

LECTURE NOTES  
On  
Corrosion Engineering



Course code: Th4

Semester: 6<sup>th</sup>

Course Co-ordinator: Goutam Kumar Majhi (Lect.)

Metallurgical Engineering Department

Govt Polytechnic, Sonapur

Session- 2023-24

# INTRODUCTION TO CORROSION

## **Definition**

- It is the loss of material as a result of chemical or electrochemical reaction with its environment.
- This phenomena is most likely occur in metals as compare to ceramics or plastics.  
Ex- Rusting of steel, tarnishing of silver.
- Corrosion engineering is the science & art to protect materials from corrosion economically & safely.

## **Cost of corrosion**

- Losses due to corrosion could be direct or indirect.

### Direct loss

1. Inability to use desired materials.
2. Over-design/ allowance for corrosion component.
3. Cost of repair or replace of corroded component.
4. The cost of anti-corrosive painting or other protection methods.

### Indirect loss

1. Contamination of product.
2. Loss of valuable product from a container that has corroded through.
3. Loss of production.
4. Safety.
5. Loss of appearance.

## Importance of corrosion studies

- Increasing use of metals in all fields of technology.
- Use of rare & expensive metal and alloys.
- Use of new high strength alloy which are prone to certain type of corrosion.
- Increasing pollution of air & water which result in more corrosive action.
- Strict safety standard.

## Classification of corrosion

- Based on corrosion mechanism it is classified is to two type:
  1. Chemical corrosion.
  2. Electro-chemical corrosion.

### 1. Chemical corrosion

- It involves direct chemical reaction of metal with its environment.

### 2. Electro-chemical corrosion

- Here the environment act as a medium for corrosion.

↑  
Transfer of  $e^-$

## Corrosion rate

- In corrosion engineering materials are compared on the basis of their corrosion resistance.

- Most commonly corrosion rate are measured by the weight loss due to corrosion.

The rate of corrosion can be calculated by:

$$R = KW / ATD \text{ (mpy or mm/yr)}$$

Where, R = rate of corrosion

K = constant

W = weight loss in gm

A = area of specimen

T = time exposed

D = density in gm/cm<sup>3</sup>

# CORROSION PRINCIPLE

Electrochemical principle of corrosion:

- Corrosion of metal can take place either by chemical or an electrochemical route or by both taking place simultaneously.

Chemical	Electrochemical
<ol style="list-style-type: none"><li>1. It takes place due to direct chemical reaction of metal with the environment.</li><li>2. There is no transport of charge.</li><li>3. Metal remains film free.</li><li>4. It occurs in dry condition.</li><li>5. Homogenous metal can get corroded.</li></ol>	<ol style="list-style-type: none"><li>1. It is due to formation of anodic area.</li><li>2. Transport of charge through electrolyte.</li><li>3. Formation of films</li><li>4. Occurs in presence of moisture or electrolyte.</li><li>5. Heterogeneous (bimetallic) surface get corroded.</li></ol>

## Chemical vs electrochemical corrosion

Types of reaction in corrosion

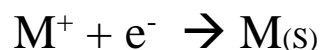
### **Oxidation**

- Removal of electron (e-) from metal is called oxidation.



### **Reduction**

- Addition of electron is reduction.



- *Summation of both the reaction is known as redox reaction.*

## **Electrolysis**

- It is a process of passing electric current through an electrolyte result in chemical reaction at the electrodes.

### Faraday's Law of electrolysis:

- Electrochemical process, including corrosion reactions obey Faradays laws of electrolysis.

#### 1<sup>st</sup> law

- When a current is passing through an electrolyte amount of substance/material deposited or liberated at electrode is directly proportional to the amount of electricity passed through it.

$$W \propto Q$$

$$(Q=i.t)$$

$$W= Z.i.t$$

Where, W= wt. of material deposited or liberated

i = Current passed

t = time

Z= Electro Chemical Equivalent

“Electro chemical equivalent (ECE) of a substance is defined as the mass which is liberated or dissolved by the pass of a current of 1amp for 1sec”.

## 2nd law

- “When same amount of electricity is passed through different electrolyte, the mass of substance deposited/liberated is directly proportional to their chemical equivalent”.

$$W \propto E$$

$$\frac{W_1}{W_2} = \frac{E_1}{E_2}$$

Where, W = wt. of material deposited/liberated.

E = chemical equivalent of the material.

(E = Atomic wt. / valency)

## Deviation from Faraday's law

- There is deviation for Faraday's law is observed during electrolysis due to following reasons :-
  - (a) Recombination of primary products
    - There is chances of recombination of cathodic & anodic products if the temperature rises.
  - (b) Discharge of other ions
    - Loss of current occurs due to discharge of other ions rather than the selected ion.
  - (c) Formation of compound
    - It has been observed that in certain cases formation of compound at electrodes.

(d) Dissolution of electrode

- Due to direct dissolution of electrode there will be error in result.

(e) Evaporation losses

- In some cases due to high temperature evaporation of metal occurs. Which will result in deviation in result.



# Type of electrochemical cell

## Electrochemical Cell

- It is a device which either generate electrical energy from chemical reaction or use electrical energy for chemical reaction to occur.

Three main types of electrochemical cells are there which are responsible for corrosion:

- (i) Galvanic cell
- (ii) Concentration cell
- (iii) Electrolytic cell

### (i) Galvanic cell

- It is a type of electrochemical cell which convert chemical energy to electrical energy.
- This type of cell is generated whenever two dissimilar metals are connected electrically.
- This dissimilarity could be due to:
  - (a) Two different metal
  - (b) Same metals undergone different heat treatment processes
  - (c) Surface roughness
  - (d) Different grain size
  - (e) Chemical heterogeneity
- In this type of cell, the process consists of redox reaction. That means one acts as anode where oxidation reaction takes place and at the other reduction reaction takes place.  
Redox= oxidation + reduction

- For example, if we connect Cu & Zn electrically then Zn electrode will get oxidized (corrode).

