

UNIT 3

Corrosion:

It is basically defined as a natural process that causes the transformation of pure metals into undesirable substances when they react with substances like water or air. This reaction causes damage and disintegration of the metal, starting from the portion of the metal exposed to the environment and spreading to the entire bulk of the metal.

Factors Affecting Corrosion

1. Exposure of the metals to air containing gases like CO_2 , SO_2 , SO_3 etc.
2. Exposure of metals to moisture, especially salt water (which increases the rate of corrosion).
3. Presence of impurities like salt (For example, NaCl).
4. Temperature: An increase in temperature increases corrosion.
5. Nature of the first layer of oxide formed: Some oxides like Al_2O_3 form an insoluble protecting layer that can prevent further corrosion. Others, like rust, easily crumble and expose the rest of the metal.
6. Presence of acid in the atmosphere: Acids can easily accelerate the process of corrosion.

Rate of Corrosion

The Deal–Grove model is often used to describe the formation of an oxide layer. This model helps in predicting and controlling oxide layer formation in a lot of diverse situations. Apart from this, the weight loss method is also used to measure corrosion. In this method, a clean, weighed piece of the metal or alloy is exposed to the corrosive environment for a certain duration. This is followed by a cleaning process that removes the corrosion products. The piece is then weighed to determine the loss of weight.

The rate of corrosion (R) is calculated as:

$$R = \frac{kW}{\rho At}$$

Where,

k = constant,

W = weight loss of the metal in time t ,

A = surface area of the metal exposed,

ρ is the density of the metal (in g/cm^3).

Types of Corrosion

Some of the corrosion types include the following:

(i) Crevice Corrosion

Whenever there is a difference in ionic concentration between any two local areas of a metal, a localised form of corrosion known as crevice corrosion can occur. For instance, this form of corrosion mostly occurs in confined spaces (crevices). Examples of areas where crevice corrosion can occur are gaskets, the undersurface of washers, and bolt heads. All grades of aluminium alloys and stainless steels also undergo crevice corrosion. This is mainly because of the formation of a differential aeration cell that leads to the formation of corrosion inside the crevices.

(ii) Stress Corrosion Cracking

Stress corrosion cracking can be abbreviated to 'SCC' and refers to the cracking of the metal as a result of the corrosive environment and the tensile stress placed on the metal. It often occurs at high temperatures.

For example, stress corrosion cracking of austenitic stainless steel in chloride solution.

(iii) Intergranular Corrosion

Intergranular corrosion occurs due to the presence of impurities in the grain boundaries that separate the grain formed during the solidification of the metal alloy. It can also occur via the depletion or enrichment of the alloy at these grain boundaries.

For example, Aluminum-base alloys are affected by IGC.

(iv) Galvanic Corrosion

When there exists an electric contact between two metals that are electrochemically dissimilar and are in an electrolytic environment, galvanic corrosion can arise. It refers to the degradation of one of these metals at a joint or at a junction. A good example of this type of corrosion would be the degradation that occurs when copper, in a salt-water environment, comes in contact with steel.

For example, when aluminium and carbon steel are connected and immersed in seawater, aluminium corrodes faster, and steel is protected.

(iv) Pitting Corrosion

Pitting Corrosion is very unpredictable and, therefore, is difficult to detect. It is considered one of the most dangerous types of corrosion. It occurs at a local point and proceeds with the formation of a corrosion cell surrounded by the normal metallic surface. Once this 'pit' is formed, it continues to grow and can take various shapes. The pit slowly penetrates metal from the surface in a vertical direction, eventually leading to structural failure if left unchecked.

For example, consider a droplet of water on a steel surface, pitting will initiate at the centre of the water droplet (anodic site).

(v) Uniform Corrosion

This is considered the most common form of corrosion wherein an attack on the surface of the metal is executed by the atmosphere. The extent of the corrosion is easily discernible. This type of corrosion has a relatively low impact on the performance of the material.

For example, a piece of zinc and steel immersed in diluted sulphuric acid would usually dissolve over its entire surface at a constant rate.

(vi) Hydrogen Grooving

This is a corrosion of the piping by grooves that are formed due to the interaction of a corrosive agent, corroded pipe constituents, and hydrogen gas bubbles. The bubbles usually remove the protective coating once it comes in contact with the material.

(vii) Metal Dusting

Metal dusting is a damaging form of corrosion that occurs when vulnerable materials are exposed to certain environments with high carbon activities, including synthesis gas. The corrosion results in the break-up of bulk metal to metal powder. Corrosion occurs as a graphite

layer is deposited on the surface of the metals from carbon monoxide (CO) in the vapour phase. This graphite layer then goes on to form meta-stable M_3C species (where M is a metal) that usually move away from the metal surface. In some cases, no M_3C species may be observed. This means that the metal atoms have been directly transferred into the graphite layer.

