near-wellbore
- Corrosion
- Injection Well Integrity
- Asphaltene precipitation



Geological Carbon Storage - Issues

This work presents new laboratory processes for assessment of CO_2 injection under dynamic conditions representing the near wellbore

Determine specific operating conditions when CO_2 injectivity is impaired

Current focus is dynamic hydrates formation and mitigation assessment

Why are we doing this?

Traditional O&G hydrate tests are conducted under bulk/static conditions

Replicates tubulars – not suitable for near wellbore/dynamic CCUS operations

CCUS industry also assesses CO_2 hydrates for their utilization, not the near wellbore risks they pose.

CO_2 Hydrates

Their formation can reduce/prevent injectivity into GCS target reservoir

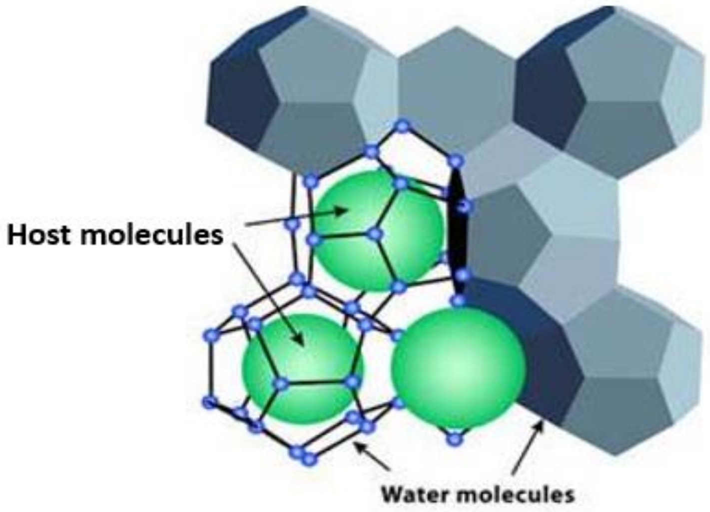
Can form in the injection system if the system itself is not sufficiently dry

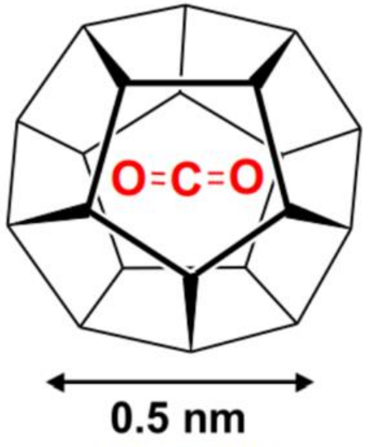
Risk of formation in the reservoir from;

- **Water almost always present in the reservoir**
- **Joule-Thomson cooling / phase change (liquid/gas) from dPs**

CO_2 hydrates generally form more readily than hydrocarbon hydrates

- **Form at lower P than CH_4 hydrates up to ~ 10 °C**
- **Kinetics can be faster**
- **Less porous than CH_4 hydrates**

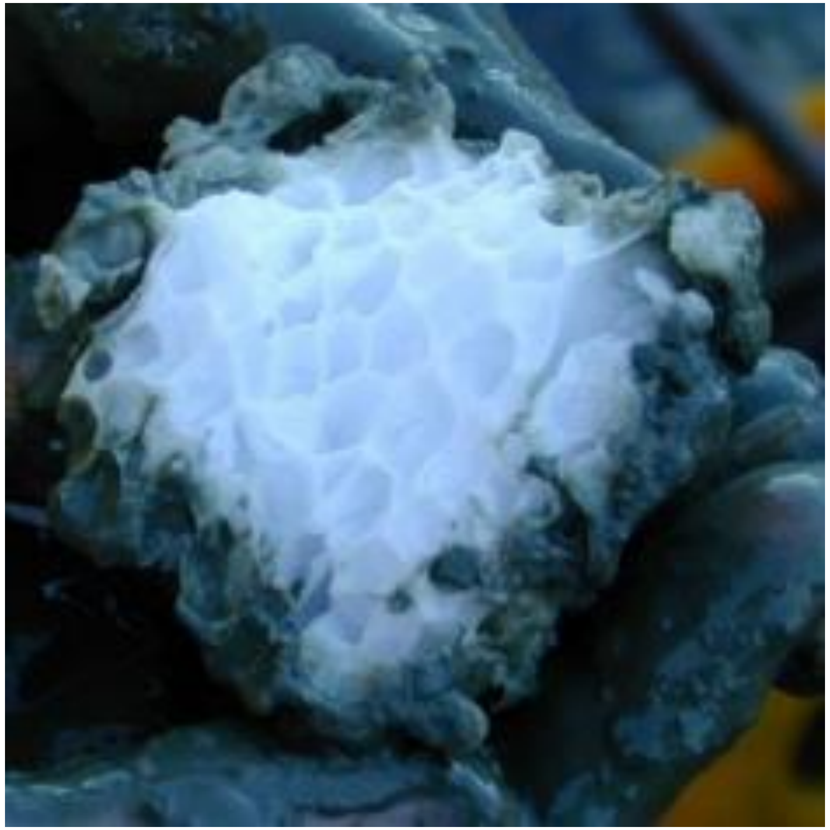




Ren *et al.* 2019

CO_2 Hydrates

Traditional hydrate formation / mitigation assessments are conducted under bulk/static conditions



Not suitable for hydrate risk assessment in reservoir matrix
- plugging mechanisms are specific to reservoir rock type
- crystal migration to pore throats
- “memory effects”

Lab testing equipment built for controlling the necessary test conditions to

I. Effectively and repeatably generate CO_2 hydrates within a core matrix
II. Allow for the assessment of potential mitigation / remediation methods for CO_2 hydrate risk
III. Leading to reliable lab qualification methodologies before field trials