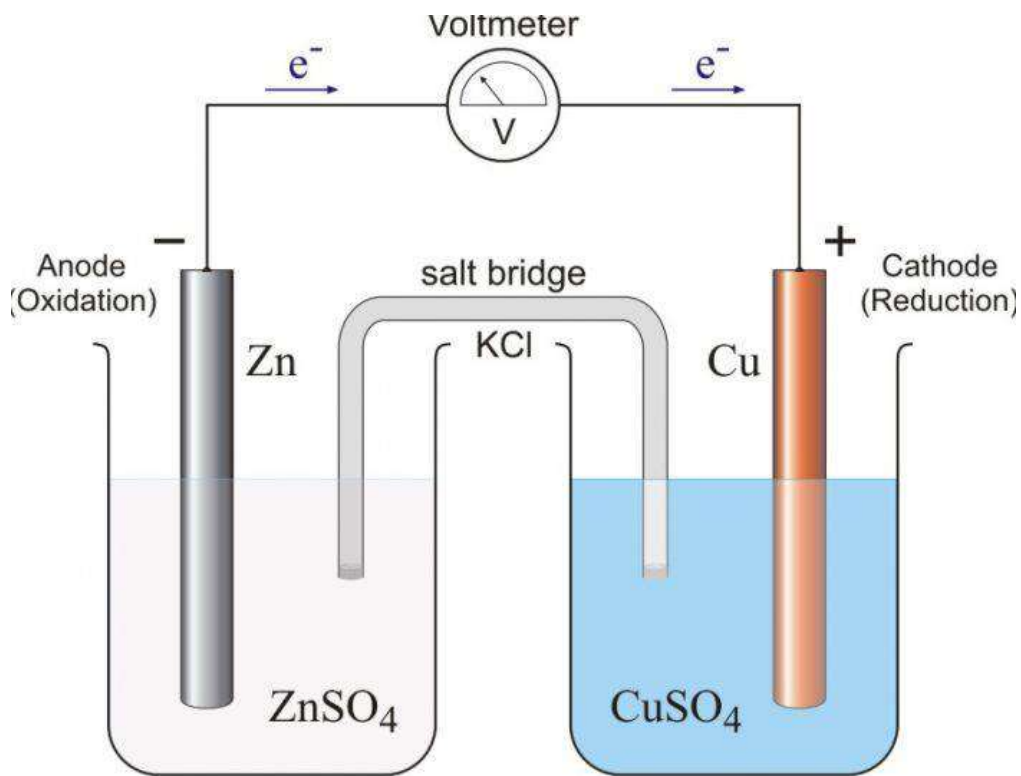


Figure: Galvanic cell

### (ii) Concentration cell

- In this type of cell, the material(s) may be homogenous in all aspect so that there won't be any cathodic or anodic area but corrosion may occur due to difference in electrolyte they are in contact with.
- It can be defined as the electro chemical cell which is a result of difference in electrolyte.
- It also converts chemical energy to electrical energy or chemical reaction results in movement of  $e^-$ .

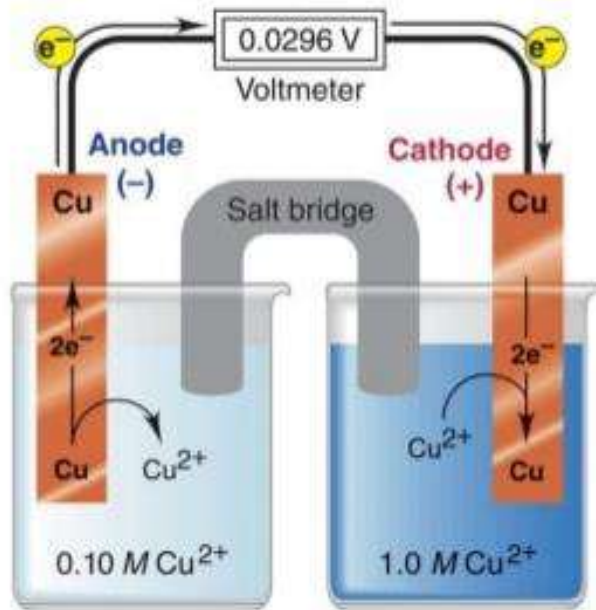


Figure: Concentration cell

Difference in electrolyte could be due to:

- (a) Different composition of electrolyte – electrodes are in contact with two different electrolyte.
- (b) Same electrolyte but different concentration- one is dilute another is concentrated.
- (c) Temperature difference- the two regions having different temperature may have different potential.
- (d) Different oxygen concentration.

### (iii) Electrolytic cell

- It is a type of electrochemical cell which uses electrical energy to drive a chemical reaction.
- When the metal(s) and electrolyte are homogenous to such an extent that no cathodic and anodic area are developed, in those cases presence of energy from external source can develop cathodic and anodic area.

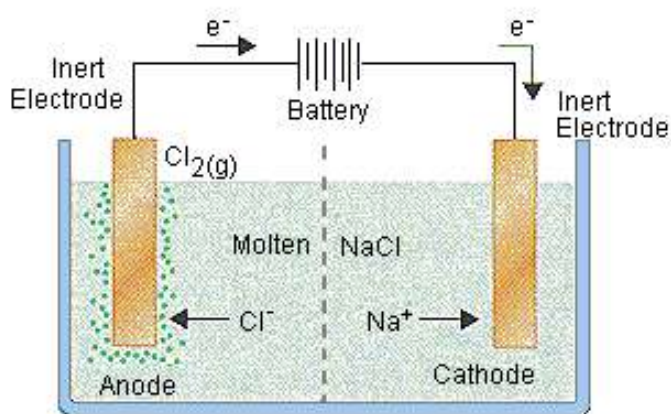


Figure: Electrolytic cell

- Corrosion can occur in metal due to development of an electrolytic cell for example, if current enters a metallic structure at same point and leaves at another point, then the area at which current leaves the metallic source become anodic w.r.t to the other.

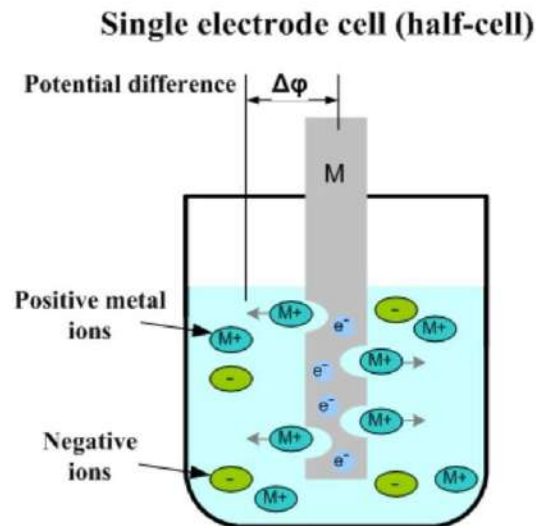
### Difference between galvanic cell and electrolytic cell

Galvanic cell	Electrolytic cell
(a) It converts chemical energy to electrical energy.	(a) It converts electrical energy to chemical energy.
(b) Electrodes are of dissimilar metals.	(b) Electrodes are of similar metal.
(c) Here spontaneous chemical reaction takes place.	(c) Here nonspontaneous chemical reaction takes place.
(d) No need of external power source.	(d) External power source is required.
(e) Anode is negative and cathode is positive.	(e) Cathode is negative and anode is positive.

