KORROSJON UNDER ISOLASJON (KUI) FOR RUSTFRIE MATERIALER

# Corrosion Under Insulation for Corrosion Resistant Alloys

Petroleumstilsynet

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Objective:

CUI on stainless steel. Describe the practice used in the oil & gas business and the standards this is supported by. Identify learning across the business.

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# 1 EXECUTIVE SUMMARY

This report gives an overview over established practices and knowledge within management of the risk related to corrosion under insulation (CUI) of corrosion resistant alloys (CRA).

The study will focus on materials used in the oil and gas industry. The information used is based on public available papers and other literature, interview, and questionnaires from operators in the North Sea and review of accidents and incident reports relevant to CUI in CRA materials.

Corrosion under insulation in CRA materials is a threat to the integrity of piping systems and offshore installations. However, there are over the last decade few reported incidents of breach of containment leading to hydrocarbon leakage on the Norwegian continental shelf related to corrosion under insulation in corrosion resistant alloys. Provided that the design is following acknowledged standard such as NORSOK M-001 /7/ and IOGP S-715 /8/ and IOGP-S738 /9/, the focus on CRA materials could be related to monitoring of temperature, salt deposit and coating condition.

Pitting in 316 materials is the most extensive seen degradation mechanism of CRA materials related to CUI This degradation can occur at rather low temperatures (down to 10˚C) at high chloride concentrations.

# 2 BACKGROUND

English

The Petroleum Safety Authority is focused in working with continuous improvement of our risk-based follow-up of activities, where follow-up of corrosion under insulation in the design and operation of offshore installations and onshore plants is a priority. A review of data in the incident register 1998-2016 showed that corrosion under insulation (CUI) is a serious contributor to major accident risk. CUI is not a separately defined hazard or accident indicator (DFU) in RNNP. Unfortunately, the cause of events is not always recorded in the description in the event data register either. This has made it difficult to map the extent of serious incidents with CUI as the main cause. But at onshore plants, our analysis of incidents have shown that around half of all leakage incidents have CUI as the main cause. The Petroleum Safety Authority has previously investigated leaks from pipes connected to KUI, such as a steam leak in 2012, a hydrogen leak in 2016, and a naphtha leak in 2017 and 2020.

Norwegian

Petroleumstilsynet jobber bevist med kontinuerlig forbedring av vår risikobasert oppfølging av aktiviteter, der oppfølging av korrosjon under isolasjon i prosjektering og drift av offshore installasjoner og landanlegg er et prioritert tema. En gjennomgang av data i hendelsesregister 1998-2016 viste at korrosjon under isolasjon (KUI) er en alvorlig bidragsyter til storulykkerisiko. KUI er ingen egen definert fare eller ulykkesindikator (DFU) i RNNP. Dessverre registreres heller ikke alltid årsak til hendelser i beskrivelse i hendelsesdataregisteret. Dette har gjort det vanskelig å kartlegge omfang av alvorlige hendelser med KUI som hovedårsak. Men på landanlegg har våre analyser av hendelse vist at rundt halvparten av alle lekkasjehendelser har KUI som hovedårsak. Ptil har tidligere gransket lekkasjer fra rør forbundet med KUI, som damplekkasje i 2012, hydrogenlekkasje i 2016, og naftalekkasje i 2017 og 2020

## 2.1 Corrosion Under Insulation

Section 2.1.1 and 2.1.2 below are extracts from Troll C investigation report /21/.

### 2.1.1 Corrosion under insulation (CUI)

In the petroleum industry process equipment are often insulated to protect them and reduce the temperature in the event of a fire. Other grounds also exist for insulating in the process plant on a facility, as specified in Norsok M-004, for example. Generally speaking, an insulation system comprises the actual insulating material with external weather protection. The latter, or jacketing, is normally in metal. Within the insulation is the actual equipment which, on mature facilities, has an external surface protection coating. See figure below.