Methodology Inputs – Key Experimental Challenges

Achieve very low test temperatures (– 25 °C)

Required significant modification to existing equipment

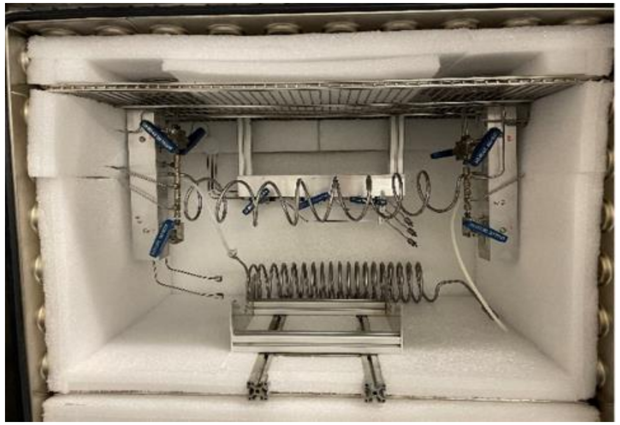
Assessing current material suitability at low temps and sourcing alternatives (metals, elastomers, confining fluids)

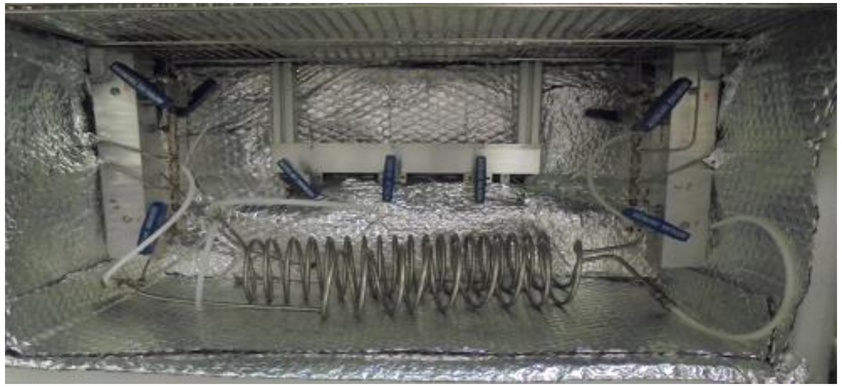
Various experimental design options were considered during initial stages.

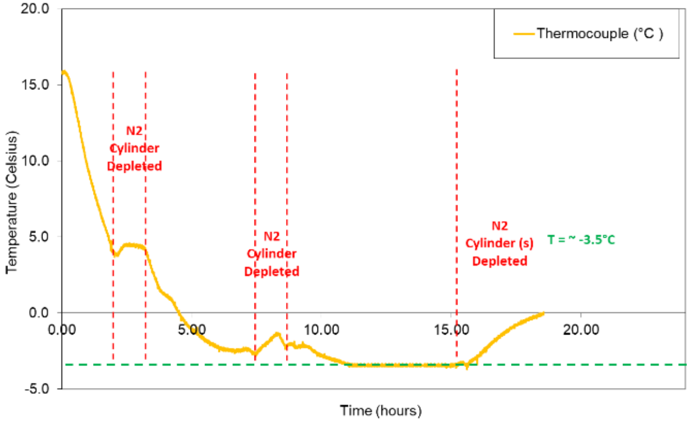
Two Experimental Setups carried forward for initial tests –

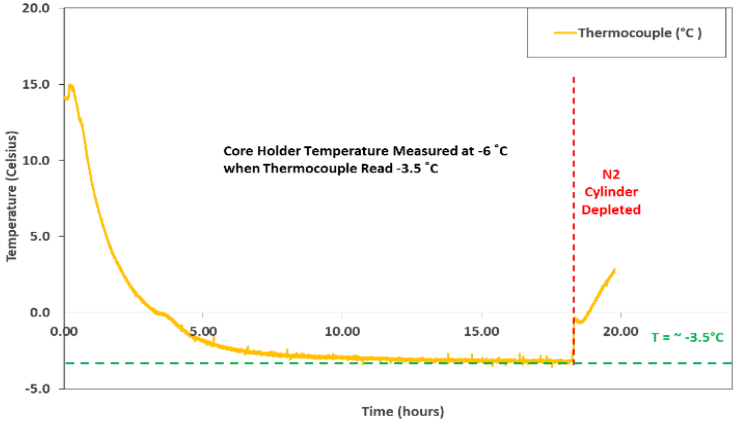
- **Insulated enclosure (lab oven) combined with in-situ chiller bath cooling system**
- **Laboratory freezer**