# Chapter 4

## Electrode Potential

- The potential difference between electrode and its ion in the electrolyte is called as electrode potential.



- There is no practical method available to determine this single electrode potential difference. Therefore, measurements are always carried out between two metal-solutions (electrode-electrolyte) for electrode potential difference.
- For assigning value to single electrode potential, one of the electrode potential is taken as reference potential and assigned a value of zero potential.

## EMF series

- Electromotive force series is an arrangement of metals according to their electrode potential.
- For construction of emf series hydrogen is taken as standard electrode (reference) and assigned an electrode potential 0V.
- That means the series has been established by measuring potential of various electrode versus standard H<sub>2</sub> electrode.

### Metals Electrode potential

Au.....	+1.70
Pt.....	+1.23
Cu.....	+0.23
H <sub>2</sub> .....	0
Ni.....	-0.25
Fe .....	-0.44
Al.....	-1.66

- Metal having higher (+ve) electrode potential remain above hydrogen in the series and vice-versa.
- Higher the electrode potential of metal it is and less tendency to oxidation and corrosion.
- Lower electrode potential metals are less stable, easily get oxidized and corroded.

## Application of EMF series

EMF series is very useful in predicting the type of reaction that is taking place at an electrode.

### *1. Displacement of metals*

- One metal will displace another metal which is present above it in emf series.
- That means, higher electropositive metal will be reduced and the less electropositive metal will get oxidised while dipped in one of its aqueous solution.
- For example if a Zn rod is dipped in  $\text{CuSO}_4$  solution. Zn will have higher tendency to remain in the solution than Cu.

So Zn will lose electron to go into the solution, and those electrons will be consumed by some Cu ion they get reduced and deposited at Zn rod.

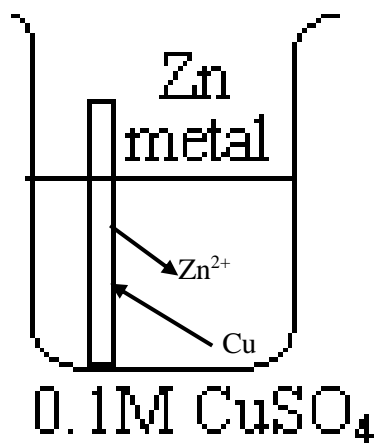
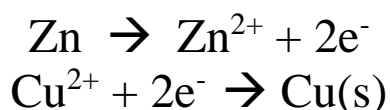
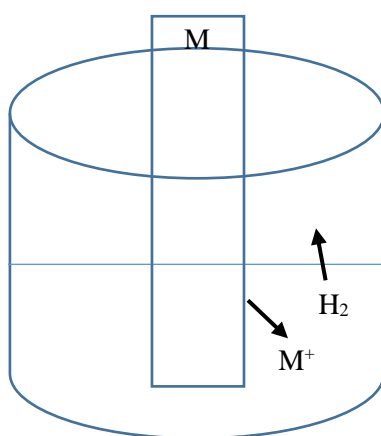
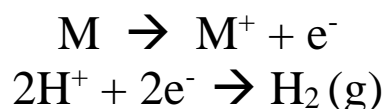


Figure: Displacement of Cu by Zn.



## 2. Displacement of hydrogen

- Corrosion of many metals occurs via evolution of H<sub>2</sub> gas, i.e. H<sup>+</sup> ion get reduced from the electrolyte and the corresponding metal electrode get oxidised.



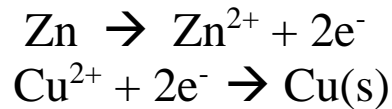
- Metals present above H<sub>2</sub> in emf series, such as Gold, Pt, Ag, Cu etc. are incapable of displacing/liberating H<sub>2</sub> while placed in acid. Whereas, metal present below H<sub>2</sub> can displace H<sub>2</sub> from acid and get oxidised/corroded.

## 3. Galvanic Corrosion

- If two metals in the emf series are electrically connected in an aqueous electrolyte, the series can be used to predict which of them is likely to corrode.
- Looking from the potential value from the emf series the more electronegative metal or the metal present lower in emf series as compared to other will get corroded.



- The tendency of corrosion will increase if the metals are placed widely apart in the series.
- For example if we connect Cu and Zn, then Zn will get corroded.



#### 4. *Electrolysis*

- More electropositive metals (metals having higher electrode potential) deposit first.
- For example, if a solution contains both  $\text{H}^+$  and  $\text{Cu}^+$  ions then copper will liberate from the solution and deposit first at cathode.
- This principle can be applied for separation of different metals dissolved in solution.

### **Limitations of EMF series**

1. Only pure metals are listed in the series. But in application we rarely use pure metal. This series cannot predict corrosion behaviour of alloys.
2. The electrode potential of metals listed in the series is determined under specified condition, i.e. 1atm pressure and 1molar electrolyte.
3. The emf series doesn't take account of surface films, which may form on the metal surface which shows passivation.  
Example: SS, Al etc.
4. Effect of temperature has not been considered in the emf series. It is only applicable at a temperature of 25°C.