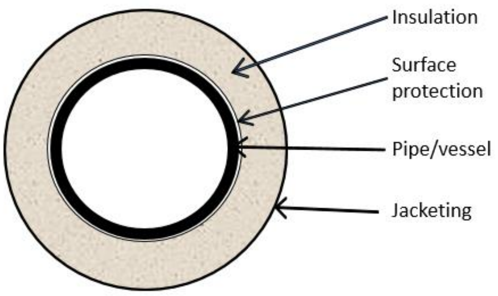


**Figure 2-1 Schematic of the insulation system for the process equipment, illustrated here by a pipe. Not to scale.**

CUI is generally associated with low-alloy steels, and involves faster corrosion with insulation than without it when exposed to same environment. The main reason for accelerated corrosion is water intrusion beneath the insulation. Modern systems make greater use other methods, such as surface treatment of piping, pipes in corrosion-resistant materials, hydrophobic (water-repellent) materials in the insulation and watertight external jackets, and in some cases with drainage. Pursuant to DNVGL-RP-G109 (DNVGL, 2019), two barriers to CUI are significant for discussion – coating (surface treatment) and protection against moisture (metal jacket, properties of the insulating material, exposure to water). Both must be taken into account in design, but perhaps even more importantly followed up during operation with the right maintenance, including inspection activities.

The PSA has investigated piping leaks related to CUI in low-carbon steel, including a steam leak in 2012 (PSA, 2013), a hydrogen leak in 2016 (PSA, 2017) and a naphtha leak in 2020 (PSA, 2020), and recently cracking in a stainless-steel gas cooler tank shell (PSA, 2023).

### 2.1.2 CUI and SCC

SCC is a generally accepted characterisation of sub-critical cracking of normally ductile materials under constant load in an environment with liquids and gas atmospheres **Invalid source specified.**. API RP 583 associates CUI in stainless materials, such as 22%Cr duplex, with external chloride stress corrosion cracking. The presence of water and chlorine, a marine atmosphere and seawater from deluge, as well as the fact that insulation retains moisture, the metal jacket cannot be assumed to be completely watertight and the surface protection is not intact, mean that the probability of CUI/SCC is increased. As a rule, the stress corrosion cracks grow stably until they reach a size which may cause unstable/rapid crack propagation leading to a possible break. Alternatively, the cracks can grow stably through the outer shell and cause leakage, which may be discovered, before a break. This is known as leak-before-break considerations.

Operating temperature often sets limits for using stainless steel materials in order to avoid CUI/SCC. API RP 583 puts the critical operating temperature for 22%Cr duplex at 140°C, while Norsok M-001 *Materials Selection* has a maximum limit of 100°C without surface protection.

# 3 SPECIFICATION AND LIMITATIONS

The study focusses on the following stainless-steel materials:

- 316 (300-series) Austenitic steel
- 22Cr Duplex steel
- 25Cr Duplex steel
- 6Mo Austenitic steel

Other stainless steel, nickel alloys or titanium material is not included in the study.

The following CUI external degradation mechanisms are considered:

- pitting corrosion
- crevice corrosion
- external stress corrosion cracking

# 4 EXPERIENCE AND KNOWLEDGE

## 4.1 Operator's experience

Experience from operators was gathered by interview and questionnaires. On the Norwegian shelf, there are currently 74 bottom fixed facilities and 23 steel floating facilities in operation /1/. There are in addition 7 different large onshore asset i.e., refineries, gas process plants and gas receiving facilities. The information gathered represent more than 90% of the offshore installations and most of the onshore refineries and gas receiving facilities. The age of installation ranges from the 1970`ties up till assets set in production in 2022. The findings and experiences discussed and reported relate to all the assets over the last 10 years.

### 4.1.1 Findings

All involved companies report to have experienced findings or incident related to CUI in CRA materials.

In this context findings are defined as identified degradation while incident is defined as loss of containment.

**Table 4-1 Material under insulation susceptibility for pitting and stress corrosion cracking**

| **Degradation type** | **Material type** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 316 Austenitic steel (or 300 series) | | 22Cr Duplex steel | | 25Cr Duplex steel | | 6Mo Austenitic Steel | |
| | Findings (identified degradation) | Incident (loss of containment) | Findings (identified degradation) | Incident (loss of containment) | Findings (identified degradation) | Incident (loss of containment) | Findings (identified degradation) | Incident (loss of containment) |
| Pitting | All operators | All operators | All operators | Some incidents | None | One single incident | None | None |
| Stress Corrosion Cracking | All operators | All operators | Some findings (one operator only) | Some incidents /5.1//5.2/ | None | None | None | None |

In general, there are few internal and external reported incidents, less than 10 cases related to pitting or SCC in duplex material. The cases reported is mostly related to specific conditions such as increased temperature due to heat tracing or high exposure to chlorides and water. For 316 steel material there are reported more pitting and SCC degradation. In recent years development projects, the design has required coating of 316 materials, and this has most probably helped to reduce pitting and SCC in 316.

