Corrosion and its Control

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Introduction

Corrosion is the degradation of a metal or alloy, as a result of chemical reaction with its environment. The degradation is caused by an oxidation reaction, In electrochemical sense, oxidation is metal atom (M) losing electrons.

$$M \rightarrow M^{n+} + ne$$

By the corrosion attack of any type, component can weaken. The rate and nature of attack is influenced by mechanical stress, thermal stress, temperature, type of environment, type and nature of corrosion product formed, etc. behavior.

Study of all parameters causing corrosion, selection of proper material, proper design and corrosion protective system and the data of corrosion testing is very useful in reducing the premature failure of the components Preventive maintenance and monitoring during service is also important for obtaining reduced hazard level of corrosion.

Classification :

Broadly corrosion process can be classified as

- Dry corrosion
- Wet corrosion.

Dry Corrosion

In hot dry gas metal tends to oxidize to form an oxide scale on the surface. If the gas is containing corrosive ingredients as sulfides or hydrogen the attack can be more severe.

Usually dry corrosion occurs or associated with higher temperature. The corrosion rate increases with rise in temperature.

The attack of hydrogen, ammonia gas, and sulfide gas is observed to the specific metals. Materials like titanium or steels when exposed to the dissolved hydrogen, they tend to reduce toughness called hydrogen embrittlement.

Wet Corrosion

When a metal is exposed to an aqueous solution of acid or alkali, wet corrosion occurs. It is electrochemical in nature. The metal gets transformed to the metal ions and goes to the electrolyte.

The electrochemical reaction takes place by at least one oxidation and one reduction reaction. These individual reactions are called as half - reactions.

If zinc rod is immersed in acid solution, Zinc will corrode by oxidation reaction. The hydrogen ions from solution are reduced by reaction $2 H^+ + 2e \longrightarrow H_2\uparrow$.

Forms of Corrosion:

For convenience, the corrosion attack is classified as following

- ❖Uniform corrosion
- ❖Intergranular corrosion
- ❖ Galvanic corrosion
- ❖ Selective leaching
- ❖ Crevice corrosion
- ❖Erosion-corrosion
- ❖ Pitting corrosion
- ❖ Stress corrosion.

Uniform Corrosion

Occurs with similar intensity over the entire exposed surface, Rusting of steel and iron, tarnishing of silver

Uniform corrosion

Galvanic Corrosion

When two metals or alloys of different compositions are electrically coupled and exposed to the electrolyte, Galvanic Corrosion takes place. Less Noble metal becomes anode and will experience corrosion. The other one which is more inert will be cathode and is protected.

If the anode area exposed is smaller, then the corrosion attack is very severe. Proper selection of adjacent materials and electrical insulation of components are used to reduce galvanic corrosion.

Galvanic corrosion

Crevice Corrosion

When the ion concentration in the electrolyte is different at different locations, a concentration cell is established. The area of electrode in contact with the low concentration electrolyte becomes anodic and corrosion is observed.

For example under the washers/rivets in an assembly, usually the crevices corrosion is observed. To avoid the crevice corrosion; sometimes riveting is replaced by welding.

Crevice corrosion

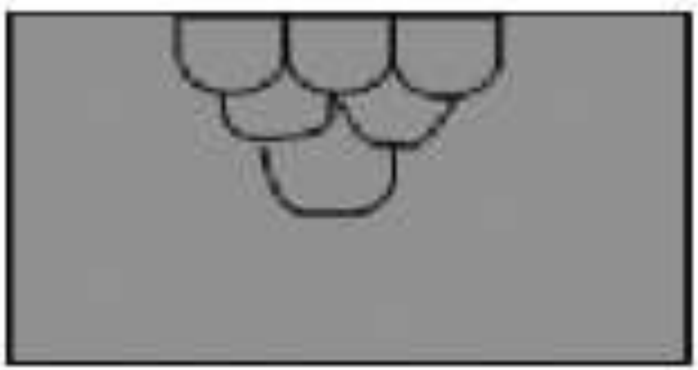
Pitting

This is a localized attack in which small pits or holes form. Pitting is very dangerous form of corrosion. A pit may be initiated by localized defect at surface such as scratch, inclusion, etc. A better surface -finish reduces the danger of pitting.

Pitting

Intergranular Corrosion

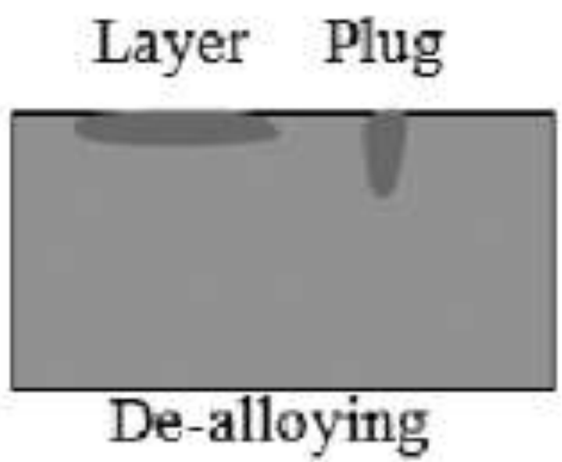
This is a corrosion, which preferentially attacks the grain boundary area and causes failure of alloy along the grain boundaries. A specific example stainless steel (AISI 304) is slow cooled in the range of $800/^0C$ to $500/^0C$, a chromium carbide precipitation takes place along the grain boundries. The steel becomes susceptible to corrosion in the grain boundary region and may lead to failure. In the welded stainless steel component, corrosion is faced by material near the weldment. It is called as weld decay.



Intergranular

Selective Leaching

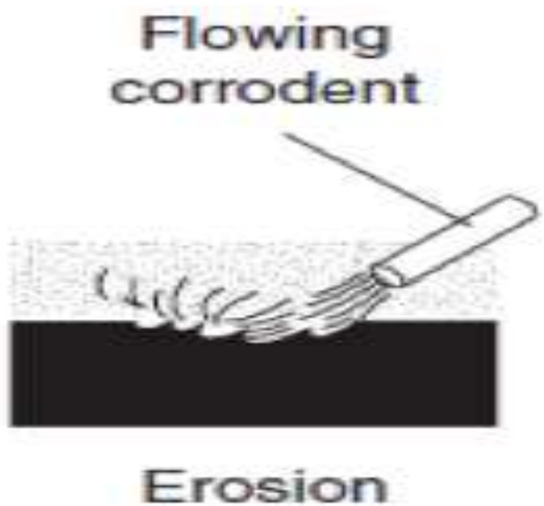
Sometimes in corrosive atmospheres, one element of alloy is removed as corrosion proceeds called as selective leaching. De-zincitication of brass is a very common example. Mechanical properties are drastically reduced by this form of corrosion.

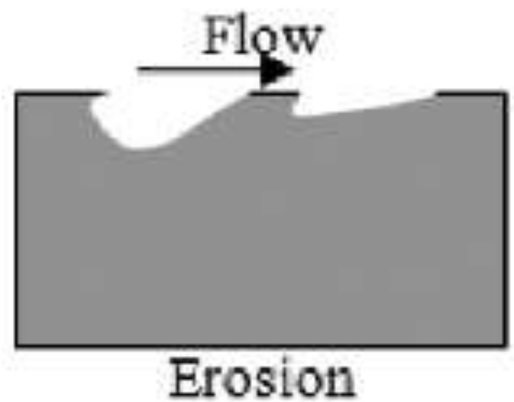


Erosion Corrosion

When mechanical abrasion or wear because of fluid motion is associated with corrosion. By erosion action, the film is removed, exposing bare metal to the farther corrosion.

