

## CORROSION AND ITS CONTROL

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The fast-growing industrialization and progress in civilization has demanded the use of metallic objects in different fields. Today it is difficult to imagine the world without metals, as it became an inevitable part of our daily life. Metals exist as such in the earth crust as ores. Metals are extracted from their ores by the application of energy[1, 2]. In the pure metallic state, the metals are unstable as they are considered in higher energy state. So, the reverse process begins and form thermodynamically stable metallic compounds. Hence, when metals are exposed to various corrosive environment, the exposed metal surface begins to decay (conversion to more stable compound). This is the basic reason for metallic corrosion. Although corroded metal is thermodynamically more stable than pure metal but due to corrosion, useful properties of a metal like malleability, ductility, hardness, lustre and electrical conductivity are lost.

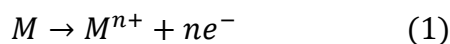
To manage the potential problem of corrosion, it is necessary to understand

1. Mechanism of corrosion
2. Classification of corrosion
3. Methods to prevent corrosion

### 1. Mechanism of Corrosion

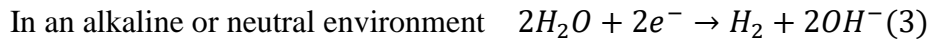
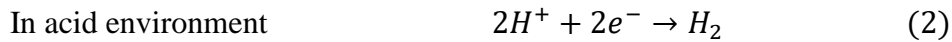
#### 1.1. Electrochemical aspects of corrosion

The basic mechanism of corrosion is the movement of ions at the metal electrolyte interface. The most acceptable electrochemical theory of corrosion is given by Whitney [3-5]. During the aqueous corrosion process, anodic oxidation of the metal and cathodic reduction in the environment creates two interrelated half-cell reactions[6]. For any metal (M) the oxidation reaction at the anodic site is given by

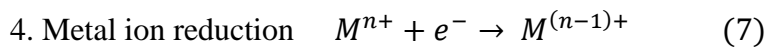
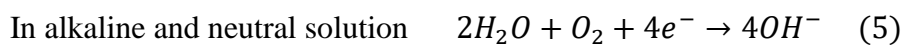
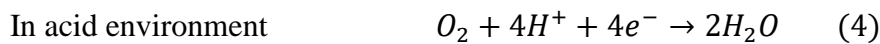


At the cathodic site, the produced electrons react with some reducible components of electrolyte through the following equations

### 1. Hydrogen evolution



### 2. Oxygen reduction



According to Faraday's law, the total flow of electrons from the anodic to the cathodic region during the corrosion process generates corrosion current ( $i_{\text{corr}}$ ) and is a measure of the corrosion rate of the metal.

## 2. Classification of corrosion

Corrosion manifests in different forms. It is desirable to know the form of corrosion since it will help in the identification of the cause of corrosion and in the choice of the most effective method of preventing it. In most corrosion failure analysis, it is necessary to know the form of corrosion, which has been responsible for the failure. Corrosion can be classified in several ways like dry corrosion and wet corrosion or low temperature corrosion and high temperature corrosion etc. Based on the appearance of the corroded metals identified either through visual inspection or using modern spectroscopy there are eight forms of corrosion [7, 8].

### 2.1. Uniform, or General Corrosion

It is a common type of corrosion that occurs on the entire surface of the metal and causes thinning of the metal and leads to a point of failure. Rusting of iron, high temperature oxidation of metals, and the Fogging of Nickel belongs to this category. This type of corrosion is predictable, controllable, and preventable by applying anti-corrosive coatings, inhibitors, or cathodic protection. So, it is considered a safe form of corrosion. Based on the

corrosion rate of uniform corrosion in millimeter penetration per year (mm/y), metals can be classified into three groups

- A. <0.15 mm/y- Metals in this group have good corrosion resistance and are appropriate for critical parts like springs, valve seats, and pump shafts, etc
- B. 0.15 to 1.5 mm/y- Metals in this category are satisfactory and can be used for valves, tanks, and piping
- C. >1.5mm/y- Metals belongs to this category are usually not suitable for application

## 2.2. Localised Corrosion

It occurs at a specific part of a structure. It is more dangerous, difficult to detect, and tends to cause the unexpected failure of structures. Localised corrosion can be further classified as

### 2.3. Pitting Corrosion

It is extremely localised and generates small pits and cavities on the metal surface due to coating failure or mechanical discontinuities. The pit area becomes anodic and the rest of the metal develops a cathodic region. The small size of pits and accumulation of corrosive products on the pits causes difficulty to predict pitting corrosion quantitatively. Pitting causes weight loss of metal and leads to complete failure of the structure.