There are only reported 3 hydrocarbon leaks in CRA materials to the PSA, see chapter /5/. Incidents due to pitting is assumed to be located at objects in non-hazardous systems.

### 4.1.2 Challenges

Specific challenges in managing CUI and incidents reported are:

- Uncoated 316SS with pitting corrosion under thermal insulation at pipe supports at ambient temperature.
- Steam piping in 316SS with TSA operating above 60ºC CSCC.
- Corrosion is observed on CRA material, and hot dip galvanized (HDG) fasteners.
- Stress corrosion cracking is observed in a CUI-situation for 316SS pipe support clamp.
- CUI on insulated instrument tubing has been observed (316SS). Instrument tubing is more often than not included in the RBA/RBI scope and is never coated under insulation.
- Temperature control of heat tracing in CRA materials is in general seen as a challenge.

The common challenges for managing the CUI risk in CRA materials by the operators are:

- Difficult to foresee where the CUI will occur.
- Lack of efficient NDT methods.
- Lack off / inadequate coating.
- Requirements related to deluge testing is one or the primary root causes of water ingress into insulation.
- Limited bed capacity on offshore installations (PoB) reduce feasibility for extensive CUI campaigns.
- Corrosion in hot dipped galvanized carbon steel bolts in CRA – systems are identified as focal susceptible areas.
- High cost to manage CUI-CRA.

### 4.1.3 Risk identifying methodology for operators

The operators use a qualitative or semi qualitative methodology to identify the areas and tags with the highest risk for corrosion under insulation in CRA materials. This is often combined with the use of historical data and inspections by field engineers and inspectors to identify most likely areas. Some is also using the DNV-RP-G109 "Risk Based Management of Corrosion Under Insulation" /2/ for identify high risk objects. All operators use the following parameters in their probability assessment:

- Type of material
- Operational temperature
- Acceptance limit for temperature
- Local environment i.e., exposure to water
- Historical inspection data

The following parameters are used by several of the operators:

- Age of installation and/or coating.
- Temperature fluctuations
- Type of coating

- Age of coating
- Quality of coating by visual inspection and / or adhesion testing
- Cladding design and geometry
- Cladding workmanship
- Lay-out
- Inspection extent
- Material in nuts and bolts.

## 4.2 Publicly available standards and guidelines

### 4.2.1 Standards and guidelines reviewed

The following standards has been reviewed:

- API RP 581 "Risk-Based Inspection Methodology". /3/
- API RP 583 "Corrosion Under Insulation and Fireproofing". /4/
- DNV-RP-G109 "Risk Based Management of Corrosion Under Insulation". /2/
- EFC no. 55 "Corrosion-Under-Insulation (CUI) Guidelines". /5/
- Energy Institute "Guidance for corrosion management in oil and gas production and processing". /6/

### 4.2.2 Risk assessment methodology in guidelines

Both API 583 /4/ and EFC no. 55 /5/ have a score-based model for assessing probability for CUI in CRA materials. API 583 cover austenitic and duplex materials while EFC no. 55 cover austenitic materials. API 583 use 7 different parameters to get to a number which correspond to a probability level. In the assessment is for stress corrosion cracking API 583 states that for duplex materials, stress corrosion cracking will only take place above 140˚C which is contractionary to NORSOK M-001" Materials Selection"/7/ or ISO 21457 "Materials selection and corrosion control for oil and gas production systems" standards. API 583 is using Figure 4-1 (below) for definition of temperature chloride combination for CRA materials and their tendency for stress corrosion cracking.

