

## CORROSION

Corrosion must be considered for any heat exchanger application, although corrosion may not be a concern for some applications. The cost of corrosion is always more significant than just the replacement of the heat exchanger or element. Process down time, change out cost, accessing the equipment and pressure testing are all additional costs of corrosion.

Corrosion is a very broad and complex topic to cover. Many large process companies have complete departments dedicated to addressing and managing corrosion. Due to the varied designs and application of heat exchangers and the fact that they can contain many different fluids under various flow and temperature ranges, several volumes can be written on this topic.

In general, heat exchanger companies will not make material recommendations to guard against corrosion because the source of corrosion can vary and change also; the fluid chemistry and environment can change over the operating life of the exchanger, even just for short periods of time (such as a spike in water chemistry). There are, however, generally accepted material that are used for most common applications. As suppliers of heat exchangers, the topic of corrosion comes up frequently and although we cannot always provide solutions or recommendations, we recognized the importance of addressing corrosion. This document is only meant to provide general information on corrosion. Each application is specific and, considering the investment involved in heat transfer equipment, the topic of corrosion should be left to the experts in the field such as metallurgists and labs.

### Factors Affecting Corrosion

- fluid chemistry
- fluid (or metal temperature)
- fluid flow rate
- metal or combination of metals
- metal working (forming or welding)
- maintenance or cleaning frequency
- fouling
- film formation

### Factors to Consider to Minimize the Effects of Corrosion

- material selection
- material coating
- material thickness
- heat exchanger type
- impingement attack
- drain & dry heat exchangers when not in use

## Types of Corrosion

### General or Uniform Corrosion

Uniform corrosion or general corrosion is best described as the more common example of corrosion we see in everyday life. It is defined as a type of corrosion attack (deterioration) that is more or less uniformly distributed over the entire exposed surface of a metal. Uniform corrosion also refers to the corrosion that proceeds at approximately the same rate over the exposed metal surface. Cast irons and steels corrode uniformly when exposed to open atmospheres, soils and natural waters, leading to the rusty appearance. In natural environment, oxygen is the primary cause of uniform corrosion of steels and other metals and alloys.

### Mechanisms

Typically a result of attack by certain mineral acids or certain corrosive organic acids.

### Prevention

This type of corrosion is very easily predicted so, although it is commonly seen on cast iron or steel components left in a field, it is uncommon in heat exchangers because it has been addressed in the design. Uniform corrosion or general corrosion can be prevented or controlled through a number of methods:

- Material selection; most common in carbon steel and cast iron
- Use thicker materials for corrosion allowance
- Use paints or metallic coatings such as plating, galvanizing or anodizing
- Use Corrosion inhibitors or modifying the environment
- Cathodic protection (SA/ICCP) and Anodic Protection

### **Galvanic Corrosion**

Galvanic corrosion, Bimetallic Corrosion or Dissimilar Metal Corrosion, as sometimes called, is defined as the accelerated corrosion of a metal because of an electrical contact (including physical contact) with a more noble metal or nonmetallic conductor (the cathode) in a corrosive electrolyte.

The less corrosion resistant or the "active" member (anodic) of the couple experiences accelerated corrosion while the more corrosion resistant or the "noble" member of the couple experiences reduced corrosion due to the "cathodic protection" effect.

The most severe attack occurs at the joint between the two dissimilar metals. Further away from the bi-metallic joint, the degree of accelerated attack is reduced.

The chart to the right is a galvanic table. This particular table lists metals in the order of their relative activity in seawater environment. A "galvanic series" applies to a particular electrolyte solution, hence for each specific solution which is expected to be encountered for actual use, there will be a different order or series. The list begins with the least active (cathodic) metal and proceeds down the to the more active (anodic) metal of the galvanic series. In a galvanic couple, the metal lower in the series (or the smaller) represents the anode, and will corrode preferentially in the environment. In general, the further apart the materials are in the galvanic series, the higher the risk of galvanic corrosion, which should be prevented by design. Conversely, the farther one metal is from another, the greater the corrosion will be. However, the series does not provide any information on the rate of galvanic corrosion and thus serves as a basic qualitative guide only. The use of the galvanic series has to be done with caution and a basic knowledge of the environments that is a necessary part of this serious form of corrosion.

