

CHEMISTRY

# Module- IV CORROSION AND ITS CONTROL

Govt. College of Engineering Kalahandi, Bhawanipatna

Dr. P K Panigrahi

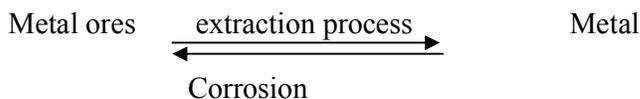
**What is corrosion?**

Corrosion is the process of gradual disintegration, degradation or deterioration of metal /alloys due to chemical or electrochemical reaction with environment.

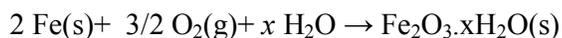
It is the one of the most severe problems faced by the advanced industrial societies. About 30-40 % of iron and steel produced annually is used to replace the rusted materials.

**Why corrosion occurs?**

Metals are generally available in nature in their compound forms (ores). These are the stable form of metals. However, for getting useful engineering materials, i.e. the metallic form, a large amount of energy needed to convert ores to their metallic form. So metals are comparatively unstable and have a general tendency to revert back to its compound form. This process is known as corrosion.



Ex : Rusting of Iron



(Chemical composition of Rust)

**Effects of corrosion:**

- (i) Loss of metal leading to reduction in thickness which may cause reduction in mechanical strength leading to sudden structural collapse or breakdown.
- (ii) Mechanical damage to valves, pumps etc. or blockage of pipes by solid corrosion products.
- (iii) Time is lost in making available of the parts to be replaced the damaged parts or equipments.
- (iv) The fluids stored in pipes or storage tanks get contaminated due to chemical reaction.

## Types of corrosion

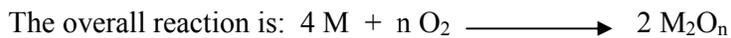
### (A) Dry Corrosion (Chemical Corrosion)

The corrosions that involve the direct attack of the atmospheric gases, generally in the absence of moisture, (i.e., conducting medium) is called as dry corrosion or chemical corrosion. Atmospheric gases include oxygen, halogens, oxides of sulphur, nitrogen, hydrogen sulphides etc. There are three types of dry corrosion:

#### (i) Oxidation Corrosion

It occurs by direct attack of oxygen at low or high temperature on metals usually in the absence of moisture. At low temperature, alkali metals (Na, Li, K, Rb etc.) and alkaline earth metals (Be, Ca, Sr etc.) are rapidly oxidised. However, all metals, except Ag, Au and Pt, are oxidised at high temperature.

Oxidation occurs first at the surface of the metal to form metal oxides as per the following reaction:



Further process of corrosion continues either due to the diffusion of oxide ions into the inner metal layer or metal ions diffuse out to the surface.

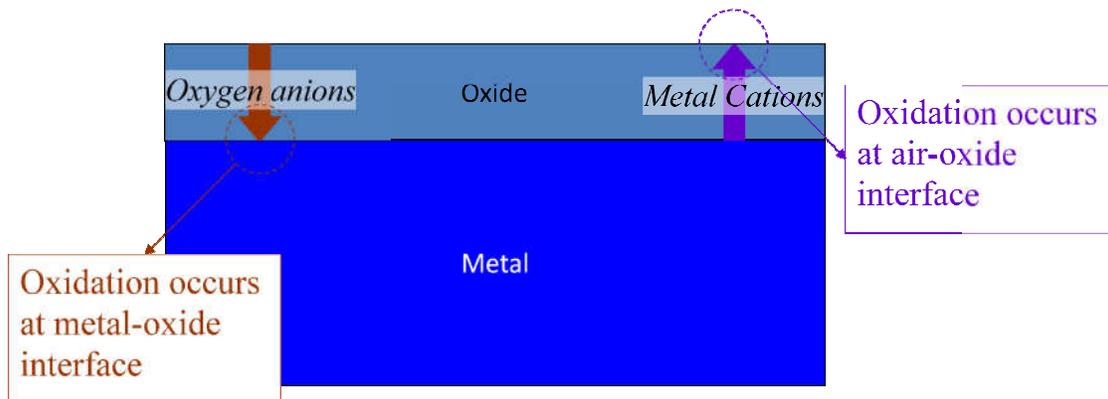


Figure 4.1: The mechanism of dry corrosion in metal oxides.

However, the nature of the metal oxide layer formed at the interface plays an important role in determining the extent of further corrosion of the metal. The metal oxides formed can be of the following types:

Stable metal oxides: It is impervious in nature and forms a protective coating, thus preventing the further oxidation of metals. Examples: oxide films of Al, Pb, Cu, Sn etc.

Unstable metal oxides: This type of oxide layer decomposes back to metal and oxygen as soon as it is formed. So no oxidation corrosion is observed for the metals. Examples: Oxides of Ag and Au.

Volatile metal oxides: The metal oxide film volatilises as soon as it is formed, thereby leaving the underlying metal exposed to the environment for further attack. Thus, rapid corrosion takes place. Example: Molybdenum oxide ( $\text{MoO}_3$ ).