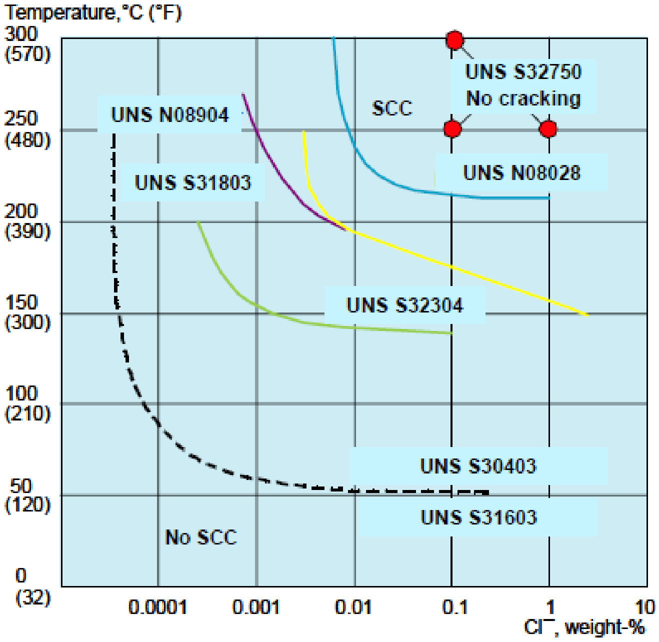


**Figure 4-1** SCC Tendency of Austenitic and Duplex Alloys [Sandvik Technical brochure S-1875 on SAF2507, (March 2000)]

The risk assessment methodology for SCC in CRA materials in EFC no. 55 is based on 4 parameters and if you have a combination of e.g., organic coating older than 5 years (or TSA older than 30 years) and e.g., mild inland climate your probability for degradation will be very high! The document is not very clear, but it is assumed that the assessment method is applicable for 300 series of stainless steels operating above 60˚C.

The DNV-RP-G109 /2/ states that "The probability of ESCC of austenitic and duplex stainless steel under insulation is considered low if the operational temperature is in accordance with NORSOK M-001 or ISO 21457". In same document the probability for pitting corrosion of corrosion resistant steels under insulation is considered relatively low for coated objects. Uncoated CRAs with a low PREN value, (< 24), such as 316 austenitic steels, should in general be given a high probability of degradation of the material barrier in a CUI assessment.

NORSOK M-001 and ISO 21457 set the following temperature limits for SCC, see **Table 4-2**

**Table 4-2** Temperature limits for SCC in CRA materials

| Material type | Alloy | Max operating temperature [˚C] | |
|---|---|---|---|
| | | ISO 21457 | NORSOK M-001 |
| Austenitic SS | UNS S31600 (316) | 50-60 | 60 |
| | UNS S31245 (6Mo) | 100-120 | 120 |
| Duplex SS | UNS S31800 (22Cr) | 80-100 | 100 |
| | UNS S32750 (25Cr) | 90-110 | 110 |

## 4.3 Recommendations to mitigate CUI in CRA materials

The following extract of quotes for recommendation to mitigate CUI in CRA materials are given in reference document or from operators:

- Insulated systems in CRA material with bolts and nuts in flange connections made of hot dipped galvanized (HDG) carbon steel should be assessed as for carbon steel, with the flanges as hotspots. /2//6/
- Wrapping of the stainless steel with aluminum foil that both serves as a barrier coating and a cathodic protection (CP) anode has proven to be effective. /3/
- It should always be remembered that a poorly applied coating system can be worse than no coating at all, because it can accelerate corrosion by concentrating the corrosive effect on areas of coating breakdown. /5/
- Periodic inspection for pitting or cracking on uncoated alloys is of limited value in pre-empting failures because once corrosion has initiated it can progress rapidly to failure. Periodic inspection of coating condition may have some value if coating breakdown is identified before water ingress trigger damage. /6/
- Inspection to confirm the presence of coating in the first place is important. Once a failure has occurred inspection plays a role in identifying the extent of the damage. If bare metal must be inspected, it ought to be two-three yearly at prone areas to be effective and of course this would require high coverage and is not practical. /6/
- For uncoated CRA crevice/pitting use the crevice temperature; vulnerable thin-walled austenitic are considered to have the highest probability of failure. /6/
- TSA or Al-foil is known to ensure low probability to CRAs for periods up to 20 years and beyond. /6/
- Coating management programs (fabric maintenance) is seen as the best mitigation strategy for CUI in CRA materials. /Section 4.1/
- Risk based approach combined with visual inspections is used to identify the most vulnerable areas for detailed inspection and / or refurbishment. /Section 4.1/
- Water management by use of efficient drainage of water or water monitoring sensors will help reduce risk or better assess the risk. /Section 4.1/*

* Drainage of water might not be effective if evaporation of water still takes place on the steel surface. If the salt concentration on the steel surface becomes high enough, the salt residue can be wetted by humidity in the air.

