

## **CORROSION**

### **INTRODUCTION**

- ✦ Definition: Corrosion refers to the degradation or deterioration and ultimate destruction of metal due to its reaction with the surroundings.

#### **Examples:**

- ◆ Rusting of iron: A layer of reddish brown scale ( $\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$ ) is formed on the surface of the iron.
- ◆ Formation of green layer of basic copper carbonate [ $\text{CuCO}_3 + \text{Cu}(\text{OH})_2$ ] on the surface of copper.
- ◆ Tarnishing of silver: Blackening of surface of silver due to the formation of black layer of silver sulphide on it.

#### **Why study corrosion?**

Corrosion can lead to failures in plant infrastructure and machines which are usually costly to repair, costly in terms of lost or contaminated product, in terms of environmental damage, and possibly costly in terms of human safety. Decisions regarding the future integrity of a structure or its components depend upon an accurate assessment of the conditions affecting its corrosion and rate of deterioration. With this information an informed decision can be made as to the type, cost and urgency of possible remedial measures.

- ◆ In a modern business environment, successful enterprises cannot tolerate major corrosion failures, especially those involving personal injuries, fatalities, unscheduled shutdowns and environmental contamination. For this reason considerable efforts are generally expended in corrosion control at the design stage and in the operational phase

### **CAUSE OF CORROSION**

- All the metals exist in nature in combined forms as oxides, carbonates, sulphides etc.
- High amount of energy is required to extract the metal from ore.
- Thus, the metal is in thermodynamically unstable state.
- It is the natural tendency of metal to revert back to thermodynamically stable state when it comes in contact with the elements in the environment.

### **CONSEQUENCES OF CORROSION**

- ♠ Enormous waste of machineries and different types of metallic materials
- ♠ It leads to sudden failure of machines.
- ♠ It leads to the decrease in efficiency of machine and frequent replacement of corroded equipment which is an expensive.
- ♠ It may leakage of inflammable gas from the corroded pipe lines resulting into fire accidents etc.
- ♠ It causes contamination of potable water.
- ♠ It has been estimated that 25% of annual world production of iron is wasted due

to corrosion.

### **THEORIES (OR) MECHANISM OF CORROSION**

There are Two theories of corrosion

- \* Dry or Chemical Corrosion
- \* Wet or Electrochemical Corrosion

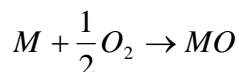
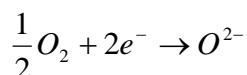
#### **1) Direct Chemical Attack (Or) Mechanism Of Dry Corrosion**

- ◆ The direct chemical action of atmosphere gases like oxygen, halogen, H<sub>2</sub>S etc in a dry environment on metals, a solid film of the corrosion product is formed on the surface of the metal.

- ◆ This is known as chemical corrosion.

##### **a. Oxidation Corrosion (Reaction With Oxygen)**

- ★ Some of the metals directly react with oxygen in the absence of moisture.
- ★ Then the metal gets oxidized to metal ions and the electrons so released reduce oxygen to form oxide ion.
- ★ The metal ion and oxide ion combine to form metal oxide on the metal surface.



- ★ The nature of metal oxide layer formed plays an important role in determining further corrosion.

**1) Protective and non porous oxide film:** Metals such as Al, Cr, Cu & W develop nonporous, stable oxide film on the surface. This film prevents further corrosion of the metal.

**2) Unstable oxide film:** Au & Pt develop unstable oxide film which instantaneously decomposes to form metal & oxygen.

**3) Volatile oxide film:** Molybdenum develops an oxide which immediately vaporizes. As a result metal surface easily undergoes further corrosion.

**4) Porous and non protective film:** Alkali and alkaline earth metals form porous oxide layer which further facilitates corrosion of the metal due to porous nature. Oxide layer cannot protect the metal from corrosion.

**Pilling Bedworth rule:** The protective or non protective nature of oxide film is determined by this rule. The ratio of volume of oxide film to the volume of metal consumed is known as Pilling-Bedworth rule.

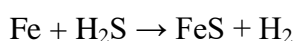
- ★ If the ratio is <1, the metal oxide layer is porous and non protective. Ex:-Oxide layer on alkaline metals
- ★ If the ratio is ≥1, the metal oxide layer is non porous protective layer. It stops

further corrosion of metal. Ex:-Oxide layer on Al, Cr, Cu, W.

$$\text{Pilling Bedworth rule} = \frac{\text{Vol.of metal oxide layer}}{\text{Vol of metal consumed}}$$

### **b. Corrosion By Other Gases:**

- ✦ This type of corrosion is due to the attack of other gases like  $\text{Cl}_2$ ,  $\text{SO}_2$ ,  $\text{H}_2\text{S}$ ,  $\text{NO}_x$  in dry atmosphere on the metal.
- ✦ The corrosion products may be protective or non-protective.
- ✦ Dry  $\text{Cl}_2$  reacts with Ag and forms AgCl which is protective layer, Eg:  $2\text{Ag} + \text{Cl}_2 \rightarrow 2\text{AgCl}$  (protective),
- ✦ where as  $\text{SnCl}_4$  is volatile,  $\text{Sn} + 2\text{Cl}_2 = \text{SnCl}_4$
- ✦  $\text{H}_2$  Embrittlement: Formation of cracks and blisters on metal surface due to high pressure of  $\text{H}_2$  gas.



