INSTITUTE OF CORROSION

Annual Corrosion Forum (ACF)

Aberdeen Branch - August 2021

trac

Sponsor: TRAC Oil and Gas

Title: Principles of External Corrosion

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Global Corrosion Cost

- The global cost of corrosion: US$ 2.5 Trillion (2013)
- 15% to 35% of the cost of corrosion can be saved by using available corrosion control practices
- These costs typically do not include individual safety or environmental
- Uhlig performed a comprehensive study in 1949 that revealed a cost of corrosion equivalent to 2.5% of the U.S. GDP.

(Ref: International measures of prevention, application and economics of corrosion technologies Study (NACE International Impact, March 2016)

- 40% to 60% of pipe maintenance costs are a result of CUI
- 10% of total annual maintenance costs is dedicated to repairing damage caused by CUI

(Ref: www.armacell.com/oilandgas)

Introduction to corrosion

- External corrosion refers to a type of electrochemical degradation mechanism that occurs on the surface of metals

- Environmental Factors:

1. Soil
2. Water
3. Air

42 Inch cooling water line leak suffered from severe external corrosion (www.metalytespipework.com)

Corrosion Cell

1. Anode
2. Cathode
3. Electrolyte
4. Electrical Connection

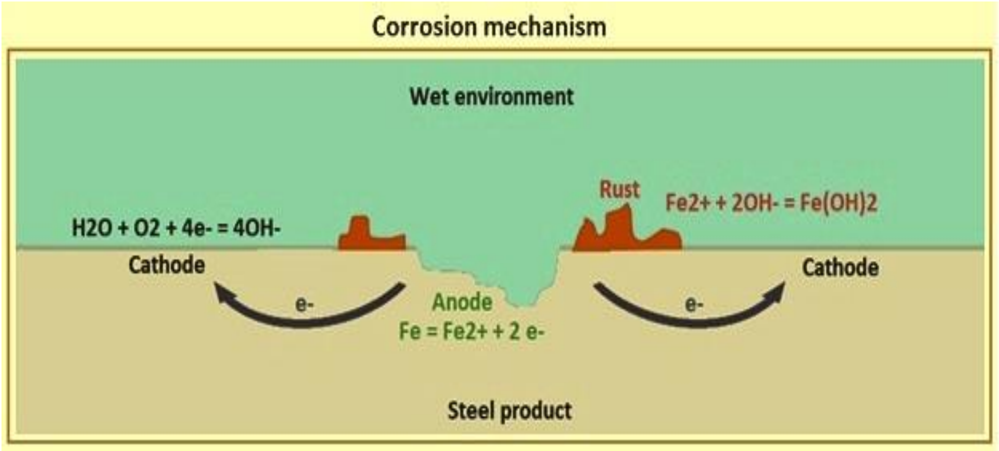
<u>External Corrosion Mechanism</u>

Anodic Reaction:

$M \rightarrow M + ne$

Cathodic Reactions:

1. $O_2 + 2H_2O + 4e \rightarrow 4OH$ aerated neutral to alkaline water
2. $O_2 + 4H^+ + 4e \rightarrow 2H_2O$ aerated acidic solutions
3. $2H^+ + 2e \rightarrow H_2$ hydrogen evolution (in acids)



www.ispatguru.com

External Corrosion Modes

Uniform corrosion is characterized by corrosive attack proceeding evenly over the entire surface area, or a large fraction of the total area. General thinning takes place until failure. On the basis of tonnage wasted, this is the most important form of corrosion.

www.nace.org

External Corrosion Modes

Localised corrosion is characterised by damage that occurs preferentially at discrete sites on a material surface and may result in the formation of pits, cracks and grooves. A large cathode-to-anode area ratio is generally required in order to form an intense local anode.

- ❑Pitting corrosion
- ❑Crevice Corrosion
- ❑Galvanic Corrosion

Stainless steel External Pitting Corrosion
www.materialgrades.com

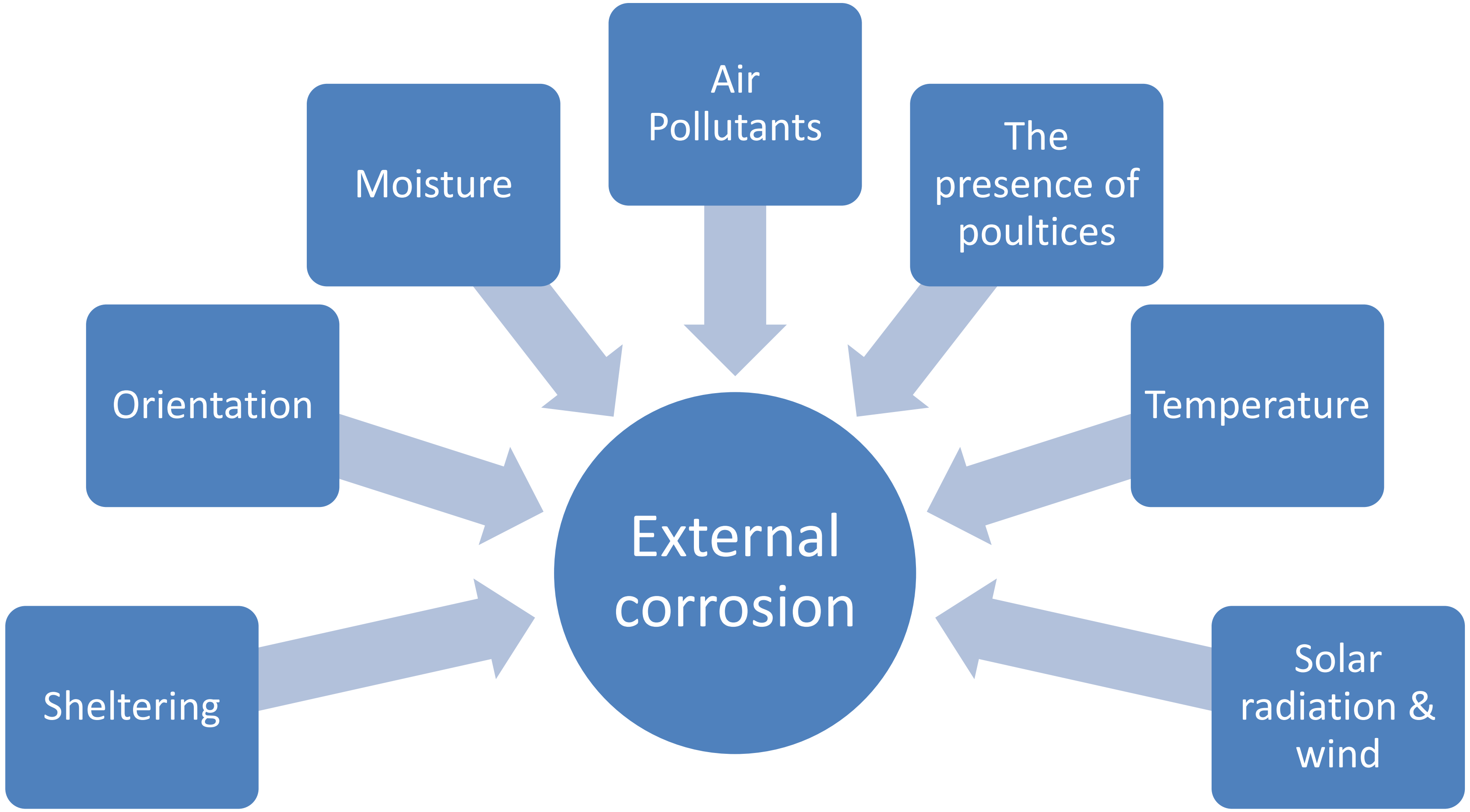
Rubber pads accelerate crevice corrosion
www.stoprust.com