For an example of galvanic corrosion, consider a system is composed of 316 SS (a very noble alloy - meaning it is quite resistant to corrosion and has a low galvanic potential) and a mild steel (a very active metal with high galvanic potential). The mild steel will corrode in the presence of an electrolyte such as salt water. If a sacrificial anode is used (such as a zinc alloy, aluminum alloy, or magnesium), these anodes will corrode, protecting the other metals.

### **Mechanisms**

When two or more different sorts of metal come into contact in the presence of an electrolyte a galvanic couple is set up as different metals have different electrode potentials. The electrolyte provides a means for ion migration whereby metallic ions can move from the anode to the cathode. This leads to the anodic metal corroding more quickly than it otherwise would; the corrosion of the cathodic metal is retarded even to the point of stopping. The presence of electrolyte and a conducting path between the metals may cause corrosion where otherwise neither metal alone would have corroded.

The potential difference (i.e., the voltage) between two dissimilar metals is the driving force for the destructive attack on the active metal (anode). Current flows through the electrolyte to the more noble metal (cathode) and the less noble (anode) metal will corrode. The conductivity of electrolyte will also affect the degree of attack. The cathode to anode area ratio is directly proportional to the acceleration factor.

### **Galvanic Series for Seawater**

#### **Most Noble or Cathodic (resistant to corrosion)**

Graphite  
Platinum  
Ni-Cr-Mo Alloy C  
Titanium  
Ni-Cr-Mo-Cu-Si Alloy G  
Ni-Fe-Cr Alloy 825  
Alloy 20 stainless steels, cast and wrought  
Stainless steel Types 316, 317  
Nickel copper alloys 400 K-500  
Stainless steel Types 302, 304, 321, 347  
Silver  
Nickel 200  
Silver-bronze alloys  
70-30 copper Nickel  
lead  
Stainless steel Type 430  
80-20 copper nickel  
90-10 Copper nickel  
Nickel silver  
Stainless steel Types 410, 416  
Tin bronzes (G & M)  
Silicon bronze  
Manganese bronze  
Admiralty brass, aluminum brass  
50 Pb-50 Sn solder  
Copper  
Tin  
Naval brass, yellow brass, red brass  
Aluminum bronze  
Austenitic nickel cast iron  
Low-alloy steel  
Low carbon steel, cast iron  
Aluminum alloys  
zinc

#### **Most Active or Anodic**

### Prevention and Control

- Galvanic corrosion can be prevented through a number of methods:
- Select metals/alloys as close together as possible in the galvanic series.
- Avoid unfavorable area effect of a small anode and large cathode.
- Insulate dissimilar metals wherever practical
- Apply coatings with caution. Paint the cathode (or both) and keep the coatings in good repair on the anode.
- Avoid threaded joints for materials far apart in the galvanic series.
- When galvanic potential exists, design with appropriate thickness in the anodic metal when practical.

### Crevice Corrosion

Crevice Corrosion refers to the localized attack on a metal surface at, or immediately adjacent to, the gap or crevice between two joined surfaces. The gap or crevice can be formed between two metals or a metal and non-metallic material. Outside the gap or without the gap, both metals are resistant to corrosion.

The damage is normally confined to one metal at localized area within or close to the joining surfaces.

Common locations for Crevice Corrosion in heat exchangers are at a gap between the tube and tube sheet or at gasketed joints.

### Mechanisms

Crevice corrosion generally occurs due to either high concentration of impurities in the crevice (e.g., chlorides, acid, or base), or a differential electrolyte chemistry inside and outside the crevice: a single metal part undergoing corrosion is submerged in two different environments.

Crevice corrosion is initiated by a difference in concentration of some chemical constituents, usually oxygen, which set up an electrochemical concentration cell (differential aeration cell in the case of oxygen).

