SMART TUBULAR SOLUTIONS

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CCS Infrastructure (Transport & Storage)

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February 23rd, 2022

Vallourec @ SPE CCUS Conference, Aberdeen

Vallourec Engagements in CO_2 Transport & Storage Projects

Past & Present Examples

BRAZIL

Offshore
Flow lines & Injection

USA

Onshore Storage

Norway, UK

NETHERLANDS

Offshore Storage

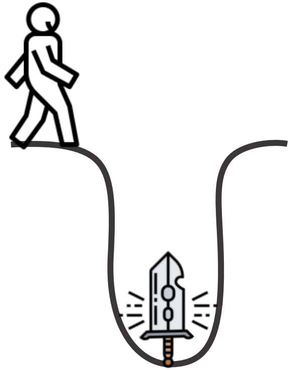
MIDDLE EAST

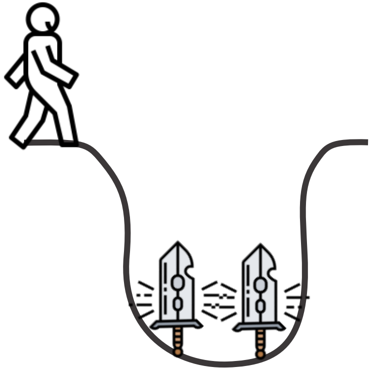
Onshore
Transport & Injection

- Material Recommendations (corrosion & low temperature)
- **Fit-for-purpose material qualification** tests based on CO_2 stream

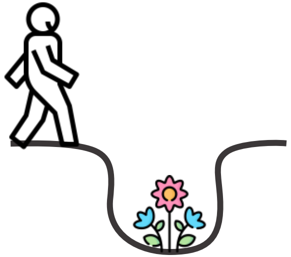
- Iterative FEA run on VAM® connections
- Vallourec leading the path to a **Connection Qualification Protocol for CCUS**

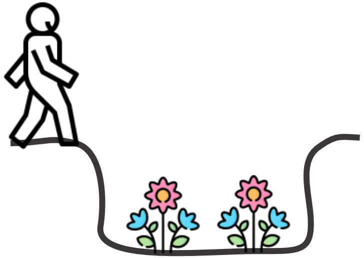
“Your biggest risk is you!”





Risk Level		Likelihood		
		Unlikely	Likely	Very Likely
Consequence	Catastrophe	M	H	H
	Major Impact	L	M	H
	Limited Impact	L	L	M





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Risk Assessment for Material And Connection Selection

Co_2 Capture

- Post combustion: SO_2, NO_x, O_2
- Pre combustion/Blue Hydrogen: H_2S, H_2, CO, O_2
- Oxy combustion
- CO_2 from natural well: H_2S

Co_2 Transport

- CO_2 compressed to supercritical phase
- Temperature drop in case of leakage
- Presence of water (condensed water in pipeline)

Injection in depleted réservoirs or acquifers

- Dry supercritical CO_2 + impurities
- Well head temperature drop during shut in

Storage

- CO_2 supercritical + impurities in contacts with brines
- Long storage duration with no pressure change in the annulus

1 How to make proper material selection ?

2 How to qualify connections ?

3 How to monitor in the annulus ?

- **No corrosion** during injection
- Materials with **good toughness at low temperature**
- **Good sealability from connection** during rapid temperature drop

- **Corrosion** due to mix of gases + formation water
- Connection **sealability**
- Annulus pressure **monitoring**

KEY CHALLENGES FOR STORAGE: **LOW TEMPERATURE + IMPURITIES**

CO_2 Transport: Running Ductile Fracture (RDF)

- RDF propagation is a unique fracture mode in **high pressure** natural gas and **CO_2 pipelines**.

✓ Mitigate: Ensure **crack arrest** with crack **initiation prevention** in design

- Condition of occurrence: when **decompression velocity** is slower than **crack velocity**
  - Decompression velocity determines pressure on crack tip
  - Crack velocity is function of **steel toughness & thickness**

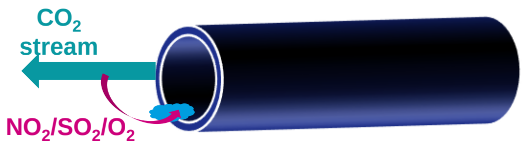
- **Knowledge Gap**: Prediction of RDF by **Battelle Two Curve** method
  - Correction factors needed to be implemented
  - Limited applicability to modern high toughness steels

- **Current Alternative to Predictive Assessment:**
  - Highly-expensive full scale tests