## 4.4 Publicly available papers

The relevant papers that have been assessed mainly focus on describing environmental limitations for different austenitic and duplex stainless steel grades including summaries of selected SCC and corrosion failures in operation, experience with different coating systems and experience with different inspection methods. The assessed environmental limitations are based on laboratory testing and case studies from facilities in operations parameters and include temperature, chloride concentration, type of chloride salt (e.g., $MgCl_2$ and NaCl) and humidity. The following limits were found:

- Laboratory testing in a concentrated calcium chloride ($CaCl_2$) solution resulted in SCC on AISI 316/316L at temperatures between 30 and 40°C. Pitting corrosion was observed at 20°C in the $CaCl_2$ solution. SCC under insulation (concentrated seawater solution by evaporation) in operation was observed at 50°C

- 22 Cr duplex stainless steel had experienced SCC in a concentrated seawater solution by evaporation at 105°C. Pitting corrosion was found in saturated $CaCl_2$ and $MgCl_2$ solutions at 40°C (lab tests) and at 50°C in operation.
- 25 Cr super duplex stainless steel also suffered SCC in a concentrated seawater solution by evaporation at 105°C. Pitting corrosion was found in saturated $CaCl_2$ and $MgCl_2$ solutions at 40°C
- Super austenitic stainless steels (904L and 6Mo) did not crack in laboratory testing with saturated $CaCl_2$ and $MgCl_2$ solutions. Pitting corrosion was found in saturated $CaCl_2$ and $MgCl_2$ solutions at 40°C

A summary of the published environmental limits is shown in Table 4-3.

**Table 4-3 Summary of published environmental limits based on laboratory testing and corrosion failures of equipment in operation**

| Material grade | Failure mechanism | Chloride concentration | Type of chloride salt | Temperature [°C] | Test type | Remarks | Ref. |
|---|---|---|---|---|---|---|---|
| AISI 316/316L | SCC | Varying (max 35 weight% | $MgCl_2$ | Varying | Lab. testing | Test results show that SCC propagation stop when chlorides are removed from metal surface | /10/ |
| | SCC | Immersion test < 200000 ppm | Varying | 100 | Lab testing | Above this chloride concentration, the temperature threshold seems to decrease drastically | /11/ |
| | CUI (SCC) | Unknown | Unknown | 121 | Case study | Non-protective coating used under insulation. Chlorides probably come from gases from the bleach plant | /12/ |
| | CUI (SCC) | > 100 ppm(w) | Unknown | > 50 | Case study | | /13/ |
| | SCC | Saturated, i.e., 400 g/l | $CaCl_2$ | 30 | Lab testing | Small cracks passing through tiny pits | /14/ |
| | | | | 40 | Lab testing | Deep cracks that passed though pits | /14/ |
| | Pitting corrosion | Saturated, i.e., 400 g/l ($CaCl_2$) and 350 g/l ($MgCl_2$) | $CaCl_2$ and $MgCl_2$ | 20 | Lab testing | | /14/ |

| Material grade | Failure mechanism | Chloride concentration | Type of chloride salt | Temperature [°C] | Test type | Remarks | Ref. |
|---|---|---|---|---|---|---|---|
| 22%Cr Duplex | SCC | Concentrated from evaporation of seawater | NaCl, $MgCl_2$, $CaCl_2$, KCl | 140 | Case study | Coated with 250 µm thick epoxy paint. Damage occurred at uncoated surface inside pipe support | /15/ |
| | CUI (pitting corrosion) | Concentrated from evaporation of seawater | NaCl, $MgCl_2$, $CaCl_2$, KCl | 55 | Case study | On removal of the insulation, extensive salt deposits were found | /16/ |
| | CUI (pitting corrosion) | Unknown | Unknown | 60 | Case study | Corrosion protection coating had poor quality | /16/ |
| | SCC | Concentrated from evaporation of seawater | NaCl, $MgCl_2$, $CaCl_2$, KCl | 130 | Lab. testing | 4-point bend test strained to 100% of $YS_{0.2}$. Uncoated sample | /17/ |
| | No failure with samples coated with TSA | Concentrated from evaporation of seawater | NaCl, $MgCl_2$, $CaCl_2$, KCl | 130 | Lab. testing | 4-point bend test strained to 100% of $YS_{0.2}$. Sample coated with TSA | /17/ |
| | SCC | Concentrated from evaporation of seawater | NaCl, $MgCl_2$, $CaCl_2$, KCl | 105 - 110°C | Lab testing | Failure occurred at temperatures close to 105°C with an applied nominal stress at about 82% of the $YS_{0.2}$ at 110°C | /18/ |
| | Pitting corrosion | Saturated, i.e., 400 g/l ($CaCl_2$) and 350 g/l ($MgCl_2$) | $CaCl_2$ and $MgCl_2$ | 40 | Lab testing | Shallow pitting. No corrosion in saturated NaCl | /14/ |
| 25%Cr Super duplex | SCC | Concentrated from evaporation of seawater | NaCl, $MgCl_2$, $CaCl_2$, KCl | 105 - 110°C | Lab testing | Failure occurred at temperatures close to 105°C with an applied nominal stress at about 82% of the YS at 110°C | /18/ |
| | Pitting corrosion | Saturated, i.e., 400 g/l ($CaCl_2$) and 350 g/l ($MgCl_2$) | $CaCl_2$ and $MgCl_2$ | 40 | Lab testing | Shallow pitting corrosion. No corrosion in saturated NaCl | /14/ |