Various Experimental Designs



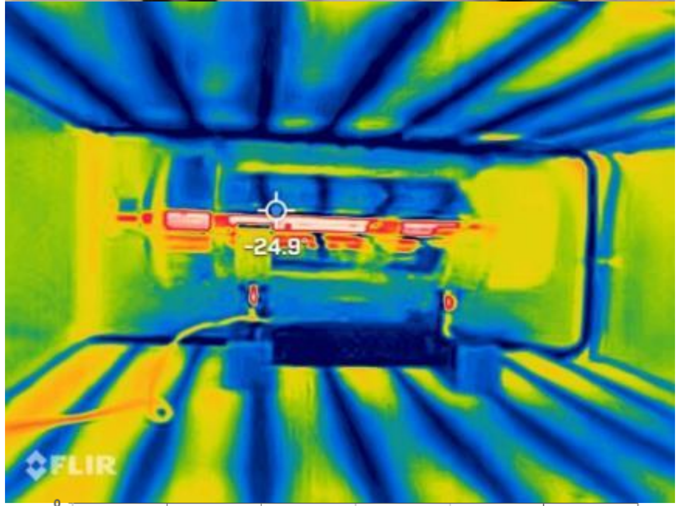


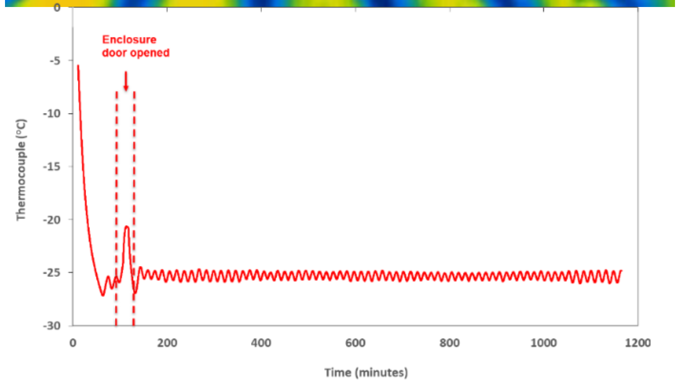




Core Holder Temperature Measured at -6 ˚C when Thermocouple Read -3.5 ˚C

Existing CF - Chiller and OFN Blanketing





Freezer

Custom-made Built Dynamic Low Temperature CO_2 Injection Rig

- **Standard core flood experimental setup required improving for challenging low temperatures**
    - **down to -25 °C**
- **Combined freezer & chiller bath core flood system designed and built.**
- **Specialized gas mixing/injection system and dual injection core holder**
    - **separate CO_2 & brine injection lines**

Figure 1: Dynamic Low Temperature CO_2 Injection Rig: Side View; Inside View; Front View with Door Closed (from left to right).

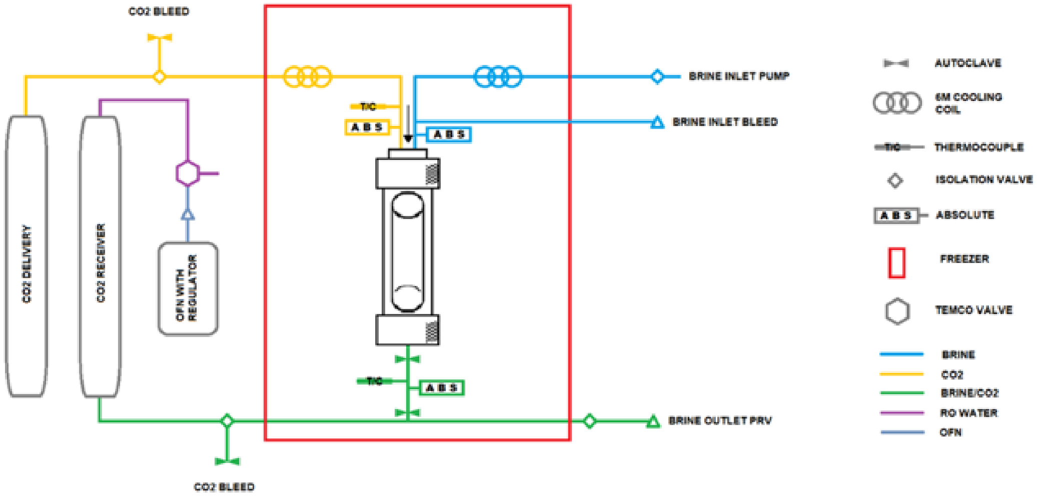
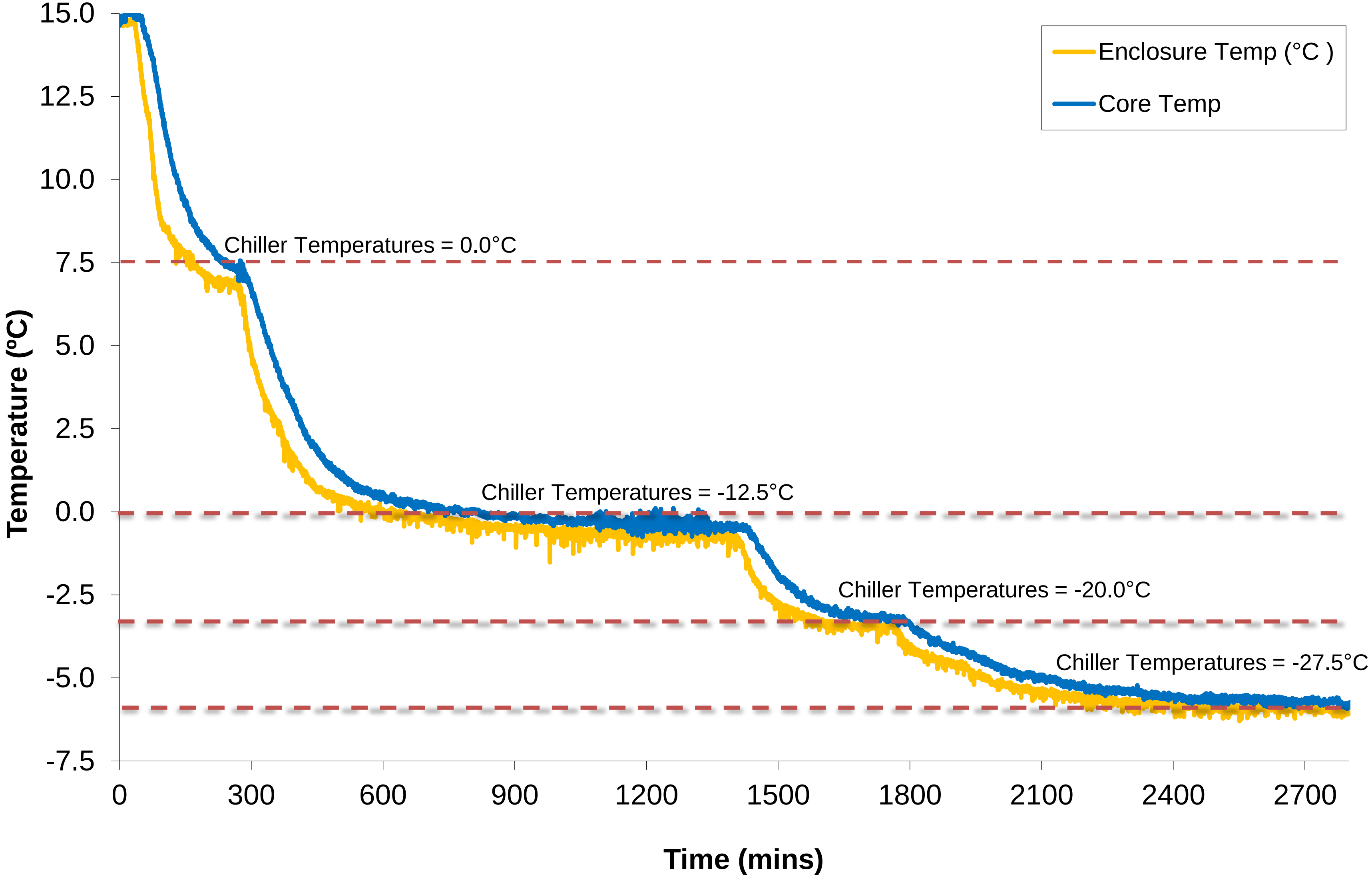