Porous metal oxides: The oxide layers have pores and cracks and allow the atmospheric oxygen to access the underlying layers of metals. This results in unobstructed and rapid corrosion of the metal. The process continues until the entire metal is converted into its oxides. Examples: Oxides of Li, Mg, Na etc.

### (ii) Corrosion by other gases, such as $\text{Cl}_2$ , $\text{SO}_2$ , $\text{H}_2\text{S}$ , $\text{NO}_x$ .

Depending on the chemical environment, these gases react with the metal and forms the corrosion products, which may be protective or non-protective. Dry chlorine reacts with Ag to form  $\text{AgCl}$ , which is protective layer. On the other hand, tin chloride ( $\text{SnCl}_4$ ) is volatile and porous. In petroleum industries, at high temperature,  $\text{H}_2\text{S}$  attacks steel forming  $\text{FeS}$  scale, which is porous in nature.

### (iii) Liquid metal corrosion

This type of corrosion occurs due to chemical action of flowing liquid metals at high temperature on solid metal or alloy. In several industries, molten metal passes through metallic pipes and causes corrosion due to dissolution or internal penetration. For example, liquid mercury dissolves most metals by forming amalgams, thereby corroding them. Also occurs in devices used for nuclear power plant in cooling system. Coolant (liquid sodium metal) leads to corrosion of cadmium in nuclear plant.

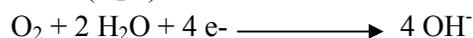
## (B) Wet or Electrochemical Corrosion

The corrosion, that occurs when a metal or two dissimilar metals or alloys are immersed or dipped partially in a conducting liquid (aqueous), is called as wet corrosion. According to wet corrosion theory, the corrosion takes place due to development of separate anodic and cathodic area/parts between which corrosion current flows through the conducting liquid or solution. At the anodic part, corrosion occurs due to oxidation, i.e., dissolution of metals with liberation of electrons.



Cathodic reaction consumes these electrons and these reactions are dependent on the constituents of the corrosion medium. The nature of corrosion medium may broadly be classified into following four types.

- If the medium is aerated and almost neutral, the oxygen is reduced in the presence of water ( $\text{H}_2\text{O}$ ) to  $\text{OH}^-$  ions.



- If the medium is aerated and acidic, the oxygen is reduced to form water (H<sub>2</sub>O).  

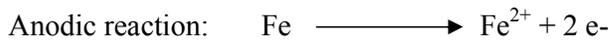
$$\text{O}_2 + 4 \text{H}^+ + 4 \text{e}^- \longrightarrow 2 \text{H}_2\text{O}$$
- If the medium is de-aerated and almost neutral, the hydrogen is liberated along with OH<sup>-</sup> ions.  

$$2 \text{H}_2\text{O} + 2 \text{e}^- \longrightarrow \text{H}_2 + 2 \text{OH}^-$$
- If the medium is de-aerated and acidic, hydrogen gas is liberated.  

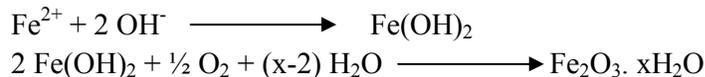
$$2\text{H}^+ + 2 \text{e}^- \longrightarrow \text{H}_2$$

**Example: Rusting of Iron in an aerated and neutral medium**

When a piece of iron is in contact with an aerated and neutral medium, the corrosion process takes place due to the following reactions:



The metal ions formed at anode combine with hydroxide ions at cathodic region due to high mobility of Fe<sup>2+</sup> ions and form Fe(OH)<sub>2</sub>. This ferrous hydroxide further oxidized to hydrated ferric oxide (rust).



Under the limited supply of oxygen gas, the corrosion product may be black anhydrous magnetite, Fe<sub>3</sub>O<sub>4</sub>.



**Types of Electrochemical Corrosion**

**(i) Differential Metal corrosion ( Galvanic Corrosion)**

It occurs when two dissimilar metals are in contact with each other in a corrosive medium (environment). The metals with low reduction potential undergo oxidation (corrosion). The greater is the electrode potential difference between the anode and cathode, the greater is the corrosion rate.

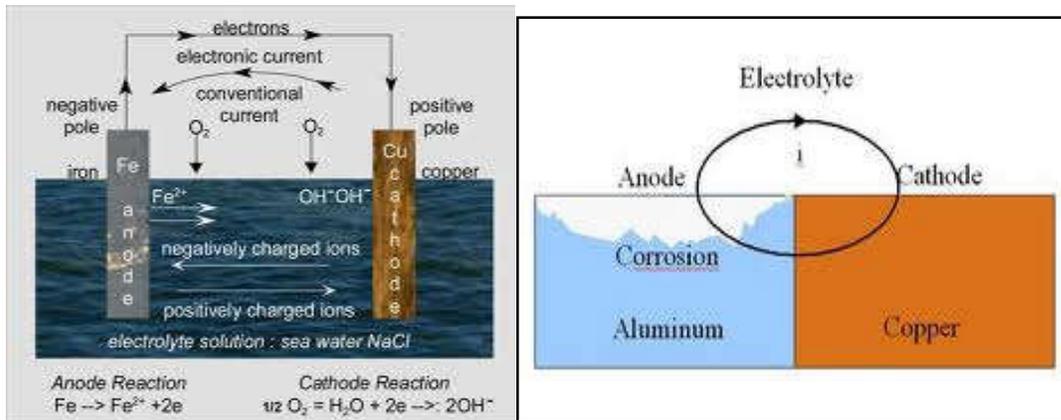


Figure 4.2: The mechanism of differential metal corrosion.