It is most commonly found in piping, at bends, elbows, propellers turbine blades, valves, pumps, etc. soft metals are more susceptible to this kind of attack.



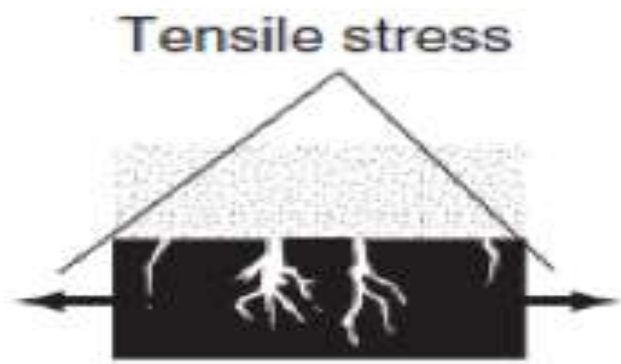


Stress Corrosion

Cracking results from combined action of tensile stress and corrosion. In the presence of corrosive atmosphere, the crack is initiated in the stressed component at stress lower than the strength of material. Ultimately it leads to the final failure of the component.

Appropriate heat treatment for reducing internal stress level or use of higher strength, higher thickness material reduces the susceptibility of stress corrosion cracking.

Stress corrosion cracking



Stress-corrosion cracking

EMF Series

The EMF series is an arrangement of various metals in the order of their electrochemical activities based on their standard oxidation-reduction potentials (E_0).

The most active metal in the series will be having a high negative potential while nobler metals possess relatively less negative (or more positive) potential (E_0).

If we consider a couple of two metals in the EMF series, the one with higher negative E_0 will act as anode compared to the other with a relatively less negative E_0 value.

EMF series lists of Electrode potentials only metals. Electrode potentials is an equilibrium potentials with concentrations at unit activity. It predicts only tendency of metal towards corrosion. But the effect of environment on corrosin is not considered.

Galvanic series

- In Galvanic series instead of standard electrode potentials, actually measured the potentials of metals and alloys in a given environment arranged with respect to nobility and activity.

- Practically its a measured potentials against reference electrode.

- Effect of coupling of metals and alloys on corrosion rate can be predicted using galvanic series.

- Galvanic series is generally good for stagnant conditions.

Reaction	E^0,V(SHE)	
$Au^{+++} + 3e = Au$	+1.42	Noble
$Pt^{++} + 2e = Pt$	+ 1.2	
$O_2 + 4H^+ + 4e = 2H_2O$	+1.23	
$Pd^{++} + 2e = Pd$	+0.83	
$Ag^+ + e = Ag$	+0.799	
$O_2 + 2H_2O + 4e = 4OH^-$	+0.401	
$Cu^{++} + 2e = Cu$	+0.34	
$Sn^{+++} + 2e = Sn^{++}$	+0.154	
$2H^+ + 2e = H_2$	0.00	Reference
$Pb^{++} + 2e = Pb$	-0.126	
$Sn^{++} + 2e = Sn$	-0.140	
$Ni^{++} + 2e = Ni$	-0.23	
$Co^{++} + 2e = Co$	-0.27	
$Cd^{++} + 2e = Cd$	-0.402	
$Fe^{++} + 2e = Fe$	-0.44	
$Cr^{+++} + 3e = Cr$	-0.71	
$Zn^{++} + 2e = Zn$	-0.763	
$Al^{+++} + 3e = Al$	-1.66	
$Mg^{++} + 2e = Mg$	-2.38	
$Na^+ + e = Na$	-2.71	
$K^+ + e = K$	-2.92	Active

EMF Series

Noble

Platinum
Gold
Graphite
Silver
Hastelloy C
18 – 8 stainless steel (passive)
Chromium steel > 11% Cr (passive)
Inconel (passive)
Nickel (passive)
Monel
Bronzes
Copper
Brasses
Inconel (active)
Nickel (active)
Tin
Lead
Lead-tin solder
18-8 Mo stainless steel (active)
18-8 stainless steel (active)
Ni-resist
Chromium steel<11% Cr (active)
Cast iron
Steel or iron
2024 aluminium
Cadmium
Commercially pure aluminium
Zinc
Magnesium and its alloys.

Active

Galvanic Series measured in sea water

Thermodynamics of corrosion

When common metals such as Fe, Cu and Zn are exposed to the environment, the surface of these materials get deteriorated due to its interaction with the oxygen, moisture and other substances present in the environment. This process is referred to as corrosion.

In the case of iron, the process is referred to as rusting. Due to corrosion, the surface of iron gets covered with brownish ferric oxide, Cu gets coated with a green deposit and Zn is covered with a white deposit.

The process of corrosion has an electrochemical (thermodynamic) basis. Thermodyanamics helped us to predict the feasible corrosion reactions.

The surfaces of metals such as Fe, Cu, contain impurities and lattice defects and are reactive when they come in contact with air, moisture, acidic and or basic environments.

One part of the surface acts as the anode of a galvanic cell and oxidation that occurs in this part results in the formation of Fe^{2+}/Cu^{2+} ions. These ions go into the solution formed by the condensed water vapour or the acidic / basic fluids which come into contact with this part of the surface.

The electrons released in this oxidation $Fe \rightarrow Fe^{2+} + 2e$/ $Cu \rightarrow Cu^{2+} + 2e$ easily travel through the conducting medium of the metal until they come into contact with H^+ of an acidic neighbourhood or O_2/H_2O in a neutral or basic neighbourhood and react with them.

The reactions involved in these reduction processes are

Reaction	Nature of the solution	E^o / V
$H^+ + e \rightleftarrows 1/2\ H_2 (g)$	acidic	0
$O_2 + 4H^+ + 4e \rightleftarrows 2H_2O$	Acidic	1.23
$O_2 + 2H_2O + 4e \rightleftarrows 4OH^-$	Neutral / basic	0.40

The movement/migrations of ions in the surrounding medium completes the "circuit" consisting of production of cations, electron flow (inside the metallic medium) and ionic movement.

The extent and the rate of corrosion depends on the presence of active sites on the metallic surface and the availability of O_2 on the metallic surface (for the cathodic reduction).

Electrochemical cells may also be formed on different portions of the same surface.

Is Cu can corrode in an acid solution pH 2.0 to produce a solution containing 0.10 M Cu^{+2} ions and 0.50 atm hydrogen gas.

