CO_2 Well Operability & Intervention Session

Technical Exploration



When will a rig need to re-engage a reservoir that contains CO_2?

New injection drilling

New or infill wells into a charged reservoir

Workover / recompletion

Planned re-entry to restore or change the completion

Well intervention

Wireline, slickline or coil on a live well

Integrity remediation

Barrier or casing repair after an integrity finding

Relief well

Emergency well control on a CO_2 blowout

P&A

Abandonment, closure and long-term verification

Whatever the reason, the rig re-engages a reservoir that now contains CO_2.



TECHNICAL FRAME

Why CO_2 changes the operating problem

From reservoir to vent line. Seven transitions, one integrated control challenge

Why this matters - CO_2 is a direct risk to people and rig systems

INVISIBLE

Colorless and odorless

HEAVIER THAN AIR

Can collect in low or enclosed areas

ASPHYXIATION HAZARD

Displaces oxygen and affects human physiology

SYSTEM IMPACT

Can reach HVAC or combustion-air intakes

Methane hazard	CO_2 hazard
Fire / explosion	Asphyxiation
Rises and disperses	Sinks and pools
You can ignite-test for it	Invisible and odorless
Stays near ambient temperature	Flashes cryogenic on expansion

Are people and critical systems protected if CO_2 reaches the rig?

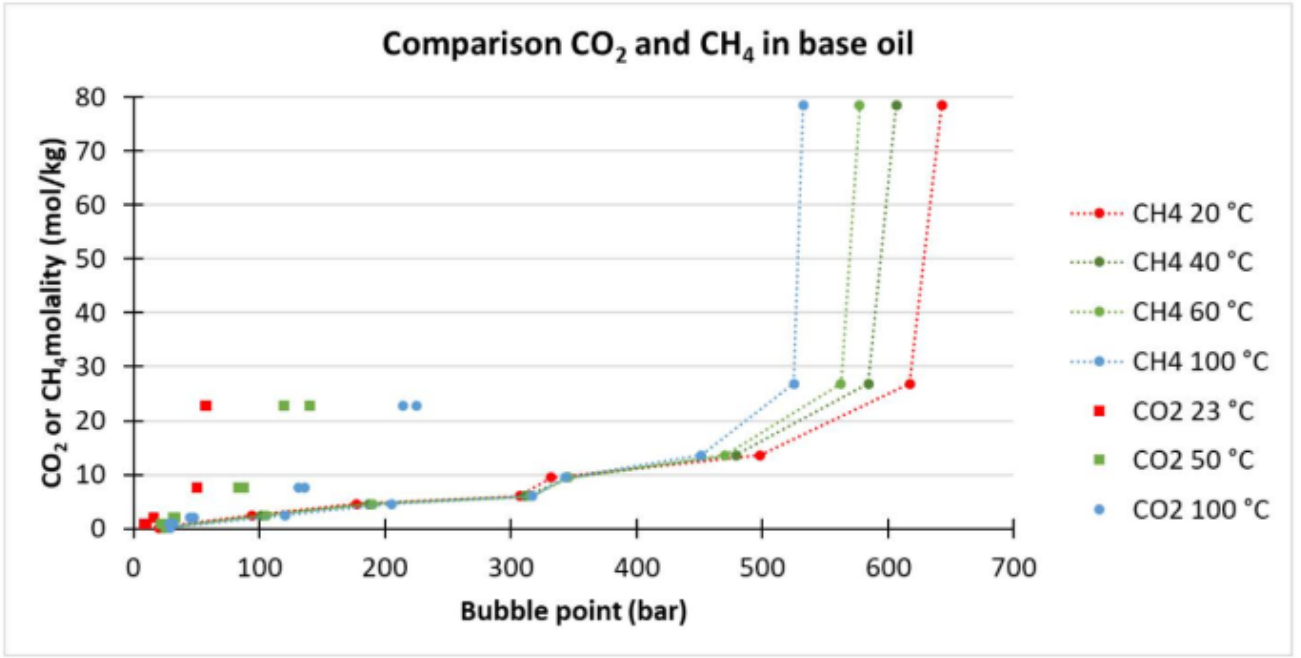
The journey of a CO_2 influx

1. Enters the well
2. Travels in the mud
3. Breaks out & expands
4. Interacts with materials
5. Crosses the choke
6. Mud-gas separator
7. Vent line & personnel

The risk changes form at each transition. No single piece of equipment sees the whole problem.

