Corrosive components in the gas stream

Peter Duineveld

THOMASSEN COMPRESSION SYSTEMS

EFRC training on challenging conditions

20 October 2010

Contents

- General corrosion theory
  - What is corrosion
  - Most common types of corrosion
- Corrosives encountered
  - Most commonly encountered corrosive components
  - Examples of failures
  - Why they are in the process
- What can be done to prevent problems?
- Conclusions

General corrosion theory

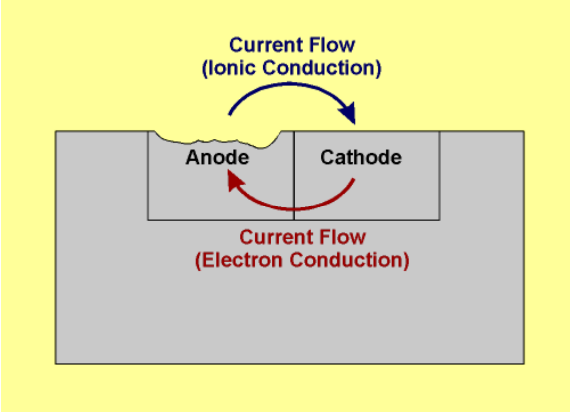
What is corrosion?

- Corrosion: wearing away of metals due to a chemical reaction.
- Difficult to predict
  - corrosion is strongly dependant on temperature, pressure, concentration and specific mix of chemicals/corrosive elements present. A small variation in these factors can make a significant difference in the actual amount of corrosion.
- Natural and inevitable – from rust to rust

General corrosion theory

- Uniform Attack
  - General surface corrosion
  - Reduced by using more resistant material., e.g alloy steel > carbon steel, stainless > alloy, austenitic > martensitic, nickel alloys > stainless, ceramics are the most resistant.

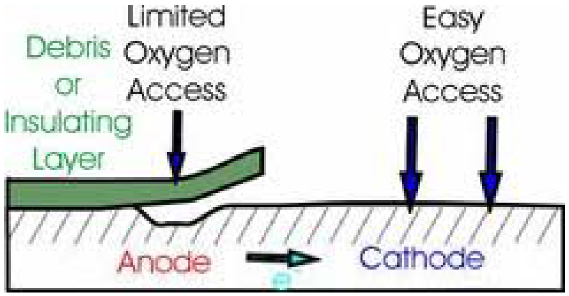
- Galvanic Corrosion
  - Caused by the same effect that gives anodic protection.
  - Most easily prevented by avoiding materials with differing chemical potential in electric contact.



General corrosion theory

- Pitting
  - Very localised corrosion, typical with materials with passive layer in Cl.
  - PREN = %Cr + 3.3 %Mo + 16 %N (Pitting Resistant Equivalent Number, higher=more resistant)

- Crevice Corrosion
  - Stagnation in the crevice causes the crevice to become anodic compared to the surrounding material, accelerating corrosion. This process also exacerbates pitting.
  - Materials that are resistant to pitting tend to be resistant to crevice corrosion.