External Corrosion Modes

Environmental Cracking (SCC/CLSCC):
Stresses that cause environmental cracking arise from residual cold work, welding, grinding, thermal treatment, or may be externally applied during service and, to be effective, must be tensile

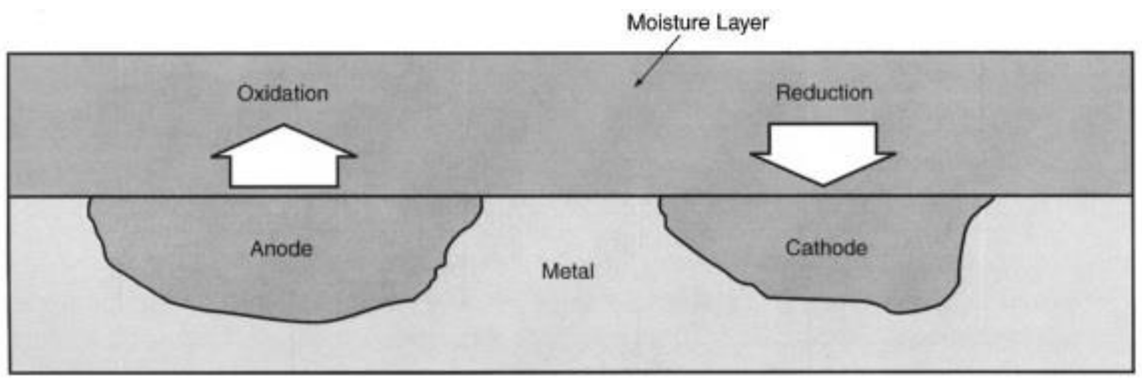
Example of stress corrosion cracking of a Type 316 stainless steel under thermal insulation at 50 to 60°C. Rinsing water containing 60 mg/lit of chloride and residual stresses are at the origin of cracking (www.researchgate.net)