| Material grade | Failure mechanism | Chloride concentration | Type of chloride salt | Temperature [°C] | Test type | Remarks | Ref. |
|---|---|---|---|---|---|---|---|
| Super austenitic stainless steel (6Mo and 904L) | Pitting corrosion | Saturated, i.e., 400 g/l ($CaCl_2$) and 350 g/l ($MgCl_2$) | $CaCl_2$ and $MgCl_2$ | 40 | Lab testing | No corrosion in saturated NaCl solutions | /14/ |

SCC of 300 series austenitic stainless steels in chloride environments from seawater usually occurs above 50°C and a minimum chloride concentration. The minimum chloride concentration for SCC to occur decreases with increasing temperature. Typical temperature – chloride curves for different stainless steel grades are shown in Figure 4-1 /10/. However, depending on alloy composition and chloride concentration, pitting and/or crevice corrosion may be possible at lower temperatures /13/.

Lab tests with 316L stainless steel small diameter pipe in hot concentrated chloride environment were performed to investigate if stress corrosion cracks already present in the material will stop propagating if the chlorides are removed from the circuit or if it is possible to slow down or even stop the propagation of a crack by injecting an inhibitor in the fluid, /10/. The results indicate that the presence of chlorides is required in the bulk environment for SCC cracks to propagate. Once the chlorides are removed, cracks slow down and stop. Injection of an inhibitor was not sufficient to stop the propagation of the crack /10/.

The durability of four coating systems were evaluated by exposing the coatings to heating cycles (30 times@8 hours heating and 16 hours natural cooling) /19/. The results are summarised below.

- Epoxy coating degraded at temperature above 120°C.
- Epoxy phenolic coating has blisters in the 150-175°C region and discoloration at temperatures above 140°C.
- Thermally sprayed aluminium (TSA) coating was severely degraded at temperatures above 190°C resulting in severe corrosion. No SCC were seen.
- Titanium modified inorganic copolymer (TMIC) coating showed only slight degradation up to 230°C (max test temperature).

# 5 REPORTS FROM SERIOUS INCIDENTS

Information regarding incidents described below are all publicly available. There might be other incidents not reported due to e.g., loss of containment in non-flammable or non-toxic systems.

## 5.1 Stress corrosion cracking of duplex stainless steel, UNS S31803 on the Gyda HP separator

Failure investigation of the separator showed cracking at two central circumferential girth welds and an oil outlet nozzle. In addition to the cracks, there were brown corrosion products and salt deposits with evidence of pitting corrosion. The insulation was found to be soaked with water along two thirds of the vessel bottom, including all the areas where cracks were detected. Seawater sustained in the wet insulation at the external non coated surface had initiated the cracking, and leakage of produced water after crack penetration had aggravated the conditions. The surface temperature was initially approximately 100°C but may have decreased quite rapidly to 40-50°C due to asphaltene deposition in the bottom of the vessel. The failure investigation concludes that the crack initiation probably occurred at 100°C but that the crack may have propagated at temperatures as low as 40 to 50°C /22/.

## 5.2 Hydrocarbon leak on Ula Production Platform

The leakage was caused by chloride induced stress corrosion cracking of AISI 316/304 bolts on a bypass valve above the emergency shut down valve for produced water from the 1st stage separator. The bolts were exposed to the internal produced water through a seep leakage resulting in salt deposits forming around the bolts. The steel temperature was maximum 120°C /20/.