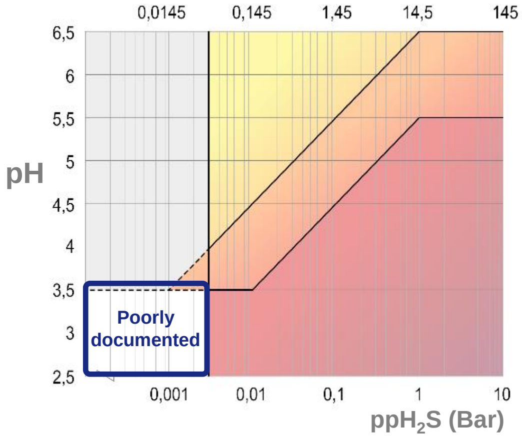
Vallourec Is Part of the Ongoing Research Activities to Find Alternative Testing and/or Prediction Models where Full-Scale Fracture Tests are not possible.

CO_2 Transport: Corrosion Risks

- CO2 transport to an underground storage site under high pressure in pipelines.
- Purity of CO2 often exceeds 95% and even 99% in some cases but different impurities can be contained such as CH_4, H_2O, H_2S, SO_X, NO_X, etc.
- Dry CO_2 stream specifications: complete mitigation against all form of aqueous corrosion.



- **What about corrosion resistance performance in case of local & temporary formation of liquid water?** possible at least during the start up phase, pressure fluctuations etc.
  - According to calculations performed with OLI Studio 10.0.2.1, the pH would decrease as low as 3 and would become negative in case of formation of strong acids like H_2SO_4 or HNO_3.
  - In case where H_2S would be also an impurity (even trace): cracking resistance performance to be evaluated.



- **What about HIC and SSC for low pH and low P_{H2S} range?**
  - No literature dealing with HIC or SSC resistance of low alloyed steels for pH < 2.5.

Preliminary results – X60Q (YS=472 Mpa)

▶ HIC – Hydrogen-Induced Cracking

- » NACE TM0284 Solution A + HCl at pH 0 / 1 bar H2S / 96 hours

No blisters and no HIC cracks were observed

Following steps :

- » More tests in progress for data accumulation: other materials, welded speciments;

▶ SSC – Sulfide stress cracking (FPB)

- » NACE TM0177 Solution A + HCl at pH 0 / 1 bar H2S / 90% AYS / 720 hours

No SSC cracks but applied stress considerably reduced due to important corrosion rate (~15mm/year).

No clear conclusion on SSC resistance at low pH so far

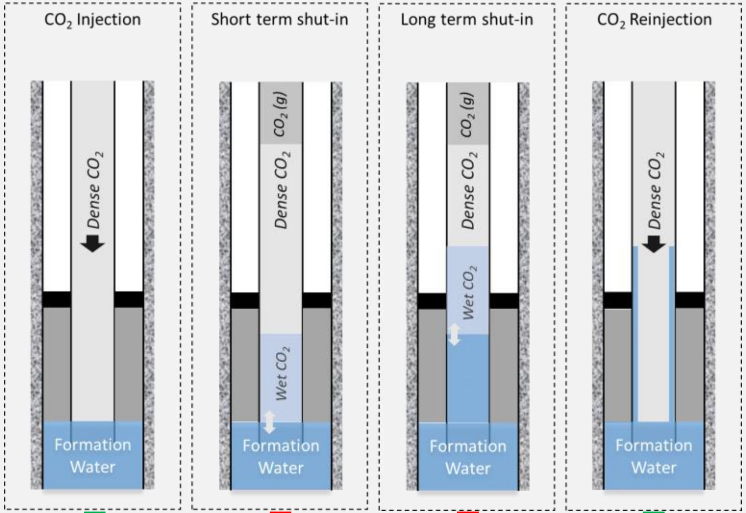
Following steps :

- » Adaptation of test protocol in order to keep target stress despite very high corrosion rate;
- » Control/Limit pH drift during the test;

CCS INJECTION CHALLENGES

CORROSION + THERMAL DROP IMPACT ON MATERIALS

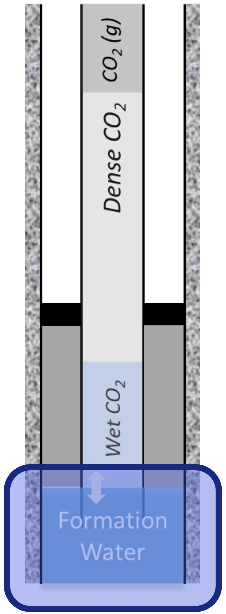
CO_2 Injection Steps



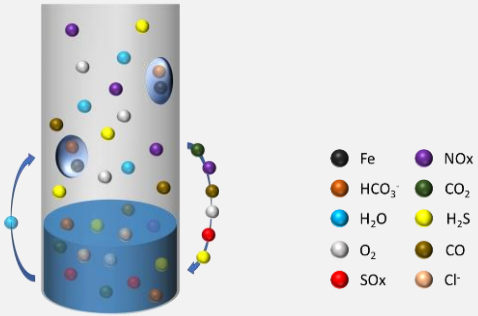
No corrosion issues

Corrosion risks

No corrosion issues



▶ Mixing **CO_2 stream and brine** at the **bottom** results in **localized corrosion, uniform corrosion** and **Stress Corrosion Cracking (SCC)** risk.