### **c. Liquid Metal Corrosion:**

- \* This type of corrosion takes place, when molten metal passes through metallic pipes due to dissolution of solid metal by liquid molten metal or due to internal penetration of solid metal into liquid metal.
- \* For example: Liquid metal mercury dissolves most metals by forming amalgams, thereby corroding them.
- \* Coolant (sodium metal) leads to corrosion of cadmium (moderator) in nuclear reactors.

### **2) Electrochemical Corrosion (or) Wet Corrosion**

- ✦ This corrosion occurs due to the existence of separate anodic and cathodic parts, between which current flows through the conducting solution.
- ✦ At anodic area, oxidation reaction occurs, thereby destroying the anodic metal due to dissolution. Hence, corrosion always occurs at anodic parts.
- ✦ At cathodic area, reduction reaction occurs.
- ✦ These anodic and cathodic regions are formed due to several factors like
  - On a metal surface if the concentration of oxygen is different
  - Due to contact of two different metals
  - If metal surface is subjected to stress

### **Anodic Reaction:**

- ✓ At anode oxidation takes place so that metal is converted into metal ions with the liberation of electrons.
- ✓ These electrons migrate towards cathode.



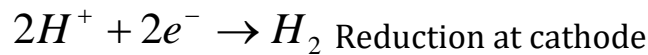
### Cathodic Reaction:

- ✓ At cathode reduction takes place. Depending upon on the nature of the corrosive environment cathodic reaction takes place in the following way:

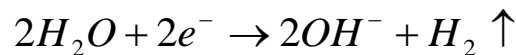
- Evolution of hydrogen.
- Absorption of oxygen depending upon the nature of corrosion environment.

#### a) Evolution of Hydrogen type:

- ★ In acidic medium and in the absence of oxygen,  $H^+$  ions are reduced to  $H_2$  gas.

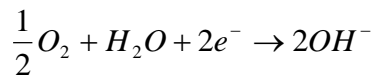


- ★ In basic medium and in the absence of oxygen, the cathodic reaction is,



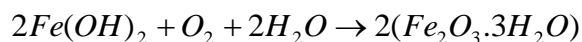
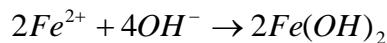
#### b) Absorption of oxygen:

- ★ In neutral and aerated medium: If the solution is neutral and aerated, hydroxyl ions are formed as follows.

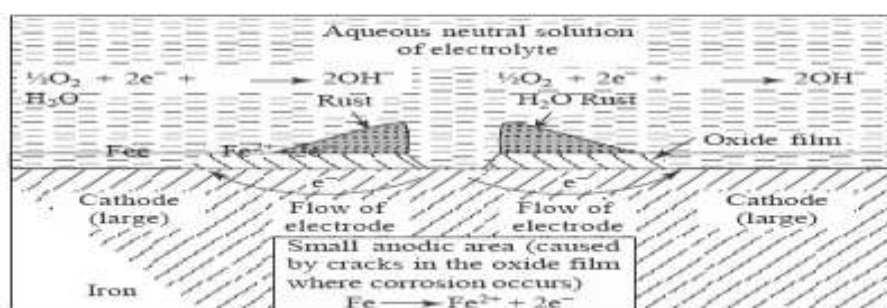
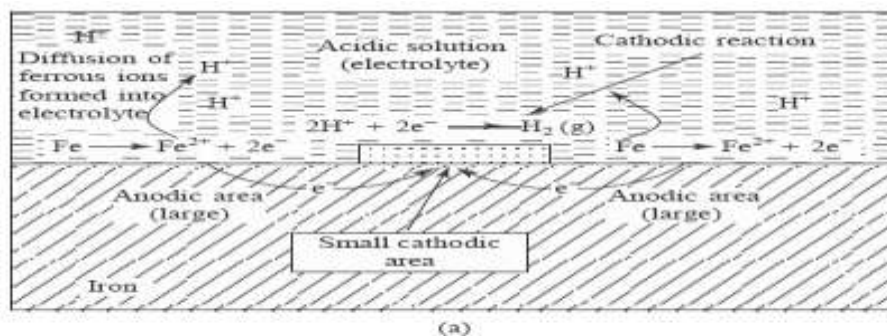


### Formation of corrosion product:

- ✓ The hydroxyl ions react with metal ions and forms corrosion product.
- ✓ In case of iron, hydroxide ions react with ferrous ions and forms insoluble hydrated ferric oxide called Brown rust.