Transition 1: Enters the well

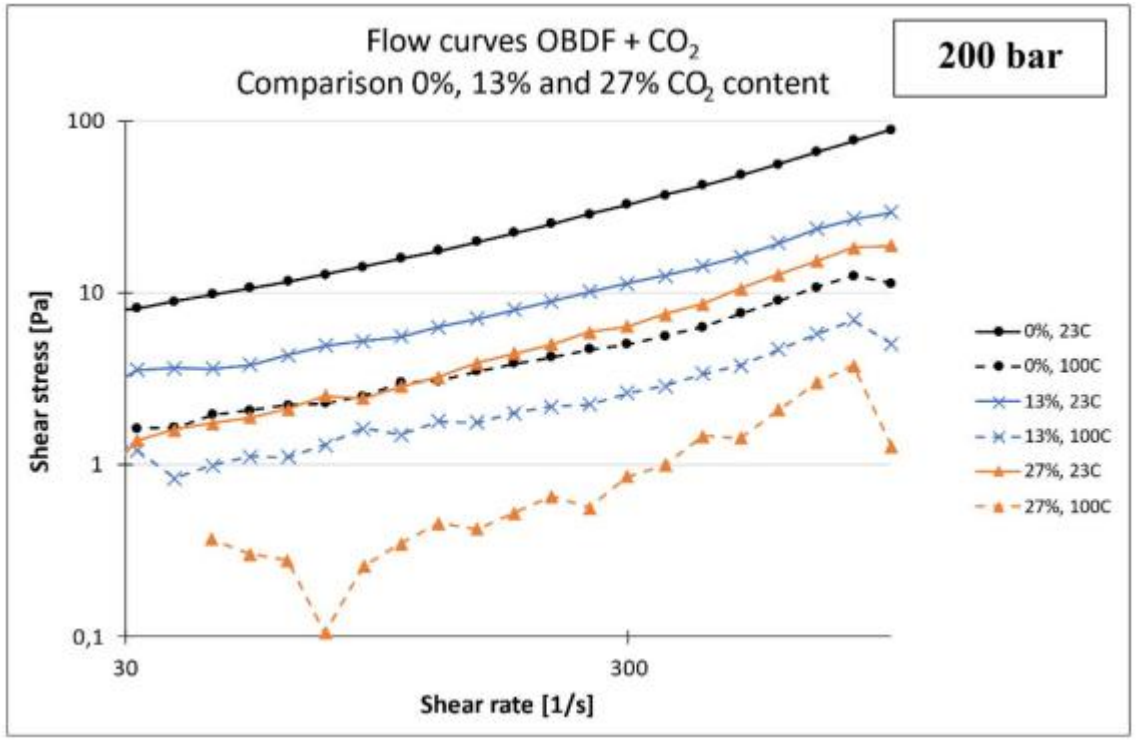
- CO_2 may enter as a dense or supercritical fluid.
- It can remain dissolved where methane would be free gas.
- The initial pit or flow response can under-read the influx.
- The kick can be mass-significant before it is volume-obvious.



Sources: SPE-210132-MS; SPE-223812-MS; SINTEF drilling-fluid barrier paper.

Transition 2: Travels in the mud

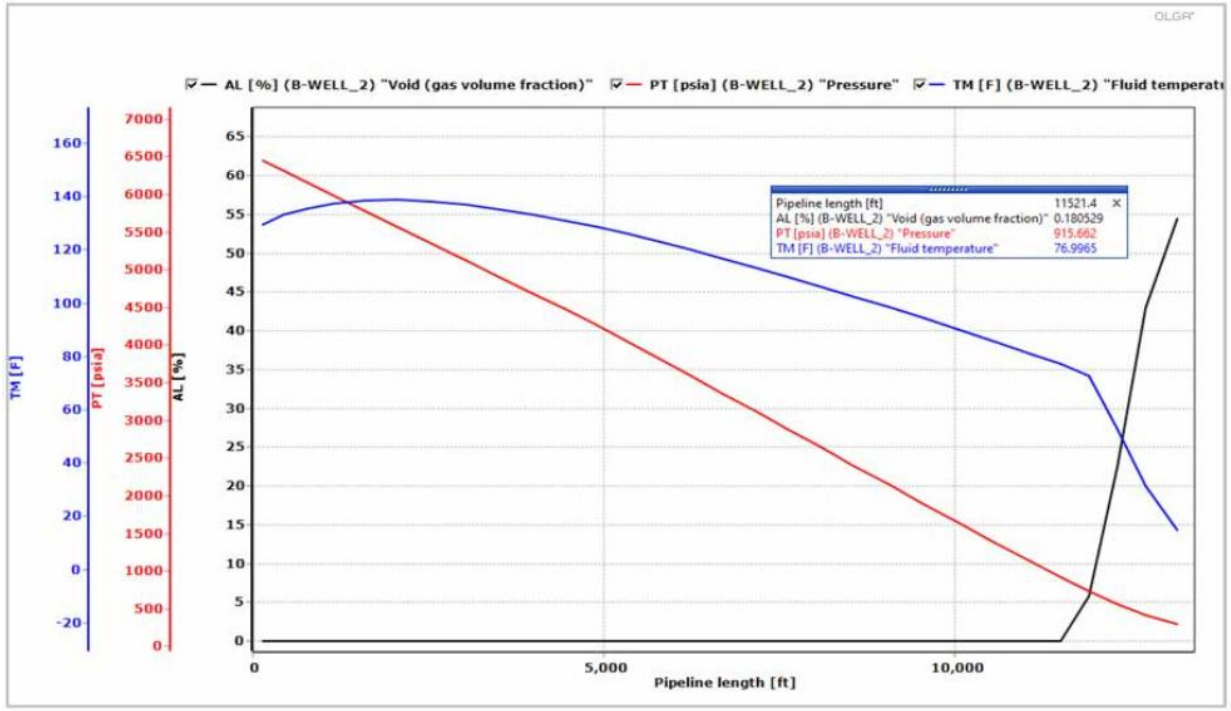
- Oil-based and water-based fluid can conceal and concentrate the influx.
- Water-based fluid can let free CO_2 migrate and string out.
- Dissolved CO_2 changes density and rheology of the drilling fluid
- Barrier and cuttings-transport performance can degrade.