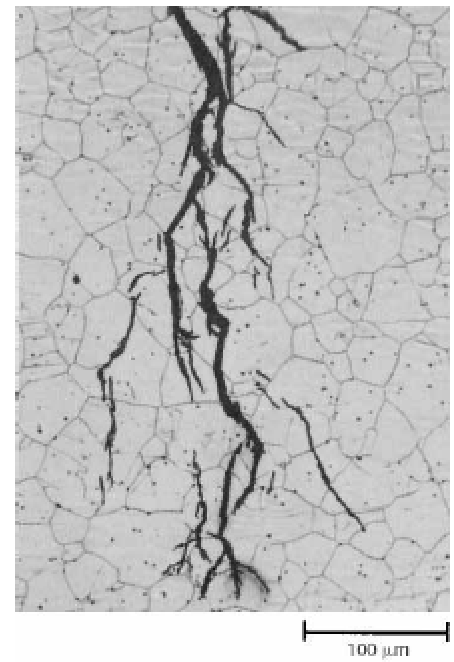
General corrosion theory

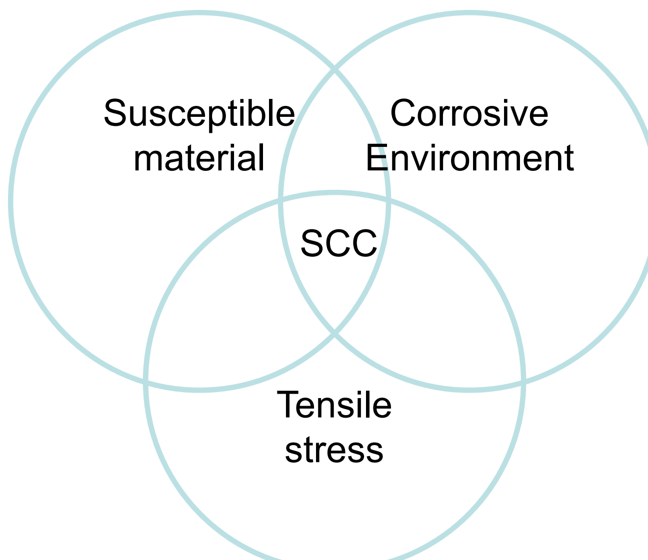
Other forms of corrosion includes:

- Corrosion Fatigue
- Erosion Corrosion
- and *most significantly, Stress Corrosion Cracking*

General corrosion theory

- Stress-Corrosion Cracking (SCC)
  - Unexpected failure of normally ductile metals subjected to tensile stress in a corrosive environment.
  - Always combination of a susceptible material, environment and stress acting together.
  - Most critical form of corrosion. Cracks can propagate quickly and destroy a part before it has the chance to corrode by another mechanism. Can occur within days of operation.





General corrosion theory

- Stress-Corrosion Cracking (SCC) – Examples:
  - Austenitic Stainless steel and Al are very sensitive to **Chlorine Stress Corrosion Cracking** in the presence of trace amounts of Cl. Residual stresses in the material are often enough to initiate cracking.
  - Carbon and Stainless Steels will suffer **Caustic Stress Corrosion Cracking** in high concentrations of very high pH environment – these are unusual conditions.

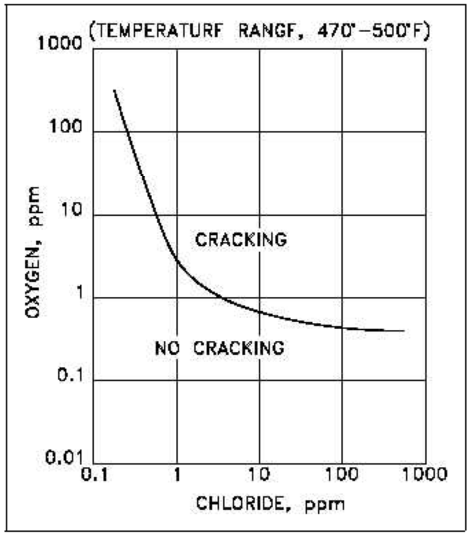


Figure 15 Austenitic Stainless Steel

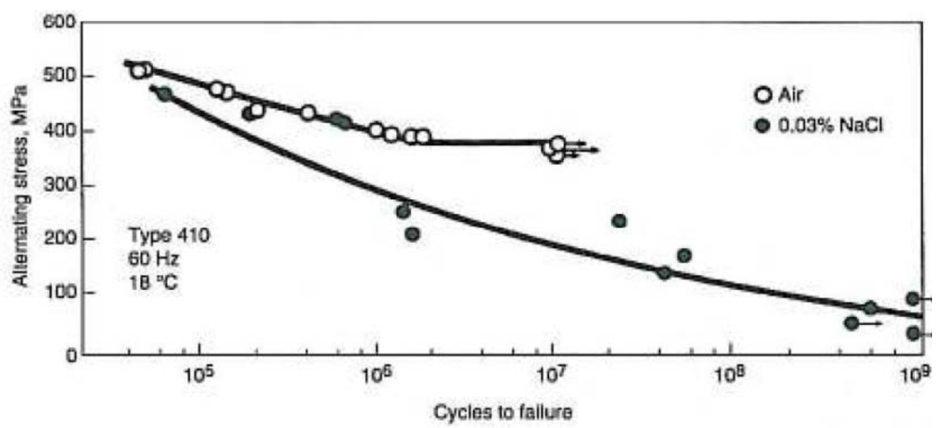
General corrosion theory

- Stress-Corrosion Cracking (SCC) – Examples:
  - **Hydrogen Embrittlement (HE)**: diffusing of H atoms into metals causing the metal to become brittle
  - Fastest crack growth, up to 1mm/s in worst case
  - High-strength steel is most susceptible to HE, can occur in Ti and Al as well.
  - Is usually prevented by controlling maximum strength or corresponding hardness.