Figure 2: Dynamic Low Temperature CO_2 Injection Rig Simplified Schematic of Dual Injection System

Peat, S., Jones, D., Boyde, D., Frigo, D., Graham, G., Le-Goff, T.-H., Lagarde, F. 2022. "Innovative Dynamic Laboratory Testing Methods and Workflow for Evaluating and Mitigating Carbon Dioxide Injection Challenges in Geological Storage Prospects". Paper SPE-210811-MS presented at ADIPEC, Abu Dhabi, UAE, 31 Oct – 03 Nov 2022.

Bespoke Built Dynamic Low Temperature CO_2 Injection Rig

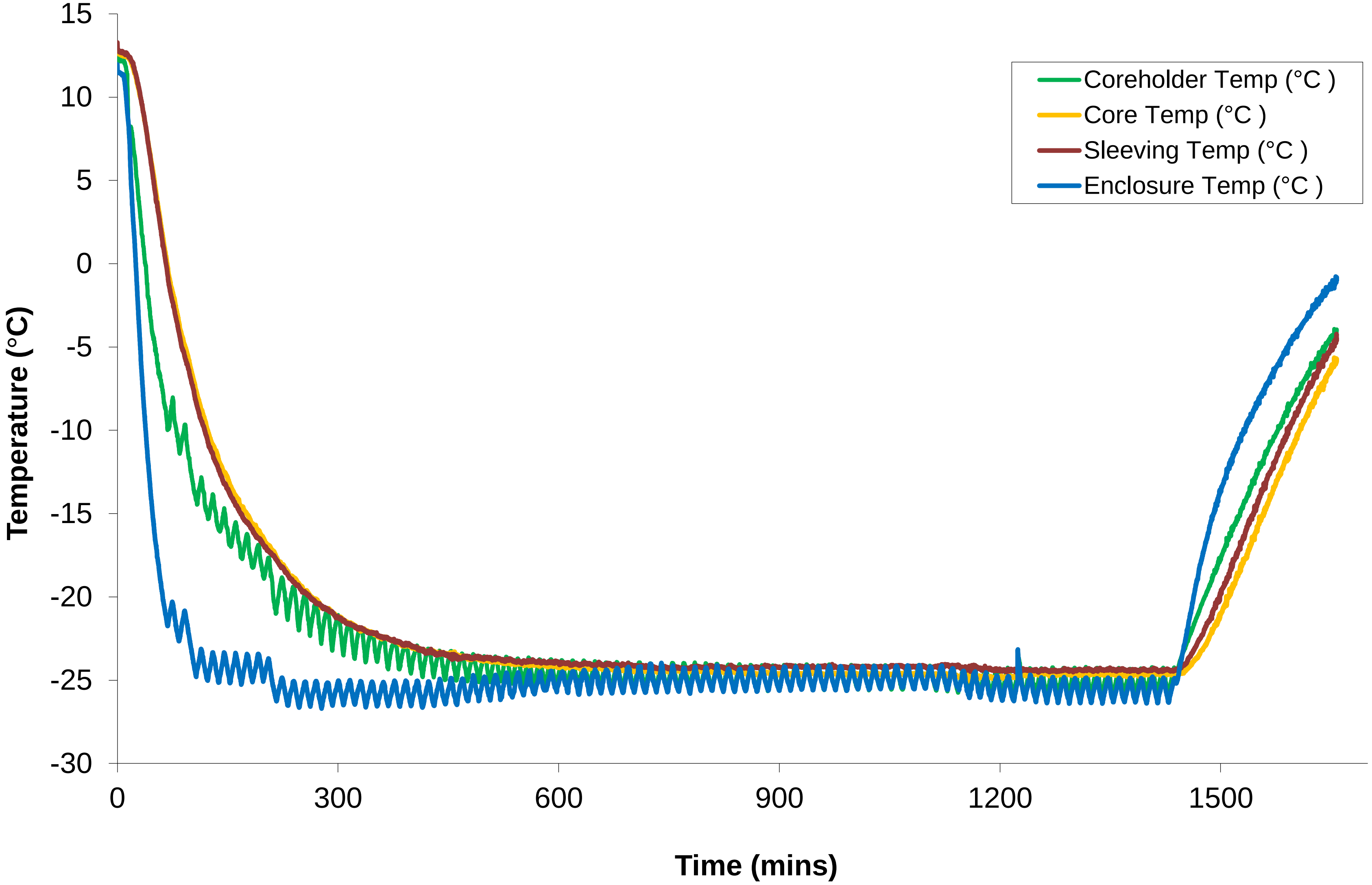
Initial Cooling Protocol Tests – Chillers only (ambient, down to -5 °C)