Sources: SPE-210132-MS; SPE-223812-MS; SINTEF drilling-fluid barrier paper.

Transition 3: Breaks out and expands

- CO_2 may remain dense or dissolved deeper in the well.
- Free-gas breakout can occur closer to surface.
- Large late expansion compresses response time.
- Once breakout begins, the free-gas volume and surface-handling demand can rise rapidly.



Sources: SPE-210132-MS; SPE-223812-MS; SINTEF drilling-fluid barrier paper.

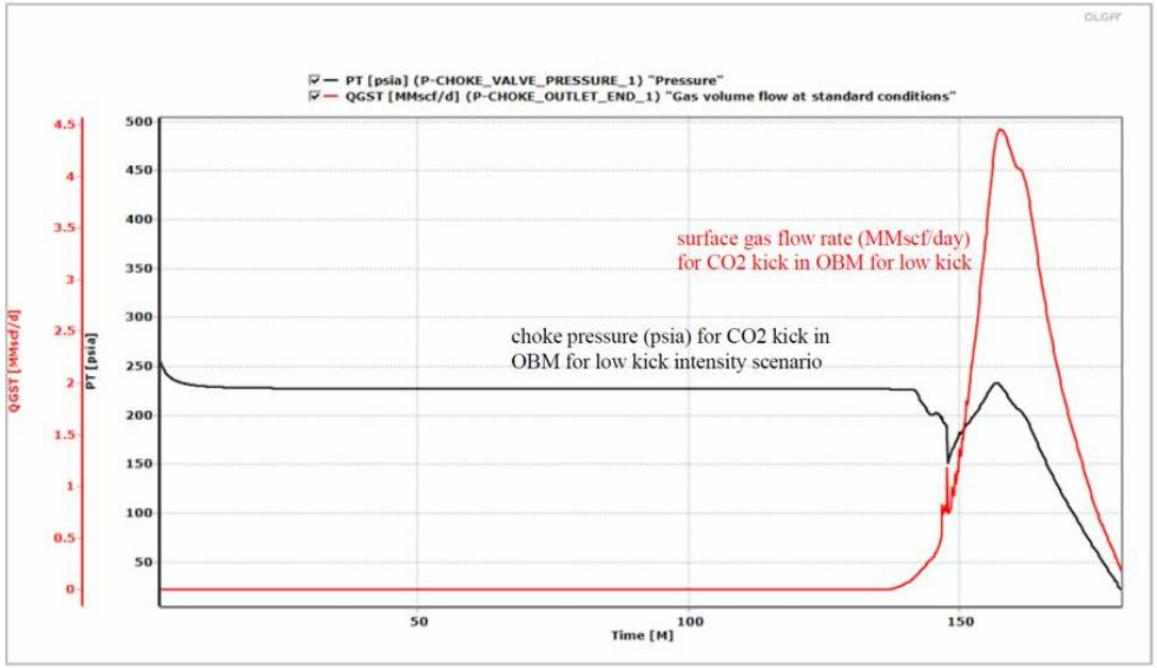
Transition 4: Interacts with materials

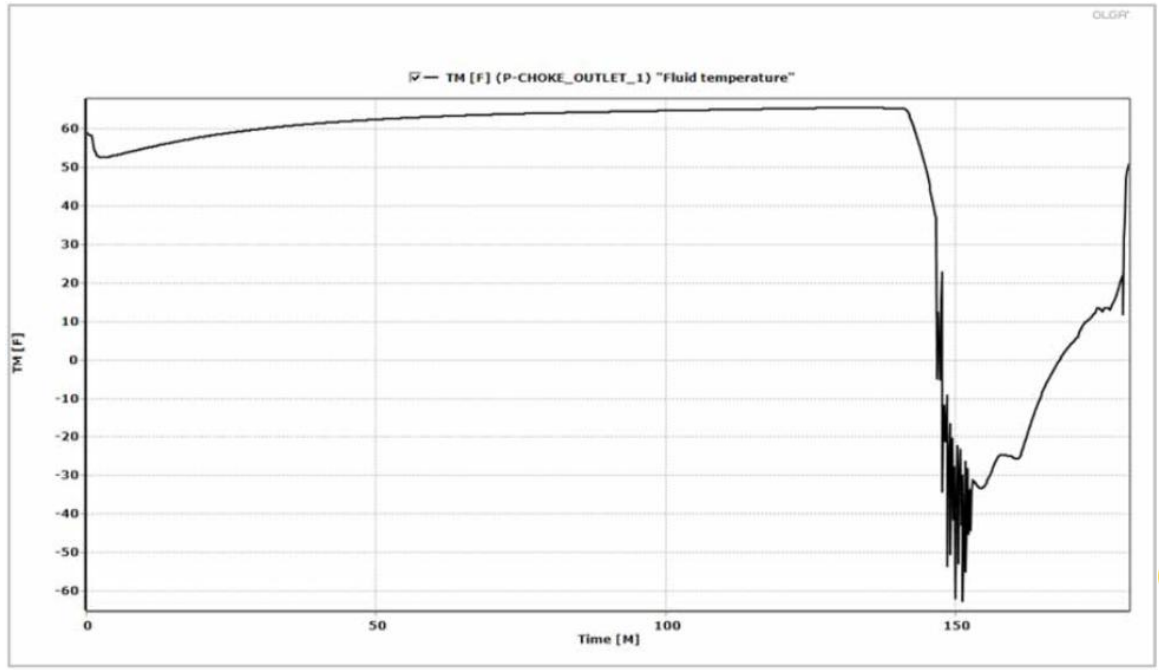
- Dry CO_2 is already corrosive; wet CO_2 forms carbonic acid which is highly corrosive.
- Turbulence and restrictions accelerate localized loss.
- CO_2 permeates elastomers, causing swelling and RGD damage.
- Materials and seals must be qualified for CO_2 service.



