

**Note:**

1. Since fuel cells create electricity chemically, rather than by combustion, they are not subjected to the thermodynamic laws that limit a conventional power plant. Therefore, fuel cells are more efficient in extracting energy from a fuel.
2. Fuel cells are usually classified into different types on the basis of the electrolyte used. The prime five categories are as follows:
  - Alkaline fuel cell (AFC): Aqueous solution of potassium hydroxide soaked in a matrix is used as an electrolyte.
  - Polymer electrolyte membrane fuel cell (PEM): Nafion membrane is used which is a perfluorinated cation exchange polymer membrane.
  - Solid oxide fuel cell (SOFC): Yettria stabilized zirconia is used as an electrolyte.
  - Phosphoric acid fuel cell (PAFC): Phosphoric acid soaked in a matrix is used as an electrolyte.
  - Molten carbonate fuel cell (MCFC): A solution of lithium, sodium, and potassium carbonates soaked in a matrix is used as an electrolyte.
3. Fuel cells have a lot of advantages.
  - (a) Fuel efficiency is very high (75–80 %) as compared to traditional thermal power plants where the maximum efficiency goes up to 40 %.
  - (b) Recharging is not required and it can operate as long as the fuel and oxidizer are supplied from outside.
  - (c) No thermal and noise pollution.
  - (d) Environmental friendly by-product.
4. It has a lot of limitations which discourage its use in regular practice.
  - (a) Not portable as fuel and oxidizer cylinders are needed to be carried along with the cell.
  - (b) High cost of catalyst.
  - (c) Lot of energy is spent in keeping the fuel in liquid form.
  - (d) Fuel free from impurities is also costly.

**CORROSION**

It may be defined as an unwanted destruction of a metallic substance due to chemical or electrochemical attack of environment on it. Metals are usually available in the form of compounds in the earth crust. During metallurgy a lot of energy is spent which gets stored in the metal as potential energy. Therefore when a metal is allowed to remain as such in the elemental form it always tends to interact with the atmospheric components and goes back to the compound form which is relatively more stable. Therefore corrosion may also be defined as the reverse process of metal extraction.

**Dry Corrosion**

This happens due to the direct interaction of atmospheric components such as  $O_2$ ,  $X_2$ ,  $SO_x$ ,  $NO_x$ ,  $H_2S$ , etc. with the metallic materials in the absence of moisture. This can be discussed under three basic categories.

## Corrosion due to oxygen

Alkali and alkaline earth metals react with oxygen at room temperature. Other metals except Ag, Au and Pt, react with oxygen at elevated temperatures. Corrosion starts at the surface of metal, i.e., at the interface of the metal and atmosphere with the formation of a thin oxide film (the mechanism is given below). Further interaction depends on the nature of the oxide film formed.

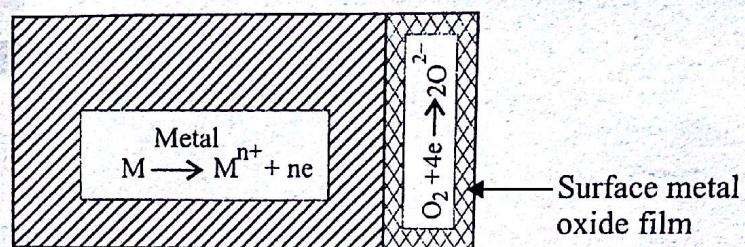
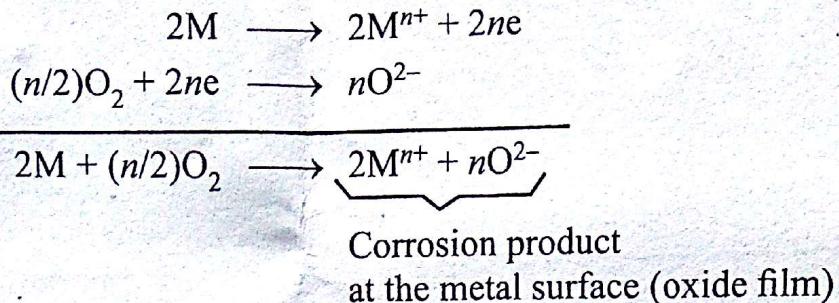


Fig. 8.20 Formation of surface oxide film

### **Stable film**

If the oxide film is stable, it remains adhered to the surface strongly and thereby acts as a physical barrier between metal and the atmosphere. This prevents further penetration of oxygen to the base metal. As a result, corrosion is restricted to the surface, e.g., in case of oxides of Al, Pb, Cu, etc.