- **Stronger alignment between recorded temps**
- **Improved stability with new test rig (no need for nitrogen)**

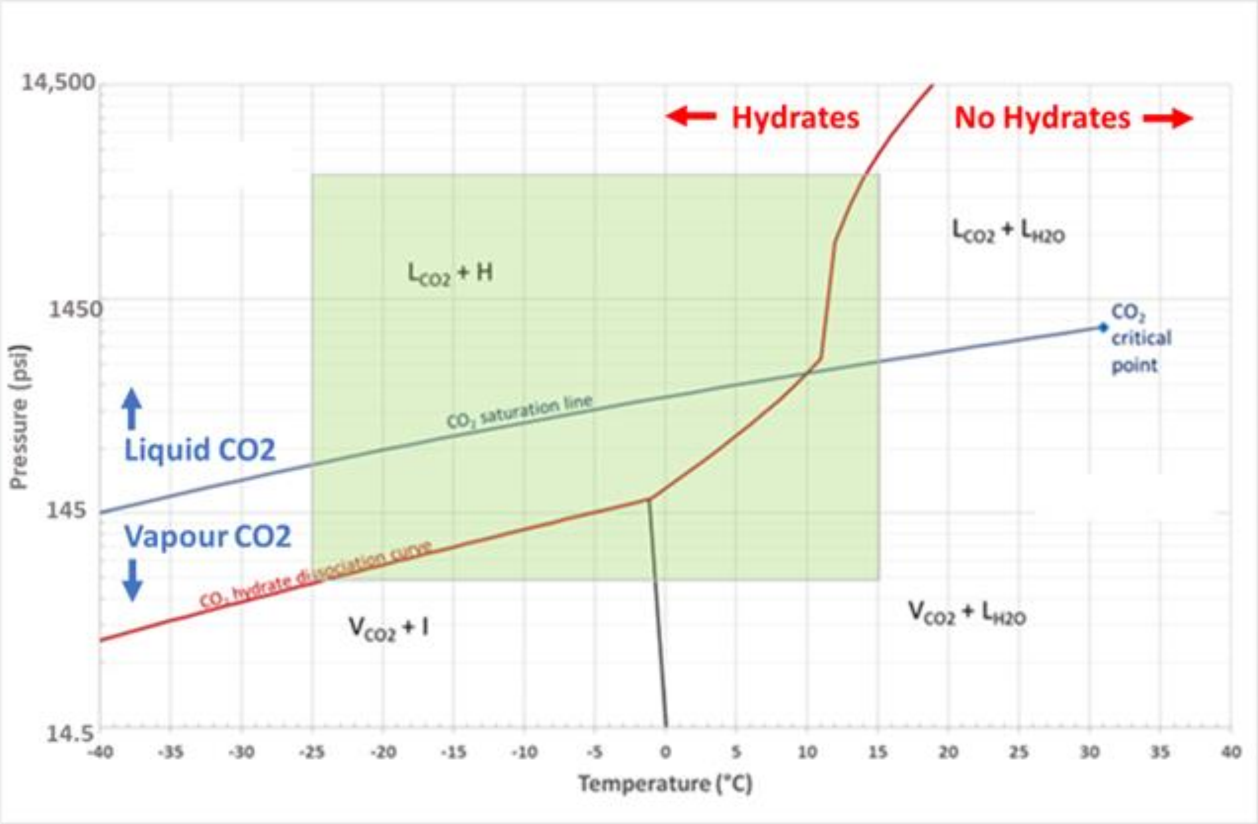
Bespoke Built Dynamic Low Temperature CO_2 Injection Rig

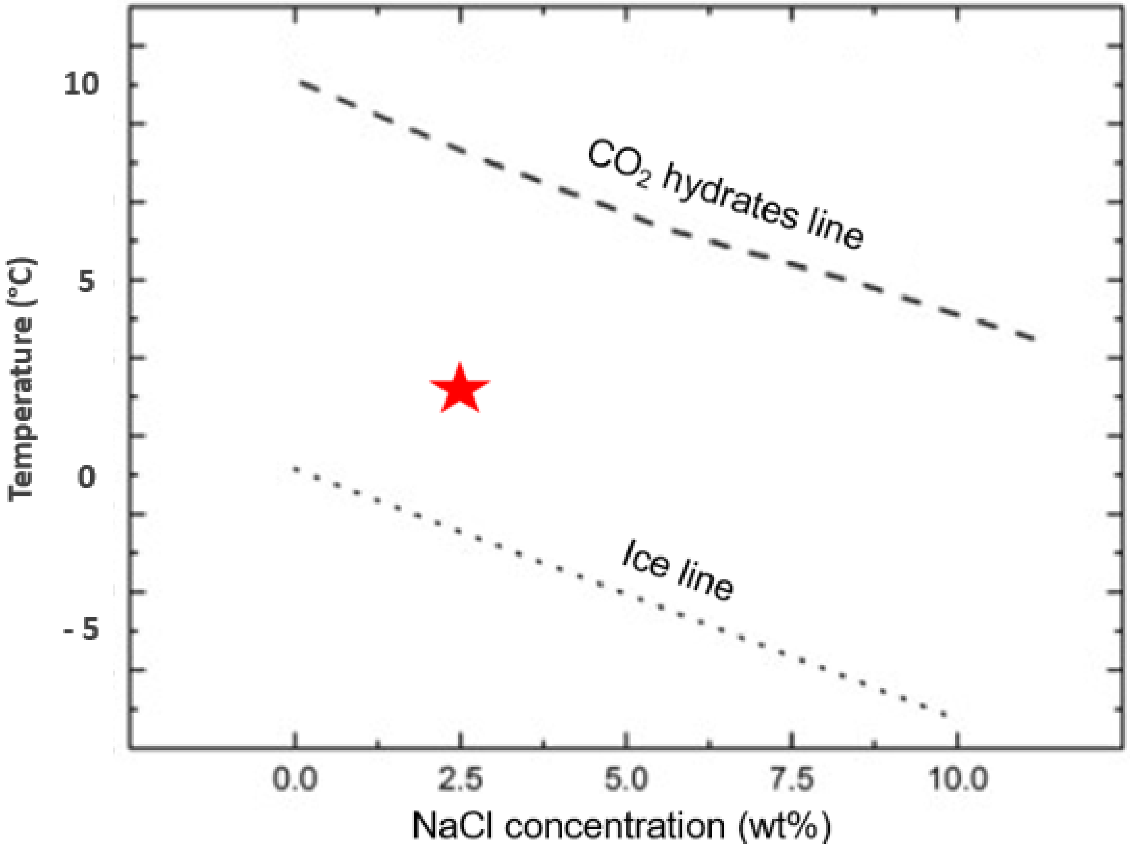
Initial Cooling Protocol Tests – Freezer on, set to -25 °C (from -10 °C)