Parameters affecting External corrosion

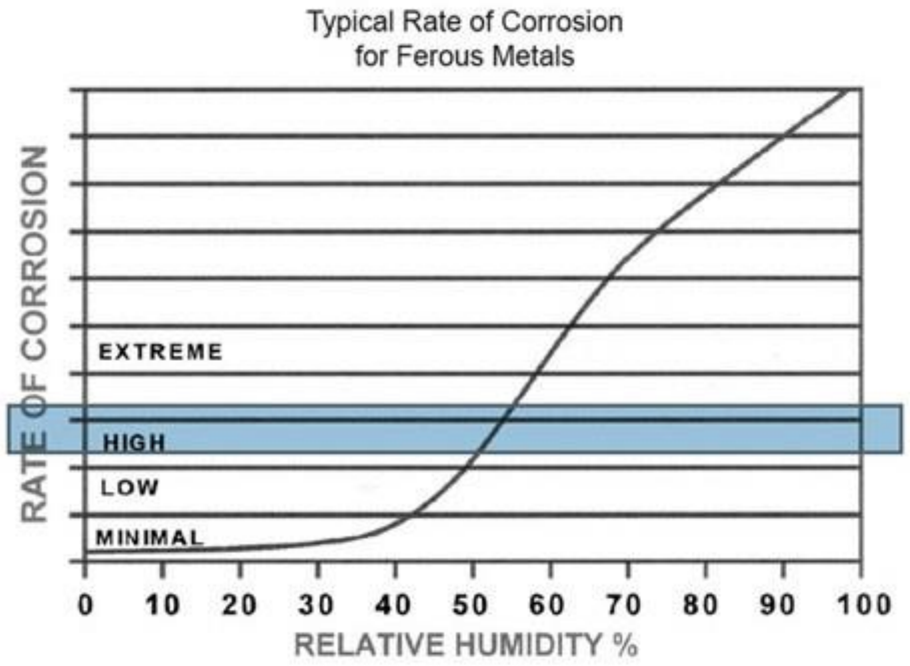


Moisture & Relative Humidity

- Presence of moisture
- Time of wetness
- Threshold humidity



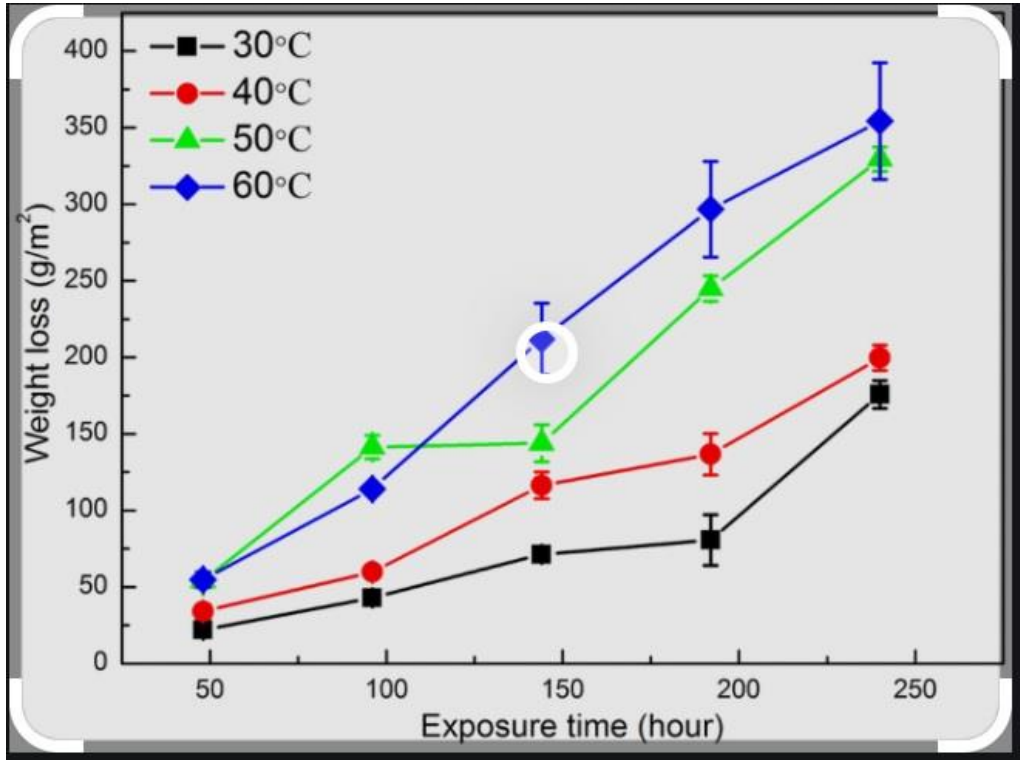
Ref: External Corrosion, Introduction to Chemistry and Control, AWWA, Manual M27, Second Edition



Ref: www.bry-air.com

Temperature

- Relative humidity and dew point
- Time of wetness
- Kinetics of corrosion reaction



Ref: Effect of Temperature on Corrosion Behaviour of Low-Alloy Steel Exposed to a Simulated Marine Atmospheric Environment, Chen Pan, Journal of Materials Engineering and Performance, February 2020

Air Pollutants

- Sulfur Oxides (Forms sulfuric acid)
- Chlorides (CLSCC)
- Particulates and aerosols (Retain moisture)
- Ammonia (Causes stress corrosion of brass)
- Sulfur dioxide (decreases threshold humidity, causing corrosion to occur at lower air moisture contents
- H2S, fly ash and other airborne contaminates from cooling tower drift, furnace stacks and other equipment accelerate corrosion

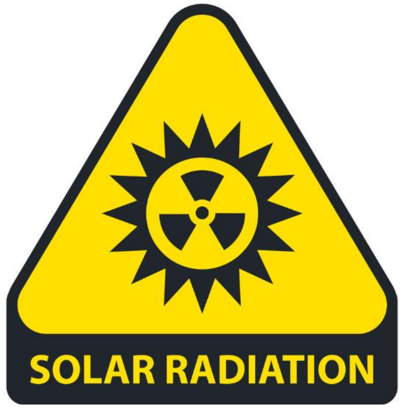
Ref: TehranTimes - And now comes the acid rain

Poultice

- A poultice is any material that traps and retains moisture and air pollutants. An accumulation of soil, dirt, organic matter, or other similar medium that can hold moisture and pollutants against the surface will increase the corrosion of that surface

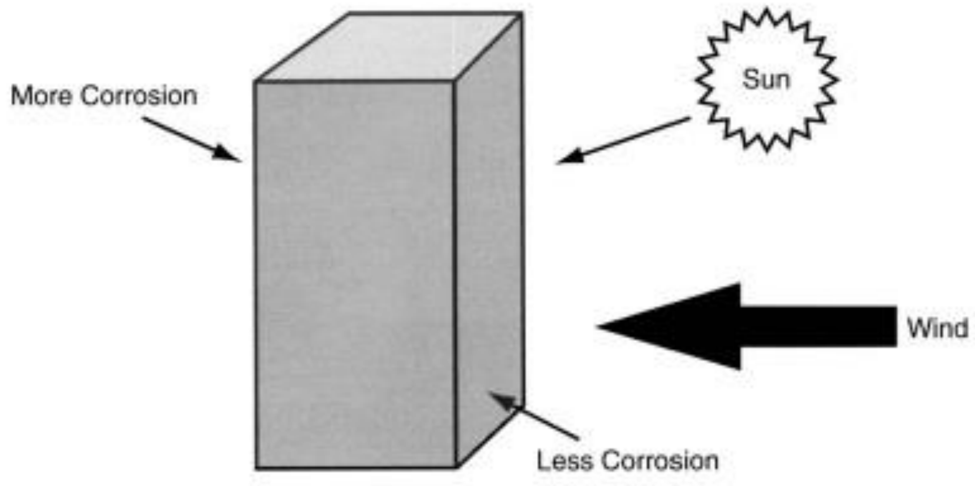
Solar radiation & Wind

- Solar radiation and wind affect the time of wetness
- Solar radiation (ultraviolet light exposure) also affects the life of protective coatings on the surface
- Wind affects the accumulation of particulates. Chlorides, moisture, or other contaminants blown by the wind can be deposited on surfaces, causing local corrosion in the direction of the prevailing wind



Orientation

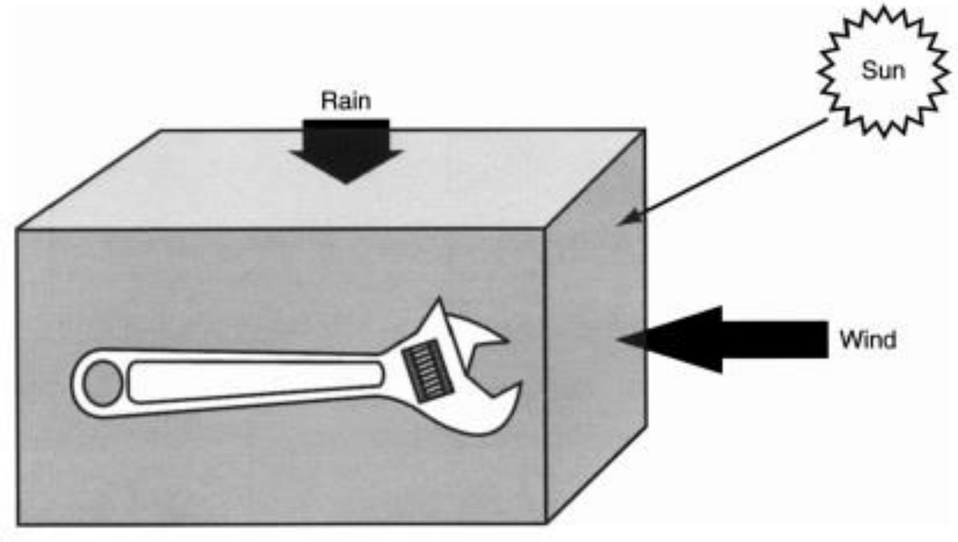
- A surface that is shaded from sunlight will tend to stay moist longer than one that is heated by sunlight. The longer moisture stays on the surface, the more corrosion (remember time of wetness).
- Similarly a surface that is shielded from the wind will tend to stay moist longer and suffer more corrosion.
- Horizontal surfaces facing up will be washed by rain and will not collect contaminants; however, if the surface is not drained and moisture collects, so can contaminants, leading to increased corrosion.
- Downward facing horizontal surfaces corrode more than their upward facing counterparts because they collect condensation.