Examples of galvanic corrosion include:

Underground iron pipelines connected to Zn bar, steel pipe connected to copper plumbing, zinc coating on mild steel.

**Problem:** The standard reduction electrode potentials of some metals are as follows: Mg (-2.52 V), Zn (-0.76 V), Fe (-0.44 V), Cu (0.34 V), Ag (0.80 V). Find out which metal undergoes corrosion in the bimetallic couples: Fe/Cu, Zn/Fe, Steel/Cu, Zn/Ag, Zn/Cu.

Preventive measures: By placing a thin layer of insulator between two metals. By selecting materials having very close electrode potentials (i.e., less electrode potential difference).

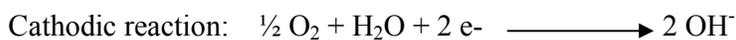
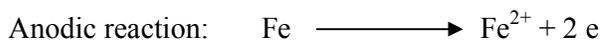
**(ii) Differential Aeration corrosion ( Concentration cell corrosion)**

It occurs when a metal is exposed to differential air concentration or oxygen concentration. Since the cathodic reaction requires oxygen, the part of the metal exposed to higher concentration of oxygen acts as cathode. On the other hand, the metallic part exposed to lower oxygen concentration acts as anodic region and corrosion occurs at this region.

**Some examples of differential aeration corrosions are described below:**

➤ **Water-line Corrosion**

Ocean-going ships, water storage steel tanks or steel pipes carrying liquid when exposed to atmosphere, undergoes this type of corrosion. The metallic part just below the waterline is more anodic to part above the waterline. Therefore, the metal just below the waterline undergoes corrosion. The reactions are:



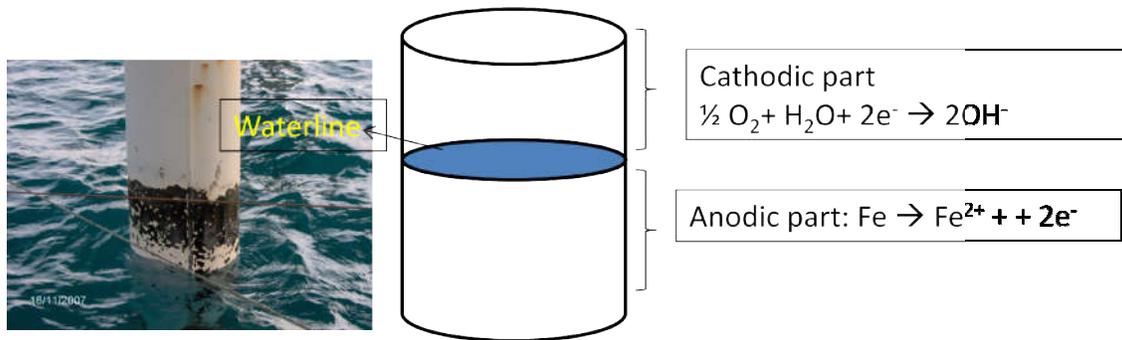


Figure 4.3: Image showing waterline corrosion.

Ocean-going ships undergo corrosion; whereas ships sunk under the sea water for several years, do not undergo corrosion. Because the ship sunk under the sea water is exposed to almost uniform concentration of air and hence, does not undergo differential corrosion.

Preventive measures: By using metallic coatings, using inhibitors in fluids.

### ➤ Pitting Corrosion

It involves localized attack resulting in the formation of cavities. this corrosion occurs when a small portion of the metal surface is defective (with cracks) or occupied by dust/ scale/ sand/ water drop.

The metal below the water drop or dust deposit is exposed to lower concentration of oxygen and undergoes corrosion. Once a pit is formed, the rate of corrosion increases. The accelerated corrosion takes place below the deposit due to small anodic area and large cathodic area.

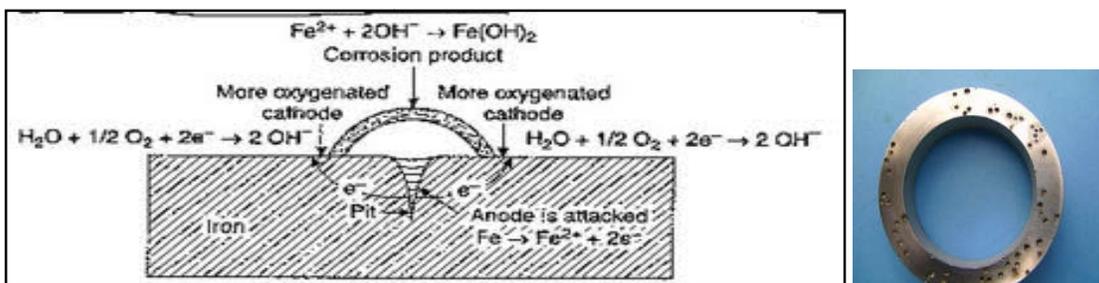


Figure 4.4: The mechanism and image of pitting corrosion.