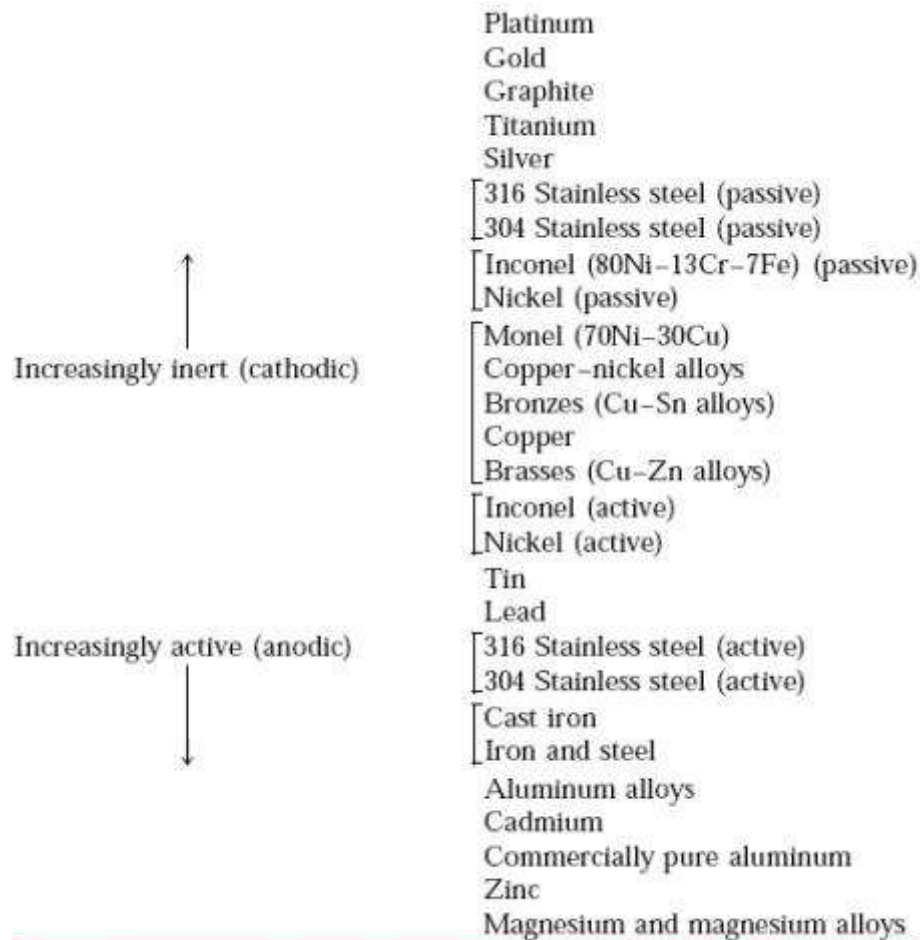
5. EMF series doesn't take account the effect of pH value of electrolyte.

### **Galvanic Series**

- This series is an arrangement of metals and alloys w.r.t. to their actual potential in a given environment.
- Galvanic series is a more practical chart showing relative tendency to corrosion in a particular environment (such as sea water)
- Magnesium at the end of the series is the most active, and Pt is on the top of the list. (Table 13-6.2)
- Ti and Ni which are more active in the electrochemical series are near the noble end of this galvanic series, by virtue of their ability to form passive films.
- Galvanic series of some commercial metals and alloys in sea water is given the table below:

### Application and features of Galvanic series

- This series contains both metal and alloys.
- Metals and alloys present towards top of the series are corroded least and those which are present at bottom corroded maximum.
- The farther apart metal and alloys are in the series more will be potential difference chances of corrosion will be more. So farther apart metal/alloys shouldn't be connected electrically.
- Chances of corrosion is minimum when metals of same group enclosed in brackets are connected together.



Source: M. G. Fontana, *Corrosion Engineering*, 3rd edition. Copyright 1986 by McGraw-Hill Book Company. Reprinted with permission.

## Limitations

- In case of emf series only one series exist but here can be several numbers of Galvanic series depending upon the environment of application.
- Corrosion between two metals connected electrically not only depend on how far they are present in Galvanic series but also the potential difference.
- This series also cannot be used to predict effect of change in pH on corrosion tendency.

## CHAPTER 5

### DIFFERENT FORMS OF CORROSION

#### **Introduction:**

- Corrosion manifest itself in various form.
- It is needed to know the type of corrosion that is taking place in the given atmospheric condition.
- Because, valuable information for the solution of a corrosion problem can often be obtained through careful observation of the corroded test specimens or failed equipment.
- The basis for this classification being the appearance of the corroded metal. Each form can be identified by mere visual observation. In most cases the naked eye is sufficient, but sometimes magnification is helpful or required.

Corrosion is classified into:

- i. Atmospheric corrosion
- ii. Intergranular corrosion
- iii. Pitting corrosion
- iv. Corrosion fatigue
- v. Galvanic corrosion
- vi. Stress corrosion cracking
- vii. Cavitation corrosion
- viii. Fretting corrosion
- ix. High temperature oxidation corrosion
- x. Stray current corrosion

## **i. Atmospheric corrosion**

- Atmospheric corrosion is the attack of a metal or an alloy by the atmospheric environment to which it is exposed.
- It represents the greatest destruction of metal on tonnage basis.
- Most common example of this type of corrosion is the rusting of iron and steel. Other examples are tarnishing of aluminium, brass and silver, formation of green patina on copper etc.
- It is a uniform type of corrosion.

Factors affecting atmospheric corrosion:

- Dust particles
  - Presence of dust particle enhance the rate of atmospheric corrosion as they absorb moisture and various gases from atmosphere.
- Gases in atmosphere
  - In industrial atmosphere gases like  $H_2S$  and  $SO_2$  might be present and they are harmful due to their conversion to  $H_2SO_4$ .
- Moisture content
  - Corrosion of metal like steel increases with increase in humidity of atmosphere.

## **Remedies**

1. Use of better alloy.
2. Use of various coatings.

3. Reduction of humidity level.
4. Reduction of atmospheric pollution.

## **Intergranular Corrosion**

- On a microscopic level, metals and their alloys have small, distinguishable regions called grains. Within an individual grain the orientation of the atomic arrangement (called a lattice) is the same.
- Individual grains have different orientations and the boundary between the grains is called the grain boundary. Normally, grain boundaries are not very much reactive in corrosion than the grain itself.
- Under certain conditions, however, the grain boundaries are altered from the grain itself by impurities and/or enrichment (or depletion) of one of the alloying elements.
- Heat treatment and welding can lead to changes in metal composition which may incite Intergranular corrosion. In severe cases, Intergranular corrosion can lead to a marked decrease in mechanical strength and can, in extreme cases, turn the metal into a pile of individual grains. Which may result in catastrophic failure.
- One of the most common examples of Intergranular corrosion occurs in stainless steels. During welding of the alloy, or heating in the temperature range of 550°C to 850°C.

- The alloy becomes sensitized or susceptible to Intergranular corrosion as illustrated in Figure below. The chromium carbide ( $\text{Cr}_{23}\text{C}_6$ ) is not soluble in this temperature range and precipitates out of the grain into the grain boundary.
- As a result, the area of the grain adjacent to the grain boundary is depleted of the chromium and becomes anodic to the rest of the grain and to the grain boundary. This phenomenon is known as *sensitization of stainless steel or weld decay*.