Transition 5: Crosses the choke

- Rapid pressure drop drives Joule–Thomson cooling.
- Expansion raises velocities and equipment demand.
- Hydrates can block the flow path where water is present.
- Low temperatures challenge steel, seals and instruments.





Sources: SPE-210132-MS; SPE-223812-MS; SINTEF drilling-fluid barrier paper.

Transition 6: Enters the mud-gas separator

- CO_2 can remain dissolved in the mud until the pressure falls near the surface.
- Breakout can create a short, concentrated gas load at the separator inlet.
- LSU testing suggests persistent foam may not be the primary concern in oil-based mud.
- Can the MGS separate a sudden CO_2 release without gas leaving with the mud or mud entering the vent line?

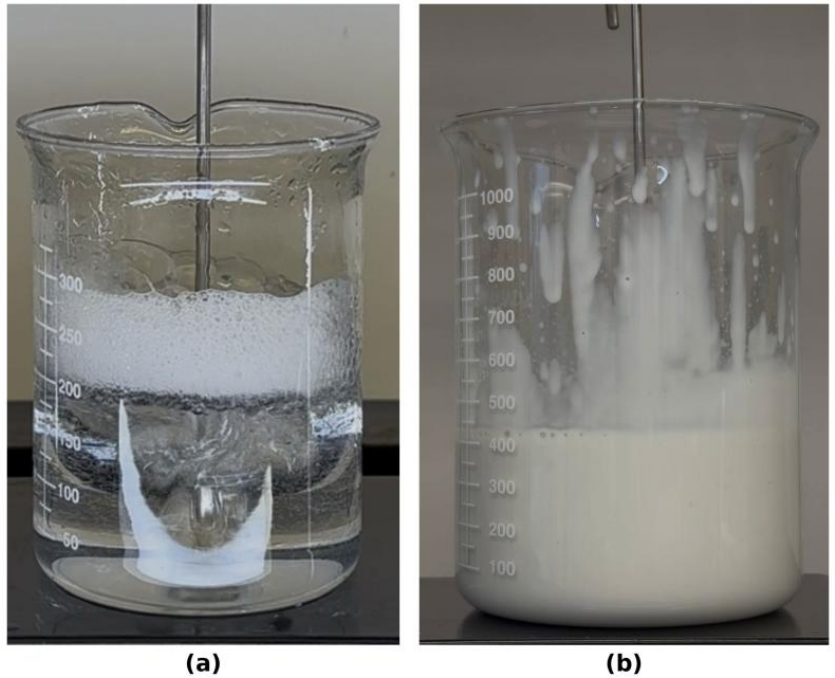
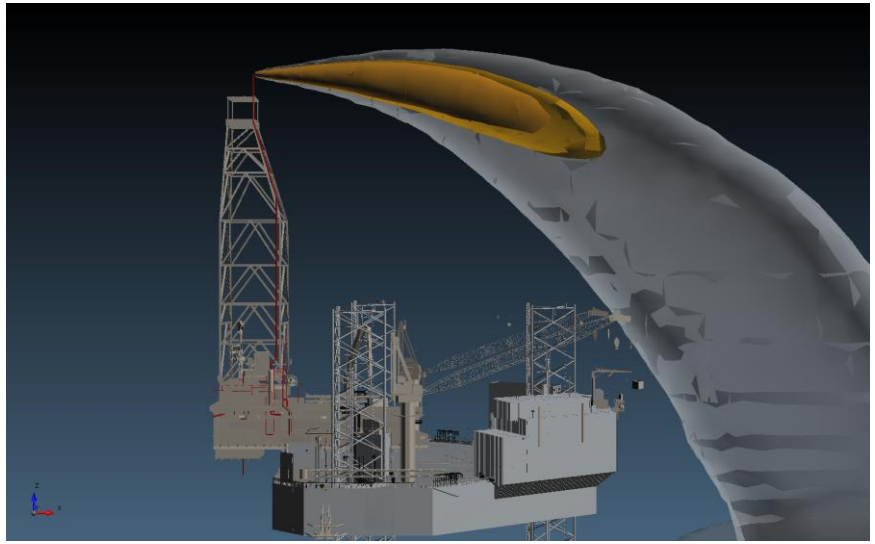
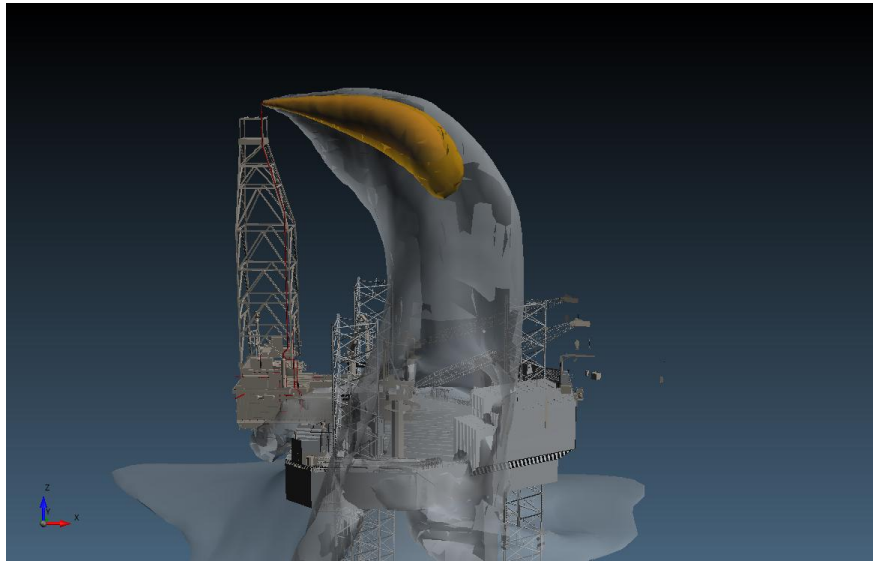