### **Unstable film**

If the oxide formed is unstable, it dissociates back to metal and oxygen. Therefore corrosion does not take place, e.g., oxides of Ag, Au and Pt.

### **Volatile**

If the oxide film is volatile, it gets volatilized to expose new surface to interact with oxygen. Here corrosion continues to eat the whole metallic structure. Therefore corrosion is rapid and continuous, e.g., oxide of molybdenum.

### **Porous**

Here the oxide film has pores or channels through which oxygen slowly diffuses to interact with the base metal. Therefore in this case corrosion is slow but continuous, e.g., oxide of iron.

### Corrosion due to other corrosive gases

The extent of corrosion depends on the chemical affinity between the base metal and the atmospheric components. Again corrosion starts at the surface with the formation of surface film. The further course of reaction depends on the nature of the surface film formed, e.g., Fe forms a sulphide film at its surface upon reaction with hydrogen sulphide at elevated temperature



which is a porous one and therefore corrosion is continuous but slow. On the other hand, Ag forms a chloride film upon reaction with atmospheric chlorine. The AgCl film so formed is very stable and sticks firmly to the surface preventing further corrosion.



Porous



Stable

### Liquid metal corrosion

This type of corrosion occurs when a molten liquid is passed continuously on a solid metal/alloy surface. The corrosion is attributed to either dissolution of the molten liquid or penetration of the molten liquid into the solid metal phase.

### Wet Corrosion

This type of corrosion occurs due to the setup of an electrochemical cell, i.e., due to the development of separate anodic and cathodic areas between which current flows through the conducting liquid. Here anode is always destroyed or corroded while cathode is protected. The basic mechanism is that the metal is oxidized at anode releasing the metal ions and electrons. The electrons migrate to cathode where the dissolved constituents accept the electron to form oxide, hydroxide ions, etc. Now the metal ions formed at anode and non-metallic ions formed at cathode diffuse towards each other through the conducting medium to form corrosion product somewhere in between cathode and anode depending on the mobility of the ions. The corrosion product may dissolve into the medium or may get deposited on the surface.