## 5.3 Chloride induced stress corrosion cracking on gas cooler on the Troll C Platform

Investigations showed that two gas coolers in duplex stainless steel had chloride induced SCC under insulation. Gas from the first-stage export compressors is routed to the second-stage export compressor coolers. It enters these coolers with a pressure of about 60 barg and a temperature of roughly 148°C. The gas is cooled down to some 25°C before continuing in the process. The cooler shells were built in 22%Cr duplex stainless steel with a 25 µm silicon coating and protected by fire insulation on tanks and flanges. Failure investigation of the gas cooler showed the cracks started externally and were through the wall thickness. The fluid entry temperature was 148°C and the exit temperature was 25°C /21/.

## 5.4 Summary of similarities

- All incidents involved CRA materials with no or deteriorated surface coating
- For two of the cases (cracking of the HP separator and gas cooler), the cracking occurred under insulation. For the last case, salt deposits build up formed on a surface exposed to the atmosphere
- The steel temperature at crack initiation was above or at the maximum temperature limits given in NORSOK M-001 for all three cases
- In addition to SCC, pitting corrosion was observed on both the duplex stainless steel vessels (HP separator and gas cooler). The observed corrosion was not through the wall thickness

# 6 EXPERIENCE TRANSFER AND LEARNING

There is only one incident reported to the Petroleum Safety Authority on the Norwegian continental shelf related to loss of containment in hydrocarbon systems due to corrosion under insulation in corrosion resistant alloys during the last decade. Provided that the design is following acknowledged standard such as NORSOK M-001 /7/, IOGP S-715 /8/ and IOGP-S738 /9/, the focus on CRA materials could be related to monitoring of temperature, salt deposit and coating condition.

The following elements should be considered when managing the risk for CUI in CRA materials:

- Monitor temperatures to ensure that operational temperature is below critical temperature in e.g., NORSOK M-001 /7/. Be aware that the temperature limit might vary dependent on salt deposits.
- Heat tracing might contribute to challenges in temperature control with respect to the limits for degradation.
- Inspection of coating condition might be more efficient than inspection for pitting or cracking.
- Carbon steel bolts and nuts in CRA systems should be considered as prone / susceptible areas for corrosion.
- The highest number of registered findings related to CUI in CRA materials are pitting in uncoated 316SS (300-series) materials.
- There are no CUI findings related to 6Mo and only one single SCC incident related to 25Cr Duplex.

# 7 CONCLUSION

Corrosion under insulation in CRA materials is a threat to the integrity of containment systems including piping and pressure vessels. Public available data for the norwegian petroleum industry reveal two hydrocarbon leak incidents since 1990 for CRA materials compared to 54 incidents in carbon steel reported to PSA in the period 1998 till 2020. This indicates a considerable higher challenge in the industry for CUI failure in carbon steel material than for CRA materials. However, there might be some uncertainty related to accuracy and extent of hydrocarbon leaks in the mentioned time span. This means that mitigating activities on CUI of CRA materials has to come in addition to and not reduce the effort on CUI of carbon steel material.

To minimize number of incidents of CUI in CRA materials it is important that guidelines like NORSOK M-001 /7/ are followed with respect to temperature limits for SCC. Temperature limits might vary dependent on exposure to chlorides and type of chloride salts. Pitting in 316SS materials is the most extensive seen degradation mechanism. This degradation can occur at rather low temperatures (down to 10˚C) at high chloride concentrations. In later years 316SS materials are coated and thereby the probability of pitting is considerably reduced.

Monitoring operational temperature, monitoring of moist in insulation and inspection of coating condition seem to be the best option for management of CUI risk in CRA material, visual inspection is in general not seen efficient unless large areas of insulation are removed. There exists no proven NDT method for detecting pitting and / or cracks without removal of insulation. Verification of operational condition versus design criteria such as NORSOK M-001 /7/, IOGP S-715 /8/ and IOGP S-738 /9/ could be a good basis for the inspection or monitoring program.

# 8 RECOMMENDATION FOR FURTHER WORK

CUI is a challenging degradation mechanism as it is difficult to predict location, extent and degradation start and degradation rate. To support a decision process in this context it would be beneficial to the industry to have access to extensive well-structured historical data. This can be achieved by establishing a database with input from across industries and companies.

Such project can have a phased approach consisting of the following elements:

**Phase 0 – Feasibility study**

Identify and review the ability and willingness to retrieve the relevant data as well as test simple methodologies for use of data to support CUI decisions. Governance principles, ownership and maintenance cost for such data base shall also be identified in an early phase.