Cathodic reaction (E_C = -0.09V): $2H^+ (aq) + 2e^- \rightarrow H_2(g)$

Anodic reaction (E_A = +0.312V): $Cu\ (s) \rightarrow Cu^{2+} (aq) + 2e^-$

Cell potential: Ecell = EC – EA

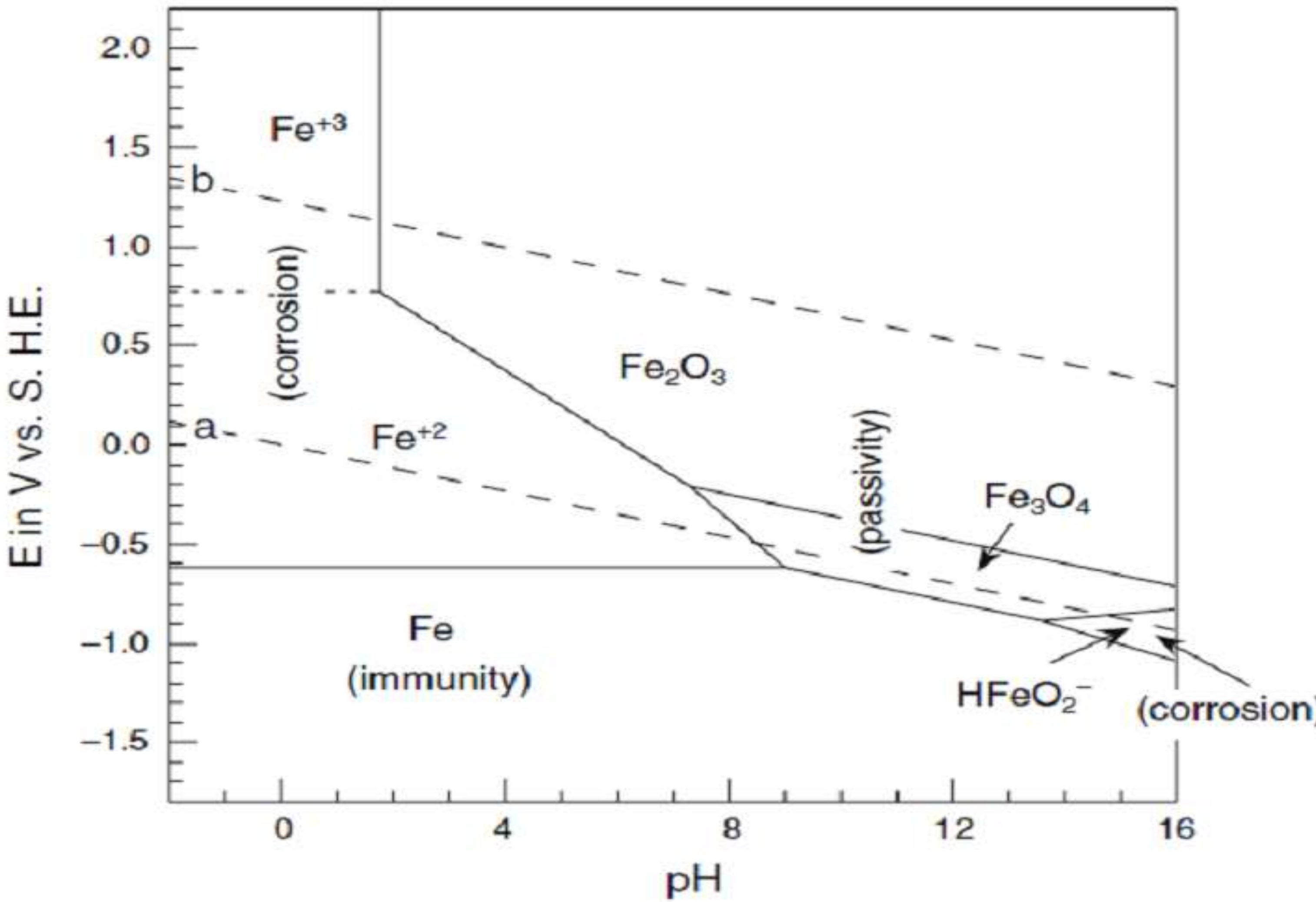
= -0.109 – 0.312 =0.421V

$\Delta G_{cell} = -nFE_{cell} > 0$, thus the reaction does not take place in the given conditions.

Pourbaix Diagrams

The electrode potentials of the metal, E and the pH of the surrounding medium are the main factors or parameters that determine the stability of the solid phases and the ionic species produced during redox reactions of metals. When iron metal is exposed to acidic/neutral/basic solutions, several reactions can occur.

The applications of thermodynamics to corrosion is generalised by E vs pH plots which are known as Pourbaix diagrams. These diagrams have wide applications in corrosion, electro-deposition, geological processes and hydrometallurgical extraction. These figures help us to analyze the regions where the metal is immune, where it is passive and where it gets corroded.



The dotted lines a and b hydrogen line and oxygen line respectively

Some of the reactions involved, their E_o values (with respect to SHE)

$$Fe(s) \longrightarrow Fe^{2+}(aq) + 2e^-$$
$$E = -0.440 - 0.0295 \log [Fe^{2+}]$$

$$3Fe(s) + 4H_2O(l) \longrightarrow Fe_3O_4(s) + 8H^+(aq) + 8e^-$$
$$E = -0.085 - 0.0591pH$$

$$3Fe^{2+}(aq) + 4H_2O(l) \longrightarrow Fe_3O_4(s) + 8H^+(aq) + 2e^-$$
$$E = 0.980 - 0.2364pH - 0.0886\log[Fe^{2+}]$$

$$2Fe^{2+}(aq) + 3H_2O(l) \longrightarrow Fe_2O_3(s) + 6H^+(aq) + 2e^-$$
$$E = 0.728 - 0.1773pH - 0.0591\log[Fe^{2+}]$$

$$2Fe_3O_4(s) + 4H_2O(l) \longrightarrow 2Fe_2O_3(s) + 2H^+(aq) + 2e^-$$
$$E = 0.221 - 0.0591pH$$

$$Fe(s) + 2H_2O(l) \longrightarrow HFeO_2^-(aq) + 3H^+(aq) + 2e^-$$
$$E = 0.493 - 0.0886pH + 0.0295 \log [HFeO_2^-]$$

$$3HFeO_2^-(aq) + H^+(aq) \longrightarrow Fe_3O_4(s) + 2H_2O(l) + 2e^-$$
$$E = -1.819 + 0.0295pH - 0.0886 \log [HFeO_2^-]$$

$$Fe^{2+}(aq) \longrightarrow Fe^{3+} + (aq) + e^-$$
$$E = 0.771 + 0.0591 \log ([Fe^{3+}]/[Fe^{2+}])$$

$$2Fe^{3+}(aq) + 3H_2O(l) \longrightarrow Fe_2O_3(s) + 6H^+$$
$$\log[Fe^{3+}] = -0.72 - 3pH$$

There are generally three types of solid lines in Pourbaix diagram each representing the equilibrium between metal and other species.

- ❑Horizontal indicates the reactions which are pH dependent
- ❑Sloping lines indicates the reactions which are both potential aand pH dependent.
- ❑The diagram also represents the area under which iron is stable in different forms.

Advantages:

- ✓Predicts the spontaneity and feasibility of reaction.
- ✓Estimating composition of corrosion product.
- ✓Predicting environmental changes that prevents or reduce corrosion.