Preventive measures: Preparing surfaces with best possible finish, removing all contaminants from the surface, designing and fabricating to avoid trapped and pooled liquid on the surface.

### ➤ Crevice Corrosion

It occurs generally at the crevices between two metallic objects, e.g. bolts, nuts, rivets etc. in contact with liquids. Crevice area has lack of oxygen and thus becomes anodic region with respect to remaining part of the metal, which acts as cathode. Crevice corrosion can thus be explained as accelerated attack at the junction of two metals exposed to a corrosive environment.

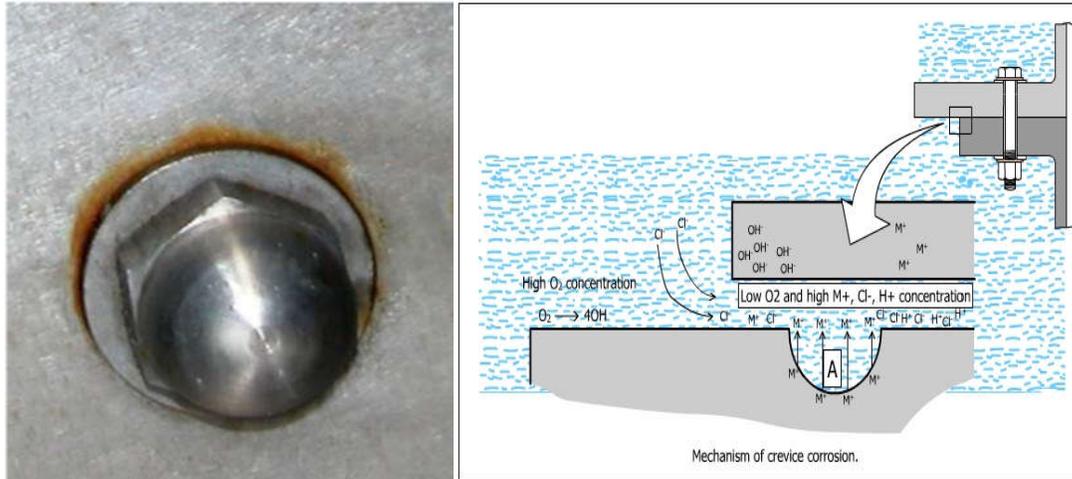
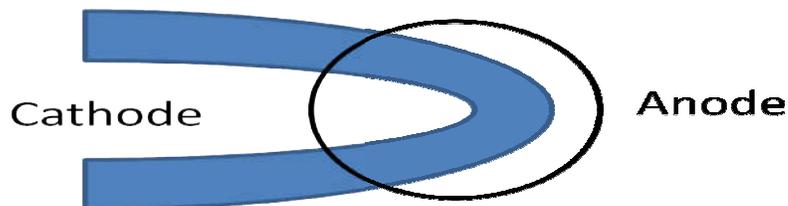


Figure 4.5: The image and mechanism of crevice corrosion.

### Stress Corrosion

It is a localized electrochemical corrosion resulted due to the combined effect of static tensile stress and the corrosion environment on a metal. Metal components are subjected to uneven stresses during their manufacturing processes, which involve cold working, quenching, bending, rolling, pressing, heat treatment. The metal atoms under stress are always at higher energy levels as compared to stress free atoms. Therefore, the stressed parts are more reactive and act as anode and other areas act as cathode, resulting in corrosion at stressed part in corrosive environment. The corrosion initiates crack which propagates through the metal. However, pure metals are relatively immune to the stress corrosion. Typical examples of stress corrosions are: Seasonal cracking, Caustic embrittlement of steel boiler.



➤ **Seasonal cracking (stress corrosion of brass)**

This type of corrosion was first observed during the British rule in India during monsoon season. Due to diminished military activity during monsoon season, brass cartridges are stored for later usage. After some days, it was found that cracks are developed on the surface of the cartridges. It takes place due to action of susceptible agents like Cu and its alloys and attacking agents like ammonia or amine and the residual stress.

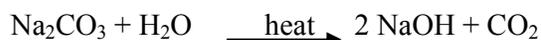
➤ **Caustic embrittlement of steel Boiler**

It occurs in mild steel when exposed to alkaline solution at high temperature and stresses. This is often associated with steam-boiler and heat transfer equipments, in which mild steel is attacked by water of high alkalinity at the stressed part of the boiler, when operating pressure is between 10-20 atm. Fine cracks may develop at the stressed part of the boiler and alkaline impurities pass into these cracks by capillary action. This water evaporates and leaves behind caustic soda in the cracks, whose concentration thus increases. Thus, a galvanic cell is set up between iron at the iron under stress and the iron in the main body. The cell can be represented as:

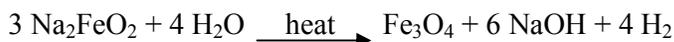
*iron (under stress) | Conc. NaOH (in cracks) | dil NaOH (in boiling water) | Iron (main body)*

Iron under stress thus act as anode and gets corroded resulting in boiler failure.