- **Stronger alignment between recorded temps**
- **Improved stability with new test rig (no need for nitrogen)**
- **Freezer and core / core holder achieving near -25 °C in ~ 300 mins**

Testing Variables



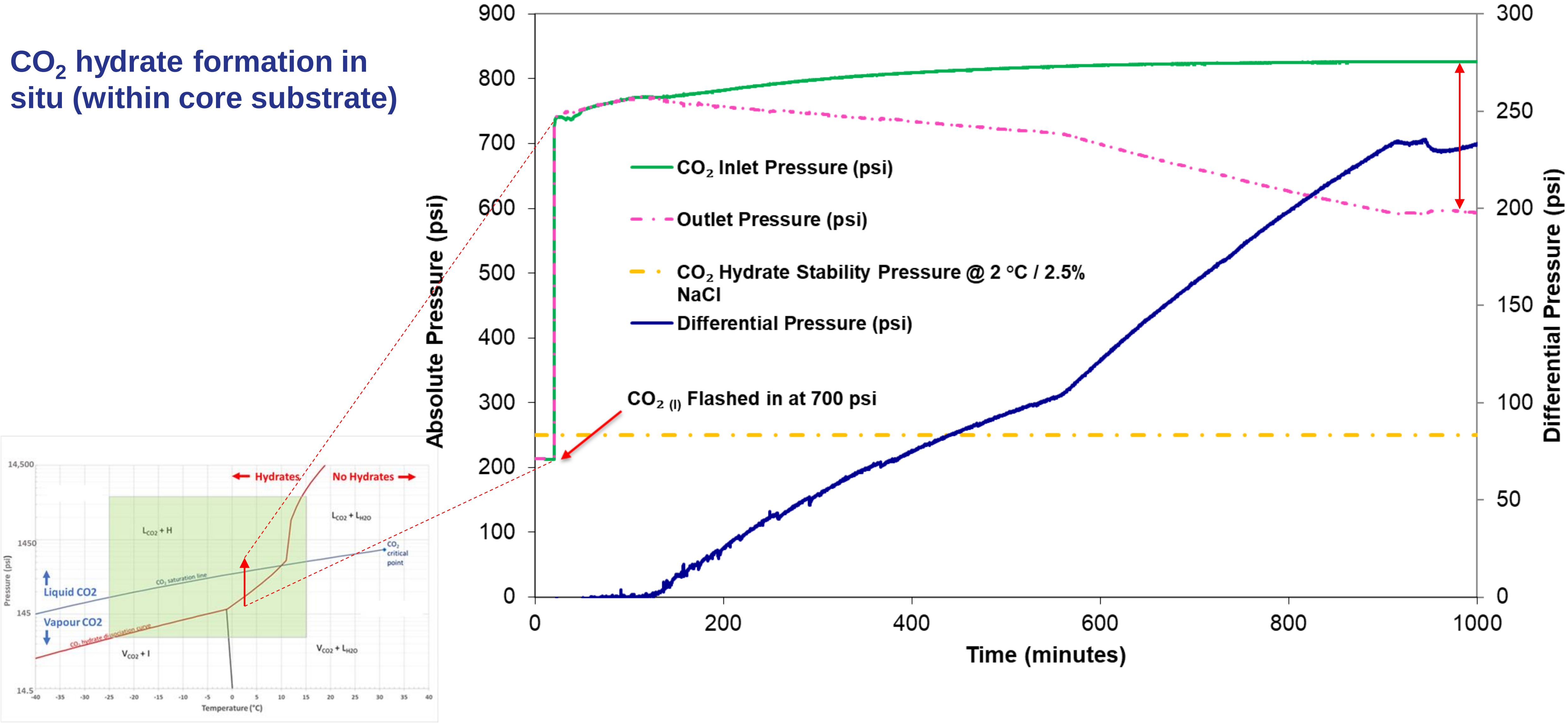


- 99% CO_2 Gas
- 2.5 wt% NaCl Brine

- Temp Range = Ambient to -25 °C
- Pressure Range = 220 – 700 psi

General result – Hydrates successfully formed within core rig

CO_2 hydrate formation in situ (within core substrate)