### Prevention

- Use welded butt joints instead of riveted or bolted joints in new equipment
- Eliminate crevices in existing lap joints by continuous welding or soldering
- Use solid, non-absorbent gaskets such as Teflon.
- Use higher alloys for increased resistance to crevice corrosion

### Stress-Corrosion Cracking

Stress-corrosion cracking (SCC) is a cracking process that requires the simultaneous action of a corrodent and sustained tensile stress. This excludes corrosion-reduced sections that fail by fast fracture. It also excludes intercrystalline or transcrystalline corrosion, which can disintegrate an alloy without applied or residual stress. Stress-corrosion cracking may occur in combination with hydrogen embrittlement.

### Mechanisms

Stress corrosion cracking results from the conjoint action of three components: (1) a susceptible material; (2) a specific chemical species (environment) and (3) tensile stress. For example, copper and its alloys are susceptible to ammonia compounds, mild steels are susceptible to alkalis and stainless steels are susceptible to chlorides.

Stress corrosion cracking presents an especially difficult problem, since not only is it highly localised but it can occur in environments that are merely mildly corrosive to the material. The damaging concentration of the harmful ions in that environment may be quite small and difficult to detect and, even in the absence of applied stress, residual stresses in a structure can often be of a sufficiently high level to cause SCC and failure in service.



Prevention

- Control of stress level (residual or load) and hardness.
- Avoid the chemical species that causes SCC.
- Use of materials known not to crack in the specified environment.
- Control temperature and or potential

**Pitting Corrosion**

Pitting Corrosion is the localized corrosion of a metal surface confined to a point or small area that takes the form of cavities. Pitting is one of the most damaging forms of corrosion.

The driving power for pitting corrosion is the lack of oxygen around a small area. This area becomes anodic while the area with excess of oxygen becomes cathodic, leading to very localized galvanic corrosion. The corrosion penetrates the mass of the metal, with limited diffusion of ions, further pronouncing the localized lack of oxygen.

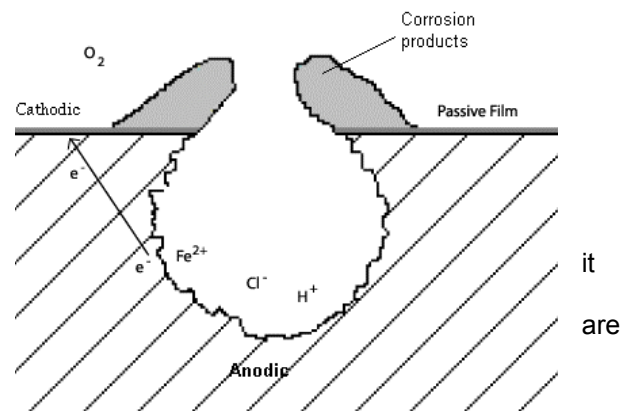
Failures due to pitting corrosion can be found in many different environments ranging from processing plants to residential water distribution systems. For example:

- Carbon steel – often used as a construction material for heat exchanger tubes employed in process manufacturing (e.g., ammonia, nitric acid and sulphuric acid processes) are susceptible to pitting corrosion. Depending on a plant's cooling water chemistry and operating conditions, heat exchanger tubes may be subject to this form of damage.
- Stainless steels – Pitting corrosion is often associated with components that process the wet pulp mix containing chlorides and thiosulfates.
- Copper – Copper is normally resistant to corrosion in water service, although under certain conditions (related to water chemistry, pH and temperature) pitting corrosion may occur on the water side of the tubing.
- Aluminum and aluminum alloys - Good performance of aluminum in corrosive environments is due to a protective oxide film. Corrosion of aluminum and aluminum alloys is commonly caused by pitting, and often induced by presence of insoluble intermetallic compounds or single elements.

Mechanisms

Pitting can be initiated by a small surface defect, being a scratch or a local change in composition, or a damage to protective coating. Polished surfaces display higher resistance to pitting. The most conventional explanation is that the acidity inside the pit is maintained by the spatial separation of the cathodic and anodic half-reactions, which creates a potential gradient and electromigration of aggressive anions into the pit.

This kind of corrosion is difficult to identify, often after it is too late, as causes little loss of material with small effect on its surface, while it damages the deep structures of the metal. The pits on the surface often obscured by corrosion products.