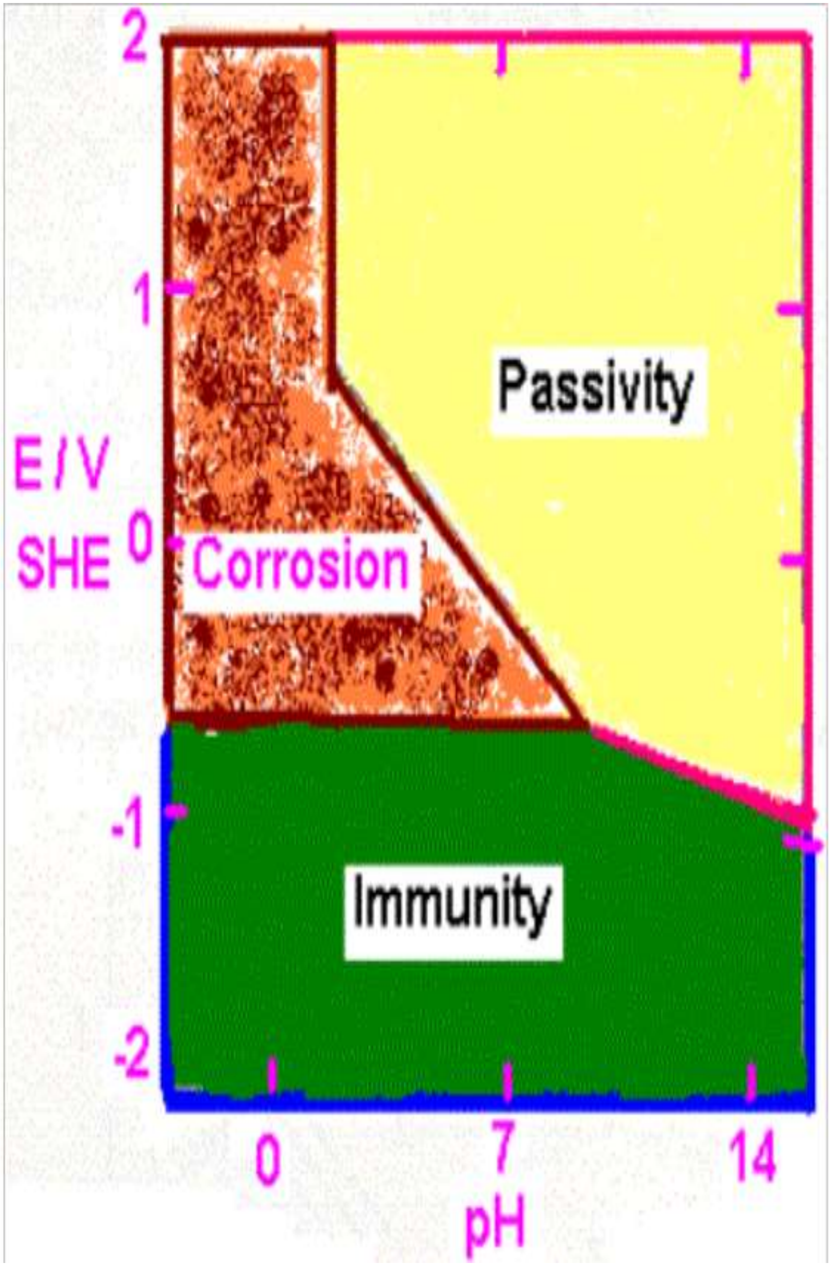
Drawbacks:

- The diagram is based purely on thermodynamics, no information regarding kinetics, stability, adhesion of passive film.

- Only consider pure metals, practically not all metals are pure.

- Localised pH change is not considered.

- The diagram refers to 25^0 C and it fails to explain at drastic conditions and at lower lever of ions concentrations.



The area between these dotted lines indicates zone where the water is stable. Below it hydrgen evolution occurs and above it oxygen evalution occurs.

The three main zone in diagram are:

Immunity: Metal as thermodynamically stable

Corrosion: Compounds of metal in thermodynamically stable state.

Passivity: Resulted when sparingly soluble metal compounds forms a thin protective film on surface resulting in negligible corrosion rate.

Kinetics of Corrosion:

Let us consider the following electrochemical reaction at an equilibrium :

$$M^{n+} + ne^- \underset{I_{red}}{\overset{I_{ox}}{\leftrightarrows}} M$$

An electrochemical reaction involves an electron flow *i.e.* an electrical current.

At the equilibrium, a current of equal magnitude flows in both directions.

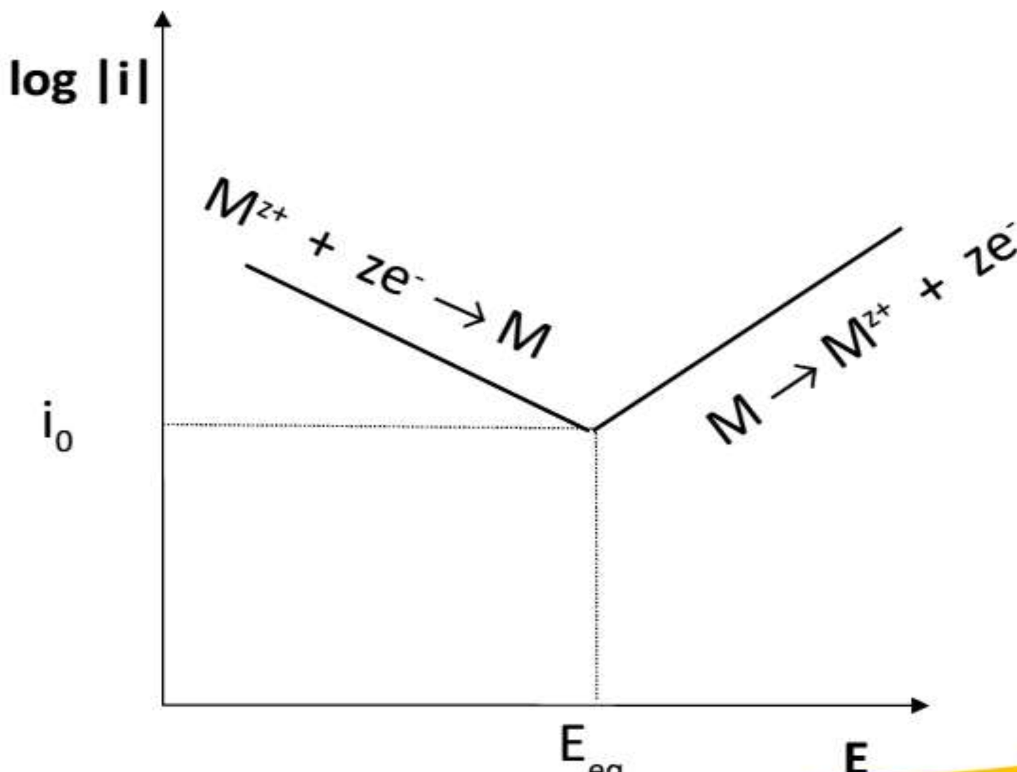
$I_{net} = I_{ox} + I_{red} = 0$

$I_{ox} = |I_{red}| = I_0$

I_0 is the exchange current, which is equivalent to reversible reaction rate at the equilibrium.

The exchange current density i_0 (= I_0/A) depends on the catalytic properties of the material used for the electrode.

When the potential of the electrode of the considered reaction moves away from the equilibrium potential , then Oxidation occurs, If the potential is above E_{eq}(anodic potential), If the potential is below E_{eq}(cathodic potential),then Reduction occus. Depending on how far the potential is from E_{eq}, the oxidation or reduction current will change.