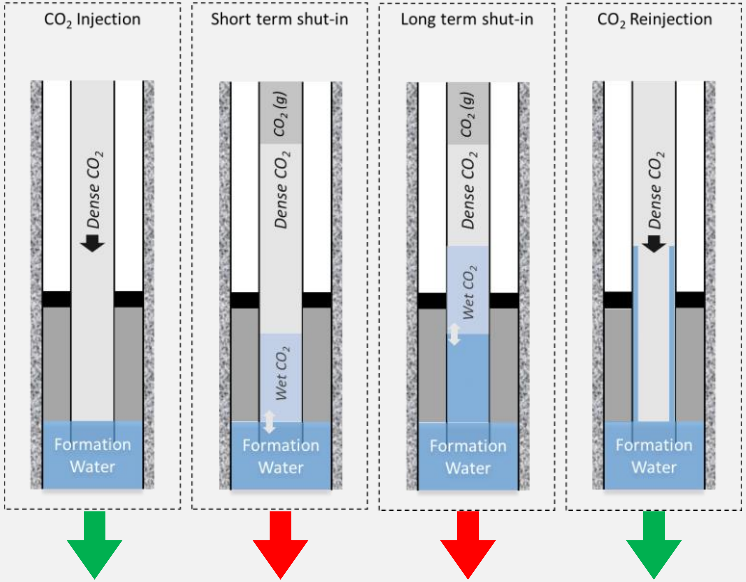
Localized corrosion occurs when the tube's bottom part is heated:

- Impurities present in CO_2 stream partitions in the water phase
- Water will dissolve and saturate the CO_2 phase

CCS INJECTION CHALLENGES

CORROSION + THERMAL DROP IMPACT ON MATERIALS

CO_2 Injection Steps



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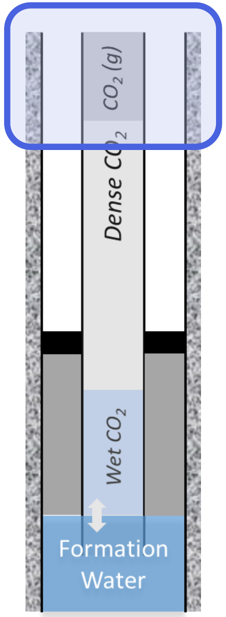

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- **Sulfide Stress Cracking (SSC)** in presence of **H_2S** due to the condensed water **on the pipe walls and well-heads** resulting from long or short **shut-in conditions**

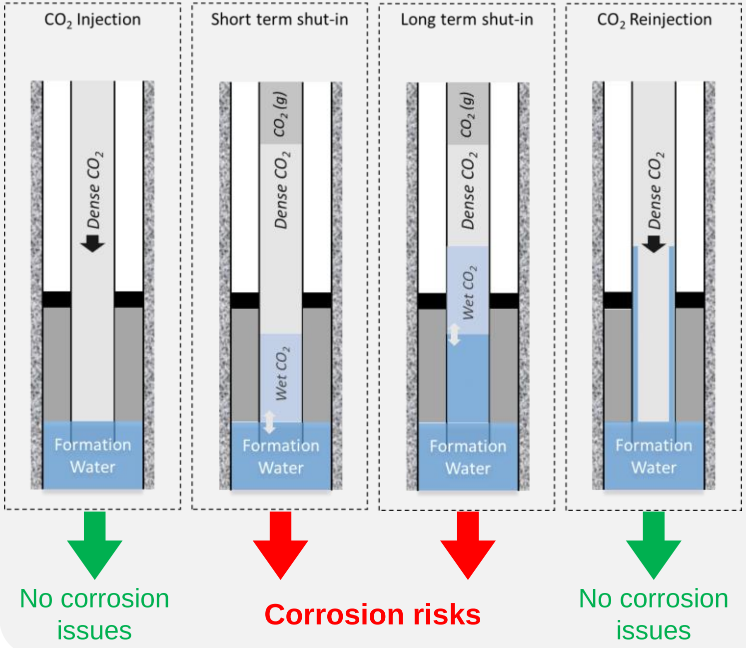
NACE TM 0177 method A

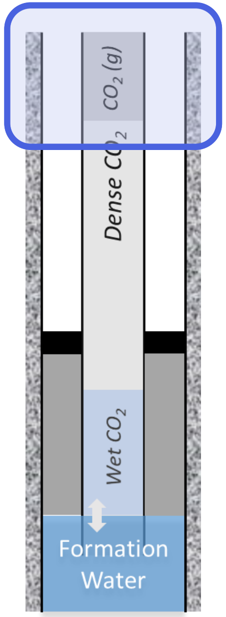
SSC failure

CCS INJECTION CHALLENGES

CORROSION + THERMAL DROP IMPACT ON MATERIALS

CO_2 Injection Steps





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- Issues of **very low temperature** where **material toughness** needs to be addressed.

