Fitness for Service of Casing materials for sour service

Challenges with high H_2S levels in new subsea wells

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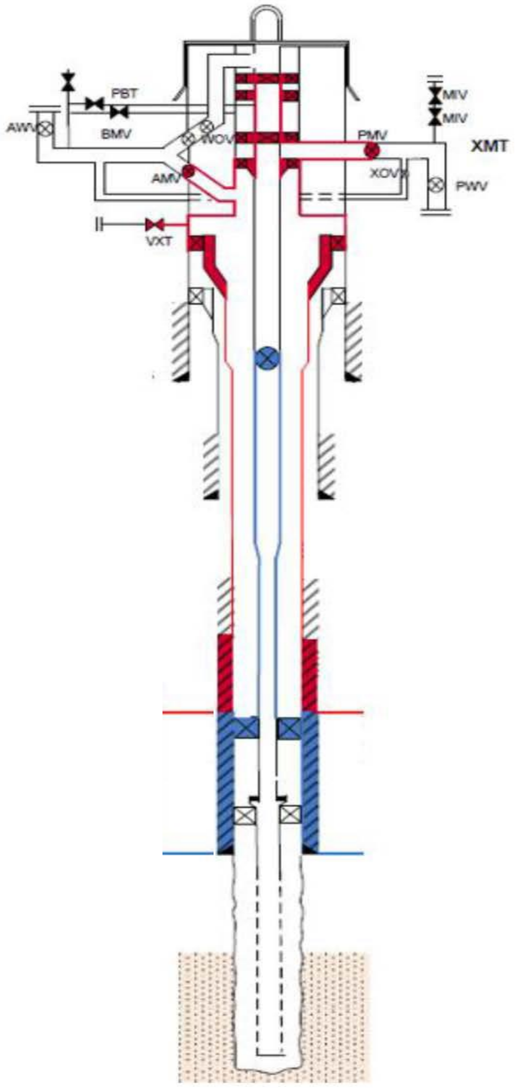
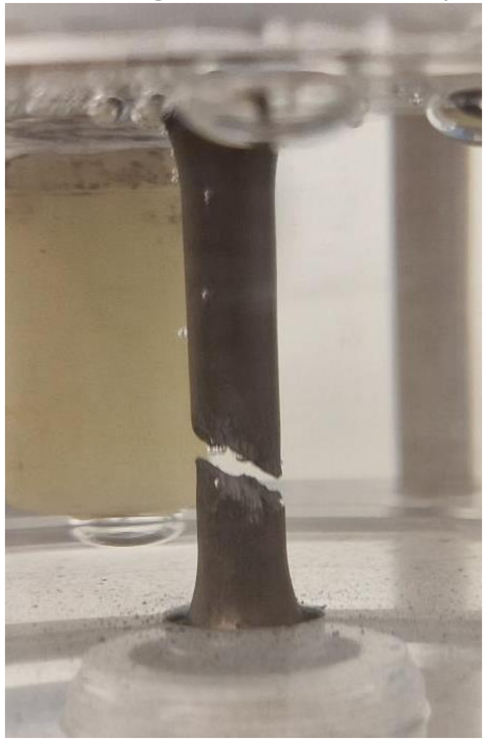
Case Description

- New subsea gas field
- Close to the high pressure , high temperature envelope
- Well construction
  - Tubing – 13CrS -110 (ISO 11960)
  - Production casing: Q-125 (ISO 11960)
- Unexpected high levels of H_2S levels were measured during initial clean up
  - Production casing materials not pre-qualfied according to ISO 15156
  - Risk for sulphide stress cracking SSC
- Norwegian regulation requires two independent barrier envelopes.
  - If the primary barrier fails the secondary barrier shall be able to withstand the loads and fluids exposed as a mimimum until the leak can be repaired or barrier replaced safely
  - A rapid failure of the of the casing due to cracking corrosion mechanism would mean that the well barrier is not designed in accordance with the regulation

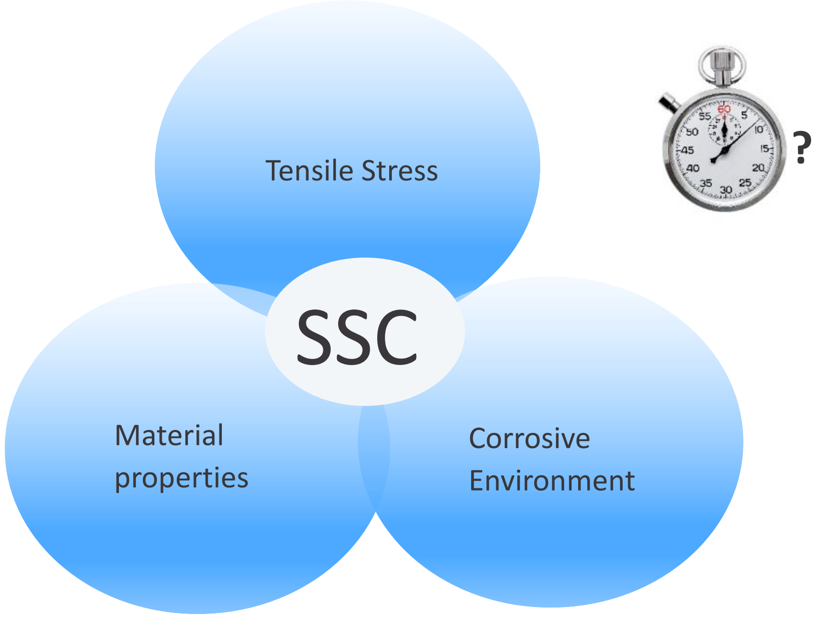


SSC, Sulfide Stress Cracking

SSC casing failure in labratory



Failed coil tubing (*)