The boiler water contains  $\text{Na}_2\text{CO}_3$ , which hydrolyzed at high temperature to give NaOH.



The so-formed NaOH flows into the hair-line cracks and crevices, where it reacts with the iron and forms sodium ferroate ( $\text{Na}_2\text{FeO}_2$ ). This sodium ferroate decomposes under heat to give NaOH, which further reacts with iron to cause corrosion. This is called caustic embrittlement.



Preventive measures: By applying protective coatings, using corrosion inhibitors, performing stress releasing heat treatment.

➤ **Difference between Dry corrosion and Wet Corrosion**

<b>Dry Corrosion</b>	<b>Wet corrosion</b>
1. It takes place in absence of moisture	1. It takes place in presence of moisture
2. It involves direct attack of atmospheric gases.	2. It involves development of a large number of tiny galvanic cells.
3. It is less prevalent	3. It is more prevalent
4. It can be explained by chemical reactions	4. It can be explained by electrochemical theory.
5. It is comparatively a slow process	5. It is a fast process

6. This corrosion is uniform.	6. This corrosion is non-uniform as corrosion takes place only at the anodic region, not at the cathodic part.
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### Pilling-Bedworth Ratio

On exposure to environment, the metals get oxidized and an oxide layer is formed. If this oxide is more stable than the metal, it protects the metal from further corrosion (oxidation). In 1923, N. B. Pilling and R. E. Bedworth proposed that the resistance of the metal to further corrosion is determined by the adherence of this oxide layer to the metal surface. So for good oxidation resistance, the oxide layer should be adhered to the surface of the metal very tightly. Adherence of the oxide formed to the metal surface is represented by a factor known as Pilling-Bedworth Ratio or Specific Volume Ratio (R), which can be calculated as follows:

#### Pilling-Bedworth Ratio or Specific volume ratio (R)

= (volume of metal oxide) / (volume of metal from which oxide is formed)

$$= \frac{M_{\text{oxide}}}{d_{\text{oxide}}} \bigg/ n \left( \frac{A_{\text{metal}}}{d_{\text{metal}}} \right)$$

Where,  $M_{\text{oxide}}$  and  $A_{\text{metal}}$  are the molecular weight of the metal oxide and atomic weight of the metal respectively.  $d_{\text{oxide}}$  and  $d_{\text{metal}}$  are the density of the metal oxide and the metal respectively and  $n$  refers to the number of metal atoms per molecule of the metal oxide.

Thus, this rule describes the protective and non-protective nature of oxide layer which is formed during the corrosion.

If  $R < 1$ , the oxide layer is non-protective. Examples: oxides of Mg, Na, K, Ca.

If  $1 < R < 2$ , the oxide layer is passive and causes corrosion process slow. Examples: Oxides of Fe, Ni

If  $R > 2$ , Stable oxide layer is formed and further corrosion is prevented. Examples: Oxides of Cr, Si, Nb.

### Factors affecting Corrosion

If two iron rods are kept at two different environmental conditions (e.g. one in distilled water, other one in saline water), then their rate of corrosion will be different. Similarly, if we put an iron rod and zinc rod in the same corrosion environment, again there will be difference in their rate of corrosion. Thus, the rate of corrosion depends on the nature of the metals and the nature of the environment and the factors affecting corrosion can be categorised into two groups as discussed below.

## 1. Nature of Metals

- (a) **Position in the galvanic series:** Metals with low reduction electrode potentials exhibit high reactivity and hence, are more susceptible to get corroded. Thus, the tendency of a metal to get corroded decreases with increase in the reduction potential. Metals, such as Li, Na, Mg, Zn etc. undergo severe corrosion in corrosion environment due to their low reduction potentials. On the other hand, noble metals with high reduction potentials, like Ag, Au, Pt etc. are less susceptible for undergoing corrosion. However, few metals deviate from their normal tendency due to their ability to develop passive layers.
- (b) **Electrode Potential Difference:** The potential difference between the anodic and cathodic regions is known as open circuit potential difference (OCPD). Larger is the OCPD, higher is the rate of corrosion. For example, the potential difference between Fe & Ag is 1.14 V and that between Fe & Sn is 0.84 V. Therefore, Fe corrodes faster when it is in contact with Ag than with tin in a corrosion environment.
- (c) **Surface State of the Metal:** State or conditions of the surface of the metals also affect the rate of corrosion process. For example, if the surface is covered with sand or dust particles, then severe pitting corrosion occurs. Corrosion at the surface is also accelerated by the presence of water droplets. Heterogeneity at the surface of the metal also results in high corrosion rate. Presence of uneven stress helps in high corrosion.
- (d) **Hydrogen Overvoltage:** In most of the electrochemical corrosion process, the competing cathodic reaction involves the liberation of hydrogen gas due to the reduction of hydrogen ions. Hydrogen overvoltage is the measure of the tendency of an electrode to liberate hydrogen gas. A metal with low hydrogen overvoltage is more susceptible to corrosion. Because low hydrogen overvoltage accelerate the cathodic reaction, which in turn increases anodic reaction rate and hence, corrosion rate.
- (e) **Formation of protective film of corrosion products by metals:** A few metals show tendency to develop passive, but protective films on exposure to corrosive medium. The passive layers, being stable, highly insoluble with low conductivity, act as a protective layer and prevent further corrosion. Metals like Al, Ti and Cr, develop such a layer on their surface and become passive to corrosion. On the other hand, if the layer of the corrosion products is soluble, non-uniform, volatile or porous, then the corrosion continues to occur. For example, metal oxide layers of Fe & Zn cannot prevent the corrosion process completely as they are porous.
- (f) **Relative area of Anode and Cathode:** When the relative area of anode is small compared to that of cathode, corrosion rate becomes high. It is because of the high anodic current density. For example, any gap on the tin coated iron results in severe corrosion due to small anodic area and large cathodic area.