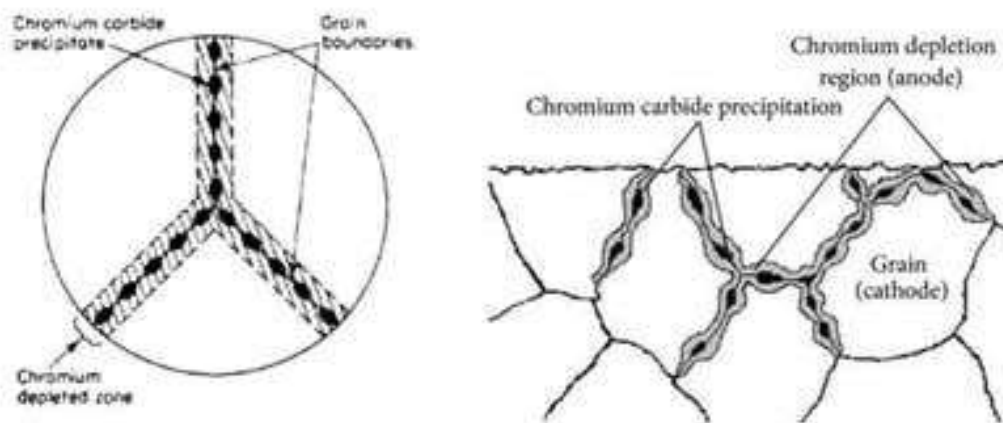


Fig: Formation of chromium depleted region.

- The corrosion of this depleted grain boundary area is very severe and occurs in environments and acids where the alloy would not normally corrode.
- In practice sensitization of SS may occur due to one of the three following reasons:
  - Slow cooling of the alloy in the sensitization temperature range during solidification or heat treatment.
  - During tempering after quenching.

- During welding of the alloy. During welding operation the parent metal on both side of weld is heated to sensitization range and this may result in precipitation of  $\text{Cr}_{23}\text{C}_6$  and cause Intergranular corrosion. This is known as weld decay.

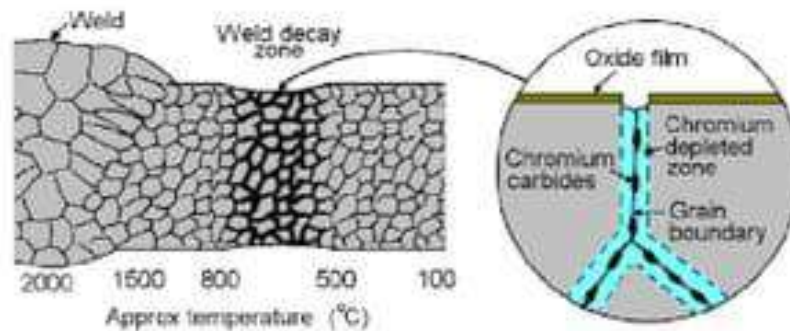


Fig: Weld decay phenomena

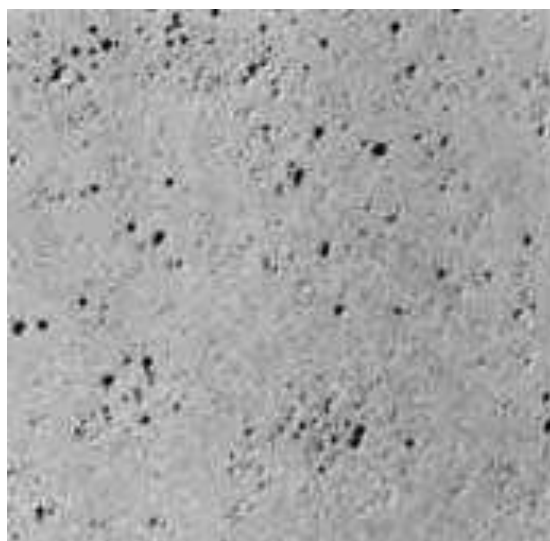
### Remedies:

- The simplest solution to the stainless steel Intergranular corrosion problem is to decrease the carbon contents below 0.03%. This prevents the formation of the chromium carbide and the chromium stays in solution.
- Rapid cooling in the sensitization temperature range.
- Addition of strong carbide former like Nb, W, V etc.



### iii. Pitting corrosion

- Pitting is an extremely localized attack that eventually results in holes in the metal.
- It is one of the most destructive forms of corrosion and results in sudden failure.
- Basically, the alloys subject to pitting are those that rely on an oxide film for protection, such as stainless steels.
- The initiation of a pit can be the result of the following:
  - a) Chemical attack, such as seawater on stainless steel.
  - b) Mechanical attack such as an impact or scratching that removes small areas of the protective film.
  - c) Due to compositional inhomogeneity or surface defects.



Pitting in 18-8 SS by acid chloride solution

## **CHARACTERISTICS**

Following are the characteristics of pitting corrosion:

1. Active metals are most susceptible to this type of attack, e.g. chromium, aluminium and alloys containing these elements.
2. Pits are usually formed randomly on the surface. They are sometimes isolated or so close together that they look like a rough surface.
3. Pits are, generally, described as a hole or cavity with the surface diameter about the same or less than the depth.
4. It is often difficult to detect pits because of their small size and because they are covered with corrosion products.
5. Pitting is a corrosion process which is autocatalytic, self-stimulating and self-propagating.
6. Pits are usually elongated in the direction of gravity.
7. Pits are generally initiated on the upper surface of the horizontally placed specimens.
8. Pitting usually occurs under stagnant conditions such as crevices, liquid trapped in the part of an inactive pipe system, or liquid stored in a container.

### **Mechanism**

- Pitting nucleates by formation of a corrosion cell between a small anodic area and large cathodic area. This small anodic area is known as pit.

- This could be due to heterogeneity in metal, or in the film on metal surface or presence of small areas of more plastic strain.

### **Remedies**

- Select suitable materials that show minimum proneness to pitting in the type of environment being used.
- Control of environment aggressiveness through monitoring chloride concentration level, acidity.
- Use of protective coatings.
- Application of cathodic protection.

### **iv. Corrosion Fatigue**

- The simultaneous action of cyclic stress and chemical attack is known corrosion fatigue.
- It can be defined as the reduction of fatigue strength due to presence of corrosive environment.
- Corrosion fatigue can be defined as the reduction in fatigue strength due to presence of corrosive environment.
- Previously formed pits act as notches and decreases the fatigue strength. The rate of fatigue crack propagation increases under corrosive environment.