* https://www.havtil.no/contentassets/83365639d7fc48bba4814a3654558906/2023_172_-rapport-eng-gransking-gullfaks-c-brudd-i-kveileror_skjult-innhold_2.pdf

Well Barrier Requirements – Casing Material Selection

HAVTIL (facility regulation)

§ 48 Well barriers

Section

Well barriers shall be designed such that well integrity is ensured, and the barrier functions are safeguarded during the well's lifetime.

Well barriers shall be designed such that unintended well influx and outflow to the external environment is prevented, and such that they do not hinder well activities.

When a production well is temporarily abandoned without a completion string, at least two qualified and independent barriers shall be present.

When a well is temporarily or permanently abandoned, the barriers shall be designed such that they consider well integrity for the longest period of time the well is expected to be abandoned.

When plugging wells, it shall be possible to cut the casings without harming the surroundings.

The well barriers shall be designed such that their performance can be verified.

Section last changed: 01 January 2014

Guideline

The well's life span as mentioned in the first subsection, means time in use and time subsequent to permanent plugging and abandonment.

In order to fulfil the requirement regarding well barriers, the NORSOK D-010 standard Chapters 5, 6, 10 and Annex C should be used in the area of health, working environment and safety. See also Section 5 of the Management Regulations and Section 8 of these

NORSOK D-010:2021+AC2

Published: 2021-12-24

Language: English

Well integrity in drilling and well operations

INTERNATIONAL STANDARD

ISO 11960

Sixth edition 2020-03

Petroleum and natural gas industries — Steel pipes for use as casing or tubing for wells

ISO 15156 Part 1-3

Norsk Standard NS-EN ISO 15156-1:2020

Norsk Standard NS-EN ISO 15156-2:2020

Norsk Standard NS-EN ISO 15156-3:2020

Publisert: 2020-12-09

Språk: Engelsk

Petroleums- og naturgassindustri

Materialer for bruk ...

og gassproduksjon

Del 3: Sprekkmotstandsdy...

(korrosjonsmotstan...

andre legeringer

(ISO 15156-3:2020)

Petroleum and natural gas ...

Materials for use in H2S-co...

and gas production

Part 3: Cracking-resistant C...

and other alloys

(ISO 15156-3:2020)

§ 12 Materials

Section

Materials to be used in or on facilities shall be selected considering

a) the load requirements mentioned in Section 11,
b) manufacturing, joining and construction processes,
c) possible use of materials protection,
d) fire-resistance properties,
e) probable changes in operating conditions,
f) the opportunity to reduce future use of chemicals and pollution,
g) the opportunity to reduce, reuse and recover waste,
h) the employees' health and working environment,
i) potential future removal.

Section last changed: 01 January 2011

Guideline

In order to fulfil the requirement regarding materials and material protection as mentioned in literas a, b and c, the following standards should be used in the area of health, working environment and safety:

a) NORSOK M-001 for material selection,

NORSOK STANDARD

M-001

Edition 5, September 2014

Materials selection

ANSI

NACE INTERNATIONAL

ANSI/NACE TM0177-2016

Item No. 21212

Standard Test Method

Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H_2S Environments

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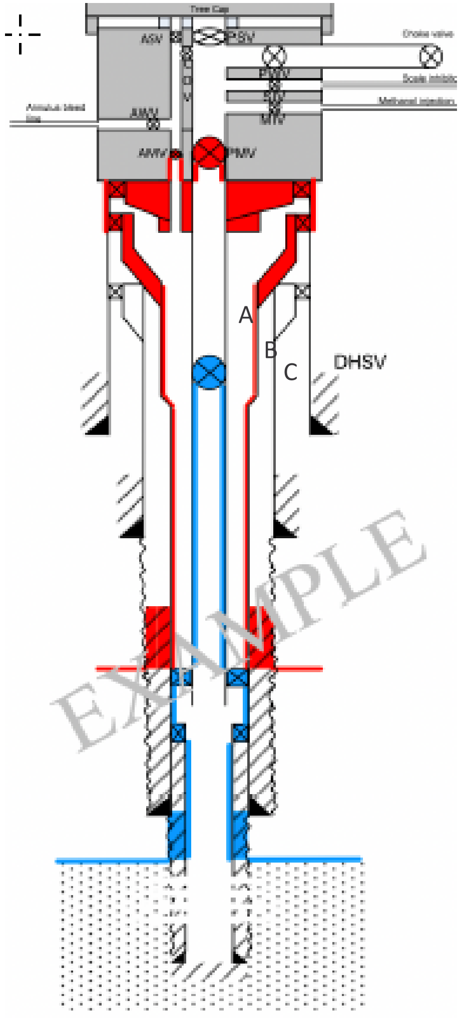
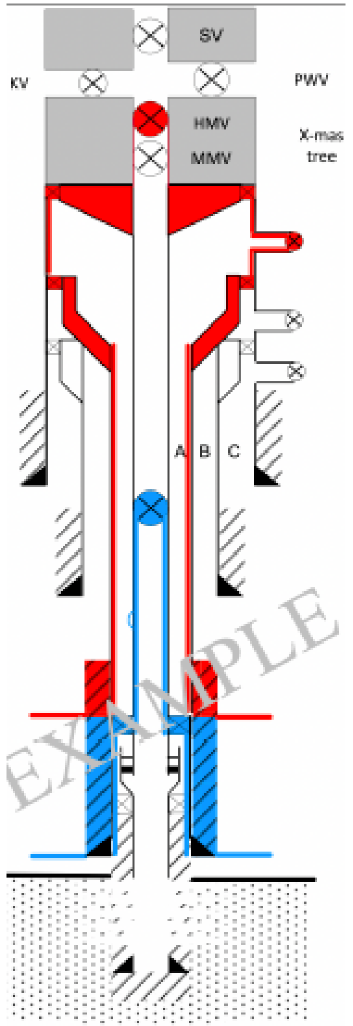
Well Integrity Differences - Subsea/Platform Wells

Subsea well



Subsea well	Platform well
No personnel above the wells in normal operation – low personnel risk	**High number of personnel located close the wells – high personnel risk**
WH fatigue could be a medium/high risk	Low risk of WH/conductor fatigue
Normally no P/T monitoring of B/C annulus	Normally full P/T monitoring on all annuli
Not possible to bleed/fill up annuli B/C	Possible to bleed, liquid, and sampling possible on all annuli
Slow emergency response to kill and secure well – weather dependent	**Fast emergency response to kill and secure well – less weather dependent**
Sampling of fluid chemistry quite difficult on a well basis to verify operation within well operating envelope (CO_2, H_2S, O_2….)	**Sampling of fluid chemistry normally quite easy to verify well within operating envelope (CO_2, H_2S, O_2….)**
Fixed service lines hooked up to tubing/annulus - adjust pressure/MEG inhibit	Normally no lines are permanently hooked up to any of the annuli.
Corrosion protection of XMT, conductor is better using cathodic protection	Corrosion protection of XMT/WH/conductor will introduce risk for old wells in late life
More complicated to monitor for leaks in control lines with return to sea/host via SCM	Possible to verify locally for leaks at WH exit blocks
Annulus B designed to bleed off at the casing shoe to avoid collapse/burst	Annuli monitored and bleed off during start up if casing design cannot take pressure

Platform well



Actual Design Parameters - SSC risk

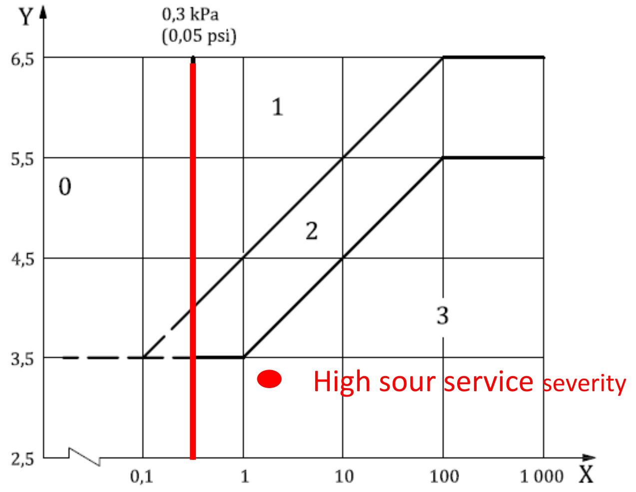
- Design basis Hydrogen Sulphide
  - **No hydrogen sulphide expected based on analysis done from DST test**. The upstream hardware should cater for a max H_2S content of 5 ppm

- H_2S measured during clean-up of the wells
  - 16 and 19 ppm (two different reservoirs)

- **Actual conditions**
  - SIWHP= 621 bar
  - Partial pressure H_2S (19 ppm) = 12 mbar/1,2 Kpa
  - pH for condensed water = 3,23-3,5 (24/149 ºC)