## 2. Nature of Corroding Environment

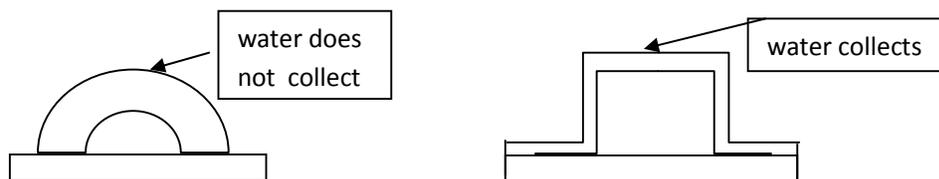
- (a) **pH:** Lower is the pH, higher is the corrosion rate. In acidic medium, generally the corrosion rate is more. If the  $\text{pH} < 3$ , severe corrosion occurs even in the absence of air due to liberation of hydrogen gas at the cathodic area. At  $\text{pH} > 10$ , corrosion of Fe practically ceases due to formation of protective coating of hydrous oxide. However, metals like Al, Zn undergo high corrosion in highly alkaline solution.
- (b) **Temperature:** The rate of any chemical reaction generally increases with increase in temperature and increase in temperature also enhances the conductivity of the medium. As the corrosion process is either chemical or electrochemical reaction, the rate of corrosion increases with increase in the temperature. That means, higher is the temperature, more is the corrosion rate.
- (c) **Conductance of the medium:** Electrochemical corrosion involves electron transfer. The presence of conducting medium facilitates the transfer of electrons and hence, increases the corrosion rate. For this reason, the corrosion rate is higher in saline water than in normal water.
- (d) **Humidity:** Humidity is the measure of the moisture content in the atmosphere. Rate of corrosion increases with increase in humidity upto certain value, called as critical humidity. But corrosion rate abruptly increases above the critical humidity.

### Corrosion Control Methods

Corrosion control is more realistic than corrosion prevention, since corrosion of a metal is a natural process and it cannot be stopped completely though its rate can be controlled. There are many methods, which can be applied to control the corrosion process. Some important corrosion control methods are discussed below.

#### 1) Design & Materials Selection:

- In any design, the greater is the number of angles, edges, corners and internal surfaces, the more difficult it becomes for surface treatments. Hence, as far as possible, L-, T- & U-shaped profiles in construction should be minimized.
- Since corrosion rate is fast in presence of moisture, the design of the structure should be such that the retention of the moisture should be as low as possible.



- Differential metal corrosion can be avoided by using a single metal rather than dissimilar metals. If their usage is unavoidable, metals with low electrode potential difference should be used. An insulator should be positioned between the two dissimilar metals.
- Since the rate of corrosion depends on the relative sizes of the anode and cathode, smaller anode and larger cathode should be avoided as far as possible.

2) **Cathodic Protection:** The principle of cathodic protection involves the conversion of entire metal to behave like cathodic site, since corrosion occurs at anode and cathode remains unaffected. This can be achieved by two methods as follows:

- **Sacrificial Anode Method:** Here, the metal structure to be protected (called as base metal in the subsequent discussion) is connected to a more active metal, which acts as auxiliary anode and the base metal act as cathode. Thus, the base metal is protected and corrosion occurs at the auxiliary anodic metal. Since the anodic metals are sacrificed to protect the metal structure, this method is known as sacrificial anodic method. New auxiliary anodes replace the exhausted sacrificial anodes, whenever required. The most commonly used sacrificial anodes are Zn, Mg, Al. For example, to protect the underground pipelines, Mg block is connected to it. Mg bars are fixed to the sides of ocean-going ships for controlling corrosion.