Moving away from the equilibrium potential of an electrode is considered as it is Polarizing, then the overpotential is defined as

$$\eta = E - E_{eq}$$

We assume that the current only depends on the rate of electron transfer across the charged interface. Charge transfer at the metal/electrolyte interface does not follow the Ohm's law due to the very high electric field present there (on the order of 10^7 V/cm). It is given by a law called the Butler-Volmer relationship.

$$I = I_0\left(\exp\left(\frac{\alpha_o nF}{RT}(E - E_{eq})\right) - \exp\left(\frac{-\alpha_r nF}{RT}(E - E_{eq}\right)\right)$$

where α_o is the oxidation symmetry factor and α_r is the reduction symmetry factor ($\alpha_o + \alpha_r = 1$)

$$I = I_0 \exp\left(\frac{\alpha_o nF}{RT}(E - E_{eq})\right) - I_0 \exp\left(\frac{-\alpha_r nF}{RT}(E - E_{eq})\right)$$

Anodic term

Cathodic term

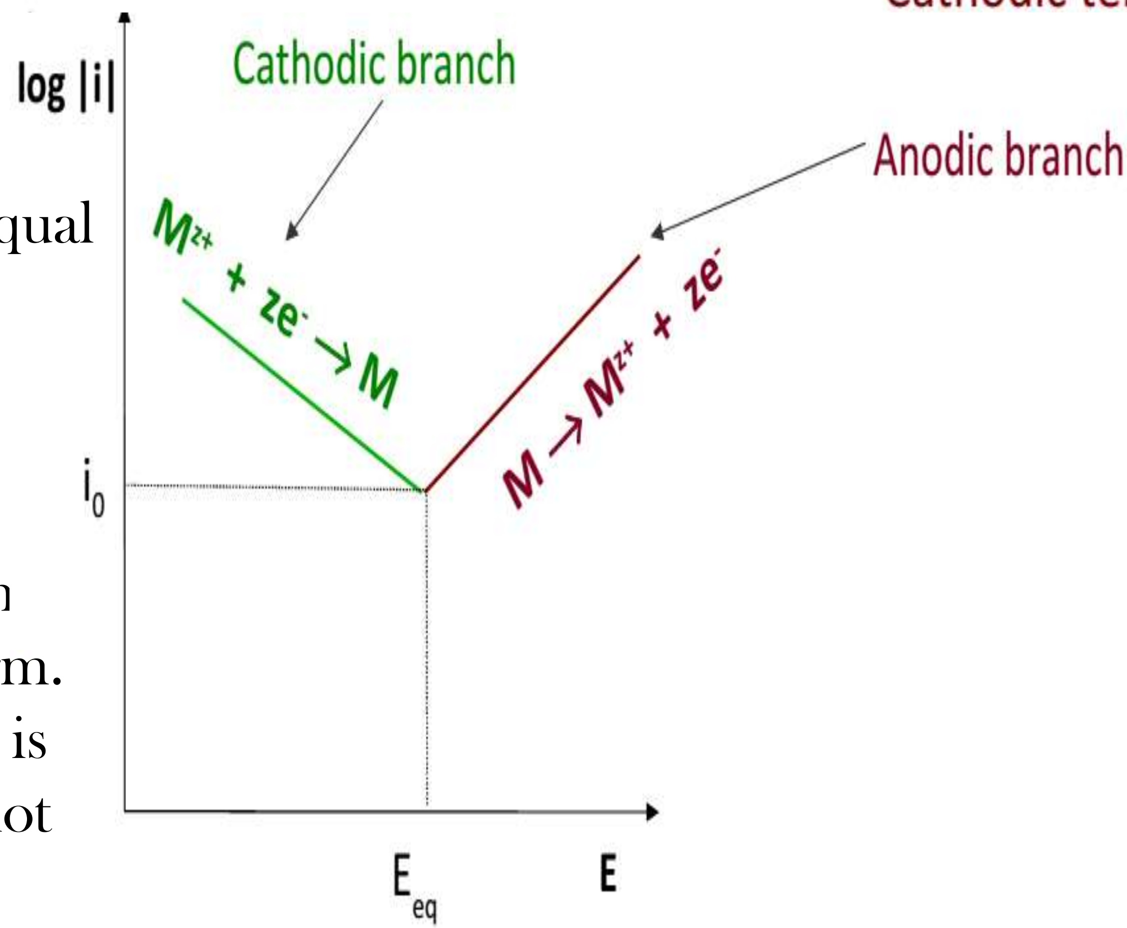
Considering the absolute values :

At E_{eq} the anodic term is equal to the Cathodic term.

At $E>E_{eq}$, the anodic term is larger than the cathodic term.

At $E<E_{eq}$, the cathodic term is larger than the anodic term.

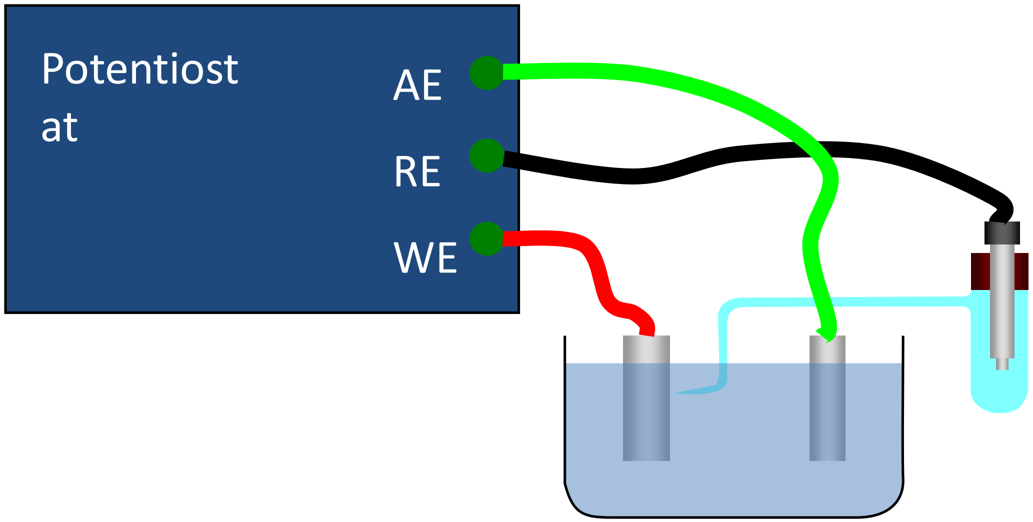
Butler-Volmer relationship is valid only if the current is not limited by mass transport



Corrosion Rate Measurements :