Figure 15. CO_2 sparging of (a) the base oil and (b) the invert-emulsion mud: the base oil develops a thin, transient foam band, whereas the invert-emulsion mud shows no measurable surface foam and no phase separation. (Source: This work.)

Transition 7: Exits through the vent line

- CO_2 is denser than air and can fall back to deck level.
- It can accumulate in low or enclosed spaces.
- Vent height, direction, wind and geometry drive dispersion.
- Detection, HVAC, intakes and exclusion zones all matter.





Seven transitions, seven different control questions

1. Did we detect what entered?
2. Where is the CO_2?
3. When will it expand?
4. Did exposure impact equipment?
5. Can the choke control it?
6. Can the MGS separate it?
7. Has it been discharged safely?

Every transition changes the risk, but the system must manage the entire journey.

PRACTICAL LESSONS

What several years of CO_2 work has taught us

Simulation, materials testing, OEM engagement, project work and the JIP

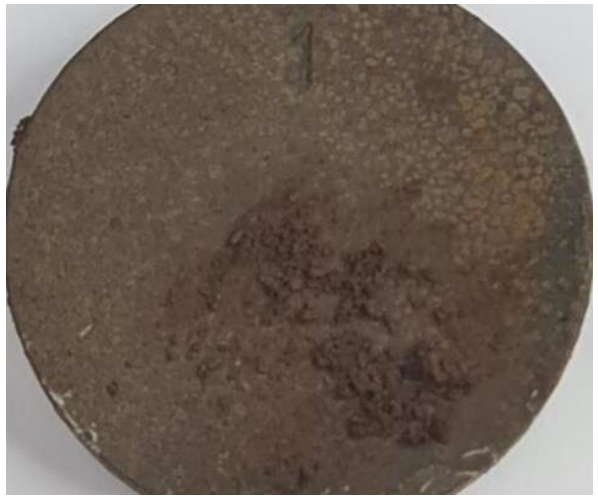


Lesson 1: The scenario has to come before the solution

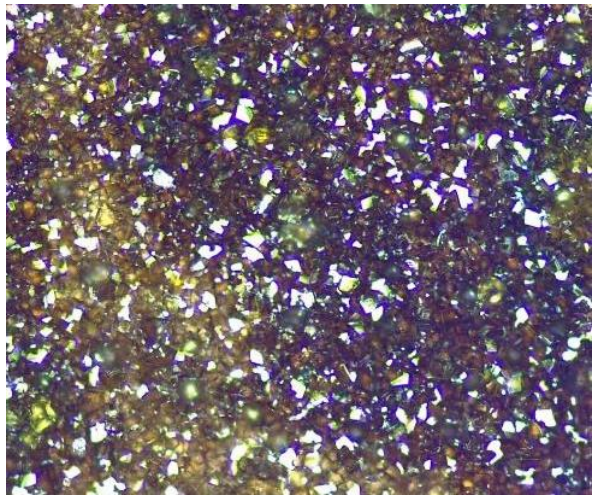
CO_2	WATER	DURATION	TEMPERATURE	FLOW
~90–100%	**Present**	**1–6 hr**	**−20 to −40 °C**	**Multiphase**
with impurities	wet CO_2 assumed	dynamic; up to 48 hr static	BOP to choke	flashing across restrictions

The same scenario anchors materials testing, equipment limits, inspection planning and architecture selection.