- ✓ If the supply of oxygen is limited, the corrosion product may be black magnetite
- ✓  $Fe_3O_4$ .



### **.Wet Corrosion: or Electro Chemical Corrosion:**

Wet corrosion of metals occurs through electron transfer, involving two processes, oxidation and reduction. In oxidation, the metal atoms lose electrons. The surrounding environment then gains the electrons in reduction. The metal, where electrons are lost, is called the anode. The other metal, liquid or gas which gains the electrons is called the cathode.

Eg:  $\text{Fe} + \text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Fe}(\text{OH})_2$

Mechanism:

At Anode:            Oxidation occurs             $\text{Fe} \rightarrow \text{Fe}^{2+} + 2\text{e}^-$

At Cathode:        Reduction occurs and it depends on nature of the environment

### **Acidic environment:**

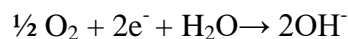
**Hydrogen evolution:** All metals above  $\text{H}_2$  in electrochemical series undergo this type of corrosion

Example: Iron metal in contact with  $\text{HCl}$  .

(  $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$  )

### **Neutral or basic environment:**

**Absorption of oxygen:** or Formation of hydroxide ion type corrosion.



Example: Iron metal in contact with a neutral solution.

Net Corrosion is                       $\text{Fe}^{2+} + 2\text{OH}^- \rightarrow \text{Fe}(\text{OH})_2 \rightarrow \text{Fe}(\text{OH})_3 \rightarrow [\text{Fe}_2\text{O}_3, 2\text{H}_2\text{O}]$  Rust

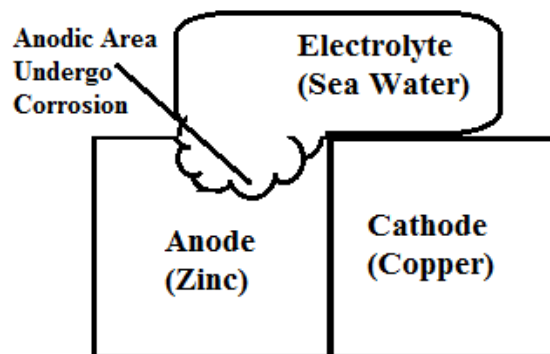
An example of wet corrosion is copper fitting on a steel pipe carrying water. Steel pipe acts as the anode, copper fitting, the cathode. The pipe is in direct contact with the fitting for the connection.

Water acts as electrolyte, allowing for migration of the ions, and completion of the circuit.

## TYPES OF CORROSION

### 1. Galvanic Corrosion:

- When two dissimilar metals are connected in presence of a corrosive environment, then the metal higher in electrochemical series undergoes corrosion.
- This type of corrosion is also called galvanic corrosion or bimetallic corrosion.
- For example, zinc and copper constitute a galvanic couple, where zinc acts as anode and undergo corrosion and copper behaves as cathode and get protected from corrosion.
- The extent of corrosion depends on the potential difference between the two metals.
- This galvanic corrosion can be minimized by
  - Avoiding galvanic couple
  - Selecting metals closely placed in electrochemical series as galvanic couple
  - Providing an insulating material between the two metals

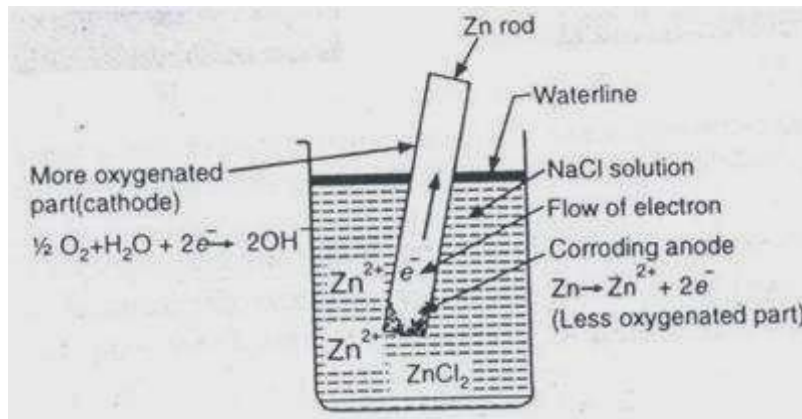
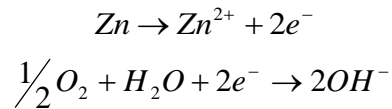


### 2. Concentration Cell Corrosion (Differential Aeration Corrosion)

- This type of corrosion arises due to exposure of metal to varying concentration of electrolyte or of varying aeration.
- Differential aeration corrosion occurs when one part of metal is exposed to a different air concentration from the other part.
- Then, part of the metal exposed to **less concentration of oxygen acts as anode** and other parts exposed to **high concentration of oxygen act as cathodes**.
- Anodic part undergoes corrosion.
- Differential aeration accounts for the corrosion of metals, partially immersed in a solution, just below the waterline.