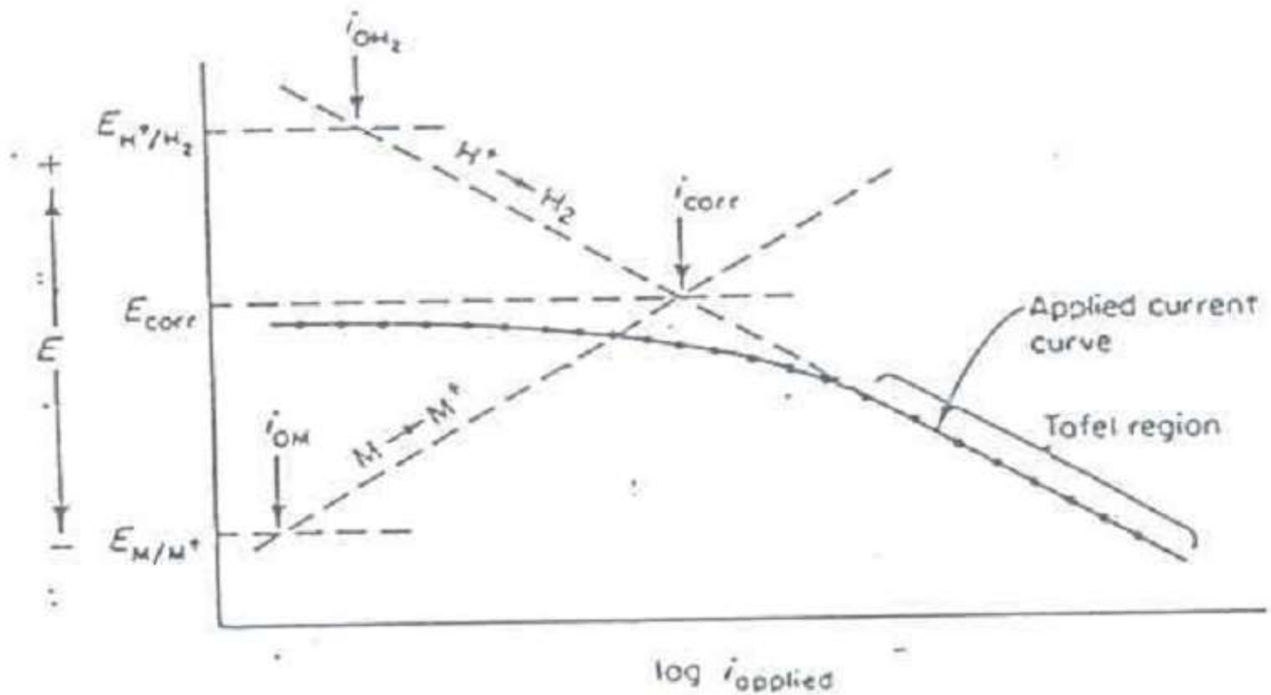
Tafel Extrapolation Method:

This method for determining corrosion rate was used by Wagner and Traud to verify the mixed potential theory by using the datas of anodic and cathodic polarisation measurements.

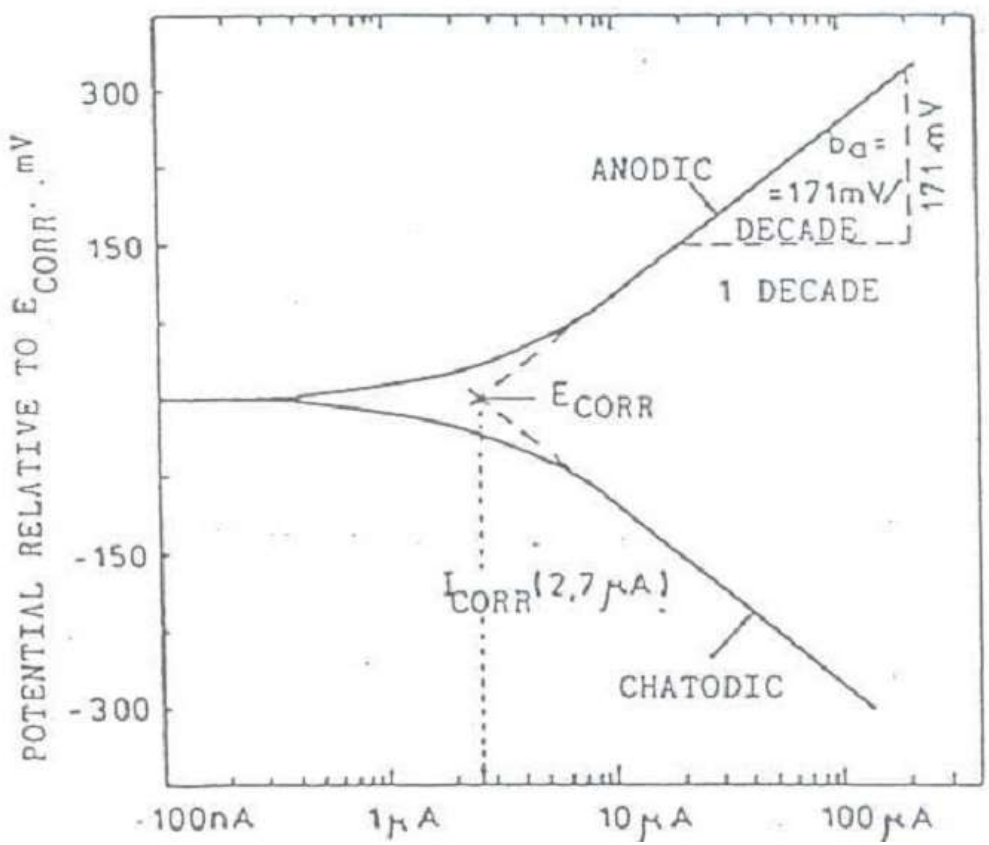


Schematic representation of set up used for electrochemical measurements

This technique uses data obtained from cathodic and anodic polarization measurements. Cathodic data are preferred, since these are easier to measure experimentally. In Figure the total anodic and cathodic polarization curves corresponding to hydrogen evolution and metal dissolution are superimposed as dotted lines.



It can be seen that at relatively high-applied current densities the applied current density and that corresponding to hydrogen evolution have become virtually identical. To determine the corrosion rate from such polarization measurements, the Tafel region is extrapolated to the corrosion potential, as shown in figure below



At the corrosion potential, the rate of hydrogen evolution is equal to the rate of metal dissolution.

The corrosion rate is determined using the following relation

$$i_{corr} = \frac{\alpha\beta}{2.3(\alpha+\beta)}\frac{\Delta i}{\Delta E}$$

$$i_{corr} = \frac{\alpha\beta}{2.3(\alpha+\beta)}\frac{1}{R_p}$$

where ΔE/Δi=slope of the polarization curve

Rp=Polarization Resistance.

α and β = Cathodic & Anodic Tafel constants.

Tafel constants must be calculated from both the anodic and cathodic portions of the Tafel Plot. The units of the Tafel constants is V/decade. A decade of current is one order of magnitude. A Tafel constant calculation is illustrated in the above Figure. These measurements may be complicated by two interfering phenomena namely, concentration polarization and resistance drop effect.

Concentration polarization occurs when the reaction rate is so high that the electro active species cannot reach the electrode surface at a sufficient rapid rate and the reaction rate becomes diffusion controlled.

Resistance drops across the solution can also cause nonlinear Tafel behaviour at high currents