(viii) Microbial Corrosion

Microbial corrosion, which is also known as microbiologically influenced corrosion (MIC), is a type of corrosion that is caused by microorganisms. The most common one is chemoautotrophs. Both metallic and non-metallic materials, either in the presence or absence of oxygen, can be affected by this corrosion.

(viii) High-temperature Corrosion

High-temperature corrosion, as the name suggests, is a type of corrosion of materials (mostly metals) due to heating. Chemical deterioration of metal can occur due to a hot atmosphere that contains gases such as oxygen, sulphur, or other compounds. These compounds are capable of oxidising the materials (metals in this case) easily. For example, materials used in car engines have to resist sustained periods at high temperatures, during which they can be affected by an atmosphere containing corrosive products of combustion.

CORROSION TESTING METHODS:

These methods enable engineers and scientists to assess the resistance of materials to corrosion, identify potential vulnerabilities, and develop effective strategies to mitigate corrosion-related risks.

Salt Spray Testing

Salt spray testing, also known as the ASTM B117 test, is one of the most prevalent and well-established methods for evaluating corrosion resistance. It aims to simulate the corrosive effects of salt-laden environments, such as coastal regions or areas exposed to de-icing salts. In this test, the material under evaluation is exposed to a controlled mist or fog of saltwater, typically containing sodium chloride, for a specified duration.

The sample's performance is assessed by observing the formation and progression of corrosion, blistering, or other visible signs of degradation. Salt spray testing provides valuable information on the material's ability to withstand corrosive environments.

Copper Strip Corrosion Test

The copper strip corrosion test is a widely used method to evaluate the corrosivity of petroleum products containing sulfur compounds. A clean copper strip is immersed in the test sample and subjected to controlled conditions, typically at elevated temperatures. After a specified period, the strip is visually inspected for corrosion or discoloration.

The severity of corrosion observed on the strip provides insight into the potential of the tested product to cause corrosion in practical applications. This simple and cost-effective test aids in quality control, formulation, and material selection, helping industries manage the corrosive effects of petroleum products and ensure the integrity of storage tanks, pipelines, and fuel systems.

Corrosion Coupon Testing

Corrosion coupon testing is a widely used method for assessing and monitoring corrosion in various industries. It involves the exposure of small metal specimens, known as corrosion coupons, to the same environment as the equipment or structure being monitored.

These coupons are then analyzed to evaluate the extent of corrosion, providing valuable data on corrosion rates, characteristics, and the effectiveness of corrosion control measures. By regularly monitoring corrosion coupons, industries can make informed decisions regarding maintenance schedules, material selection, and corrosion mitigation strategies, ultimately ensuring the integrity and longevity of their assets.

Electrochemical Testing

Electrochemical testing methods are widely used for studying the corrosion behavior of materials. These techniques involve measuring the electrical properties of a material immersed in a corrosive solution. Two common electrochemical methods for corrosion testing are potentiodynamic polarization and electrochemical impedance spectroscopy (EIS).

Potentiodynamic polarization determines the corrosion potential and corrosion rate of a material by measuring its current response to a range of applied potentials. It provides insights into the material's ability to resist corrosion and helps determine its critical parameters, such as the breakdown potential.

EIS measures the impedance response of a material to an applied sinusoidal electrical signal. By analyzing the frequency-dependent impedance, EIS provides valuable information on the material's resistance to corrosion, the presence of protective oxide layers, and the kinetics of corrosion processes. EIS is particularly useful for studying the long-term behavior of materials in corrosive environments.

Immersion Testing

Immersion testing involves submerging material samples in corrosive liquids for extended periods. This method allows for the assessment of a material's susceptibility to corrosion under specific conditions. Immersion testing can be conducted in various corrosive solutions, including saltwater, acidic or alkaline solutions, or chemicals relevant to the intended application. The samples are evaluated by measuring weight loss, surface appearance changes, or alterations in mechanical properties. Immersion testing provides insights into the material's corrosion resistance and can help identify the most suitable materials for specific environments.

Cyclic Testing

Cyclic corrosion testing is designed to replicate real-world conditions that materials may experience throughout their service life. It exposes samples to cycles of different corrosive atmospheres, temperature changes, humidity variations, and salt spray. By subjecting materials to these cyclic stressors, this method simulates the effects of corrosion fatigue, thermal cycling, and exposure to environmental pollutants. Cyclic testing provides a comprehensive evaluation of a material's resistance to degradation mechanisms such as cracking, pitting, or general corrosion.