**Phase 1 – IT solution**

Build a cloud data base with relevant reporting and data extract features. Reporting should be built smart to enable the use of machine learning algorithms. Reporting to be aligned with elements used in DNV-RP-G109.

**Phase 2 – Data population and data implementation**

This phase will include cleansing and quality control of data for upload to the data base. Data anonymization and data security can be included (here or in phase 1).

The data to be uploaded is primarily from recent history (2023 and onwards) as the detailing level of old historical data might be inaccurate. A potential phase 2b can include review and quality control of old historical data for upload.

**Phase 3 – Development of smart algorithms for decision support**

Develop machine learning algorithms to support users end optimize the use of historical data.

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# APPENDIX A
## Questionnaire

### CUI-CRA (SS316, 22Cr Duplex, 25Cr Duplex and 6Mo) management, challenges, and parameters:

Company name: Contact name, technical:

1. Have your company had any findings or incidents related to Corrosion Under Insulation in CRA materials?

- ☐ Yes
- ☐ No
- ☐ N/A or do not want to answer

If yes, please describe type of findings and general experience:

| |
|---|
| |

The incident / findings relate to:
- ☐ Pitting in 316 (or 300 series) materials
- ☐ Pitting in 22Cr materials
- ☐ Pitting in 25Cr materials
- ☐ Pitting in 6Mo materials
- ☐ Stress corrosion cracking in 316 (or 300 series) materials
- ☐ Stress corrosion cracking in 22Cr materials
- ☐ Stress corrosion cracking in 25 Cr materials
- ☐ Stress corrosion cracking in 6Mo materials

2. What is your company`s main challenge(s) with respect to avoiding a major accident due to corrosion under insulation on CRA? (Multiple answers possible)

- ☐ Difficult to foresee where CUI-CRA will occur
- ☐ Difficult to coordinate and involve all necessary disciplines
- ☐ High cost to manage CUI-CRA
- ☐ Access to perform planned activities during operation
- ☐ Difficult to monitor temperature / Lack of relevant (online) temperature sensors
- ☐ Lack of efficient NDT methods
- ☐ Lack off / Inadequate coating
- ☐ Insulation is always wet
- ☐ We do not have any particular challenge with CUI-CRA
- ☐ Lack of knowledge / competence
- ☐ Other, fill in below:

3. How do you discover CUI-CRA? (Multiple answers possible)

- ☐ Monitoring for CUI-CRA
- ☐ Inspection for CUI-CRA
- ☐ Fabric maintenance campaigns
- ☐ During maintenance or modification work
- ☐ Operational incidenses
- ☐ Other, fill in below:

4. What is the most common consequence of CUI-CRA?

- ☐ Cleaning of pipe/equipment surface
- ☐ Removal of corrosion products and coating spot repair
- ☐ Mechanical repair
- ☐ Process shutdown
- ☐ Minor leaks (< 0.1 kg/s)
- ☐ Major leaks (> 0.1 kg/s)
- ☐ Personnel exposure to HC/hazardous substances
- ☐ Other, fill in below:

5. How is your assessment model for CUI-CRA built (multiple answers possible):

- ☐ Quantitative model
- ☐ Qualitative model
- ☐ Semi-Q model (combination of the above)
- ☐ Score based model
- ☐ Model based on Bayesian network
- ☐ Following given standard(-s)/RP(-s) (name:________________________________________)
- ☐ Using monitoring data (online temperature sensors)
- ☐ Using historical inspection data
- ☐ Primarily using Consequence assessment
- ☐ Field engineers and inspectors are identifying most exposed locations
- ☐ We do not have a specific model for CUI-CRA
- ☐ Other, fill in below:

6. Parameters used in CUI-CRA probability assessment:

| | Type of material | Age of material | Operational temperature | Temperature fluctuation | Acceptance limit for temperature (ESCC / Pitting) | Type of coating | Age of coating | Quality of coating | Local environment, access to water | Dew-point | Insulation type | Cladding type | Cladding workmanship | Cladding design & geometry incl. drainage | Wall thickness | Pipe dimensions | Lay-out | Inspection results | Inspection extent | Heat tracing | Material selection in nuts and bolts | Other elements |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Y/N | | | | | | | | | | | | | | | | | | | | | | |
| Comment | | | | | | | | | | | | | | | | | | | | | | |

Please fill in Y (yes) or N (no) relevant to which parameters that are considered in the probability assessment used in your company`s management of CUI.
If need for comment on each of the parameters, you can use the comment field underneath.

## About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

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