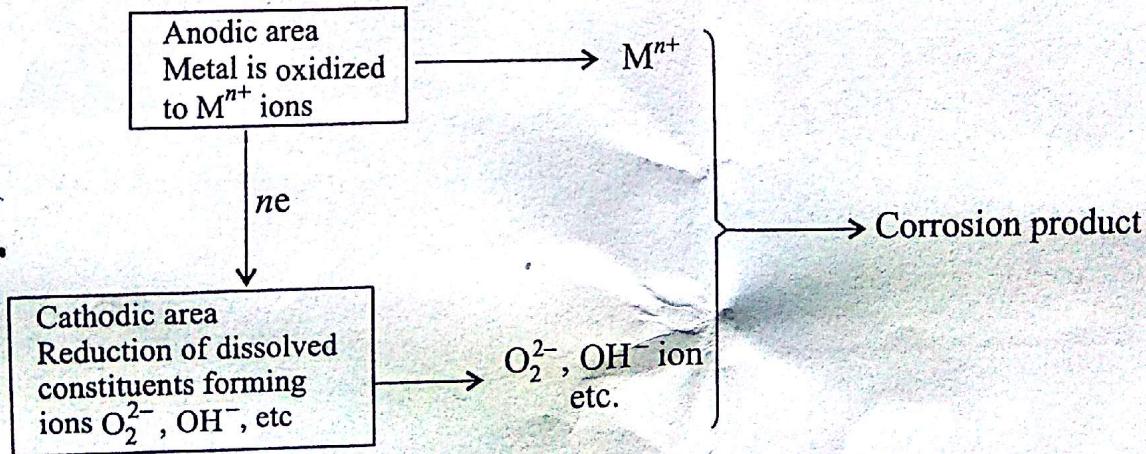
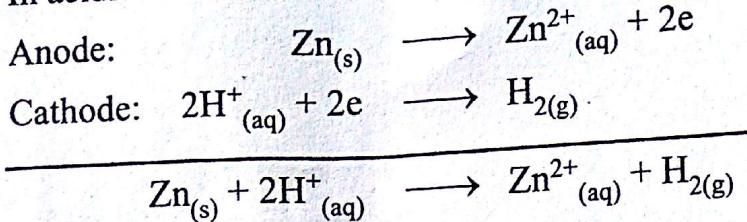
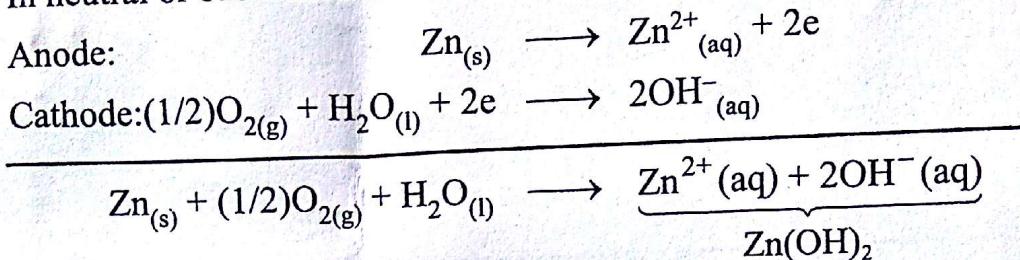


Fig. 8.21 Formation of corrosion product in wet corrosion

Wet or non-uniform corrosion is of different kinds. Some of them are as follows:

#### ✓ Galvanic cell corrosion

When two dissimilar metals remain in contact in the presence of a conducting liquid then the more electropositive metal acts as anode and gets corroded. Such corrosion is known as Galvanic corrosion, e.g., in Zn–Cu couple Zn being more electropositive acts as anode and gets corroded in preference. The possible mechanism in both acidic and neutral medium is given as follows.

**In acidic medium****In neutral or basic medium****Concentration cell corrosion**

Such corrosion occurs when a metal surface is exposed to a conducting liquid of varying concentration. The portion of the metal that remains in contact with lower concentration of metal ions acts as anode and gets corroded. This is known as metal ion concentration cell corrosion.

Another important type in this category is oxygen concentration cell corrosion or differential aeration corrosion. If two portions of a metal have different access to oxygen then the portion which has limited access to oxygen behaves anodic with respect to the portion which has more access to oxygen. This can be included in concentration cell corrosion. For example, a Zn rod kept partially immersed in water. Here the portion of the rod that is inside the water has lesser access to oxygen and behaves anodic with respect to the portion that remains outside. The reactions will be similar to those discussed in Galvanic corrosion.

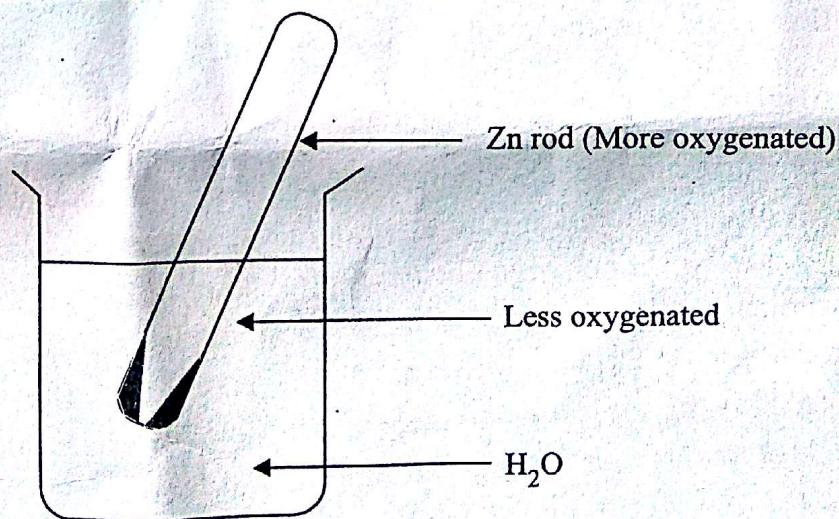
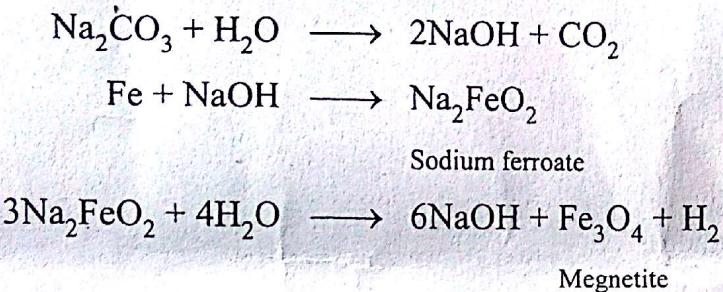