Ref: External Corrosion, Introduction to Chemistry and Control, AWWA, Manual M27, Second Edition

Sheltering

- Parts that are sheltered from the elements may be corroded less than those that are exposed.
- On the other hand, moisture can condense on sheltered objects and the sheltering will prevent drying.
- Moisture can diffuse through seals and condense inside an enclosure, resulting in a build up of moisture.
- The temperature inside sheltered environments can rise higher than outside the enclosure, increasing corrosion rates.



Ref: External Corrosion, Introduction to Chemistry and Control, AWWA, Manual M27, Second Edition

Atmospheric Corrosion (Carbon Steel)

- Atmospheric corrosion is a form of **oxygen corrosion**. General corrosion will occur where surfaces are continuously or intermittently wetted with aerated water

- **Affected Materials:** Carbon steel, low alloy steels and copper alloyed aluminium

- **Corrosion rate**

❑ Marine Environment 5-10 mpy,
❑ Inland locations with moderate humidity 1-3 mpy,
❑ Dry Environments <1mpy

- **Appearance or morphology of damage**: General or localised

- **Prevention and mitigation:** Surface preparation and proper coating/paining

- **Inspection and monitoring:** VT & UT

Atmospheric Corrosion of an LPG line in close proximity to a cooling tower (API 571)

Pitting Corrosion

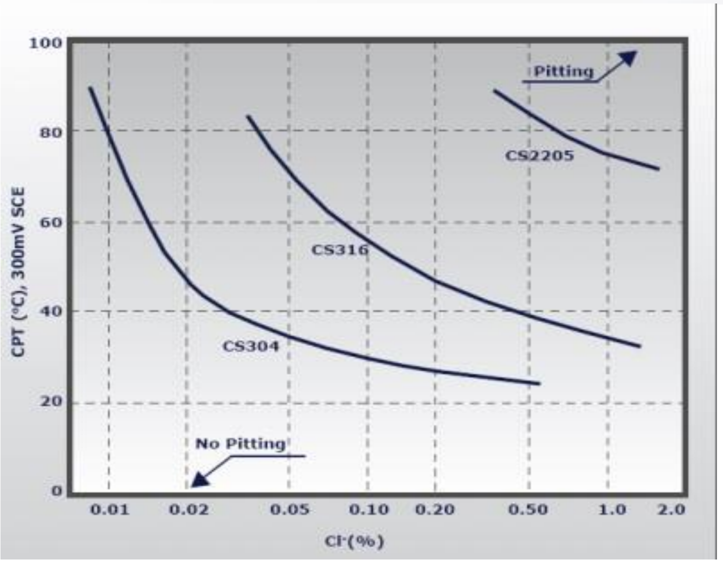
- External corrosion in the atmospheric environment can occur in the form of pitting or cracking in presence of chloride

- **Critical Pitting Temperature (CPT):**

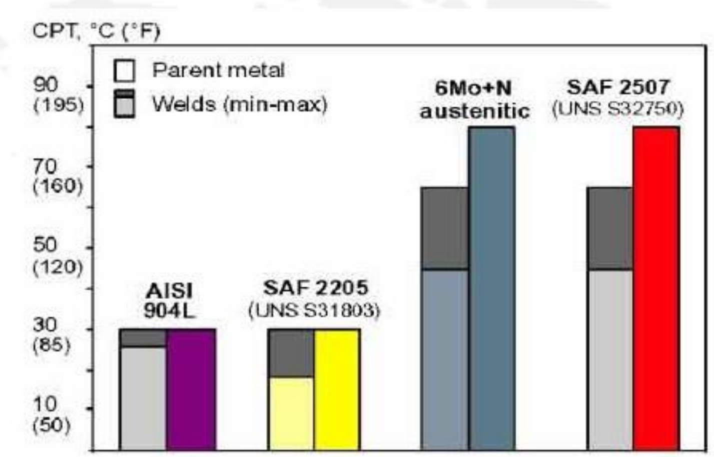
❑ A material's resistance to pitting corrosion is usually evaluated and ranked using the critical pitting temperature

❑ ASTM Standard G48-03: Standard Test Methods for Pitting and Crevice Corrosion of Stainless Steels and Alloys by Use of FeCl3

❑ The critical pitting temperature is the minimum temperature (°C) to produce pitting corrosion and CPT is usually higher than the critical crevice temperature (CPT).



Critical Pitting Temperature
Ref: www.northamericanstainless.com



Critical Pitting Temperature
Ref: www.corrosionclinic.com

Crevice Corrosion

Crevice corrosion is a localised attack at the gap or crevice between Two joining surfaces. The gap or crevice can be formed between two metals
Or a metal and non-metallic material.

- **Affected Materials:**

❑ All grades of stainless steel and aluminium alloys

- **Critical Factors**

❑ Crevice type, metal to metal or metal to non-metal
❑ Crevice geometry: gap size, depth, surface roughness
❑ Material: alloy composition (e.g. Cr, Mo)
❑ Environment: pH, Temp, Halide ions, Oxygen

- **Prevention:**

❑ Use welded butt joints instead of riveted or bolted joints
❑ Eliminate crevices at gap joints by continuous welding
❑ Avoid stagnant conditions and ensure complete drainage
❑ Use solid, non-absorbent gaskets such as Teflon
❑ Use higher grade alloys with higher resistant