#### Example:

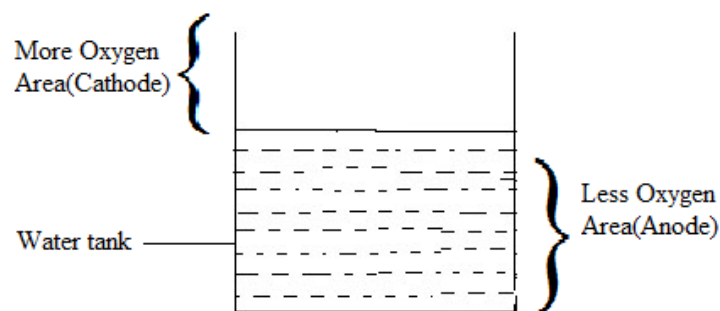
- If a metal is partially immersed in a dilute solution of a neutral salt solution, then the parts above the solution are more strongly aerated hence, become cathodic.
- If a metal part immersed to greater depth show a smaller oxygen concentration and thus become anodic.



**Examples:** Water line corrosion, Drop corrosion

### Water Line Corrosion:

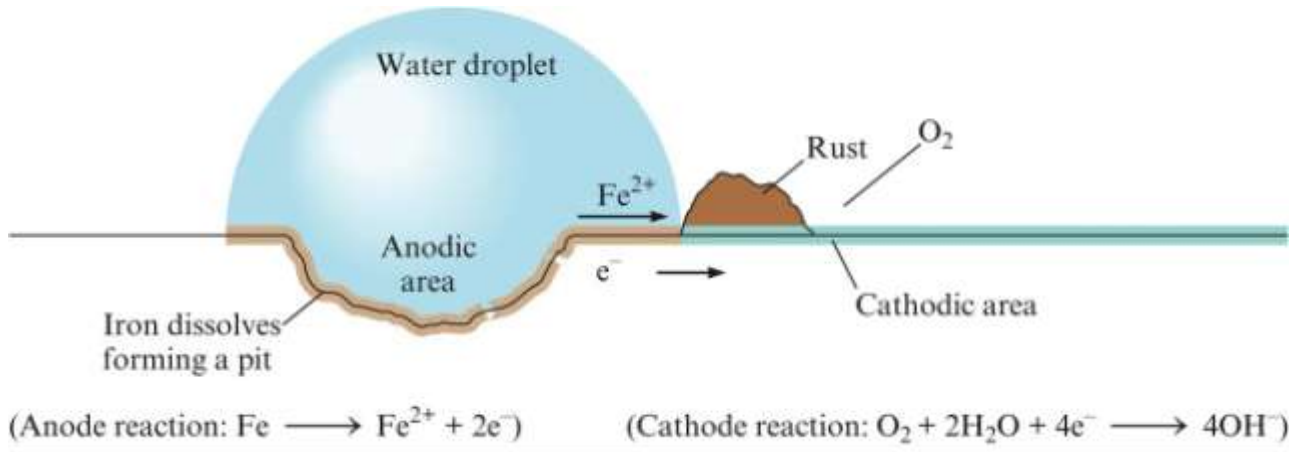
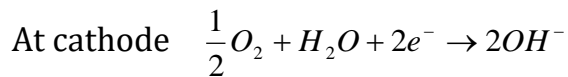
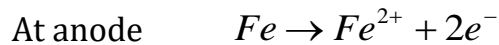
- \* It has been observed in rusting of an iron tank takes place along the line just beneath the level of water in it.
- \* It is also due to differential aeration.
- \* The area above the waterline (well aerated) acts as cathode where as the area below the waterline (less aerated) acts as anode and is corroded.



### Drop Corrosion:

- For instance iron metal surface is covered with a drop of water.

- The area covered by a drop has low oxygen concentration and thus acts as an anode and suffers corrosion, the uncovered area of the metal acts as large cathode due to high O<sub>2</sub> concentration.