### 2.4. Crevice corrosion

Crevice or contact corrosion occurs at the metal surface or adjacent to the gap or crevice between two joining surfaces. It is usually associated with a small volume of stagnant solution on the microenvironmental level and occurs under gaskets, washers, surface deposits, rivets, and bolts, etc. The development of crevice depends upon various factors like pH, the concentration of oxygen, and constituents. Since the pH and concentration of oxygen are quite low inside the crevice compared to bulk solution, an electrochemical cell set up with anodic metal oxidation in the crevice and cathodic oxygen reduction develop a passive hydroxide layer at the mouth of the crevice and further propagation mechanism of corrosion takes place[9].

### 2.5. Galvanic corrosion

Also known as bimetallic corrosion and occurs when two electrochemically different metals are in physical contact with the electrolyte, the less noble metal act as anode and tend to corrode faster and the noble metal act as a cathode and corrodes at a slower rate. The effect of galvanic corrosion can be minimised by selecting metals close to each other in the electro potential series.

### 2.6. Erosion corrosion

Erosion is the removal of metal by the movement of corrosive fluids against the metal surface. The combination of erosion and corrosion creates aggressive pitting on the metal substrate and increases the rate of deterioration. The abrasive particles in the moving fluid cause the depletion of the outer layer. The rate of erosion-corrosion depends upon the physical condition and velocity of the fluid. It is characterized by the appearance of rounded holes, grooves, waves, and typically shows a directional design [10].

### 2.7. Intergranular corrosion

This type of corrosion occurs by the formation of precipitate and segregates in the specific region of grain boundaries or adjacent to grain boundaries, causing selective dissolution of grain boundaries and affect the mechanical properties of the metal [11].

### 2.8. Stress corrosion cracking (SCC).

It refers to cracking caused by the repeated presence of tensile stress in a corrosive environment and leads to sudden failure of the structure. SCC is caused either by external stress or residual stress inside the material

### 2.9. Fatigue corrosion

It is a special type of stress corrosion caused by the combined effects of cyclic stress and a corrosive environment. It generally occurs at surface irregularities or pits.

## 3. Methods to prevent corrosion

Corrosion never stops but its severity can be controlled by various methods either by elimination of any one of the components of electrochemical cells which accelerates the corrosion process or by isolating the metal from the aggressive environment. The different strategies to prevent corrosion of a metals are anodic or cathodic protection, corrosion inhibitors, and corrosion resistant coating.

### 3.1. Anodic or Cathodic Protection

Anodic protection is based on the formation of a protective film on metals by externally applied anodic currents and Cathodic protection is a technique used to control the corrosion of a metal surface by making it the cathode of an electrochemical cell.

### 3.2. Corrosion resistant coatings

Corrosion protection by coating has attracted much attention due to its high efficiency and durability in various aggressive environments. An effective coating must have adhesion with the metal substrate, intrinsic durability, and keep its appearance when subjected to stress, swell, or weathering. Coatings can be classified into noble, sacrificial, metallic, inorganic, organic, and organic-inorganic hybrids (OIHs). Metal coatings are applied by

electro deposition, flame spraying, hot dipping, vapour deposition, etc. Inorganic coatings are applied or formed by spraying, diffusion, or chemical conversion. Inorganic coatings include ceramic coating, cement, silicate, ceramics, conversion coating, and sol-gel coatings. OIHs offer an effective coating on the metal substrate by linking both inorganic and organic phases covalently on the molecular scale. OIHs coating developed by sol-gel process is considered as an effective alternative to Chromate conversion coatings for the metallic substrate.

### 3.3. Corrosion Inhibitors

Acid solutions are extensively used in industry, the most important of which are industrial acid cleaning, acid de-scaling, acid pickling, and oil well acidizing[12, 13]. Corrosion inhibitors are usually used to minimize the corrosive attack of metallic materials by different aggressive media. An efficient inhibitor should be economical, environment friendly, and inhibit the corrosion process when present in a small concentration[14]. Corrosion inhibitors can be classified into vapor phase, liquid phase, and environmental conditioners. The inhibitor interacts with the metal surface and forms an inhibitive surface film at the metal/electrolyte interface[15, 16]. Liquid phase inhibitors are classified as cathodic, anodic, or mixed type inhibitors, based on whether they inhibit the anodic, cathodic, or both the electrochemical corrosion process. Anodic inhibitors develop a protective oxide film on the surface of the metal and causing a large anodic corrosion potential shift and thereby force the metal surface into the passivation region and hence commonly referred to as passivators. Cathodic inhibitors inhibit the corrosion process by either decreasing the cathodic reduction rate or by selectively precipitating an insoluble species onto the cathodic sites to limit the diffusion of reducing species to the metal surface. Mixed (adsorption) inhibitors work by reducing the anodic and cathodic corrosion reactions[17].

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