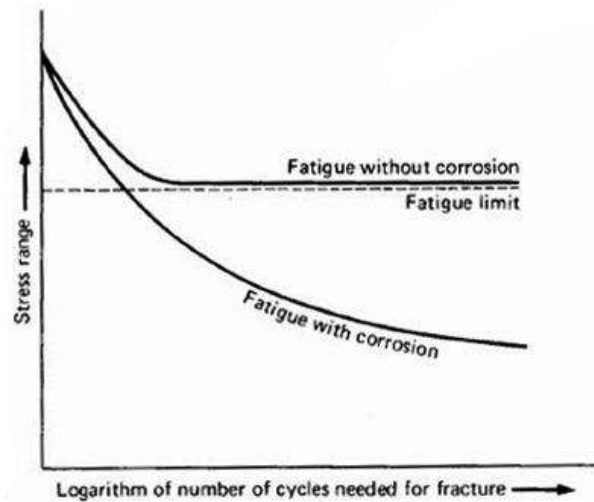


Fig: Fatigue curve(S-N) of ferrous material with and without corrosion

## Prevention

- Lowering the tensile strength of the material.
- Reducing stress on the component.
- The choice of material for this type of service should be based on its corrosion resistant properties rather than fatigue properties.
- Nitriding, shot peening is done to avoid corrosion fatigue.
- Application of cathodic protection and inhibitor.

## v. Galvanic Corrosion

- When two or more dissimilar metals/alloys immersed in a corrosive solution(electrolyte) and externally brought in electrical contact with each other, the existence of a potential difference between them results in a flow of current in the external circuit.
- Less corrosion resistant metal acts as anode suffering degradation and the more resistant metal acts as cathode with almost no degradation as compared to their behaviour

in the same solution if they were not electrically connected or would have been individually immersed in the solution.

- Driving force for the flow of current or corrosion is the developed potential difference between the two metals.

### **Prevention**

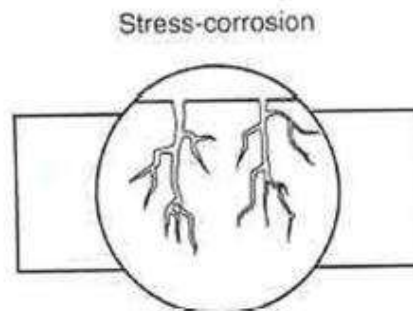
- Choose alloys which are close to each other in the Galvanic series.
- Avoid area effect of a small anode and large cathode.
- Electrically insulate dissimilar metals wherever possible.
- Apply coatings with caution and arrange regular maintenance particularly for the anodic portion.
- Using inhibitors to reduce the aggressiveness of the environment.

### **vi. Stress corrosion cracking (SCC)**

- The failure of material by combined action of a tensile stress and corrosive medium is known as stress corrosion cracking.
- It is believed that the corrosion causes a pit or surface discontinuity to form on the metal which then functions to act as a stress concentrator.
- The presence of a minimum threshold tensile stress, coupled with the corrosion, causes the crack to propagate. Additionally, during the initial corrosion, the tensile stresses could cause the protective films on the surface to

rupture, thereby exposing the metal to the corrosive environment.

- In this type of corrosion, the tensile stress ruptures the passivated film which results in easy corrosion of the structure, which eventually results in initiation of crack.
- Stress-corrosion-cracking occurs with specific alloys under certain conditions like: Specific corrosive environment solution composition, minimum tensile stress levels, temperature, and metal composition.
- Some examples of SCC are the brass and stainless steel alloys. Specific brass alloys will crack in ammonia containing environments when a minimum threshold tensile stress is reached. Stainless steel alloys do not crack in ammonia environments, but will crack in chloride solutions.

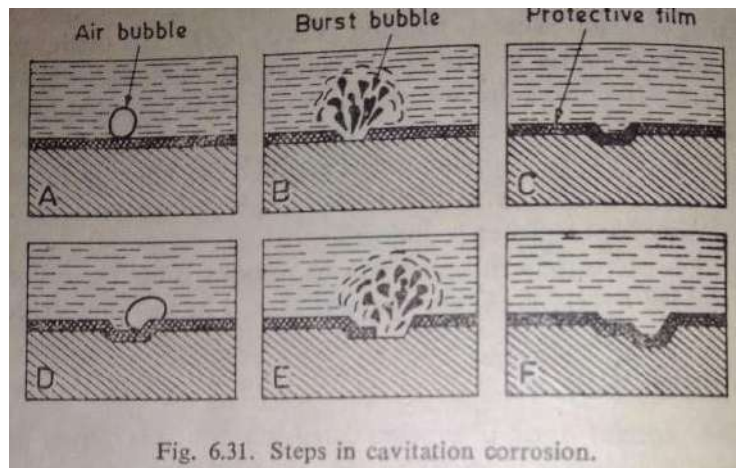


## Prevention

- Lowering the stress by annealing, or by using thicker section, or by reducing the load.
- Modification or elimination of critical environment by degasification or by adding inhibitors.
- Selection of proper alloy and by cathodic protection.

## **vii. Cavitation corrosion**

- Cavitation is the deterioration of a surface caused by the sudden formation and collapse of bubbles and voids due to the turbulence in the liquid. It is generally marked by a pitted or rough metal surface.
- Cavitation damage occurs on surfaces which are in contact with fluids at high velocities and where frequent pressure changes are encountered, e.g., hydraulic turbines, ship propellers, etc.
- Cavitation damage can also occur in the absence of a corrosive environment, but the attack becomes more severe when there is combine action.
- Cavitation corrosion has been attributed to the combined action of mechanical effect and corrosion.
- It is assumed that the collapsing vapour bubbles destroy protective surface films increased corrosion. This mechanism is shown schematically in Fig.
- The steps are as follows: (i) cavitation bubble forms on the protective film; (ii) the bubbles collapse and destroy the film; (iii) the newly exposed metal surface corrodes and the film is reformed; (iv) Cavitation bubble forms at the same spot; (V) the new bubble collapses and destroys the film (vi) the exposed area corrodes and the film reforms. Repetition of this process results in deep holes.



## Prevention

- Proper selection of material.
- Use of cathodic protection.
- Application of coatings.
- By changing the design of structures.