  - Q-125 casing material not qualified

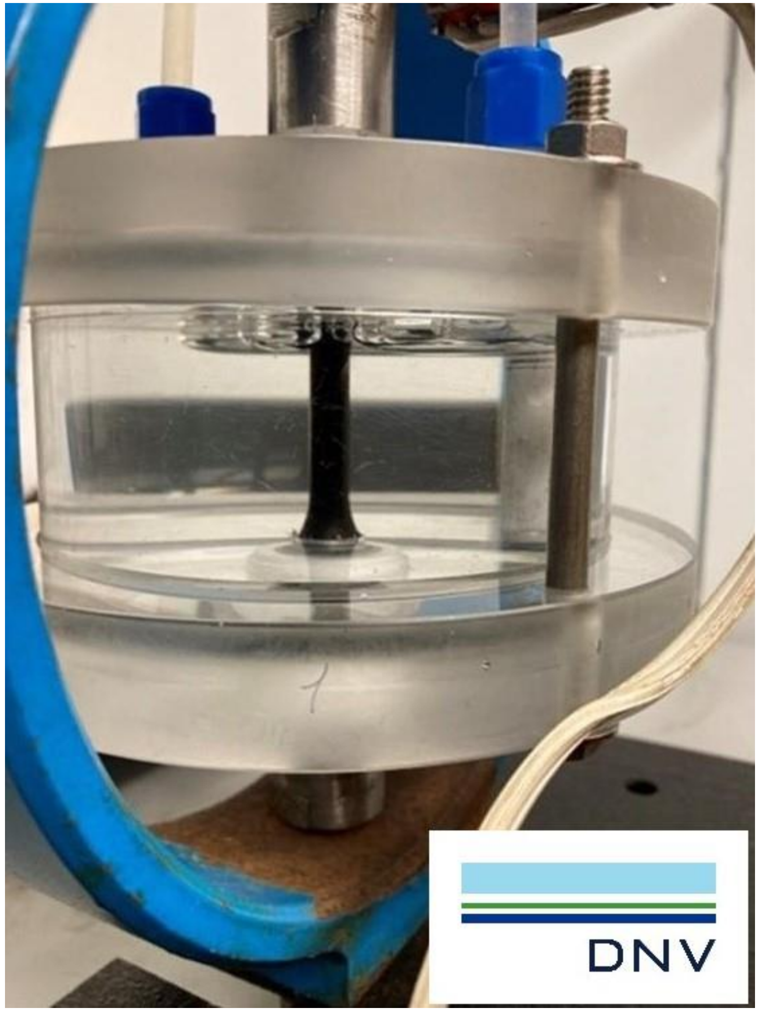
- **ISO 15156 -2** Materials for use in H_2S containing environments in oil and gas production



Key
X H_2S partial pressure, expressed in kilopascals
Y in situ pH

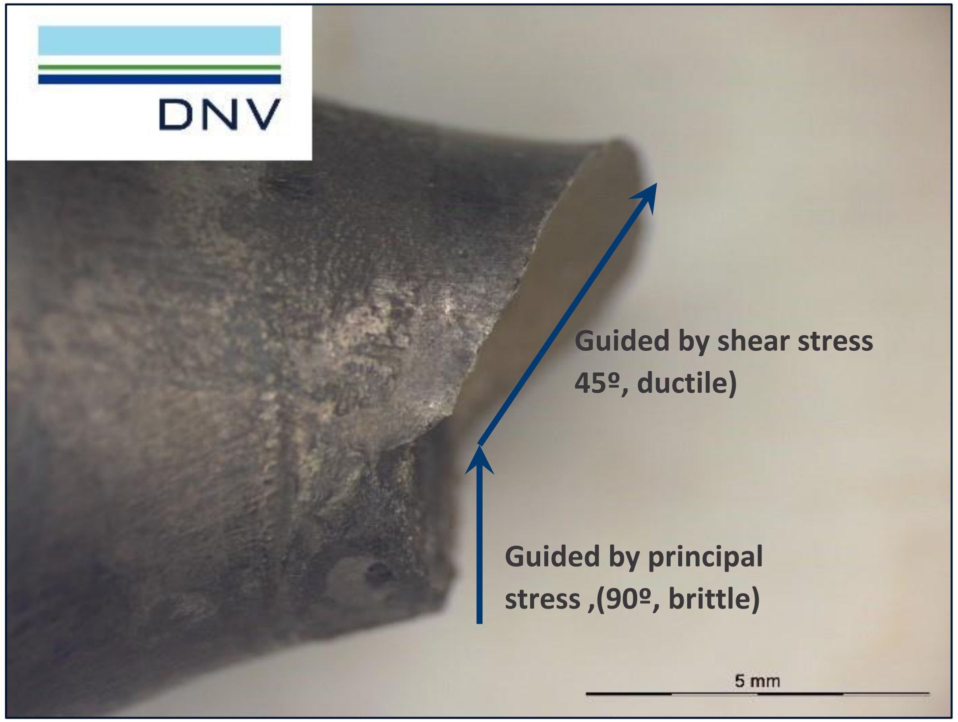
Testing

- In accordance with NACE TM0177
  - Method A
- Input factors
  - Test material for the specimens
    - Material used from the well construction phase
  - Test temperature
    - ISO 15156 recommends to test for SSC on Q-125 at 24ºC (± 3 K)
  - Test fluid, including salinity, pH, H_2S and CO_2
    - In accordance with recommendations, but
      - With adjusted pH for Q-125 due to corrosion products
      - H_2S fugacity was used (test at 5 mbar)
  - Test stress
    - Significant work to understand stress levels (test at 90% AYS)