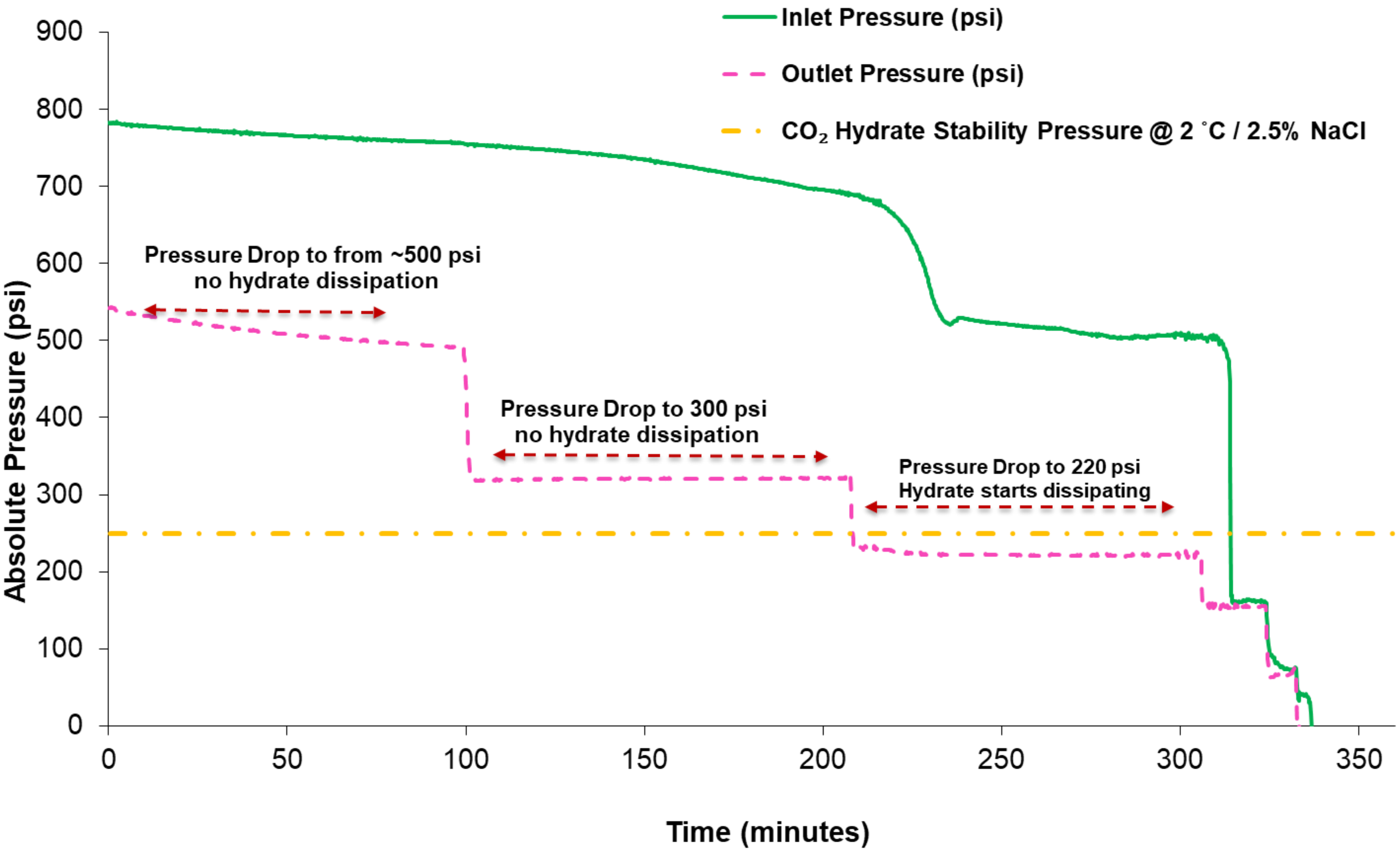


General result – Hydrates successfully dissipated within core rig

CO_2 hydrate dissociation in situ by pressure reduction

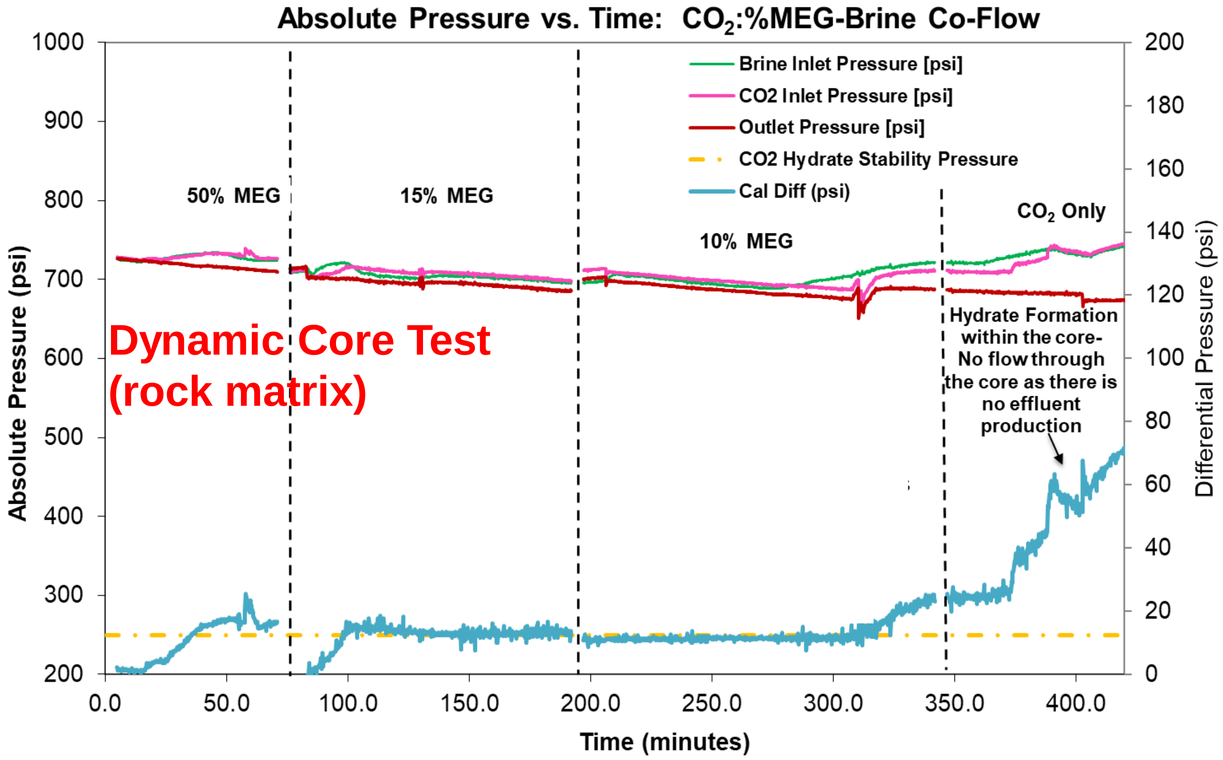
No communication between inlet and outlet indicates blockage between them (i.e. within the core)