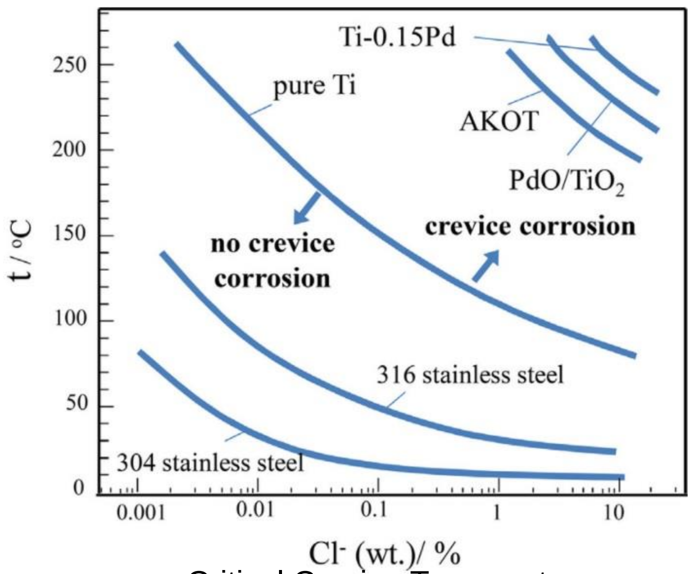
External corrosion of a pipe at a pipe support. Both the pipe and support Are corroding at the crevice formed between the two. The coating is also breaking back as it under rust the crevice at the edge (Ref: Guidance for corrosion management in oil and gas production and processing, second edition, HSE & Energy Institute)

Crevice Corrosion

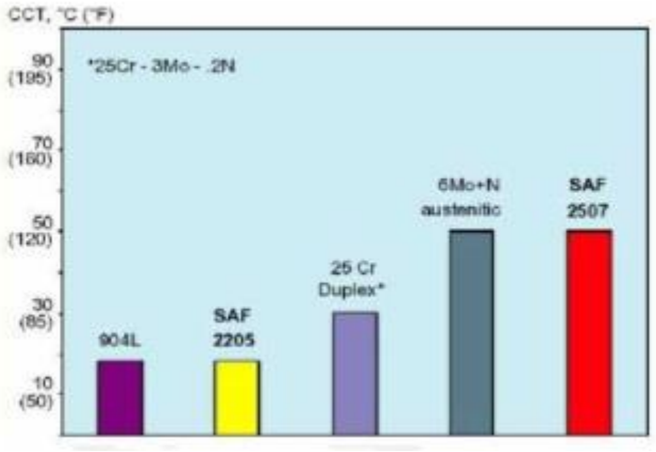
- **Critical Crevice Temperature (CCT)**

❑ A materials resistance to crevice corrosion is evaluated by using the CCT in accordance with the ASTM standard G48-03: Standard test method for pitting and crevice corrosion of stainless steel and alloys by use of FeCl3

❑ The critical Crevice Temperature is the minimum temperature (°C) to produce crevice attack and CCT is usually lower than the critical pitting temperature (CPT)



Critical Crevice Temperature
Ref: www.researchgate.net



Critical Crevice Temperature
Ref: www.corosionclinic.com

Environmental Assisted Cracking

- **Affected Materials:**

❑ Pitting: Stainless Steels, Aluminium Alloys, etc.
❑ CLSCC: All 300 Series SS are highly susceptible, Duplex stainless steels are more resistant

- **Critical Factors**

❑ Chloride content, pH, temperature, stress, presence of oxygen and alloy composition are critical factors.
❑ Increasing temperatures increase the susceptibility
❑ Increasing levels of chloride increase the likelihood of cracking.
❑ No practical lower limit for chlorides exists because there is always a potential for chlorides to Concentrate.

- **Temperature:**

❑ Pitting: At any temperature for SS/DSS and above 30°C for SDS
❑ CLSCC: At temperatures above 60°C (Exceptions at lower temp)

External cracking of Type 304SS instrument tubing under insulation (API 571)

Atmospheric Corrosion (CRA Materials)

- **Appearance or morphology of damage**:

❑ Surface breaking cracks can occur from the process side or externally under insulation

❑ Characteristic stress corrosion cracks have many branches and may be visually detectable by a craze-cracked appearance of the surface

❑ Metallography of cracked samples typically shows branched transgranular cracks

❑ Sometimes intergranular cracking of sensitized 300 Series SS may also be seen

- **Prevention and mitigation:**

❑ Selection of resistant material

❑ Proper surface preparation and coating application

❑ Avoid stagnant regions during design where chlorides can concentrate or deposit.

❑ Stress Relief

- **Inspection and monitoring:**

❑ VT

❑ PT or phase analysis EC techniques are the preferred methods (Extremely fine cracks may be difficult to find with PT)

❑ RT is not sufficiently sensitive to detect cracks except in advanced stages

External cracking of Type 304SS instrument tubing under insulation (API 571)

Galvanic Corrosion

- **Affected Materials:** All metals with the exception of most noble metals

- **Critical Factors**

❑ Presence of an electrolyte, galvanic corrosion occurs externally only when you have water accumulation on the surface
❑ Two different materials or alloys known as the anode and the cathode
❑ An electrical connection must exist between the anode and the cathode

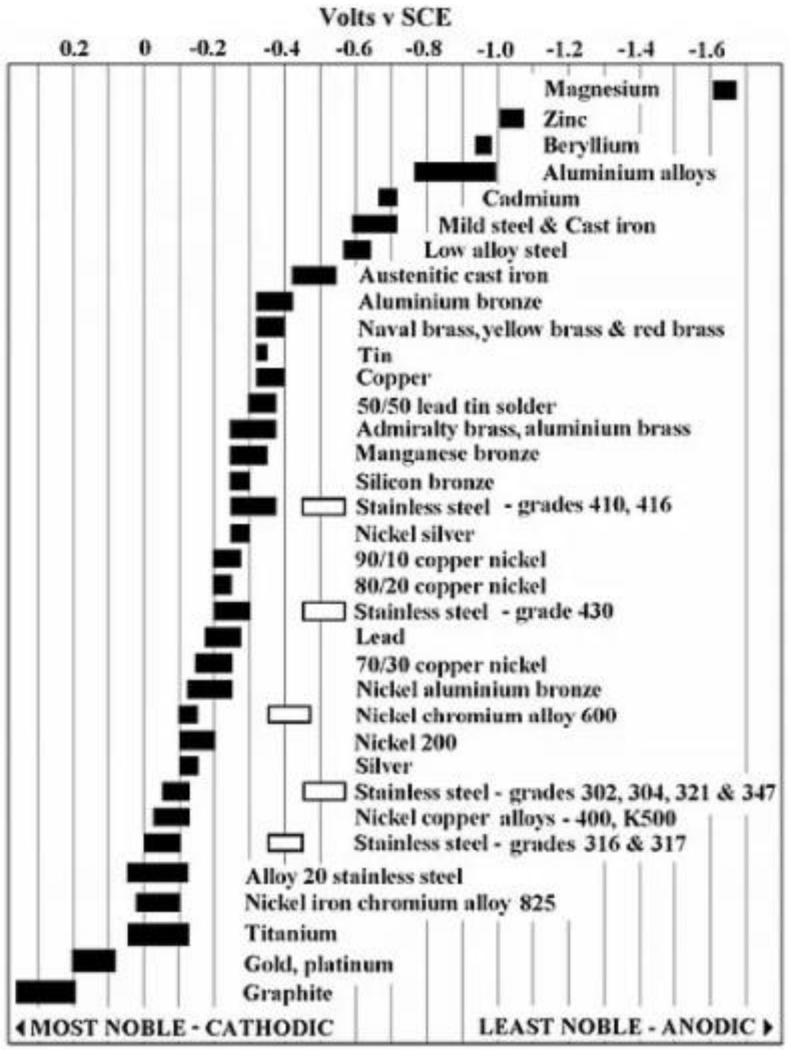
- **Appearance or morphology of damage:** Generalized loss in thickness or may have the appearance of a crevice, groove or pitting corrosion, depending on the driving force, conductivity and relative anodic/cathodic areas ratio