VAM@ Connection Qualification: Risk of Low Temperatures

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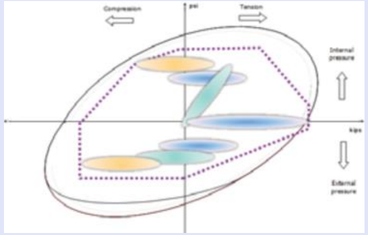
- ► Successful qualification for CCS operations conditions:
  - Thermal cycling: from ambient to -15°C, -25°C and -35°C.
  - Integrity in blow out conditions: absolute min temperature tested -80°C
  - Delta temperature: 60°C

Tubing Connection Evaluation Envelope - FEA

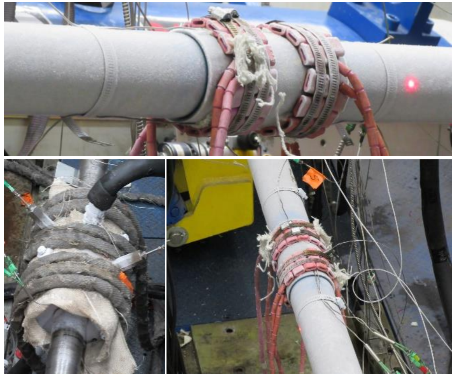
Well & Projects inputs: Design, Loads, Lifecycle, LowTemp, etc.

VAM® Premium connections + Corrosion Resistant Alloys (CRA)

Suitable Connection Envelope & Qualification Protocol Proposal



Illustrations are shown as an example. Not referring to CCUS project data



Ongoing Assessment of Various sizes and materials:

- ► Blow-out with 100% CO_2

SINTEF ENERGY advise us on fluid thermodynamics

VAM® CONNECTION ASSESSMENT FOR CCUS
OVERVIEW DEVELOPMENT & QUALIFICATION ROADMAP

- ► Vallourec involved in several CCUS projects worldwide

- ► Fast-paced Development Roadmap + Additional Innovation ideas
  - ► First Successful Connection Qualification done in 2021
  - ► Major CCS Project Qualifications already **on-going at our VRCC labs**

Scope of Qualification – H1’2022

- **Up to 7” for CCUS injection string**
- **VM 25S 80 Material (CRA 25S CR) and S13CR**
- **Minimum Operational Temperature Cycles -40°C**
- **Absolute Minimum Temperature -80°C**
- **Maximum △Temperature Pin/ Box 80°C**

THANK YOU

Vallourec @

SPE CCUS Conference
February 23rd, 2022

VAM® CONNECTION ASSESSMENT FOR CCUS

FULL-SCALE QUALIFICATION PROTOCOL

► Vallourec proposing **Connection Qualification Protocol for CCUS**

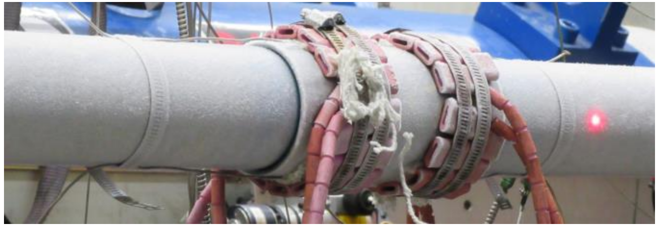
- Relevant way to validate VAM® Premium connections for CO_2 Injection & Storage Wells
- Based on API 5C5 Load Calculation & Sequence

Qualification = Testing Protocol and Associated Connection envelope

- Assessment Before and After Thermal Shock
- Simulation of Box Expansion / Pin Shrinkage

5-Phase Sealability Testing (worked-out & discussed with Energy Majors involved in CCUS)

- **Phase 1:** Seal-ability on Installation & Operational Mode
- **Phase 2, 3 and 4:** Seal-ability under CCUS thermal/ cycling
- **Phase 5:** Seal-ability on Operational Mode after Thermal constraints
- **Limit Test:** EP + Tension to failure



Successful Qualification Done

✓ 3 ½” 9,20# L8013CR

✓ Specific Testing Equipment & Methodologies

✓ Thermal Cycles at Very Low Temperatures