Lesson 2: Corrosion follows geometry



Before exposure

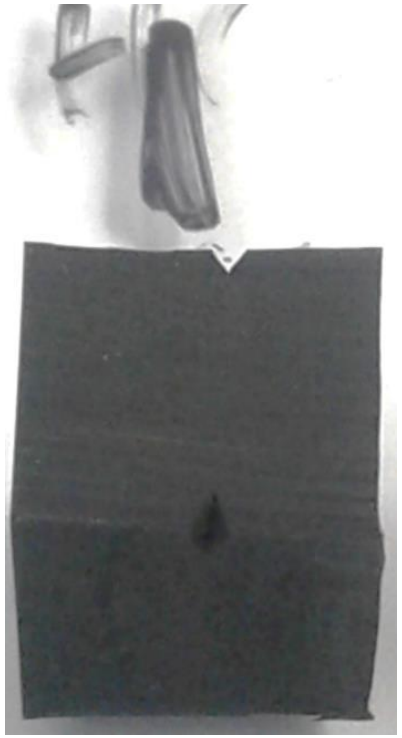


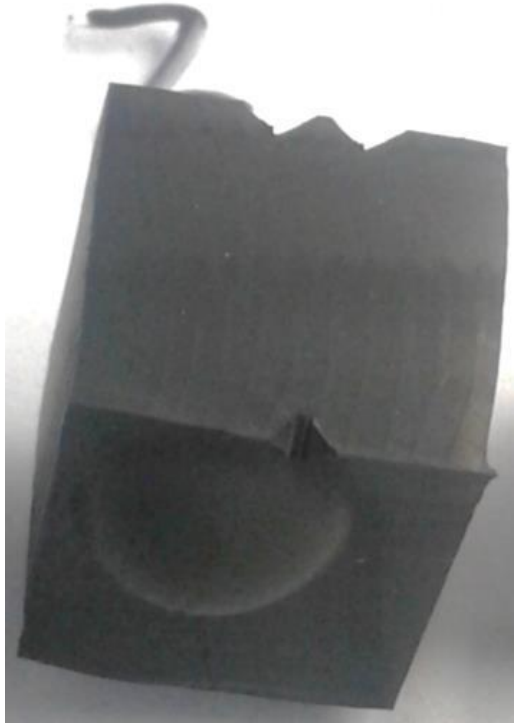
After exposure and cleaning

- IKM coupon testing confirmed measurable carbon-steel corrosion in CO_2-saturated brine, even under relatively controlled conditions.
- Modelling produced wet-CO_2 uniform corrosion rates ranging from approximately **1.6 to 69 mm/year** as severity increased.
- At contractions, cavities and choke-like restrictions, geometry could amplify localized degradation by approximately **4–20 times.**
- Under severe conditions, localized loss could plausibly reach approximately **0.75 mm to more than 5 mm within 24–72 hours**, including at sealing and tolerance-critical surfaces.

Average corrosion sets the baseline. Local geometry determines where the equipment becomes vulnerable.

Lesson 3: Elastomers may become the limiting component





- The tested BOP rubber expanded by approximately **50% within 30 minutes** after decompression, with visible cracking and blistering.
- The damage was attributed to **rapid gas decompression**, where absorbed CO_2 expanded inside the elastomer as pressure was released.
- Alternative EPDM and FPM specimens showed approximately 10% swelling without the same cracking or blistering, demonstrating that compound selection materially changes performance.
- An annular sealing element must close and maintain a pressure seal around the tubular or string after exposure to wet CO_2, pressure cycling, decompression and the expected low-temperature envelope.

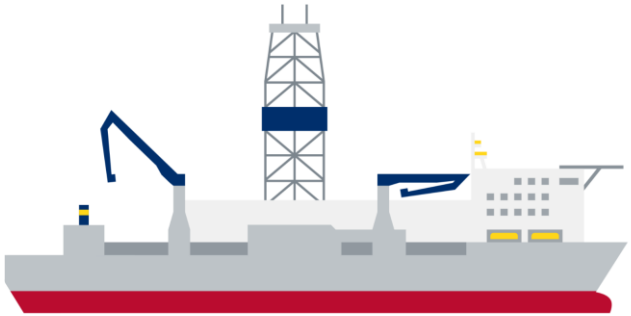
The requirement is not simply a CO_2-compatible elastomer. It is a sealing element that still functions throughout the complete exposure and decompression cycle.

Lesson 4: Low-probability events can dictate the rig response

Sensors & alarms

HVAC & air intakes

Well-control systems



Temporary refuge

Procedures & training

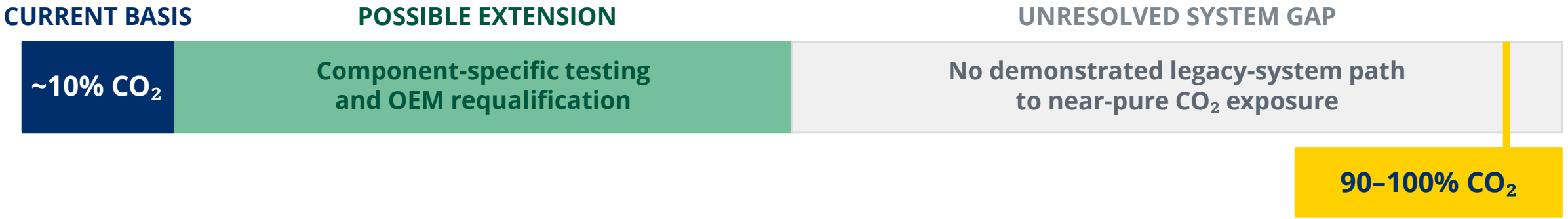
Muster & evacuation

- CO_2 detection and alarms must cover the areas where gas could collect or enter occupied spaces.
- HVAC, engine-air intakes and emergency systems may need new shutdown and response logic.
- Muster, temporary refuge and evacuation plans must account for a dense gas that can settle around the rig.
- Procedures, training and WSOGs must address CO_2-specific detection, isolation, venting and recovery.