- **Prevention and mitigation:**

❑ Good design
❑ Coatings
❑ Insulating bolt sleeves and gaskets can eliminate the electrical connection.

- **Inspection and monitoring:**

❑Visual inspection and UT
❑The damage may sometimes be hidden underneath a bolt or rivet head



Galvanic Series of Metals

CUI

- Corrosion of piping, pressure vessels and structural components resulting from water trapped under insulation or fireproofing

- **Affected Materials**: Carbon steel, low alloy steels, 300 Series SS, and duplex stainless steels

- **Temperature range**:

❑ 0°F (–12°C) and 350°F (175°C) for carbon and low alloy steels,
❑140º F (60°C) and 400º F (205°C) for austenitic stainless steels and duplex stainless steels

- **Appearance or morphology of damage**:

❑ Carbon and low alloy steels: localised pitting or localised wall loss
❑ 300 SS and Duplex SS: Pitting or SCC if chloride present

- **Insulation Types**

❑ Mineral Wool
❑ Fiberglass
❑ Polystyrene
❑ Cellulose
❑ Polyurethane Foam

CUI can take the form of localized external corrosion in carbon and low-alloy steels, external stress corrosion cracking or pitting in austenitic and duplex stainless steel (www.offshore-mag.com)

CUI

- **Prevention and mitigation:**

❑ Appropriate painting/coating

❑ Careful selection of insulating materials is important. Closed-cell foam glass materials will hold less water against the vessel/pipe wall than mineral wool and potentially be less corrosive

❑ Low chloride insulation should be used on 300 Series SS to minimize the potential for pitting and chloride SCC

❑ If possible, removing the insulation on equipment where heat conservation is not as important

- **Inspection and monitoring:**

❑ Partial and/or full stripping of insulation for visual examination

❑ UT for thickness verification

❑ Real-time profile x-ray (for small bore piping)

❑ Neutron backscatter techniques for identifying wet insulation

❑ Deep penetrating eddy-current inspection (can be automated with a robotic crawler)

❑ IR thermography looking for wet insulation and/or damaged and missing insulation under the jacket.

❑ Guided wave UT

Tee in a 1000 psig ethylene line
BEFORE insulation removal (API 571)

Tee in a 1000 psig ethylene line
AFTER insulation removal (API 571)

Soil Corrosion

- The deterioration of metals exposed to soils is referred to as soil corrosion.
- **Affected Materials**: Carbon steel, cast iron and ductile iron
- **Affected Equipment:** Tank Bottoms, Buried pipelines and structures
- **Critical Factors**

❑ Temperature
❑ Moisture
❑ Oxygen
❑ Soil Resistivity
❑ Soil Type
❑ Homogeneity
❑ Cathodic Protection
❑ Stray Current
❑ Coating Type

www.nace-txlagulfsection.org

Soil Corrosion

- **Appearance or morphology of damage**:

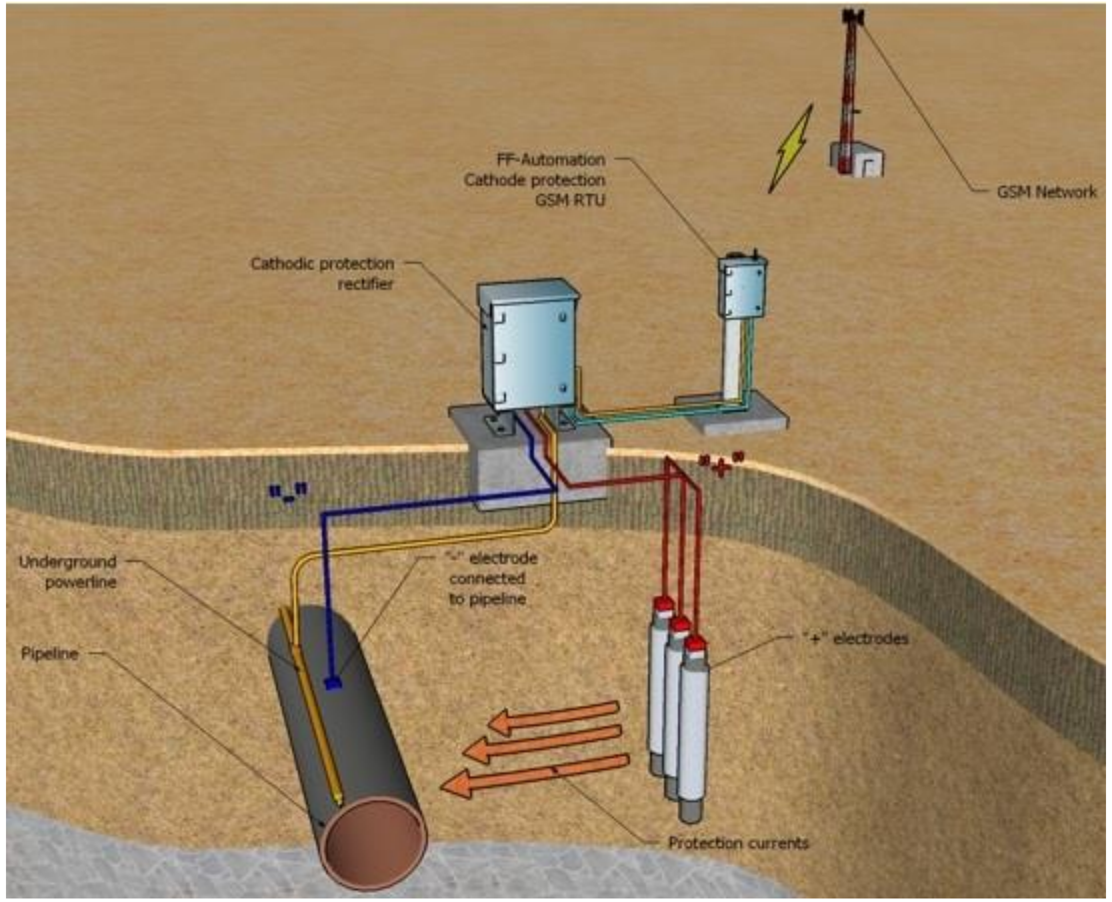
❑ Soil corrosion appears as external thinning with localized losses due to pitting.
❑ Poor condition of a protective coating is a tell tale sign of potential corrosion damage