  - **Sulphide Stress Cracking (SSC)** in the presence of water and H_2S.
  - **SSC** is a form of Hydrogen Embrittlement.

Corrosives encountered – Cl (halogens)

- Cl causes Stress Corrosion Cracking in SS, pitting, lowered fatigue strength and general corrosion.
  - As little as 1ppm Cl can cause SSC in Austenitic Stainless Steels
  - 3ppm of Cl is counter indicator for use of Al.
  - HCl causes severe corrosion



Fatigue and Fracture, ASM Handbook, Vol. 19, 1996.

Corrosives encountered – Cl (halogens), Example 1

- Failure :Cracked Piston
- Material: CA6NM (Martensitic stainless steel)

Specified gas composition:

- **HCl 5ppm**
- H_2S 3ppm
- H_2O 400ppm

- H_2 84.3%
- CH_4 4.4%
- C_2H_6 2.6%
- C_4H_{10} 1.5%

Corrosives encountered – Cl (halogens), Example 1

- Failure analysis:
  - More Cl present than specified → Cl induced fatigue
  - problem presented after capacity increase - separators, purifiers over capacity, resulting in higher contamination levels

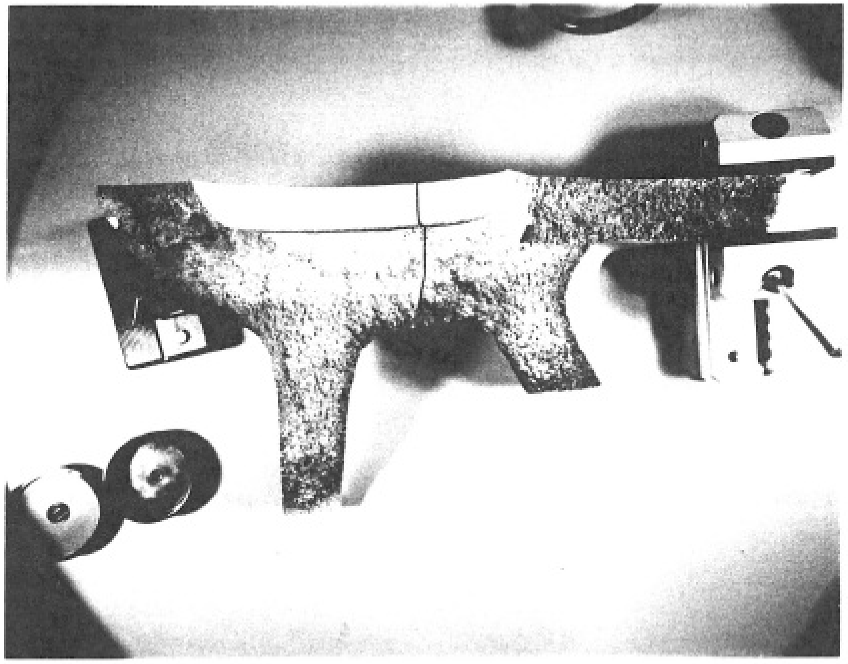
- Remedy:
  - Ni coating as a barrier
  - Improved design for lower alternating stress – higher fatigue resistance
  - Combination of improvements solved the problem

Corrosives encountered – Cl (halogens), Example 2

- Failure: Cracked Piston
- Material: AlSi7Mg

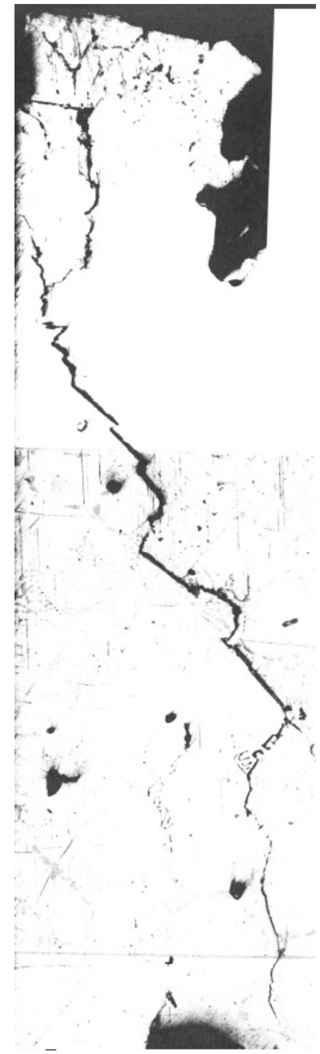
Specified gas composition:

- H_2 89.91%
- CH_4 1.90%
- C_2H_6 2.51%
- C_3 +
- **No Cl specified**



Corrosives encountered – Cl (halogens), Example 2

- Failure analysis:
  - Cl and C found on fracture surface
  - No Cl specified in gas composition
  - Corrosion fatigue under influence of Cl
- Remedy:
  - Find origin of Cl and replace piston with Martensitic Stainless Steel



Corrosives encountered - H_2S

- H_2S causes cracking in parts with high tensile strength
  - Wet H_2S above 0.0035bar or 50ppm is called sour gas and gives Sulphide Stress Corrosion (SSC) risk
  - For most steels a max. hardness of 22HRC is considered safe in sour gas
  - H_2S also causes general corrosion in most steels

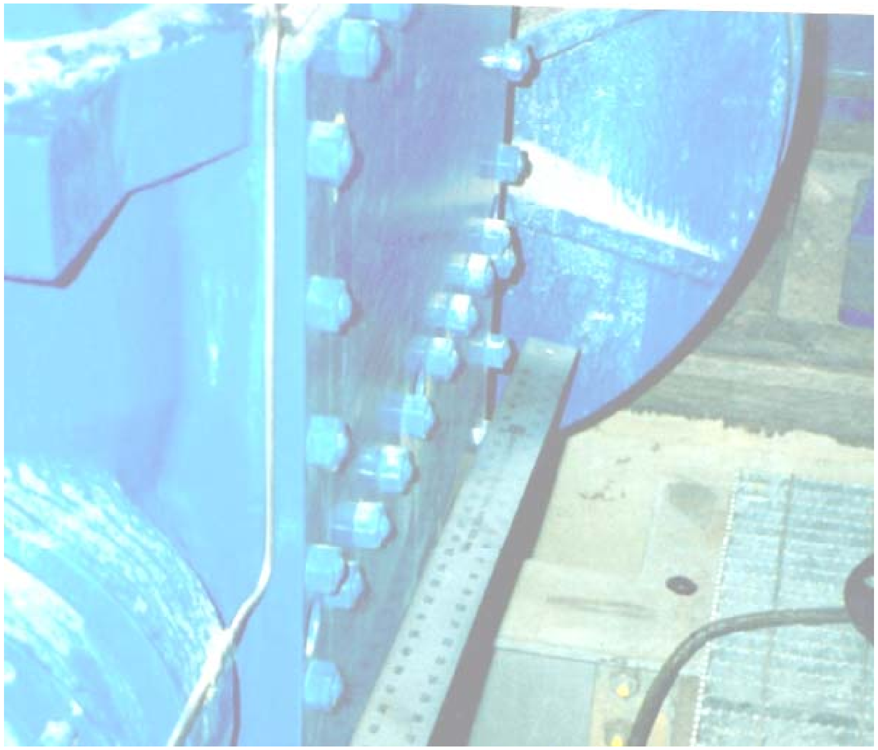
Corrosives encountered – H_2S, Example

- Failure: Failed bolts,cover blew off causing extensive damage
- Material: Hardened Carbon Steel (45RC)

Specified gas composition:

- H2   80.74%
- H2O 0.26%
- CH4 14.92%
- C2 + 4.00%
- NH3 0.01%
- **H2S 10 ppm**

- 30°C, 63.5 Bar



Corrosives encountered – H_2S, Example

- Failure analysis:
  - More H_2S (9000ppm!) and water than specified, causing a sour environment. Combination of H_2S and water simultaneously present.
  - Material hardness in excess of 22 HRC
  - Hydrogen Sulphide induced Cracking, Sulphide Stress Cracking (SSC)

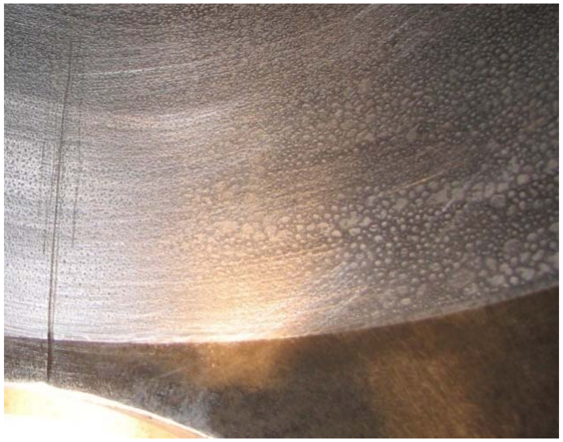
- Remedy:
  - Material Changed to ASTM A193 B7 (CrMo steel) – more bolts needed because the material has lower tensile strength