A credible CO_2 release scenario changes how the entire rig detects, responds and protects people.

Lesson 5: Qualification will be conditional, not universal

CO_2 concentration exposure

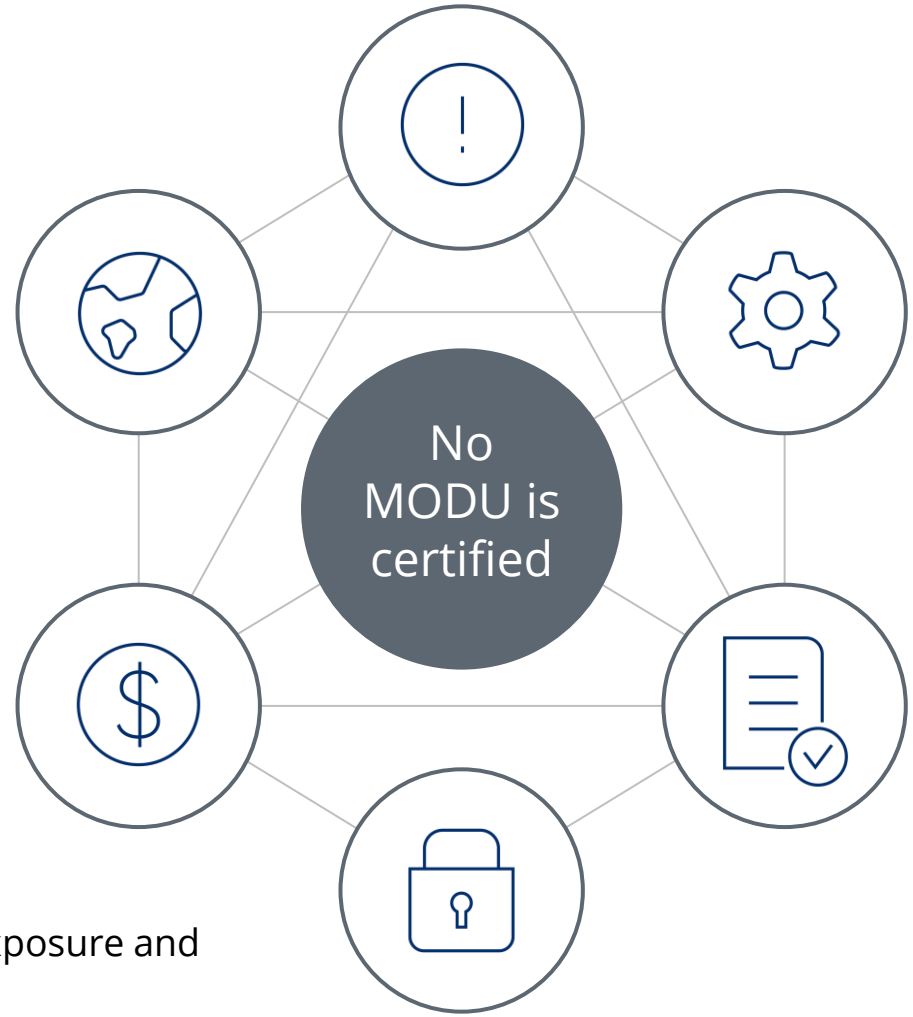


- Much of the existing well-control package is currently limited to approx. **10% CO_2**, depending on the component and OEM basis.
- Testing, material changes and OEM-led requalification may extend the envelope for selected equipment.
- **Achievable limits will vary** across chokes, valves, MPD equipment, seals and other subsystems.
- The complete package remains **constrained by its lowest-rated component**, and no credible path to near-pure CO_2 has been identified.

Lesson 6: Risk Stack

HSE
- Personnel exposure and dispersion
- CO_2-specific emergency response

Regulatory
- No standardized approval pathway
- Project-specific regulator and class acceptance