- **Prevention and mitigation:**

❑ Special Backfill
❑ Coating
❑ Cathodic Protection

- **Inspection and monitoring:**

❑ Measuring the structure to soil potential
❑ Visual Inspection
❑ Guided wave Ultrasonic
❑ Pressure testing



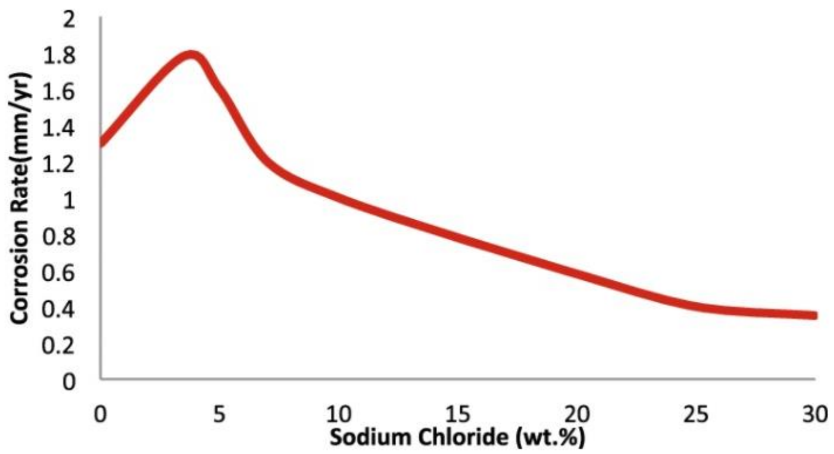
www.ff-automation.com

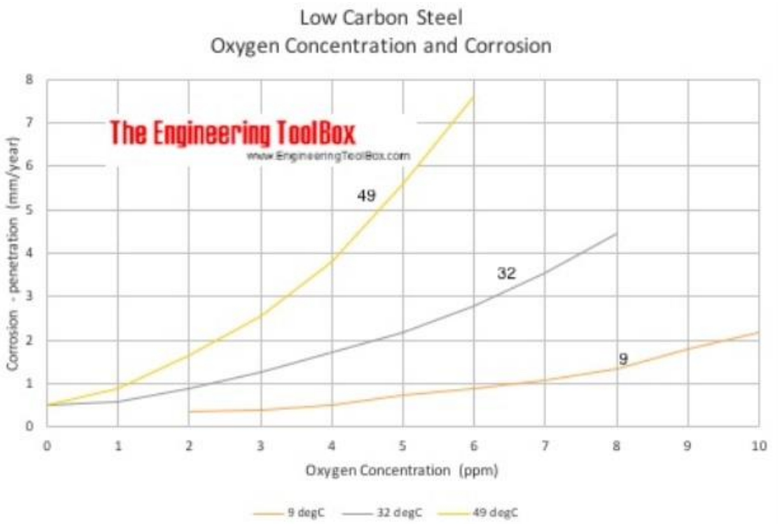
Seawater

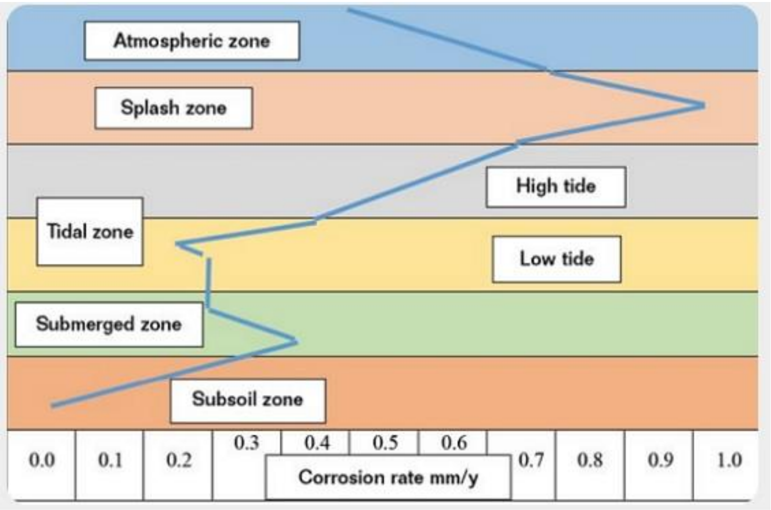
- **Corrosion Types**
- Oxygen corrosion for CS
- MIC for CS
- Pitting and cracking for CRA materials

- **Critical Factors**
- ❑ Chloride Concentration
- ❑ Oxygen
- ❑ Temperature
- ❑ Depth of water
- ❑ Flow velocity

- **Materials in Seawater**
- ❑ Plain Steels
- ❑ Stainless Steels
- ❑ Copper alloys
- ❑ Concrete
- ❑ Aluminium
- ❑ Titanium and Titanium Alloys