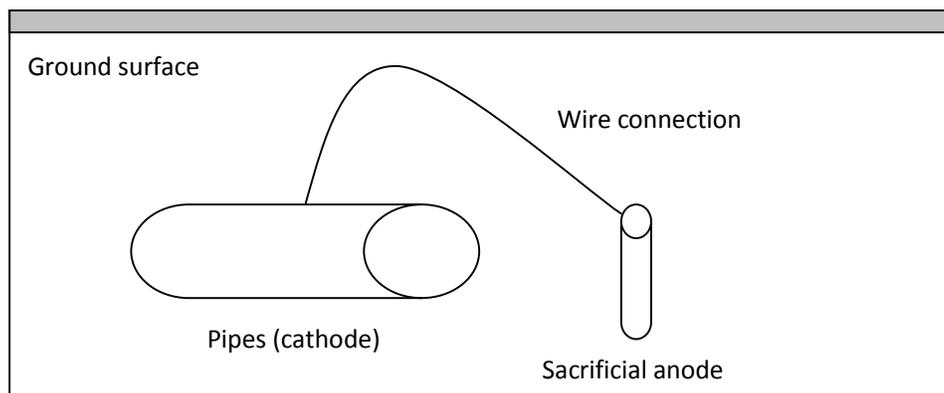


Figure 4.6: The image shows the mechanism of protection of metal by sacrificial anode method.

- **Impressed Current Method:** In this method, the base metal is protected by applying a direct current (DC) larger than the corrosion current. This is done by connecting the negative terminal of DC source to the base metal and positive terminal to an inert anode like graphite. The base metal, being acting as cathode, does not undergo corrosion.

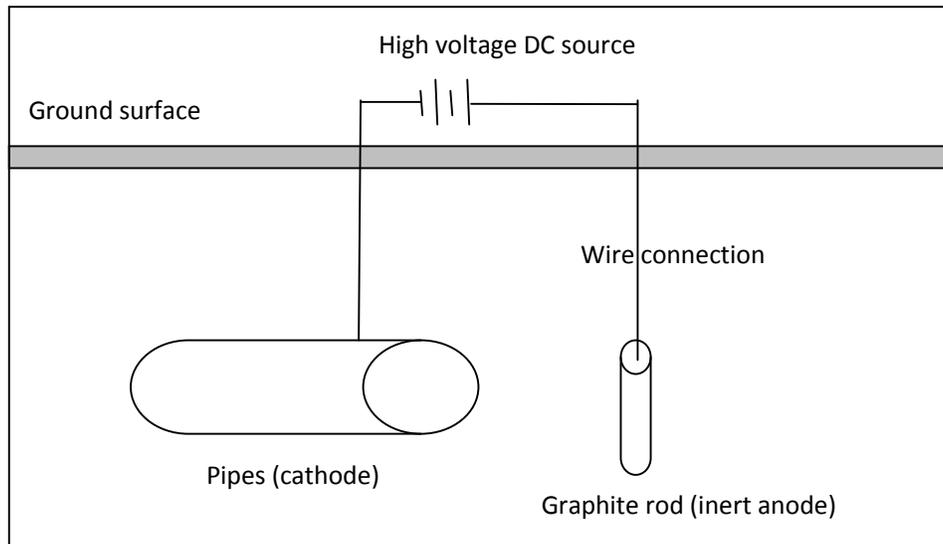


Figure 4.7: The image shows the mechanism of protection of metal by impressed current method.

3) **Anodic Protection:** The principle behind the prevention of the corrosion by this method is to force the metal structure to behave like more anodic by supplying impressed anodic current. Few metals like Ti, Cr, Ni and alloys like steel, when made as anode, exhibit passivity by forming their oxide layers. In these cases, applications of suitable anodic current make them passive and decrease their rate of dissolution. The potential required to protect the metal can be obtained from the potential-current curve.

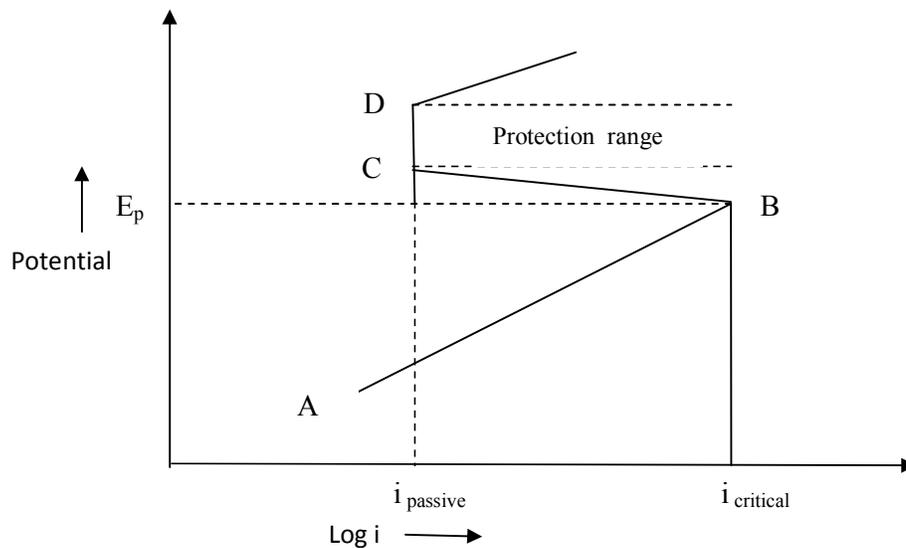


Figure 4.8: Potential current curve.