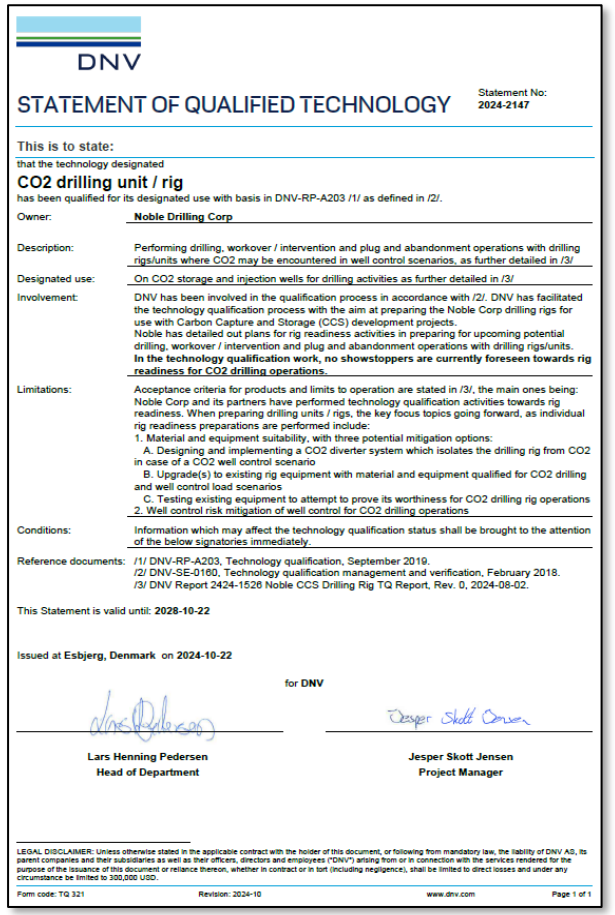
Technical
- Equipment capability and system design
- Defined operating and exposure limits

Commercial
- Ownership of development and qualification costs
- Allocation of downtime and deployment risk

Legal
- Liability and indemnity structure will be novel, extensive and require project-specific negotiation
- No established contracting precedent

Insurance
- Coverage for CO_2 exposure and equipment damage
- Treatment of uninsured residual risk

Lesson 7: There are three practical pathways to a certified system



DNV

STATEMENT OF QUALIFIED TECHNOLOGY

Statement No: **2024-2147**

This is to state:

that the technology designated

CO2 drilling unit / rig

has been qualified for its designated use with basis in DNV-RP-A203 /1/ as defined in /2/.

Owner:	**Noble Drilling Corp**
Description:	Performing drilling, workover / intervention and plug and abandonment operations with drilling rigs/units where CO2 may be encountered in well control scenarios, as further detailed in /3/
Designated use:	On CO2 storage and injection wells for drilling activities as further detailed in /3/
Involvement:	DNV has been involved in the qualification process in accordance with /2/. DNV has facilitated the technology qualification process with the aim at preparing the Noble Corp drilling rigs for use with Carbon Capture and Storage (CCS) development projects. Noble has detailed out plans for rig readiness activities in preparing for upcoming potential drilling, workover / intervention and plug and abandonment operations with drilling rigs/units. **In the technology qualification work, no showstoppers are currently foreseen towards rig readiness for CO2 drilling operations.**
Limitations:	Acceptance criteria for products and limits to operation are stated in /3/, the main ones being: Noble Corp and its partners have performed technology qualification activities towards rig readiness. When preparing drilling units / rigs, the key focus topics going forward, as individual rig readiness preparations are performed include: 1. Material and equipment suitability, with three potential mitigation options: A. Designing and implementing a CO2 diverter system which isolates the drilling rig from CO2 in case of a CO2 well control scenario B. Upgrade(s) to existing rig equipment with material and equipment qualified for CO2 drilling and well control load scenarios C. Testing existing equipment to attempt to prove its worthiness for CO2 drilling rig operations 2. Well control risk mitigation of well control for CO2 drilling operations
Conditions:	Information which may affect the technology qualification status shall be brought to the attention of the below signatories immediately.
Reference documents:	/1/ DNV-RP-A203, Technology qualification, September 2019. /2/ DNV-SE-0160, Technology qualification management and verification, February 2018. /3/ DNV Report 2424-1526 Noble CCS Drilling Rig TQ Report, Rev. 0, 2024-08-02.

This Statement is valid until: **2028-10-22**

Issued at **Esbjerg, Denmark** on **2024-10-22**

for **DNV**

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Head of Department

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Project Manager

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1. Fully Upgrade the Whole System Including the BOP

+ **Pros:** Integrity, Reliability, Compatibility

÷ **Cons:** Cost, Lead times, Downtime

2. Conduct Materials Testing and Research to Certify the Legacy Package

+ **Pros:** Targeted upgrade, Preservation, Custom solution

÷ **Cons:** Uncertainty, Time-consuming, Research costs, Approvals

3. Install a CO_2 Grade Bypass System to Circumvent the Legacy Package

+ **Pros:** Cost-effective, Faster, Lower risk

÷ **Cons:** Integration, Logistics, Limited redundancy

Considering the cost, schedule, qualification uncertainty and foreseeable exposure, Noble's work has led us toward a CO_2-rated isolation and bypass approach.

Where the JIP is today

1	2	3	4
ALIGNED THE PROBLEM	**DEFINED THE BASIS**	**PRIORITIZED THE UNKNOWNs**	**MODELLING REAL WELLS**
Three operator workshops established the shared operating scenarios, workstreams and decision questions.	A worst-credible exposure scenario now anchors modelling, materials testing and architecture discussions.	The work has separated what must be known now from what can be closed after an architecture is selected.	North Sea operator well cases are moving through updated CO_2 modelling from reservoir to vent line.

Expected output this year: pressure, temperature, phase, velocity and exposure duration along the full well-control path.



Further Engagement

What's the best way to get involved?

Connect with our project team via the link on the website.