Stress calculation assumptions

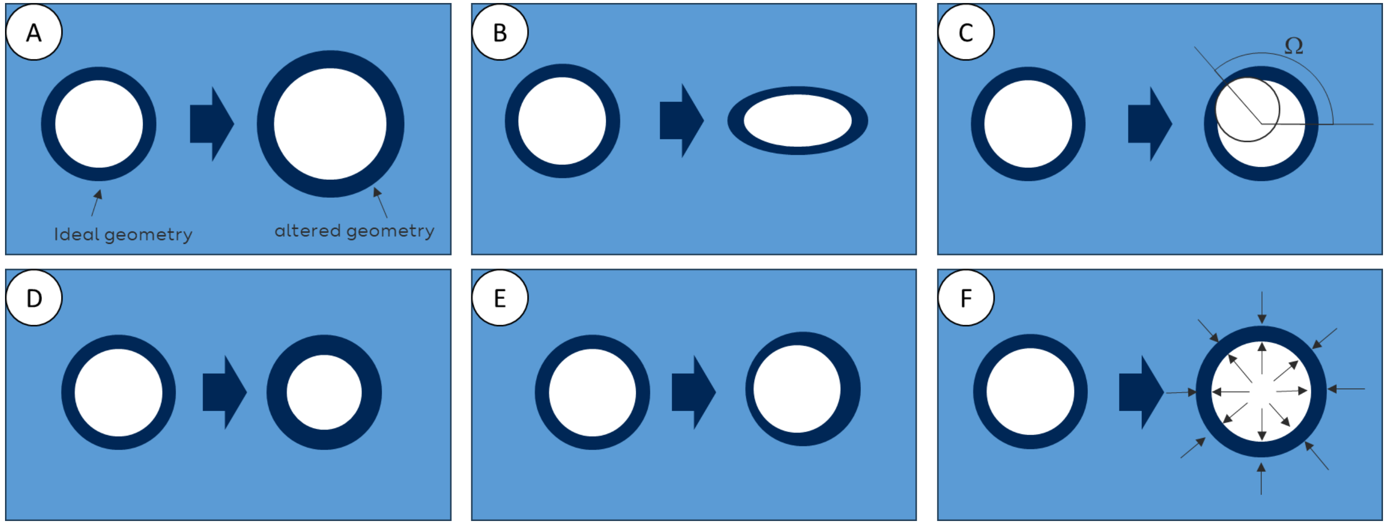
- Traditionally , casing stress level is assessed by comparing the so called “three –axial stress” to the von –Mieses yield criterion(“Tri –axial design factor”) to determine plastic yield onset.
- **But** brittle failure by SSC is possible within the elastic regime(well below reaching the YS and tri-axial design factor).
- Due to the atomic hydrogen embrittlement the material are treated as brittle materials.
- Principle tensile stress instead of Von Mieses yield criterion.
- Coupling assessed by designing company
  - Less risk than straight pipe.
- Non –ideal geometry considered
  - Stress increase due to non -idealizes



Initial Stress Calculation

- Initial FEA stress calculations was based on parameters below to find the maximum principal stress

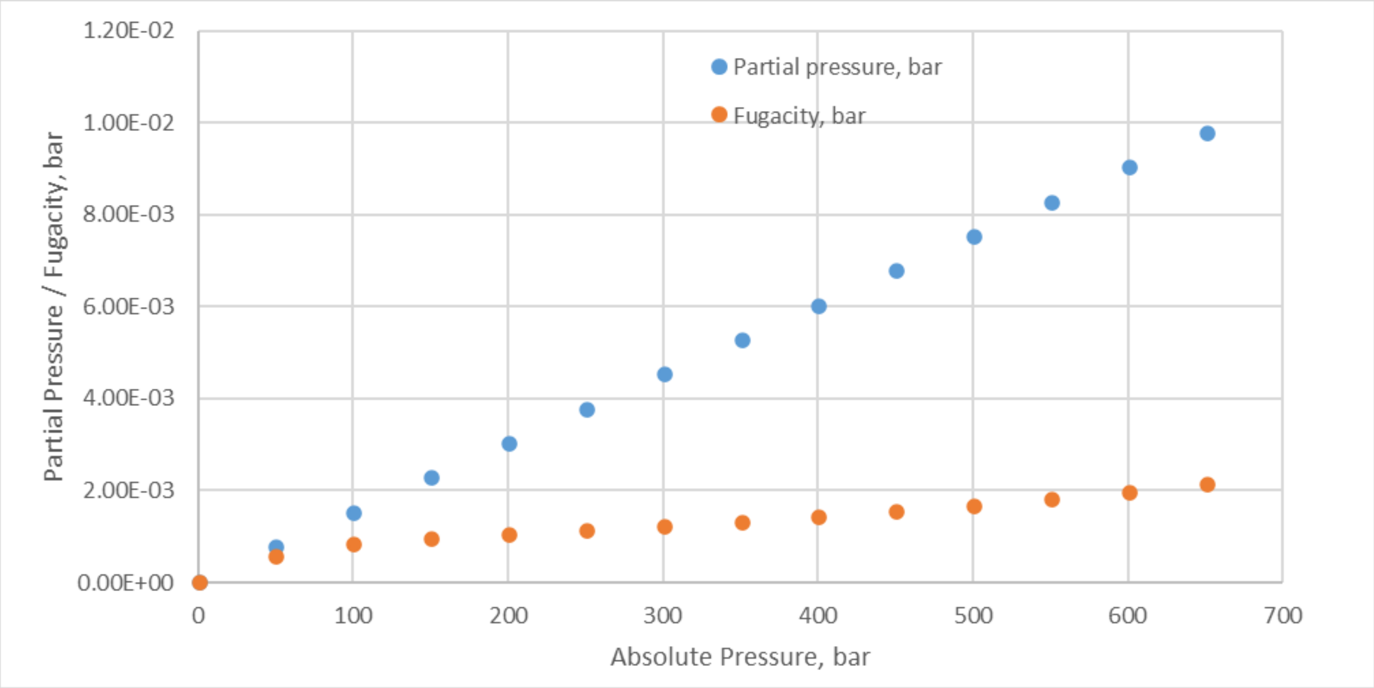
- A – Outer diameter
- B - Ovality
- C - Maximum casing wear
- D - Minimum wall thickness
- E - Eccentricity
- F - Inner and outer pressure
- Maximum defects allowed by ISO 11960
- Maximum axial loads
- Dog leg severity
- Temperature 20-28°C – SSC worst case depths at shut in conditions