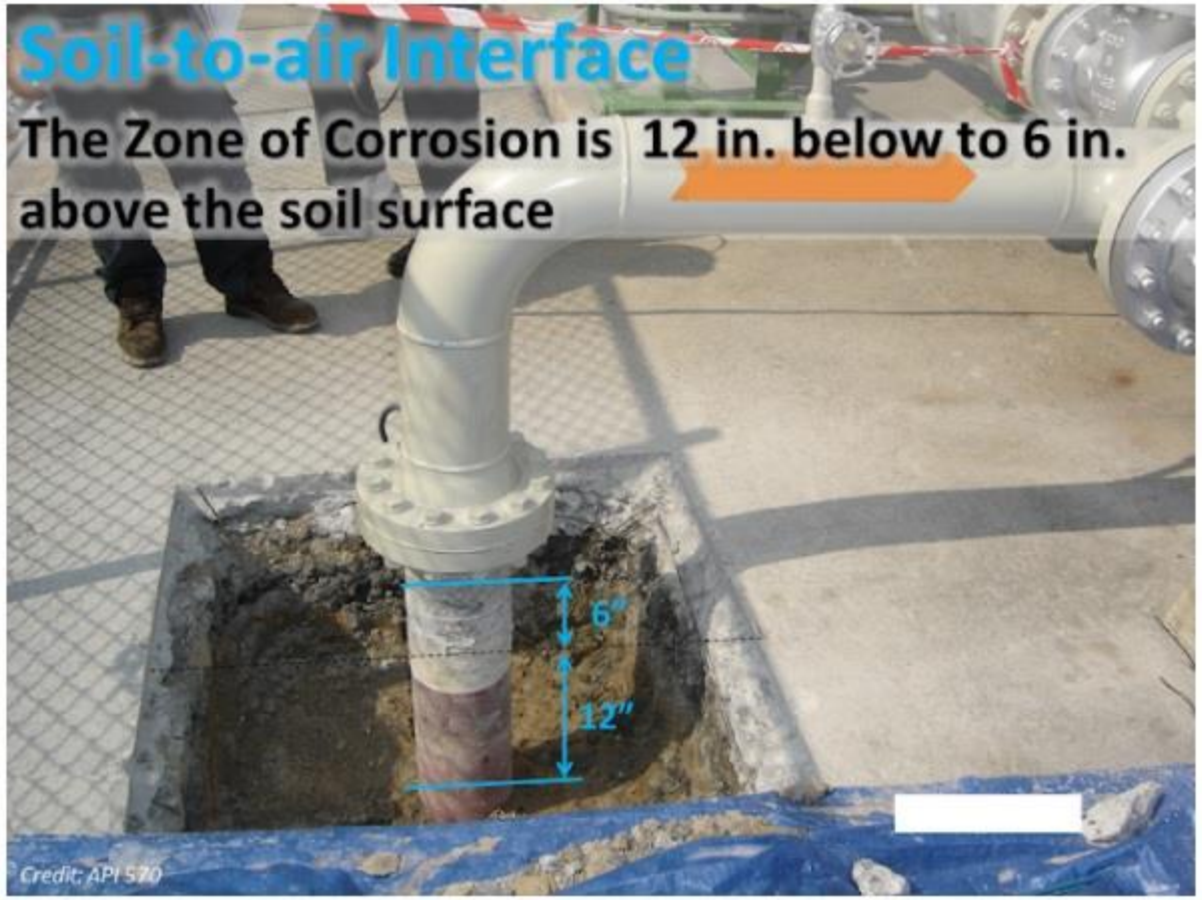
Interface Corrosion (Soil to Air)

- **Differential Aeration cell**

(This type of corrosion takes place due when there is an uneven supply of oxygen to areas of the same metal component. Differential aeration cells are concentration cells in which differing concentrations of oxygen is the driving force for corrosion)

- **Coating**
- **Cathodic protection**
- **Inspection**

Soil to air interface pipe corrosion repair
(www.banksindustrial.com)



Corrosion of carbon steel pipe at the
soil-air interface where the pipe emerges from
Underground (www.amarinblog.com)

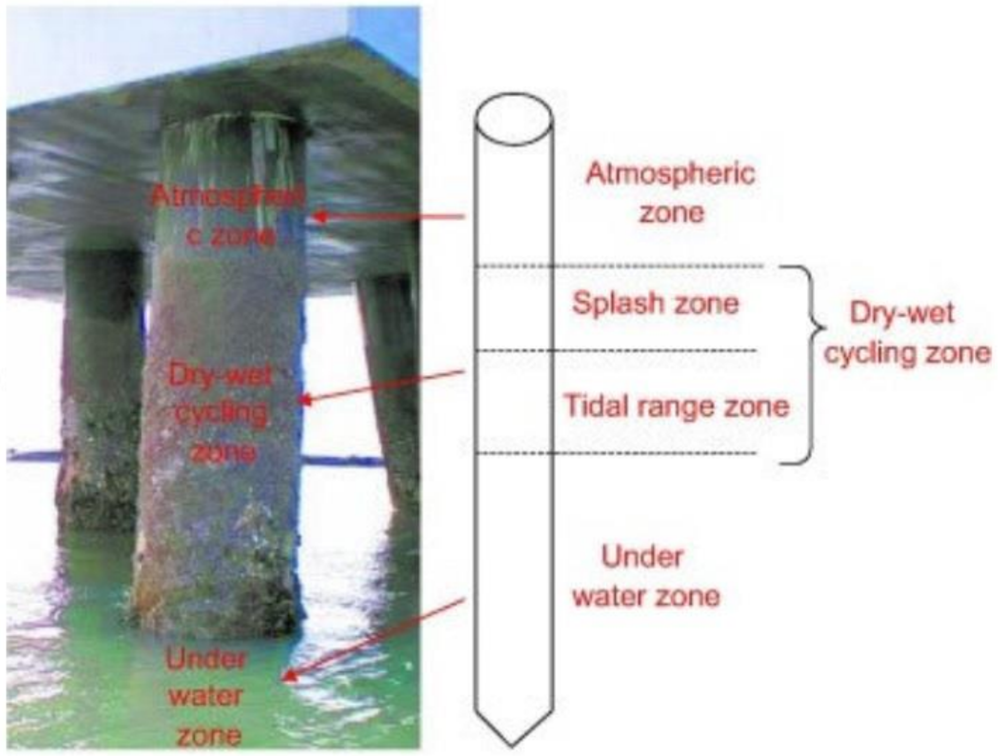
Interface Corrosion (Splash Zone)

- The splash zone is the section of the structure that is intermittently in or out of seawater due to tides and winds during the structure's service life

- Range of splash zone
  - ❑ North China Sea (3.32 ft)
  - ❑ Gulf of Mexico (6 ft)
  - ❑ North Sea (33 ft)

- Cathodic protection (may not be very effective)

- Coatings & Inspections (more effective)



Splash Zone
www.researchgate.net

References:

- API 571
- API 581
- International measures of prevention, application and economics of corrosion technologies Study (NACE International Impact, March 2016)
- www.hse.gov.uk
- Guidance for corrosion management in oil and gas production and processing, second edition, HSE & Energy Institute
- External Corrosion, Introduction to Chemistry and Control, AWWA, Manual M27, Second Edition
- www.sciencedirect.com

End of Presentation – Your Questions Please