

## What is corrosion?

### Basic corrosion principle

When a metal is exposed to certain environmental conditions, such as water (including moisture), chemicals (acid, caustic, salts), corrosive gases ( $O_2$ ,  $CO_2$ ) and/or high temperature, corrosion of the metal will occur. An anodic and a cathodic reaction will take place. The anodic-cathodic reaction is a form of oxidation reduction. An anodic reaction, (oxidation phase), takes place at the anodes of the metal. Cathodic reaction, (reduction phase), occurs at cathodic locations of metal.

### Anodes and cathodes

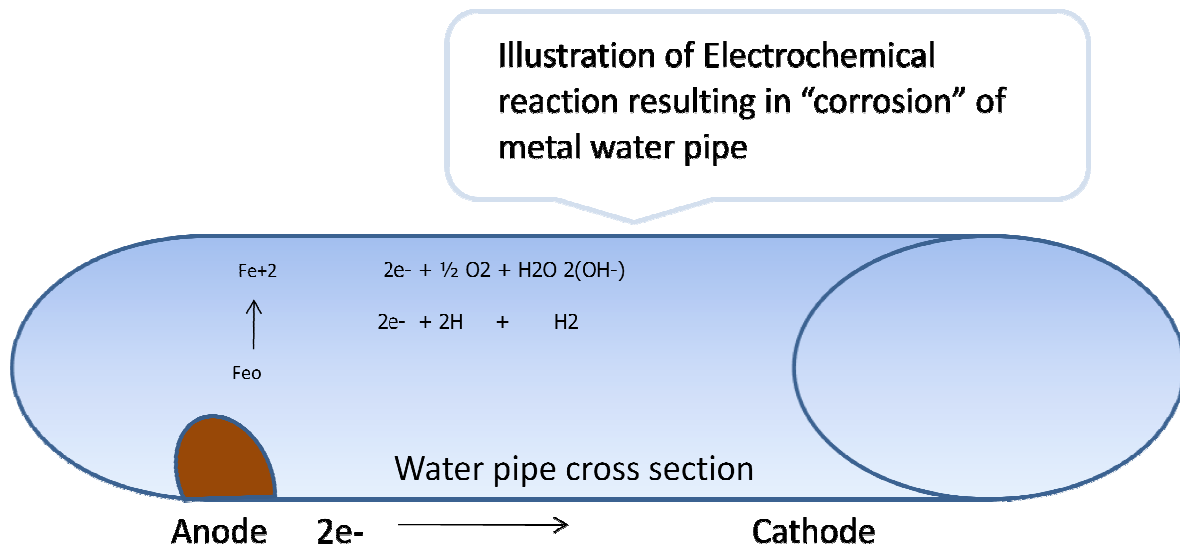
Metals, such as iron, copper, and zinc, are formed using various processing techniques including melting, extrusion, casting, forging, shaping, heat treating, welding, galvanizing, cutting, and rolling. Such processing results in microscopic irregularities in the structure and composition of the processed metal. Irregularities are more pronounced in alloyed metals (different metals are combined). Impurities may also be added during processing (to enhance or change certain properties of the metal). Metals are not one single crystal but a mixture of crystals and grains that are randomly oriented. Boundaries between such crystals are weak and active. Shaping and forming metals (i.e., cutting, bending) results in localized “stress”. In general anodic sites tend to be weak, active, and stressed areas; cathodic sites tend to be noble, inactive, and unstressed areas.

### Electrochemical process

Corrosion (pipes) takes place, when an anodic-cathodic (oxidation-reduction) reaction occurs. During the anodic/oxidation stage, metal is oxidized at the anode area. Electrons are released by oxidation. Oxidized metal is lost to the water solution. Free electrons travel through the metal to the cathode (similar electricity travelling through wires) where they react with water, dissolved oxygen, and/or hydrogen ions, completing the cathodic /reduction stage. Corrosion involves both electrical and chemical reactions, referred to as an “**electrochemical**” process.

Here is a simple illustration:

### Anodic – Cathodic reaction leading to “Corrosion”

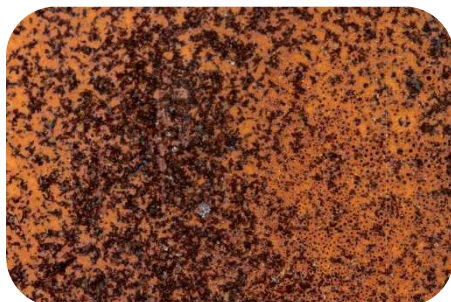


Metal at “Anode” site is “eaten” and waste is carried away by water flow. The result of the reaction can be seen as “reddish” or “brownish” water.

(Figure 1)

### Understanding Corrosion

The cathode acts as a receptor for the electrons. A larger cathodic area will draw more electrons from the anode, resulting in more metal loss at the anode. The larger a cathodic area in relation to an anodic area, the larger will be the potential for corrosion and vice versa. To illustrate, if one has a very small anodic area, and a huge cathodic area, all the metal loss will occur in the small anodic area to satisfy the electron demand by the cathode, resulting in a localized and / or pitting corrosion.