- **Circumferential direction is experiencing highest stress**

H_2S Fugacity in Test Gas Phase

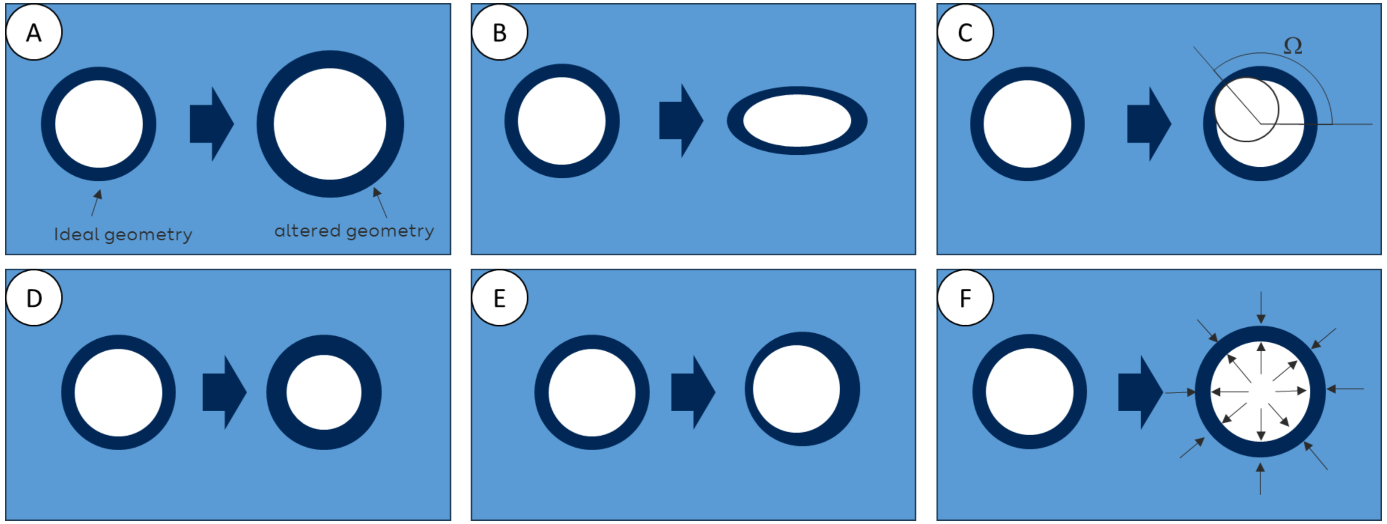
- Little experimental data publicly available for high system pressures combined with low H_2S concentrations
- Various EoS (Equation of States) and simulators tested for fugacity
- Direct discussions with software producers and comparison of literature
- H_2S partial pressure in test cell reduced from 20 to 5 mbar due to use of fugacity.
- Maintain conservatism by including
  - Conservative PC SAFT EoS
  - Total H_2S fugacity, not only in the water phase
  - Temperature up to 28°C, not only 24°C
  - Elevated pressure at location of 28°C