Fig. 8.22 Differential aeration corrosion

**Stress corrosion**

Metallic materials remain under strain due to mechanical operations like welding, bending, pressing, hammering, etc. During corrosion the stressed portion acts as anode with respect to the normal portion leading to highly localised corrosion.

For example, *caustic embrittlement*, which occurs in mild steel exposed to alkaline solution at stressed areas such as crevices or rivets, joints and bent portions at high temperature. It is often found in steam boilers and heat transfer equipments in which water with alkalinity corrode the mild steel plates particularly at the crevices. Boiler water contains sodium carbonate that has been added as water softening agent and breaks down to give sodium hydroxide making the water alkaline. This alkaline water flows into the hair line cracks and crevices by capillary action where the water evaporates building up the caustic soda. It is this concentrated alkali which dissolves iron as sodium ferroate ( $\text{Na}_2\text{FeO}_2$ ) in crevices and cracks where the metal is under stress. Sodium ferroate then decomposes to magnetite regenerating caustic soda. The caustic soda generated further enhances corrosion. The reactions involved are given as follows.



### Pitting corrosion

The metal surface having pits or cavities undergo corrosion due to development of separate anodic and cathodic areas. Pitting is usually a result of breakdown or cracking of the protective film on a metal at specific points. Here pits/cavities act as anode with respect to the normal portion. A typical pitting corrosion cell in iron surface is illustrated below. Here corrosion is due to the development of an oxygen concentration cell (Fig. 8.23).

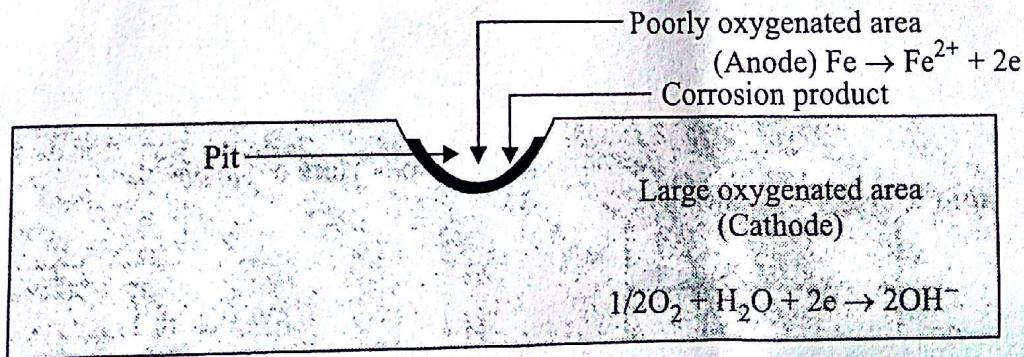


Fig. 8.23 Pitting corrosion

### Factors Affecting Corrosion

Basically the analysis is made with respect to the nature of metal and environment.

#### Metals

1. **Position in galvanic series:** The galvanic series, shown below, arranges metals and alloys according to their tendency to corrode. This series has been developed by studying their corrosion tendency in a given environment, like standard sea water.