Cathodic protection is effected by forcing the potential to a negative region where metal is completely stable. Traditionally this can be done by using a sacrificial anode made from a more reactive metal, or using an external power supply to change the amount of charge on a metal's surface.

Conversely, if you have a large anodic area and a small cathodic area, given the same environment and conditions, corrosion rate will decrease, usually resulting in a general and uniform corrosion.

In the cathodic/reduction stage, the electrons react with oxygen and water at the cathode to form hydroxyl ions ( $\text{OH}^-$ ). They also react with hydrogen ion ( $\text{H}^+$ ) to form hydrogen gas ( $\text{H}_2$ ).

The hydroxyl ions and/or the hydrogen gas are formed at the cathodes. Under laboratory like conditions they will act as barriers preventing the water, oxygen, hydrogen, and electrons from further converging and reacting. The barrier will reduce available cathodic sites, slow down the electron transfer, and eventually slow down the corrosion rate. This phenomenon is called **Polarization** of the cathodes.

However, a cathode may also be **depolarized**. Such barriers can be stripped by water turbulence/flow. If a water solution is acidic, for example in the presence of dissolved carbon dioxide ( $\text{CO}_2$ ), ( $\text{CO}_2$  and water forms carbonic acid), the dissociated hydrogen ions will react with the hydroxyl ions to form water, stripping the hydroxyl ion barrier while introducing water again to the cathode. Dissolved Oxygen can also depolarize the cathode, by combining with the hydrogen at the cathode, destroying the hydrogen barrier, producing water at the cathode, resuming the cathodic/reduction process.

The anodic-cathodic corrosion can be controlled by disrupting the oxidation-reduction reactions described above, i.e., by reducing dissolved oxygen, increasing pH, inhibiting the anode/cathode, prevention of depolarization, and creating other forms of barrier, i.e., coatings.

### Deposit and/or Crevice Corrosion

Basically, when you have a deposit and/or a crevice on a metal surface, the concentration in the deposit/crevice will change over time and can be substantially different from the bulk water or environment.

In the case of dissolved oxygen (DO), it gets depleted in the deposit/crevice over time while it remains higher outside the deposit/crevice, resulting in an **oxygen differential cell**. The area in the deposit/crevice becomes anodic to the outside area, accelerating corrosion in the deposit/crevice. As dissolved oxygen content (DO) increases between the deposit/crevice and the bulk environment a higher corrosion potential will develop.

The deposit/crevice also acts like a trap allowing corrosive elements like chlorides and sulfate to enter but not to leave, similar to a greenhouse effect. Over time, these

corrosive elements build up, creating a **concentration cell**, corroding the surface in the deposit/crevice.

### **Tuberculation corrosion**

Metal may be oxidized and lost at the anode. This metal will react with available oxygen and alkalinity to form iron oxide and iron hydroxide, both of which are insoluble voluminous solids. These solids can settle on inner walls of pipes for example forming a heap. Like other deposits, tuberculation will cause concentration cell corrosion. Tuberculation can also slough off and plug other critical areas in existing pipes or in equipment attached to such pipes. Large tuberculation can lead to a reduced inner pipe diameter, increasing water flow resistance, and other related problems.



### **Micro-biologically induced corrosion (MIC)**

Certain microorganisms can also thrive in a deposit/crevice. This can lead to bacteria producing acid metabolites as part of their metabolism. Some bacteria produce slime which can attract deposits, causing differential cell corrosion. Iron depositing bacteria cause oxidation and subsequent deposition of tuberculation.

Corrosion inhibitor is usually employed to control corrosion, but it cannot penetrate the deposits/crevices leaving these areas unprotected and vulnerable to corrosion. The mode of corrosion control here is to prevent the settling of any deposit via chemical dispersion, purging, and filtration. A good microbiological program must also be employed to control any microorganism activity.

### **Dissolved Gases**

Dissolved gases such as oxygen, carbon dioxide, ammonia, sulfur can all contribute to corrosion, by direct oxidation, depolarization, and chelating. To reduce their impact on corrosion, you may consider reducing these gases via mechanical pre-treatment methods such as de-aeration, and chemical methods such as oxygen scavengers.

### **Temperature**

Higher temperature increases chemical reaction rate. Corrosion is an electrochemical reaction. A rise in temperature will result in an accelerated corrosion rate. As a guideline, for every 15°C increase in temperature, the rate of corrosion doubles. In an open system, where dissolved oxygen (DO) is allowed to escape at higher temperature, corrosion peaks at about 65°C then drops off as (DO) drops. In a closed system, where the (DO) is trapped, the rate of corrosion continues to increase with temperature.

### **Mechanically Induced Failure**

There are other types of metal failure that are mechanically induced, such as erosion, impingement, cavitations, stress caused by metalworking such as bending, stretching, rolling, shaping, and fatigue caused by repeated stress. In turn, they can cause or accelerate corrosion at the stress points. High stress areas are very active and are at a higher energy state. As such, these areas become anodic to the low stress areas. For example, the stress points on a boiler tube are at the ends where they are rolled onto the tube sheets. It is not uncommon to experience premature failures around these rolls. Such failure should not be blamed entirely on the corrosion inhibition program, unless all the tubes are corroding away.