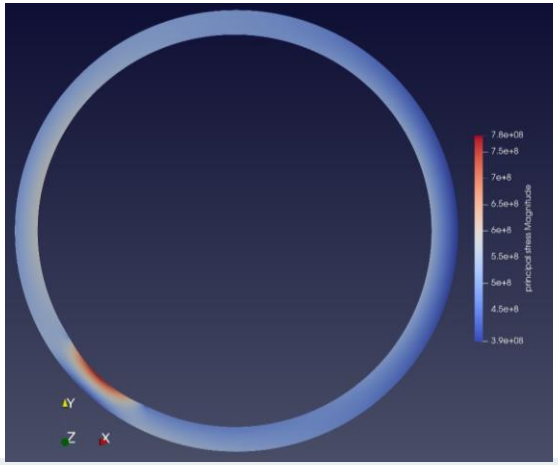


Imperfections and Probabilistic Analysis (Monte Carlo)

- Extreme values allowed by procurement standard ISO 11960 lead to excessive stresses > 90 % AYS
  → probabilistic approach required
- 5000 calculations with randomly determined values for each feature
- Selection of underlying probability distribution functions conservatively from own data or literature (ISO 10400)

- FE model set up and maximum principal tensile stress on inner surface detected automatically



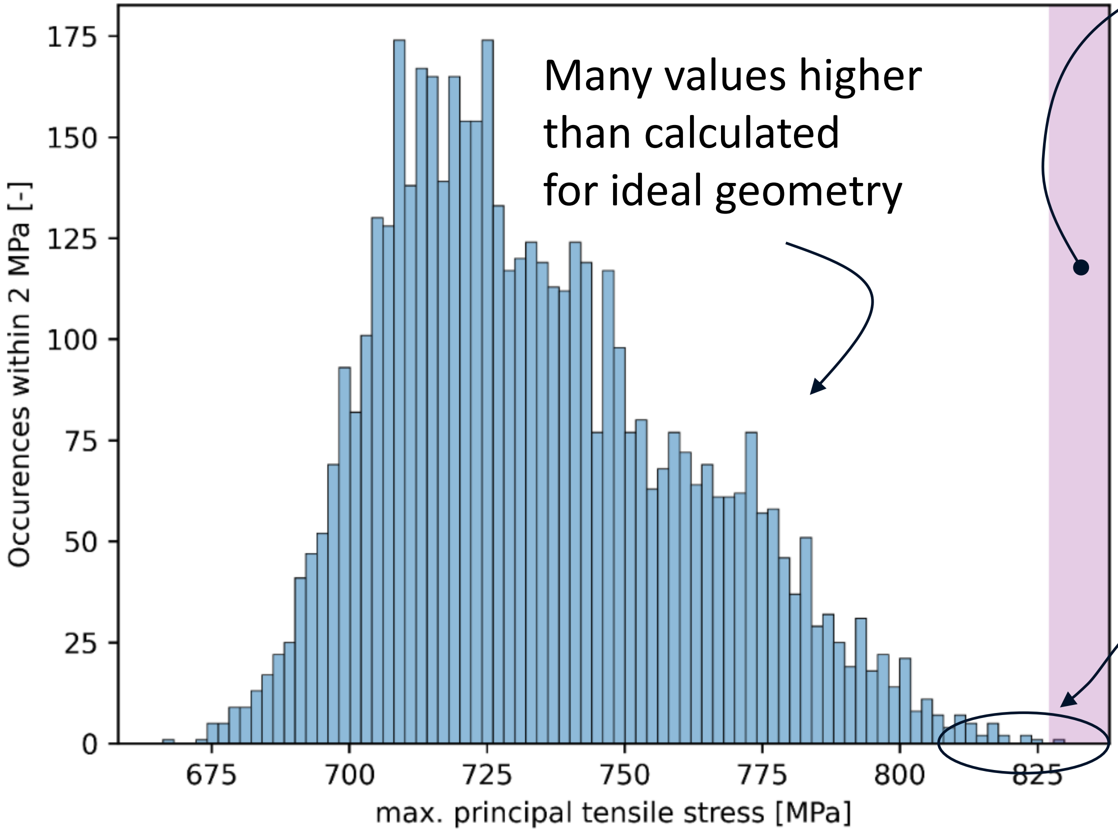


10 3/4in vs. 9 7/8in casing size

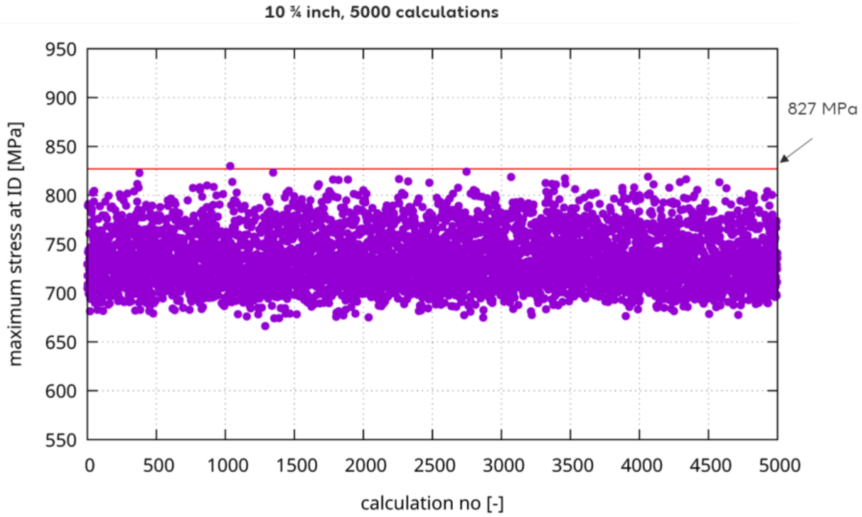
Stress above safe value 90% AYS

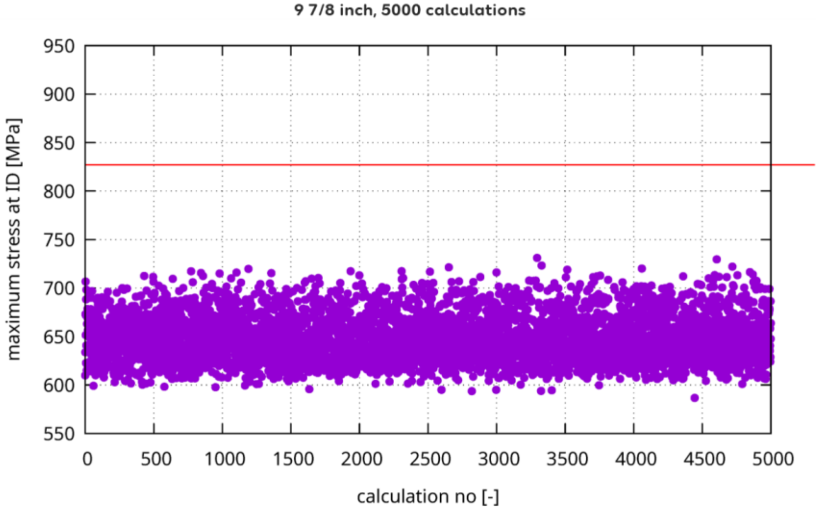
Most critical well (10 3/4 in section)

Many values higher than calculated for ideal geometry



Yes, we implemented additional risk reducing measures.





Additional Risk reducing measures implemented

H_2S Scavenger injected into annulus A

- H_2S scavenger mixed in a high-density pill have been injected in all wells on field into the annulus A on all wells and can treat up to 3,5 times the tubing/annulus volume in the well.

Kill plan

- Detailed kill plan prepared before wells started up. A flood cap was installed on the manifold to reduce response time for the rig to connect and be ready for killing the well. Rig on contract located in the area drilling another well.

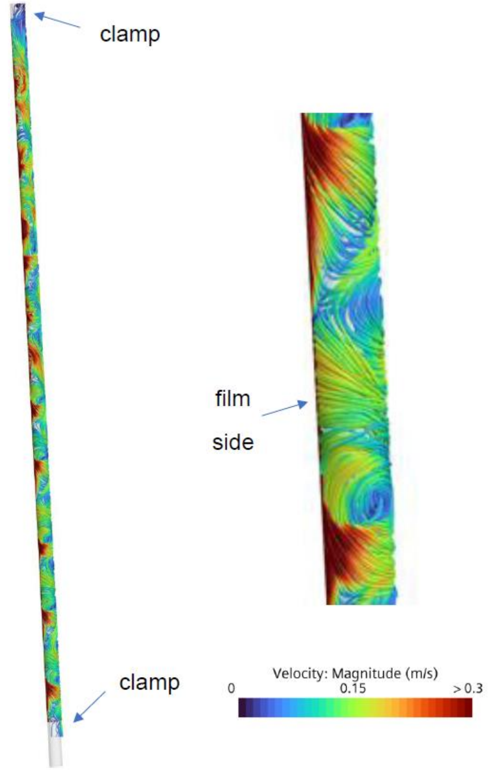
H_2S scavenger to be pumped from host platform via Umbilical

- H_2S Scavenger mobilized on host platform. Plan prepared to pump H_2S scavenger into MEG tank and inject into annulus A/ tubing as mitigation to remove H_2S before rig arrival.

Risk session

- Several session with risk assessment has been performed to identify and assess the risk using internal multi discipline team and involvements from partners.

- Use of external support/expertise from DNV, IFE, NORCE, Peleton, ORS, Casing manufacturer, subsea supplier, BLADE and experience from other operators in Norway has been used to find solution that enabled as safe startup of the field.



CFD – Computational Fluid Dynamics to study inhibitor effectiveness in annulus A

Summary

- Design parameters in early phase must be risk assessed and sensitivities of parameters can be an input to material selection.
- Secondary barrier is the foundation of well and the cost to select the correct material is low due to fact THAT the material is carbon steel.
- More accurate pipe dimensional data should be requested from the casing manufacturer. For critical wells.
- Traceability through pipe tallies is important to maintain with traceability to material certificate/pipe dimensions.
- Always run one log to verify/tune the casing wear model.
- Risk-based approaches help where deterministic models fail but extensive non-standard information of the well is required
- Use of cross functional teams within the company, partners and service companies are critical to solve complex cases like this.