## viii. Fretting Corrosion

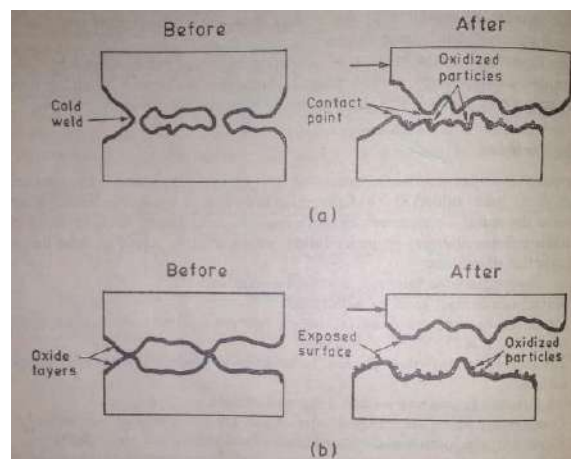
- It is a type of corrosion occurring at contact areas between two surfaces under load subjected to vibration and slip.
- The basic requirements for this type of corrosion are: the surface in contact must be under load, vibration or repeated relative motion and plastic deformation.
- There are two mechanisms which have been proposed to explain damage due to Fretting corrosion:

1. *Wear Oxidation Mechanism:* According to this mechanism, the two surfaces make contact at only a small number of high points, where cold welding or fusion occurs due to applied load. These contact points are ruptured during subsequent relative motion and as a result fragments of metal are removed. These fragments



immediately get oxidized due to their small size and frictional heat (Fig. a). This process repeats itself.

2. *Oxidation Wear Mechanism:* According to this mechanism, metal surfaces are protected from atmospheric Oxidation by an adherent oxide film. When metals are placed in contact under load and are subsequently subjected to repeated motion, the oxide layer ruptures at high points and results in oxide particles (Fig. b). The exposed metal surface re-oxidizes, and the process repeats itself.



## Prevention

- Using hard-metals, or even cold-worked or shot-peened metals reduce Fretting-corrosion.
- Use of gaskets to absorb vibrations and exclude oxygen at surfaces.
- Increase the load on surfaces to prevent slip of surfaces.
- Lubricate the parts with low viscosity oils and grease.

## ix. High temperature oxidation corrosion

- Corrosion of metal can occur in the absence of a liquid electrolyte when it is exposed to an oxidizing gas, e.g., oxygen, Sulphur, or halogens, at ambient or elevated temperatures. This is sometimes called scaling, tarnishing, dry corrosion, or high temperature oxidation.
- As the temperature increases, Oxidation resistance of most metals decreases. This type of attack is a serious problem in many major industries, such as an aircraft, automobile, chemical, electrical, metallurgical, paper and pulp, and power.
- In one of the earliest studies on oxidations, Pilling and Bedworth proposed that the oxidation resistance is related to the volume ratio of oxide and metal. This ratio is called *Pilling-Bedworth ratio*.
- The ratio  $R$  indicates the volume of oxide formed from a unit volume of metal. If the value of  $R$  is close to unity (1) then the oxide layer is supposed to be a protective layer.

### Prevention

- The loss due to high temperature oxidation can be minimized by using High temperature alloys like Ni-alloys, use of coatings.

## **x. Stray Current Corrosion**

- Corrosion can be accelerated by the action of electrical currents entering a metal from some external source such as a generator or a battery and leaving the metal to continue its flow in whole or part.
- Stray current corrosion refers to type of corrosion resulting from stray current- the current flowing through paths other than the intended circuit.
- All metallic structures buried underground are susceptible to this type of corrosion. Ex: DC railways, tunnels, underground pipe lines etc.
- This corrosion is independent of the environmental factors.

### **Prevention**

- Identification of the stray current source.
- Maintaining good electrical connection and insulation.
- Installation of impressed current cathodic protection.

## **Chapter - 6**

### **Corrosion Prevention**

Corrosion occurs when metals come in contact with a corrosive atmosphere. Thus, corrosion can be prevented by:

1. Change of metal/alloy
2. Design improvement
3. *Change of metal electrode potential*
4. *Use of coating*
5. *Change of environment*

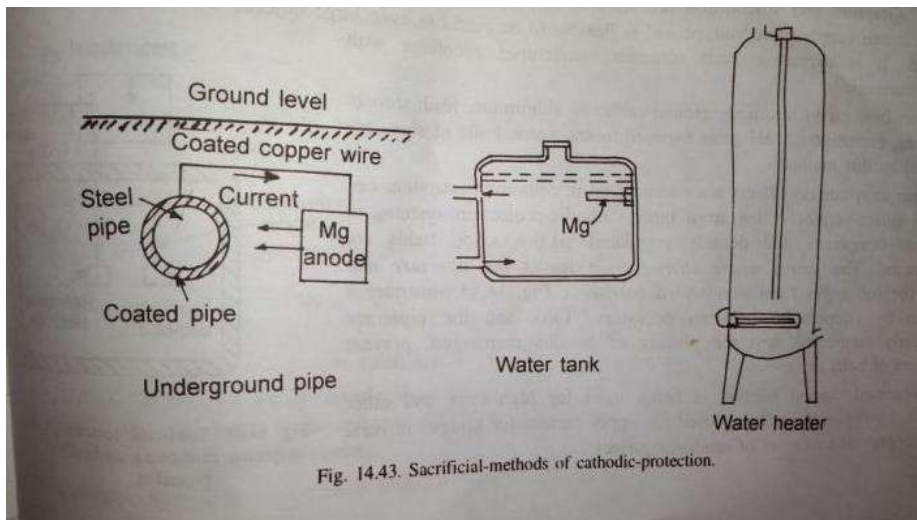
#### **Cathodic Protection**

- It is a method of reducing or preventing corrosion of a metal by making it cathode in the electrolytic cell. There are two methods available for cathodic protection:

- I. Sacrificial anode method
- II. Impressed current method

#### **I. Sacrificial anode method**

- In this method, another metal, which has more negative electrode potential than the structure to be protected, is connected electrically to the structure, which now acts like a cathode.
- The structure is protected at the sacrifice (corrosion) of another metal, and that is why, this name is given to the method.