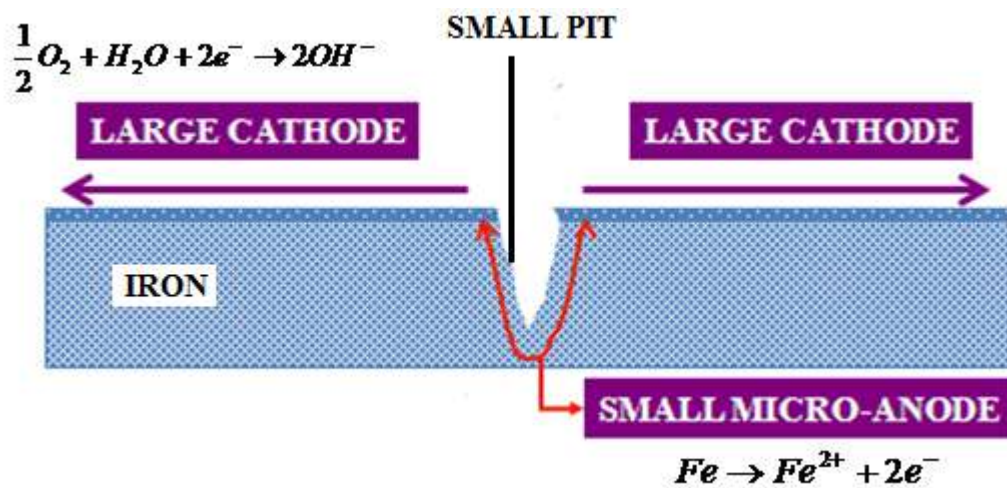


### 3.Pitting Corrosion:

- \* Pitting of metal occurs where there is a break in the protective layer.
- \* Pitting corrosion is a non uniform corrosion resulting from a localized accelerated attack and results in the formation of pits, cavities and pin holes in the metal.
- \* This gives rise to the formation of small anodic and large cathodic areas.
- \* The presence of the impurities (like sand, dust, scale etc) on the surfaces of metals also leads pitting.
- \* A part below the impurity become the anodic area undergoes corrosion and the surrounding part become the cathodic area.
- \* Once a small pit is formed, the rate of corrosion will be increased.







### **GALVANIC SERIES**

- ✓ Electrochemical reactions are predicted by electrochemical series.
- ✓ A metal having higher position can replace (reduce) other metals that have lower position in the series.
- ✓ For example:
 
$$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu \quad (\text{or})$$

$$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$$
- ✓ Or in other words, zinc will corrode faster than copper.
- ✓ Some exceptions have been observed in this generalization. For example, Ti is less reactive than Ag.
- ✓ Galvanic series is the series of metals that is made keeping in view the process of corrosion of a metal in a particular atmosphere, i.e., sea water. In galvanic series, oxidation potential of metals is arranged in the decreasing order of activity of a series of metals. The series is towards the increasing noble character.

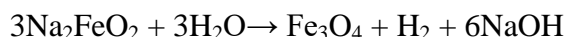
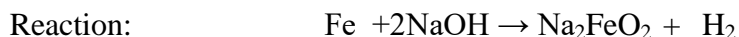
More anodic: **Mg, Mg alloys, Zn, Al, Cd, Fe, Pb, Sn, Ni-Mo-Fe alloys, Brasses, Cu, Ni, Cr-alloy, Ag, Ti, Au, Pt** towards noble nature.

From **left to right, anodic nature decreases**, corrosion tendency decreases.

**Stress corrosion:** In a metallic structure, if there is a portion under stress, it acts as anode and rest part of the structure acts as cathode. It is now a galvanic system and hence anodic part which is small in area would corrode more. Stress corrosions are observed in the following systems:

(i) Caustic embrittlement is a type of stress corrosion occurring in steel tank (Boiler) at high temperature and in alkaline medium. Boiler water has  $Na_2CO_3$ ; it will be hydrolysed at high temperature to give NaOH. It flows into hair cracks and crevices. There it reacts with

iron and forms  $\text{Na}_2\text{FeO}_2$  (sodium ferroate) which decomposes to give  $\text{Fe}_3\text{O}_4$  (ferric oxide) and  $\text{NaOH}$ .  $\text{NaOH}$  thus formed further reacts with iron to cause corrosion. It is called caustic embrittlement.



### **Comparison Between Galvanic Series And Electrochemical Series**

<b>Galvanic series</b>	<b>Electrochemical series</b>
<ul style="list-style-type: none"> <li>• It predicts the corrosive tendencies of metal alloys.</li> <li>• Calomel electrode is used as a reference electrode.</li> <li>• Position of metal or alloy may change.</li> <li>• This series was developed by the studying corrosion of metals and alloys in unpolluted sea water without their oxide film.</li> <li>• Electrode potentials are measured for both metals and alloys.</li> </ul>	<ul style="list-style-type: none"> <li>• It predicts the relative displacement tendencies of metal.</li> <li>• Standard hydrogen electrode is used as a reference electrode.</li> <li>• Position of metal is fixed. It cannot be change.</li> <li>• This series is developed by dipping pure metals in their salt solution of 1M concentration with out any oxide film on them.</li> <li>• Electrode potentials are measured only for metals and non metals.</li> </ul>

### **FACTORS INFLUENCING THE RATE OF CORROSION**

#### **1. Nature of The Metal And Its Surface**

##### **a. Position of metal in galvanic series:**

- It determines the extent of corrosion.
- The metal higher in the electrochemical series acts anode which undergoes corrosion easily, the metals lower in the series acts as cathode which is protected from corrosion due to their higher oxidation potentials.
- The greater difference in their electrode potential faster is the rate of corrosion.