As the potential is increased, initially the current is increased (Line AB), indicating the dissolution of metal. This trend continues until the current reaches a critical value ( $i_{\text{critical}}$ ) and passivation starts due to the development of oxide layers. This potential is called passivating potential ( $E_p$ ). Above  $E_p$ , the current flow decreases and reaches a minimum value, called the passivating current ( $i_{\text{passive}}$ ). If the potential is further increased, the metal remains unaffected till a particular potential is reached (line CD). This potential is called protection range.

The advantage of this method is that it requires a small current. However, the corrosion rate can't be reduced to zero as in cathodic protection. A drawback of this method is that it cannot be applied to metals that do not passivate. This method is utilized in the transportation of concentrated acids.

#### 4) Corrosion Inhibitors

The corrosion inhibitors are those substances, which reduce corrosion by retarding either anodic or cathodic reactions. So there are two types of inhibitors.

- **Anodic Inhibitors:** These inhibitors prevent the formation of metal ions (anodic reactions) and thereby retard the corrosion process. This is achieved by addition of the anions such as chromates, molybdates, tungstate etc., which combine with the metal ions formed at the anodic region. This results in the formation of sparingly soluble salts, which deposit on anodic site and form a protective barrier between the metal and the corrosion medium. Thus, further corrosion is prevented.
- **Cathodic Inhibitors:** These act by inhibiting the cathodic reaction that involves the liberation of hydrogen gas in acidic solution and hydroxide ions in alkaline medium. Organic cathodic inhibitors, such as amines, mercaptans, thioureas, sulfoxides, form a protective layer on cathodic region and prevent the evolution of hydrogen gas and hence, decrease the corrosion rate.

Inorganic cathodic inhibitors such as sulphates of Mg, Mn, Ni & Zn are used in neutral or alkaline medium. These inhibitors react with  $\text{OH}^-$ , liberated at cathode. This forms insoluble hydroxides, which creates protective film on the cathodic area and prevent corrosion.

#### 5) Protective Coating

Protective coatings are used to prevent corrosion at the surface of the materials. The coatings may be (a) metallic coatings, (b) organic coatings (c) inorganic coatings.

- (a) **Metallic Coatings:** This is either anodic metallic coatings or cathodic metallic coatings.

- **Anodic metal coatings** are produced by coating a base metal with more active metals or metals with high oxidation potentials or metals with low reduction potentials. These coatings are anodic to the base metal. For example, Metals like Al, Zn, Mg, Cd coating on Iron. A characteristic feature of anodic coating is that even if the coating falls off at some places, the base metal does not undergo corrosion as the base metal is cathodic in nature. Galvanization is the example.
- **Cathodic metal coatings** are produced by coating base metals with more noble metals or metals having high reduction potentials or metals with low oxidation potentials. Cathodic coatings are effective only when the coatings are continuous, nonporous and free from gaps. Otherwise, rapid corrosion of the metal takes place as a result of formation of large cathodic and small anodic areas. Tinning is an example of this category.

The metallic coatings can be carried out by different methods, such as Cladding, Hot dipping, and Metal spraying.

**Cladding:** It is used to protect the metal in form of sheets. The metal sheet to be protected is sandwiched between two sheets of anodic metals and squeezed by rolling under pressure and heat. Example: cladding of aluminium by duralumin sheets.

**Hot dipping:** It involves the dipping the base metal in molten form of metal. For examples. Galvanization and tinning process

**Galvanization:** Coating of zinc on iron is known as galvanization. This process involves pre-treatment of iron material with organic solvents, followed by dil.  $H_2SO_4$ . Iron is then treated with  $ZnCl_2$  &  $NH_4Cl$  and then it is dipped in molten zinc at 430-470 °C.

**Tinning:** Coating of tin on iron is known as tinning. This process involves pre-treatment of iron material with organic solvents, followed by dil.  $H_2SO_4$ . The base metal is then treated with  $ZnCl_2$  &  $NH_4Cl$  and then it is dipped in molten tin. Finally, it is dipped in palm oil to prevent oxidation of tin.

**Metal spraying:** It is done through flame spraying technique where metal particles are sprayed by an air blast on the surface of the metal to be protected.

- (b) **Organic Coatings:** These coatings are of materials that are applied to protect or beautify a surface. These include paints, varnishes, industrial maintenance coatings and they can be applied to stationary and/or mobile sources. Coating of metal surface with organic paints is the most widely used anti-corrosion coatings. Organic paint is a dispersion of one or more finely divided solids in a medium, which consists of non-volatile, film-forming materials like drying oils and resins in thinners. When a properly treated metal surface is painted, the thinner evaporates leaving behind a film formed and pigments on the surface.

- (c) **Inorganic Coatings (Ceramic Coatings):** For thin film coatings, hard materials are suitable which includes carbides, nitrides, borides and silicides of Group 14, 15 & 16 of periodic table. These coatings are formed by introducing nitrogen, hydrocarbons or silicides during the sputtering process (depositing a metal on the surface of another by using fast ions). Thus, the ceramic compound is formed at the surface of the substrate. Commonly available ceramic coatings are TiN, CrN, TiCN and TiAlN. Alloyed elements such as Al, V, Cr etc. improve the oxidation resistance of ceramic coatings.

### **References:**

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