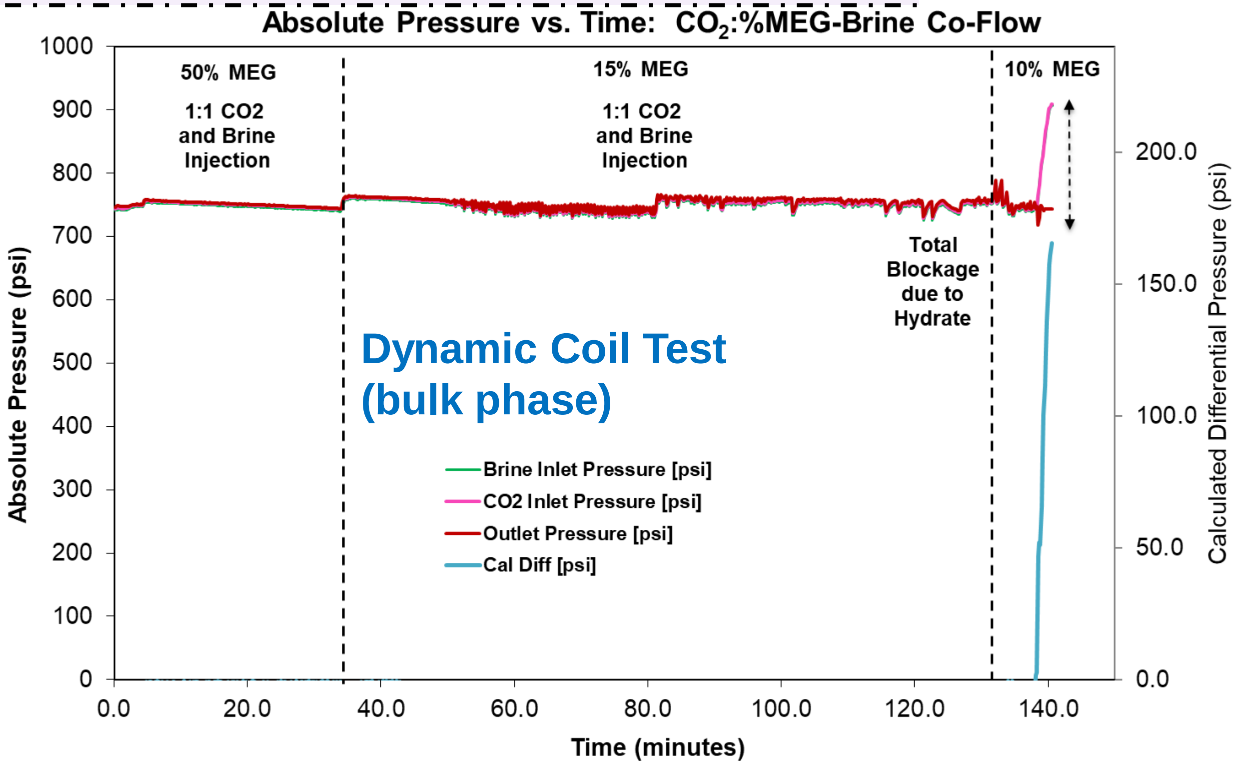
No dissipation of blockage until below hydrate stability pressure (i.e. confirming the blockage was due to hydrate)



Example result core vs bulk phase dynamic hydrate inhibition

Blockage is almost immediate in the coil while it is gradual in the core which can be ascribed to porous media effects





Differences also observed in terms of hydrate formation (in absence of THI)
And in hydrate dissipation with and without inhibitors
But dynamic bulk phase represents good screening

Conclusions

- Lab assessment crucial for determining which conditions injectivity of CO_2 could become impaired
    - Traditional hydrate laboratory assessment conducted under bulk/static conditions
    - Static lab equipment is not suitable to assess risk to CO_2 injectivity within a reservoir formation matrix

- Project successfully designed core flood system to assess CO_2 hydrate formation and dissociation in flowing conditions within porous media under selected CCUS field conditions

- Further work modified approach to allow simpler dynamic bulk phase inhibitor tests under a coil / filter blocking approach to screen THI and KHI under dynamic flow conditions

- Work is now moving forward to assess field prevention and mitigation approaches for selected field cases with known CO_2 hydrate risk

Thank you

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