##### **b. Over voltage:**

- Over voltage decreases rate of corrosion increases.

(Hydrogen overvoltage/over voltage is the potential difference that can be found between an electrode and a reversible hydrogen electrode within a single solution. This is where hydrogen (H<sub>2</sub>) undergoes formation from ions of hydrogen.)

**c. Purity of the metal:**

- The impure metals are prone to corrosion than the pure ones.
- Impurities cause heterogeneity and form tiny electrochemical cells where anodic part gets corroded.
- The effect of even traces of impurities on the rate of corrosion will be as follows.

Metal	% purity	Corrosion rate
Zinc	99.999	1
Zinc	99.99	2650
Zinc	99.95	5000

**d. Surface of metal:**

- A rough surface metal readily undergo corrosion due to collection of more dirt.
- A polished surface does not corrode easily.

**e. Stressed part of a metal:**

- Stress in metal surface is produced by mechanical operations such as welding bending, pressing etc.
- The portion subjected to more stress acts as anode and other portion acts as cathode.

**f. Ratio of anodic area to cathodic area:**

- The rate of corrosion increases with decrease in the ratio of anodic area to cathodic area.
- The smaller the ratio larger is the cathodic area and higher is the demand for electrons i.e. Rapid corrosion of small anodic area.
- For example, steel rivets (anode) are in copper sheets, steel rivets are completely corroded.

**g. Physical state of the metal:**

- ✓ The rate of corrosion is influenced by the physical state of a metal.
- ✓ For instance, the smaller the grain size of the metal or alloy, the greater will be the rate of corrosion.

## **PASSIVITY**

- ✓ Passivity or passivation is the phenomenon in which a metal or an alloy exhibits a much higher corrosion –resistance than expected from its position in the electrochemical series.
- ✓ Passivity is the result of the formation of a highly protective, but very thin (0.0004mm) and quite invisible film on the surface of metal or alloy, which makes it more noble.
- ✓ Passive film is insoluble, non-porous and self healing nature (when broken, it will repair itself).
- ✓ Examples of passive metals and alloys are Ti, Al, Cr and wide variety of stainless steel alloys, containing Cr.
- ✓ Passivation is not a constant state, but exists only in certain environment condition, which tend to maintain thin protective oxide films on their surfaces.
- ✓ In presence of oxygen, the oxide film is automatically repaired, whenever any damage occurs, but in oxygen absence, the passive metals and alloys become chemically active and are rapidly corroded.
- ✓ Fe and Al produce a thin protective oxide layer with action of concentrated  $\text{HNO}_3$ . In case of stainless steels and titanium, the protective oxide film is maintained, even in dilute  $\text{HNO}_3$ .
- ✓

## **2. Nature of Corrosive Environment**

### **a. Temperature:**

- Temperature increases the rate of almost every chemical reaction.
- Thus, the rate of corrosion also increases with increase in temperature.

### **b. Humidity of air:**

- Corrosion increases with increase in humidity of air.
- This is due to the fact that humidity acts as solvent for oxygen which is essential for setting up a corrosion cell.

### **c. Nature of atmosphere:**

- ◆ Corrosion increases if the air is polluted by smoke or gases like  $\text{H}_2\text{S}$ ,  $\text{SO}_2$  and electrolytes like  $\text{NaCl}$  and  $(\text{NH}_4)_2\text{SO}_4$ .

### **d. Effect of $\text{P}^{\text{H}}$ :**

- In general, acidic media are more corrosive than alkaline or neutral media.
- Low  $\text{P}^{\text{H}}$  accelerates corrosion by providing more hydrogen ions.

### **e. Conductance of the corroding medium:**

- ✓ It plays an important role in corrosion.
- ✓ Dry sandy soils have lower conductance than clay or mineralized soils.

- ✓ Hence, the metallic parts submerged in clay or mineralized soils undergo faster corrosion than in dry sandy soils.

**f. Nature of corrosion product:**

- The formation of stable protective oxide films reduces the corrosion rate of metals where as the formation of volatile, non porous and non protective oxide films prolong the corrosion.