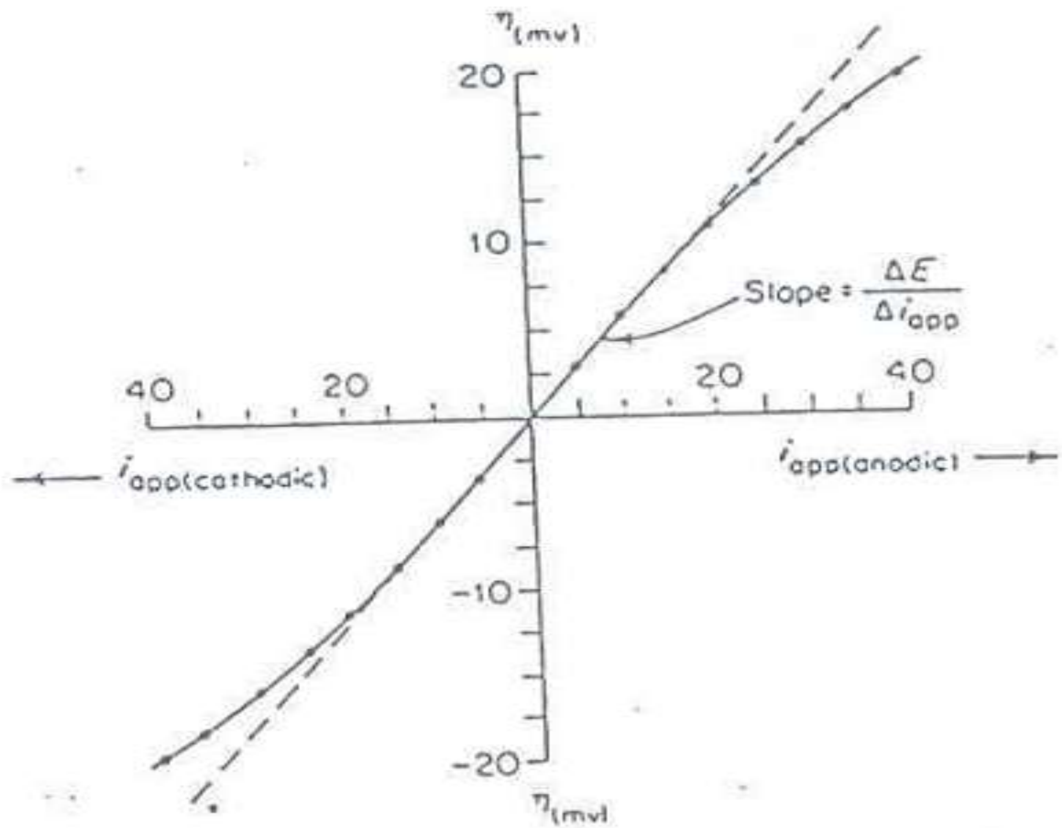
$$E_{IR} = i_{meas} R_{sol}$$

This method offers the following significant advantages:

1. Under ideal conditions, the accuracy of the Tafel extrapolation method is equal or greater than conventional weight loss methods.
2. With this technique it is possible to measure extremely low corrosion rates, and it can be used for continues monitoring the corrosion rate of a system.
3. Tafel Plots can provide a direct measure of the corrosion current, which can be related to corrosion rate.
4. The rapid determination of corrosion rates with Tafel Plots can be advantageous for such studies as inhibitors evaluation and alloy comparisons.
5. This method is applied to the system containing only one reduction process.

Linear Polarisation Method:

The disadvantages of the Tafel extraploation method can be largely overcome by using Linear Polarization Technique. Within 10 mV more noble or more active than the corrosion potential, it is observed that the applied current density is a linear function of the electrode potential.



In the Figure, the corrosion potential is used as an overvoltage reference point and a plot of overvoltage vs applied anodic and cathodic current is shown on a linear scale. This plot represents the first 20mV polarization of the applied current cathodic polarization curve shown in Figure. The slope of a linear-polarization curve is controlled mainly by i_{corr} and is insensitive to changes in α and β values. Assuming the a=b=120mV represent the average of all corrosion systems, the Tafel Equation reduces to

$$i_{corr} = \frac{0.026}{R_P}$$

This equation may be used to calculate the corrosion rate of a system without knowledge of its electrode-kinetic parameters. This equation provides a unique basis for rapidly measuring relative corrosion rates or changes in corrosion rate.

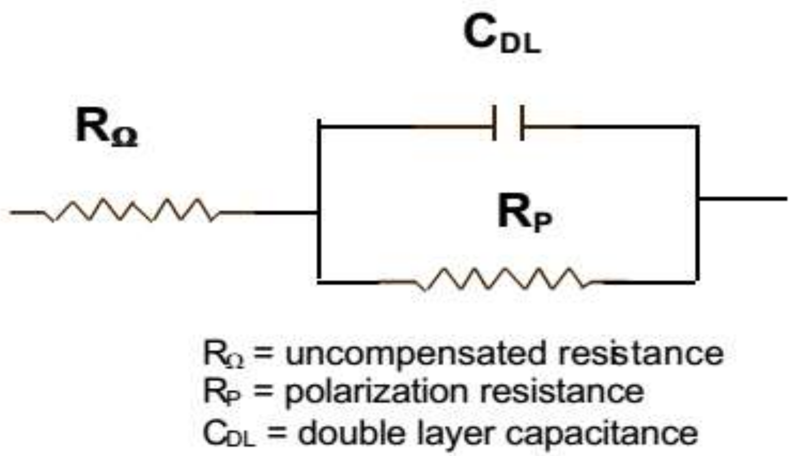
This technique offers the following significant advantages:

1. The polarization resistance method measures the instantaneous corrosion rates as compared to other methods on which metal loss is measure over a finite period of time.
2. The experiment can be completed in a minutes and the small polarization from the corrosion potential do not disturb the system. This permits rapid rate measurements and can be used to monitor corrosion rate in various process streams.
3. This technique may be used for accurately measuring very low corrosion rates (<0.1 mpy). The measurements of low corrosion rates is especially important in food processing industries where trace impurities and contamination are problems.

AC Impedance Method:

This method was first suggested by Epelboin. The circuit given below is used for cell and the cell impedance is given by

$$Z = Z' - jZ''$$



Where Z' is the real part and Z" is the imaginary part of cell impedance. Both of these can be expressed in terms of solution resistance(R_{Ω}) and polarisation / charge transfer resistance(R_p /R_{ct}).

The advantages of this method are :

1. Low conductivity of the electrolyte not afects accuracy of measurements.
2. This method provides the information about double layer capacitance also.

The drawback of this method are:

1. It is a time consuming technique.
2. It is not suitable for system where there is a large drift in the corrosion potential and when R_p itself varies with time.

Weight loss Method:

This is the simplest and most widely used classical technique for evaluating corrosion rate of component materials. The materials are cut into regular shapes of known dimensions and are subjected to pre-treatment process. Then the specimens are weighed in an accurate four digit digital balance. These weighed specimens are suspended by means of a glass hooks in a beaker containing known volume of corrosive solution and corrosive solution containing inhibitor. The beakers were kept in a thermostat for specified time. Later they are removed washed in running water, dried and placed in a decicater to attain room temperature a nd weighed. The variation in weight loss for at least three specimens in each experiment is recorded. The corrosion rate is determined by

$$v_{corr} = \frac{\Delta m}{St}$$

Expressions For Corrosion Rate:

The magnitude of corrosion rate can be expressed in number ways. The commonly used units of corrosion rates are

I. ipy – inches per year
II. mpy – mils per year (1mil=0.001inch)
III. ipmo- inches per month
IV. mdd- milligrams per square decimeters per day

The corrosion rates in mpy is calculated using the relation,

$$mpy = \frac{534W}{DAT}$$

W- weight loss in mg
D- density in g/cc
A- area in square inches
T- time in hours

Prevention of Corrosion

Corrosion process can be reduced or eliminated by various procedures as listed below.

- Proper selection of material and designing.
- Separation of corrosive environment from component surface.
- Altering the corrosive environment
- Altering the characteristic of material by heat treatment
- Use of electrical current.
- Use of galvanic couple.

Material Selection

For proper selection of materials, knowledge of exact working conditions, properties and behavior of all materials is very necessary.

Use of high purity metals tends to reduce corrosion. Alloying improves corrosion resistance e.g. Titanium is added to austetic stainless steel for stabilization. Use of high percentage of tin, in single-phase brass provides higher corrosion resistance in massive application.

For acidic environment, stainless steels are used. For caustic environments Nickel base alloys are used. Fine grained metals and alloys have less corrosion resistance than coarse grained.

In assembly, components connected should be close as per the galvanic Series. Single-phase alloys exhibit better resistance to corrosion than polyphase alloys.