Corrosives encountered - Other

- Traces of Cl and acids increase corrosivity of other corrodants (traces<10ppm)

- CO_2 is safe up to 20% if dry, 2.5% if wet

- Presence of H_2O and O_2 increase corrosion problems
  - Presence of water with other corrosive elements can cause corrosion where there would be no problem without it. Also the concentration of corrodants in water increases as the water evaporates, increasing the chance/severity of corrosion.



- Other corrodants include: NH_3, CO, various acids (sulfuric, nitric, hydrochloric, organic…) and combinations often have symbiotic effects

Corrosives encountered – Example CO_2

- Failure: Erosion/corrosion in suction valve chamber of cylinder
- Material: Nodular cast iron

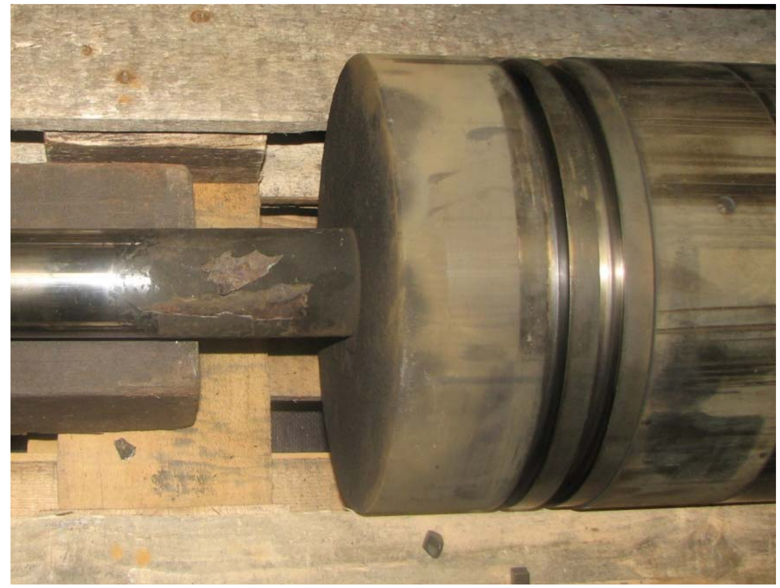
Specified gas composition:

- **CO2 Process Gas**
- H2 0.67%
- CO 0.14%
- CH4 0.045%
- N2 0.019%
- O2 + Ar 0.01%
- **No water specified**

Corrosives encountered – Example CO_2

- Failure analysis:
  - Water present in gas stream (not specified)
  - Product of wet scrubbing
  - Acid formation
- Remedy:
  - Corrosion resistant Stainless Steel “bucket” installed to protect cast-iron from acid

Corrosives encountered – Example various corrodants



- Failure: Cracked Coating on piston rod
- Material: 17-4 PH with HVOF Chromium Carbide Nickel coating

Specified gas composition:

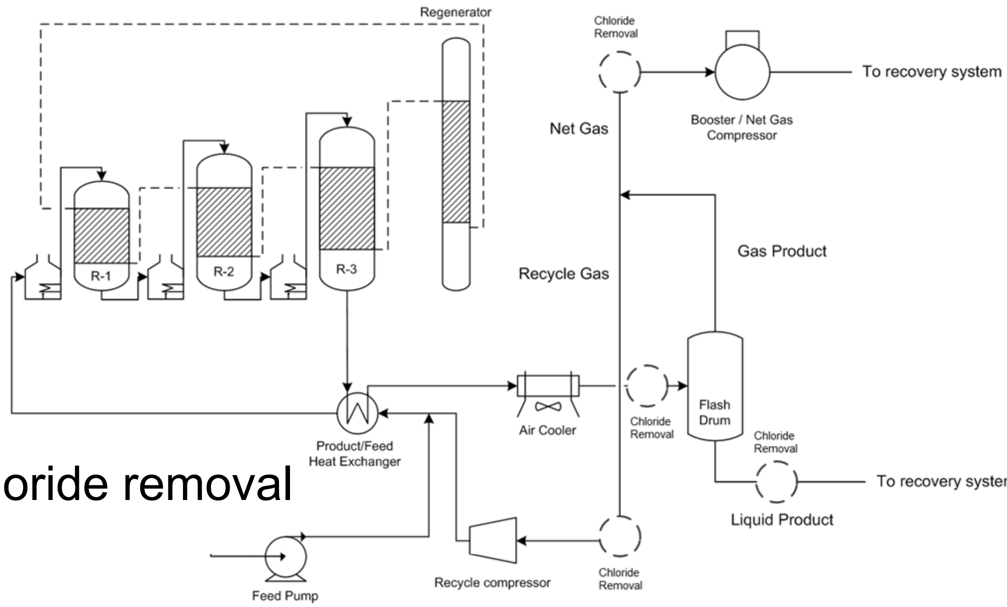
- Nitrogen
- 2.5 CO_2
- 3.3 H_2O

- Benzene 58mg/Nm^3
- Toluene 4.1mg/Nm^3
- Xylene 1.6mg/Nm^3
- Methyl acetate 510mg/Nm^3
- Methyl bromide 250-500mg/Nm^3 (peak 800mg/Nm^3)
- Acetic acid 250-500mg/Nm^3 (peak 3000mg/Nm^3)
- CO 0.27 vol%
- Suction 0.95 bar, 23°C
- Discharge 3.1 bar, 147°C

Corrosives encountered – Example various corrodants

- Failure anaysis:
  - Unusual mix of corrodants – effect more corrosive than expected
  - Coating too porous – corrosion under coating
  - as a result of diffusion through layer
- Remedy:
  - Changed to high density D-gun coating

Corrosives encountered – Why they are in the process

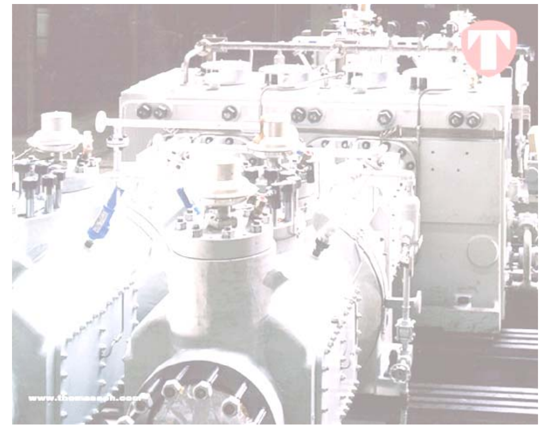


- Separators
  - **removal of fluids**
  - 50-99% efficiency
- Purifiers
  - wet scrubbing, incomplete chloride removal
- Transient Conditions
  - During transient condition separators and purification are at non-design flow – less efficient and more corrosives and fluids pas into the compressor.
  - Condensation is a problem at start-up when the machine is still cold.

Corrosives encountered – Why they are in the process

- CCR Catalytic Reforming
  - 1.0-1.3%Cl is added to the catalyst as activity promoter
  - Choride retention on the catalyst varies depending on operating condition and catalyst condition. As a result, some chlorides end up downstream.
  - This Cl is partially removed by activated alumina – this does not remove organic chlorides (green-oil) and can lead to additional green-oil formation
- Hydrotreating
  - Compulsory removal of sulfur produce high levels of H_2S and NH_3
  - H_2S and NH_3 can be removed by Wet/Amine Scrubbing with varying success – reduction to 1ppmv is possible, but not always achieved

What can be done to prevent problems?



- Various preventative standards
  - NACE, API, OEM
- Efficient removal of corrodants
  - activated alumina, wet/amine scrubbing, hydrotreating, separators
- Correct material selection based on given conditions
  - Corrosion of less than 0.125mmpy is considered safe. More than 1.25mmpy is severe.
- Knowledge of application (process characteristics, corrosives, liquids)

What can be done to prevent problems? - Standards

- NACE - sulphide stress cracking / **stress corrosion cracking**
  - MR-01-75 - General metals
  - MR-01-03 - Metals for compressors

- API 618
  - **General guidelines**; reciprocating compressors, petroleum industry

- OEM Guidelines for Material selection against Corrosion

What can be done to prevent problems?

Watch out for:

- H_2S, Cl, CO_2, O_2… above trace amounts
- Water (low temperature, dew point)

Conclusions

- Specification should include all details about corrosive components.
- Knowledge of the application can be critical.
- Many challenging corrosive components in the gas stream that are a potential threat to the compressor's reliability, if ignored in the design phase.

- It is a joint responsibility to design for the actual corrosive components in the gas stream in order to assure reliable operation.