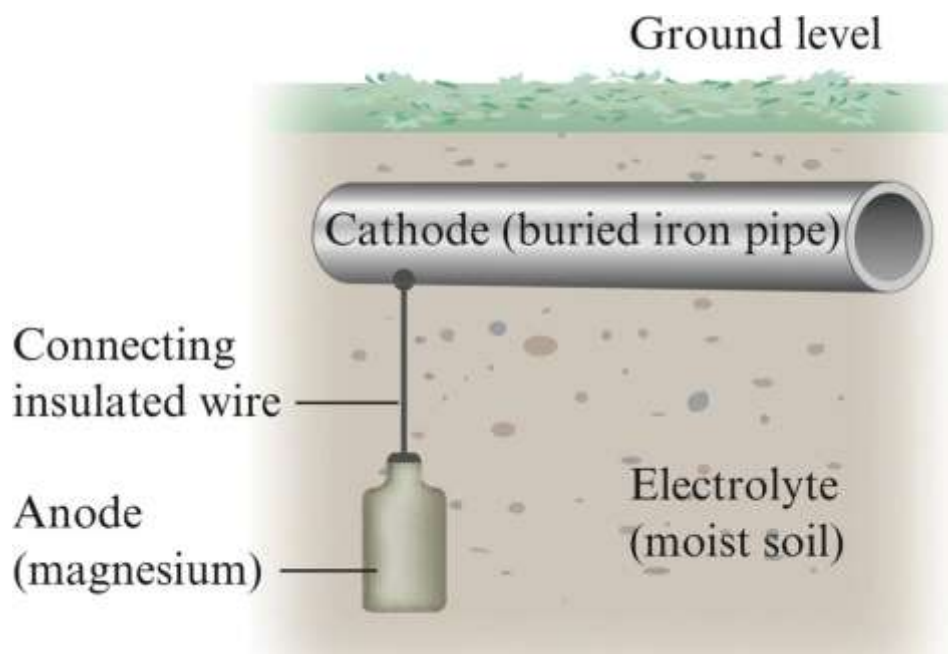
**PROTECTION METHODS OF CORROSION**

**1. CATHODIC PROTECTION:**

- ⤴ The principle involved in this method is to force the metal to be protected to behave like a cathode, there by corrosion does not occur.
- ⤴ There are two types of cathodic protection.

**a) Sacrificial Anodic Protection Method:**

- ♠ In this method, the metallic structure to be protected is connected by a wire to a more anodic metal.
- ♠ Thus during corrosion more anodic metal gets corroded while the parent metal is protected.
- ♠ The more active metal used is known as sacrificial anode which is replaced from time to time by fresh one.
- ♠ Metals commonly used as sacrificial anode are magnesium and zinc.
- ♠ This method is used for the protection of ships and boats. Sheets of zinc or magnesium are hung around the hull of the ship. Zinc and magnesium undergo corrosion.



**Sacrificial anodic protection**

### **b) Impressed Current Cathodic Protection:**

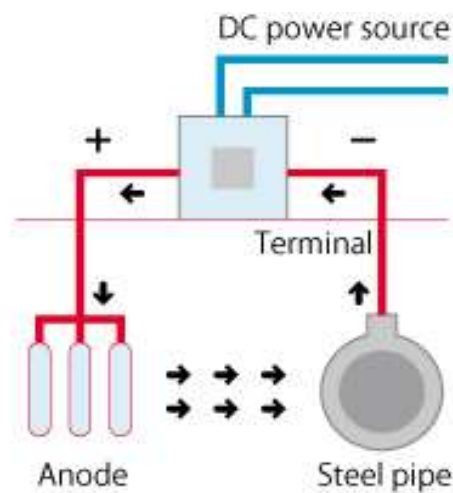
- ♣ In this method, the metallic object to be protected is made cathode by connecting it with the negative terminal of the DC source.
- ♣ The positive terminal is connected to an insoluble anode like graphite, scrap iron or platinum.
- ♣ The impressed current nullifies the corrosion current.
- ♣ The electrons flow to the metallic object as a result it acts as cathode and is protected.

### **Applications:**

- ☞ These methods are used for the protection of buried pipelines, under ground cables, water tanks etc.

### **Problems and limitations:**

- ✓ Capital investment and maintenance costs.
- ✓ Chemical reactions taking place at the surface of protected structure.
- ✓ Possibility of soil and microbiological corrosion.



**Impressed current cathodic protection**

### **ELECTROPLATING**

- It is widely used to coat the base metals with protective metallic coatings of copper, nickel, zinc, lead etc.

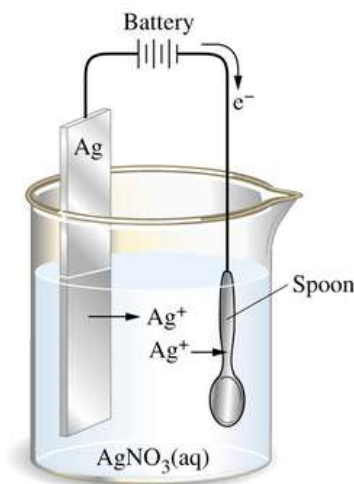
### **Process:**

- Before electroplating, the metal surface is cleaned thoroughly.
- The article to be electroplated is made cathode since metallic ions are positive and thus get deposited on the cathode.
- The anode is made of pure metal, which is to be coated on the article.
- The electrolyte is the salt of the metal to be coated on the article.