Design for Corrosion Resistances

Following points are considered for reducing corrosion attack while designing a component.

- Welding is preferred over riveted joint.
- In assembly dissimilar alloy parts are separated electrically by using rubber gasket.
- Proper drains should be provided in water storage.
- If galvanic corrosion cannot be avoided, anodic area should be large than cathodic area.
- Retention of air in the electrolyte should be avoided.

Application of Heat Treatment

- ❖The alloys susceptible to stress corrosion, stress relief treatment should be used to improve their corrosion resistance e.g. cartridge brass.
- ❖Cast alloys having tendency to coring should be heat-treated to remove coring.
- ❖Solution quenching treatment is recommended for alloy showing precipitation of a phase which lowers its corrosion resistance. This treatment is offered to homogenize the metals and alloys.

Alteration of Environment

The environment are modified to minimize the corrosion problems. The working conditions can be altered considering the following points:

- ✓Usually corrosion rate decreases with lowering temperature.
- ✓Very high velocities should be avoided to reduce errossion-corrossion effects. Passivating metals generally have better resistance to flowing liquid than stagnant solutions.
- ✓Higher moisture content of the atmosphere leads to corrosion. So the relative humidity should be controlled.

- ✓De-aeration of liquid helps prevention of corrosion. De-aeration removes oxygen from liquid. It can be done by using vacuums or purging a neutral gas or adding certain chemicals, which reacts with dissolved oxygen and reduce its percentage.

- ✓Alkaline neutralizers/ inhibitor substance should be used to reduce the effect of electrolytes if possible.

- ✓The concentration of corrosive environment should be reduced.

Cathodic and Anodic Protection

Cathodic protection is achieved by supplying electrons to the metal structure to be protected i.e. making cathode to the component to be protected. Addition of electrons to the component tends to suppress its dissolution.

Two methods are used for cathodic protection are
1) Impressed current method
2) Use of sacrificial Anode

Impressed current method

Usually, underground tanks and pipes are protected by impressed current method. In this method, an external d. c. power supply is used. The. negative terminal of power supply is connected to underground component and positive to an inert anode (graphite). Therefore, current passes to component and corrosion is suppressed.

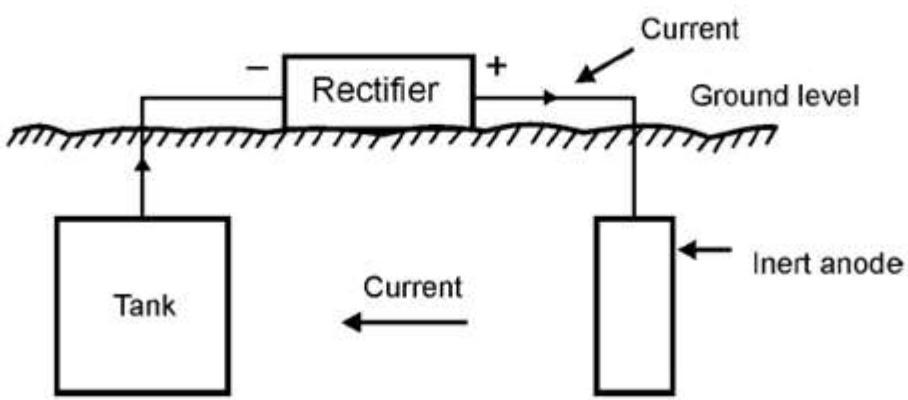


Figure 1: Impressed current method for cathodic protection of an underground tank

Use of sacrificial Anode

Cathodic protection is also achieved by coupling a component to metal which is more anodic. This metal is called as sacrificial anode

Eg. Magnesium is anodic with respect to steel and corrodes when galvanically coupled. Magnesium gets consumed to protect the steel, hence it is called as sacrificial anode. These Mg-anodes are used in the following application

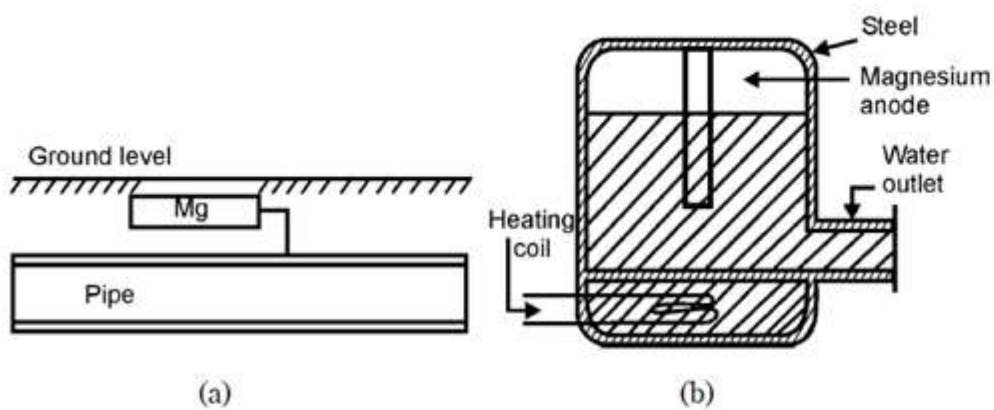


Figure 2: Sacrificial anode for cathode protection of (a) Underground pipe and (b) Domestic water heater.

Anodic protection:

In this method, the metal to be protected is made more anodic so that it forms a passive film. This is carried out by using a potentiostat which maintains a metal at a constant potential with respect to reference electrode. Formation of such passive film tends to decrease the corrosion rate. However, not all metals tend to passivate. Metals like chromium, nickel, titanium etc. show active passive transition. The anodic protection is advantageous in extremely corrosive environment.

Use of Inhibitors

Inhibitors are chemicals. They are added to corrosive solutions to reduce the corrosive effect of solution. Usually, the inhibitor forms a protective film on the metal surface. Various types of inhibitors with different compositions are used. Following types of inhibitors are used.

- **Adsorption type inhibitors:** These are the organic compounds. They are absorbed on the metal surface. This reduces metal dissolution.
- **Hydrogen evolution retarding inhibitors:** They are added to retard hydrogen evolution, process. They are effective in acidic electrolytes and control the cathodic reactions.
- **Scavengers:** They are used to remove the corrosive reagents from electrolyte, e.g. sodium sulphate. They remove dissolved oxygen from electrolyte. However, they are not recommended for highly acidic solutions.
- **Oxidizers:** Oxidizers are-used for metals which show active passive transition. For example, Chromate, Nitrate etc. are commonly used oxidizers.

- **Vapor phase inhibitors :** They are used mostly to reduce atmospheric corrosion effect. They are placed in the cavities or similar areas of a metal component. They posses a very high vapor pressure. Therefore they undergo sublimation and get condensed on metal surface thus protecting metal surface from corrosion.

Vapor phase inhibitors are used in closed spaces such as during packing or storage of metal components.

The inhibitors are also coated on a paper. Components wrapped with such a paper are better protected from corrosion.

Now—a-days, sonic of the automotive components are packed and sold in plastic bags coated with vapor phase inhibitors internally.

Use of Surface Coatings

Surface coatings are externally applied substances or compounds, which resist corrosion.

Coating will cut direct contact of metal component with environment and improve corrosion resistance i.e. the coated material will have better corrosion resistance than the metal component.

Coatings are classified as:

1) Metallic coatings;
2) Inorganic coatings and
3) Organic coatings.