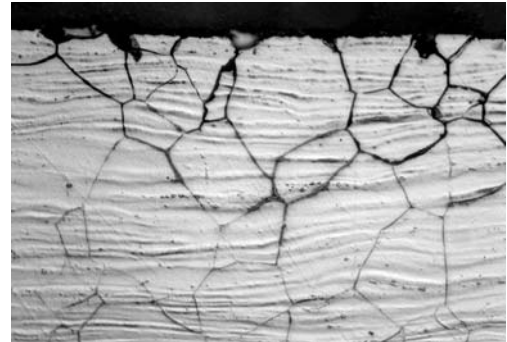
Prevention

- Proper selection of materials with known resistance to the service environment
- Control pH, chloride concentration and temperature
- Cathodic protection and/or Anodic Protection
- Use higher alloys for increased resistance to pitting corrosion

### Intergranular Corrosion

Intergranular corrosion is sometimes also called "intercrystalline corrosion" or "interdendritic corrosion". In the presence of tensile cracking may occur along grain boundaries and this type of corrosion is frequently called "intergranular stress corrosion cracking (IGSCC)" or simply "intergranular corrosion cracking".

"Intergranular" or "intercrystalline" means between grains or crystals. name suggests, this is a form of corrosive attack that progresses preferentially along interdendritic paths (the grain boundaries). identification of this type of corrosion usually requires microstructure examination under a microscopy although sometimes it is visually recognizable as in the case of weld decay.



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Positive

### Mechanisms

Intergranular corrosion occurs when the grain boundaries are depleted of the corrosion-inhibiting compound by some mechanism. There are several different types of intergranular corrosion depending on the metal, alloying material and cause of depletion. Intergranular Corrosion is typically identified by a corrosion lab and with operation history, the mechanism usually can be identified by the lab.

### Prevention

Use low carbon (e.g. 304L, 316L) grade of stainless steels

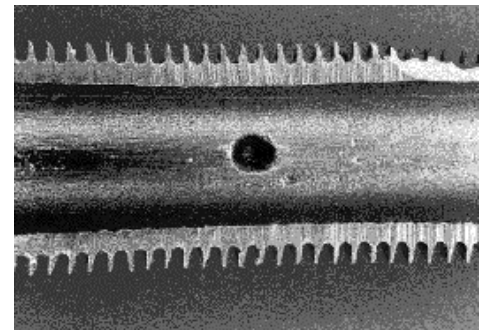
Use stabilized grades alloyed with titanium (for example type 321) or niobium (for example type 347). Titanium and niobium are strong carbide-formers. They react with the carbon to form the corresponding carbides thereby preventing chromium depletion.

Use post-weld heat treatment.

### Microbiologically-Influenced Corrosion (MIC)

Microbiologically-Influenced Corrosion (MIC), also known as microbial corrosion or biological corrosion, is the deterioration of metals as a result of the metabolic activity of microorganisms.

There are about a dozen of bacteria known to cause microbiologically influenced corrosion of carbon steels, stainless steels, aluminum alloys and copper alloys in waters and soils with pH 4-9 and temperature 10°C-50°C. These bacteria can be broadly classified as aerobic (requires oxygen to become active) or anaerobic (oxygen is toxic to the bacteria). Sulphate reducing bacteria (SRB) is anaerobic and is responsible for most instances of accelerated corrosion damages to ships and offshore steel structures. Iron and manganese oxidizing bacteria are aerobic and are frequently associated with accelerated pitting attacks on stainless steels at welds.



Positive identification of microbiologically influenced corrosion requires chemical, biological and metallurgical analysis of the waters, soils and the metal samples.

### Mechanisms

MIC is caused by specific genera of bacteria which feed on nutrients and other elements found in waters and soils. Sea water is a primary source of sulphate reducing bacteria (SRB). The biological activities modify the local chemistry (acid-producing) and render it more corrosive to the metals. For example, iron-oxidizing bacteria can perforate a 5mm thick 316 stainless steel tank in just over a month!

### Prevention

Regular mechanical cleaning if possible

Chemical treatment with biocides to control the population of bacteria

Complete drainage and dry-storage