- A direct current is passed through the electrolyte.
- The anode dissolves, depositing the metal ions from the solution on the article.

### **Electroplating With Gold:**

- **Cathode:** Article to be electroplated (Spoon)
- **Anode:** Block of gold metal
- **Electrolyte:** Aqueous solution of  $\text{AuCl}_3$  or Potassium auro-cyanide  $\text{K}[\text{Au}(\text{CN})_2]$



### **ELECTROLESS PLATING**

- ◆ In this process, the base metal article is dipped in a bath of a noble metal salt which is used for coating.
- ◆ The noble metal forms a layer on the base metal article by displacement of base metal by noble metal.
- ◆ This process is also called as 'immersion plating' or 'displacement plating'.
- ◆ For example, **Nickel coating on base metal:** The base metal article is dipped in a bath of nickel sulphate and sodium hypophosphite kept at temperature of  $100^\circ\text{C}$  and at  $\text{pH}$  from 4.5 to 5. Nickel ion from solution reduces to nickel phosphide, which forms a strong adherent thin film.

**Electroplating:** It is an electrochemical process in which a base metal is coated by Zn, Ag, Cr, Au, Sn, etc. to protect it from corrosion and also to make it shining and decorative. The base metal is made cathode, dipped in a suitable electrolyte, and the metal to be deposited is made the anode. Anodised coating is done for non-ferrous metals, such as Zn, Mg and Al. They not only protect from corrosion but also give a good look to the metal. Organic coats must have chemical inertness, good surface adhesiveness and non effectiveness towards inorganic chemicals and water. The object before subjecting to electroplating process, it is essential to clean the surface of

Koneru lakshmaiah College of Engineering

object. The following methods are used to clean the metal surface. Solvent cleaning: Organic solvents such as Trichloro ethylene and methylene chloride are used to remove organic matter and grease on the surface of cathode. Trichloro ethylene is used to remove paint varnishes, films, resins etc. Per chloro ethylene is used to remove high melt waxes and cleaning PCB. The above process is called solvent cleaning. Alkali cleaning: After solvent cleaning the metal is cleaned with alkali solution. Alkali cleaners

such as soaps, detergents, sodium carbonate, sodium hydroxide, sodium phosphate etc are commonly used. iii) Mechanical cleaning: The object is subjected for mechanical cleaning to remove oxide scales, rust and other impurities on the metal surface. The mechanical cleaning methods involves, cleaning with Bristle brushes, mechanical polishing, grinding using polishing machines, and sand blasting. Pickling: In this method the oxides scales are removed by dipping the base metal in a dilute acids. Pickling of steel involves dipping in dilute HCl or dilutes  $H_2SO_4$  to remove rust and other oxide scales. Rinsing with water: After surface cleaning process the metallic surface is thoroughly rinsed with water, dried and subjected for electroplating process. Procedure: Cathode: the cleaned article is made as cathode. Anode: the anode is the coating metal itself Or an inert material of good electrical conductivity like graphite. Electrolyte: the electrolyte is a solution of a soluble salt of the coating metal. The anode and cathode are dipped in the electrolyte. When direct current is passed, coating metal ions migrate to the cathode and get deposited there. A thin layer of coating metal is obtained on the article made as cathode. For brighter and smooth deposits, low temperature, medium current density, low metal-ion concentration are used.

### **Electroplating of Copper:**

Step 1:

The article to be electroplated is first treated with organic solvents like  $CCl_4$  (Carbon tetra chloride) to remove oils, greases etc.,

Step 2:

The metal to be coated i.e. the base metal after step-1 is cleaned with Dil HCl to remove scales or the oxide layer.

Step 3:

Anode – pure copper, Cathode – base metal

Electrolyte is  $CuSO_4$  solu. Taken in an electrolytic tank.

Anode and Cathode immersed in the electrolyte.

Reactions:



At anode:  $\text{Cu(s)} \longrightarrow \text{Cu}^{2+}(\text{aq}) + 2\text{e}^-$  (Oxidation)      Copper is dissolved.

At cathode:  $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \longrightarrow \text{Cu(s)}$  (Reduction)      Copper is deposited

	Sulphate bath	Cyanide bath
Plating bath solution	200-250 g $\text{CuSO}_4$ , 50-75 g $\text{H}_2\text{SO}_4$ , per L of	40-50 g $\text{CuCN}$ , 20-30g $\text{KCN}$ , 10 g $\text{K}_2\text{CO}_3$ per L
Operating temperature	20-40°C	40-70°C
Current density	20-50 $\text{mA/cm}^2$	10-40 $\text{mA/cm}^2$
Addition agents	Gelatin, dextrin, sulphur containing brighteners, sulphonic acids	Sodium thiosulphate
Current efficiency (%)	95-99	60-90