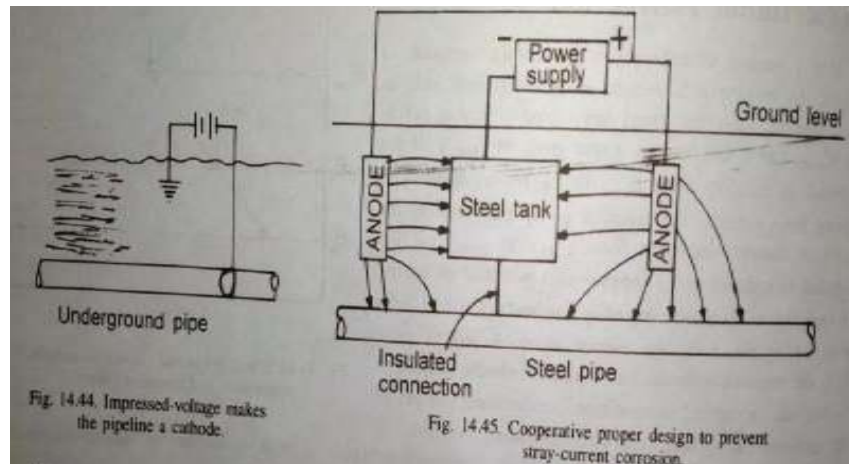


- Mg and Mg alloy are widely used. Zn is also often used. Sacrificial anodes are replaced as soon as consumed.
- This method is used for protection of under-water parts of ships, underground pipes, steel water-tanks, water heaters, condenser-tubes, oil-cargo-ballast tanks etc. Galvanised sheet is basically sacrificial-protection of steel, where Zn is sacrificed.

## II. Impressed current method

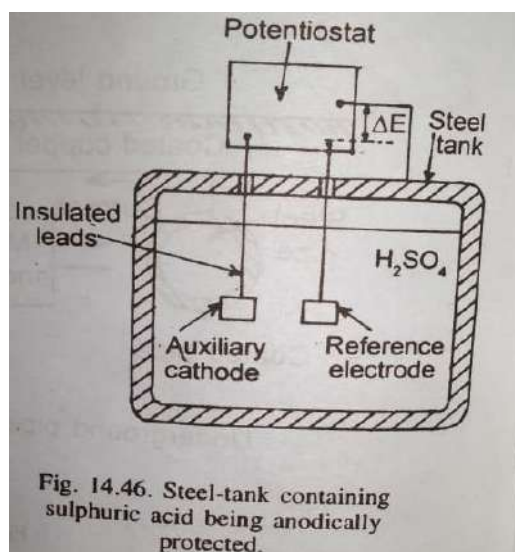
- In this method, the given metallic structure is made cathode by the use of external current by connecting the negative terminal of the external power-supply source to the metallic structure, and the positive is connected to an inert anode of scrap steel, aluminium, graphite, or silicon-iron.
- Apart from pipe-lines, underground cables of aluminium, lead; storage tanks, heat-exchangers, steel-gates exposed to sea-water, hulls of ships are protected by this method.

- Often stray-current effects are encountered in this type of cathodic protection.



## Anodic Protection

- It is a technique to control the corrosion of a metal surface by making it anode of an electrochemical cell by controlling the electrode potential in a zone where the metal is passive.
- This technique is only applicable to those metals which exhibit passivation (protective film).
- This technique is mostly used for steel and stainless steel in extreme corrosive conditions.



## Coatings

- Cost is a very important factor while choosing an engineering material. Instead of using a costly non-corroding material an easily corrodible alloy like steel can be used by protecting it from environment.
- By far the most important protective mean is one kind of thin coating. *The chief function of such a coating is to provide an effective barrier between the metal and its environment.*
- The coat itself should have good resistance to corrosion, should be adherent and cover the metal completely. The coatings are broadly classified as
  - I. Metallic Coatings
  - II. Non-metallic coatings

### I. METALLIC COATINGS

- Protecting the metals by metal-coating is an old and very widely used practice as they are more durable, more decorative and provide better protection against corrosion.

Metallic coatings are classified as:

#### i. Cathodic Coatings

- In such a type of coating, the coating metal is cathodic with respect to the base metal.
- Coatings of tin, nickel and chromium on steel are cathodic coatings as these are higher than steel in the galvanic series.

- These coatings provide a physical barrier between the metal and the environment. When the coating is dense, non-porous, continuous corrosive medium did not come in contact with base metal, and the base metal does not corrode.
- Coating being cathodic does not corrode. Ex- Nickel and chromium plating on steel for automobile, coating on tin plate tube used as food container.

## **ii. Anodic Coatings**

- The coating metal is anodic as compared to the underlying metal. The anodic coating provide galvanic protection to the base metal, in addition to acting as a physical barrier between the base metal and the environment. This type of coatings offers a sacrificial type cathodic protection.  
Ex: Galvanised corrugated steel sheets used for roofing, automobile parts etc.

## **II. NON-METALLIC COATINGS**

These coatings can further be divided into two types

(i) Organic coatings (ii) Inorganic coatings

### **(i) Organic coatings**

These are the inert organic barriers applied on materials as a barrier to corrosion.

Ex: Paints, varnishes, enamel etc.



These types of coatings required surface preparation, primary coating (primer) before application of organic coating.

## (ii) Inorganic Coatings

Various inorganic coatings on metal surface are:

Vitreous coating or glass-steel- Steels with glass coatings, where glass linings act as the barrier.

Portland cement – It also known as concrete which saves the TMT bars getting corroded.

Chemical conversion coating – These are some chemicals which on application on the metal surface, reacts with the metal and creates a passivated layer.

## INHIBITORS

- These are the substances which when added to the corrosive environment decreases the rate of corrosion by reducing the severity of the environment.
- Inhibitors either act as a barrier by forming an adsorbed layer or retard the cathodic or anodic reaction.

Types of Inhibitors

1. **Chemical Passivators:** Certain substances while added to the corrosive medium results in formation of passivated layer on the metal surface.

Ex: Chromate, Nitrate and ferritic salts.

2. **Absorption Inhibitors:** These are organic compounds which get absorbed on the entire anodic as well as cathodic surfaces to act as a blanket and thus affect the reactions. Inhibitors doesn't allow the acids to react with base metal.

Ex: Hexamethylene tetramine and thiourea etc.

**3. Film-Forming Inhibitors:** These are the inhibitors which stop corrosion by forming a blocking or barrier film of a material other than the actual inhibiting species.

Ex: Calcium salt, zinc salt, benzoate etc.

**4. Vapour-phase Inhibitors:** When these types of inhibitors are added a vapour, phase is created. This vapour gets condensed onto the metal surface and it is spread throughout. The condensed phase is hydrophobic (water repellent) so saves the metal from getting corroded.

Ex: Dicyclohexylamine, benzotiazole etc.