Accelerated Testing

Accelerated corrosion testing methods aim to simulate the effects of long-term exposure to corrosive environments within a shorter timeframe. These tests employ accelerated conditions, such as elevated temperature, increased humidity, or higher concentrations of corrosive agents, to expedite the corrosion process. Accelerated testing methods, including salt fog testing, cyclic wet and dry exposure, or high-temperature exposure, provide faster results compared to natural or real-time testing. However, caution must be exercised when interpreting the results, as accelerated testing may not perfectly replicate real-world conditions.

Crevice Corrosion Testing

Crevice corrosion is a localized form of corrosion that occurs in confined spaces, such as gaps, joints, or under deposits, where stagnant conditions can promote corrosion initiation and propagation. Testing methods for crevice corrosion involve creating artificial crevices or using crevice-forming devices in the sample setup. These tests evaluate the material's susceptibility to crevice corrosion by monitoring the corrosion initiation and propagation within these confined spaces. Crevice corrosion testing is essential, particularly in industries where materials are subjected to environments with potential crevices or gaps, such as offshore structures or piping systems.

Corrosion Monitoring:

(In service Monitoring, Simulated Service and Laboratory Testing)

A wide variety of corrosion measurement techniques exists, including:

Non Destructive Testing

- Ultrasonic testing
- Radiography
- Thermography
- Eddy current/magnetic flux
- Intelligent pigs

Analytical Chemistry

- pH measurement
- Dissolved gas (O₂, CO₂, H₂S)
- Metal ion count (Fe²⁺, Fe³⁺)
- Microbiological analysis

Operational Data

- pH
- Flow rate (velocity)
- Pressure
- Temperature

Fluid Electrochemistry

- Potential measurement
- Potentiostatic measurements
- Potentiodynamic measurements
- A.C. impedance

Corrosion Monitoring

- Weight loss coupons
- Electrical resistance
- Linear polarization
- Hydrogen penetration
- Galvanic current

Some corrosion measurement techniques can be used on-line, constantly exposed to the process stream, while others provide off-line measurement, such as that determined in a laboratory analysis. Some techniques give a direct measure of metal loss or corrosion rate, while others are used to infer that a corrosive environment may exist.

Corrosion monitoring is the practice of measuring the corrosivity of process stream conditions by the use of “probes” which are inserted into the process stream and which are continuously exposed to the process stream condition.

Corrosion monitoring “probes” can be mechanical, electrical, or electrochemical devices.

Corrosion monitoring techniques alone provide direct and online measurement of metal loss/corrosion rate in industrial process systems.

Typically, a corrosion measurement, inspection and maintenance program used in any industrial facility will incorporate the measurement elements provided by the four combinations of on-line/off-line, direct/indirect measurements.

- | | |
|---------------------------|--------------------|
| • Corrosion Monitoring | Direct, On-line |
| • Non Destructive Testing | Direct, Off-line |
| • Analytical Chemistry | Indirect, Off-line |

- Operational Data Indirect, On-line

In a well controlled and coordinated program, data from each source will be used to draw meaningful conclusions about the operational corrosion rates with the process system and how these are most effectively minimized.

The Need for Corrosion Monitoring

The rate of corrosion dictates how long any process equipment can be usefully and safely operated. The measurement of corrosion and the action to remedy high corrosion rates permits the most cost effective plant operation to be achieved while reducing the life-cycle costs associated with the operation.

Corrosion monitoring techniques can help in several ways:

- (1) by providing an early warning that damaging process conditions exist which may result in a corrosion-induced failure.
- (2) by studying the correlation of changes in process parameters and their effect on system corrosivity.
- (3) by diagnosing a particular corrosion problem, identifying its cause and the rate controlling parameters, such as pressure, temperature, pH, flow rate, etc.
- (4) by evaluating the effectiveness of a corrosion control/prevention technique such as chemical inhibition and the determination of optimal applications.
- (5) by providing management information relating to the maintenance requirements and ongoing condition of plant.

Corrosion Monitoring Techniques

A large number of corrosion monitoring techniques exist. The following list details the most common techniques which are used in industrial applications:

- Corrosion Coupons (weight loss measurements)
- Electrical Resistance (ER)
- Linear Polarization Resistance (LPR)
- Galvanic (ZRA)
- Hydrogen Penetration
- Microbial
- Sand/Erosion

Other techniques do exist, but almost all require some expert operation, or otherwise are not sufficiently rugged or adaptable to plant applications.

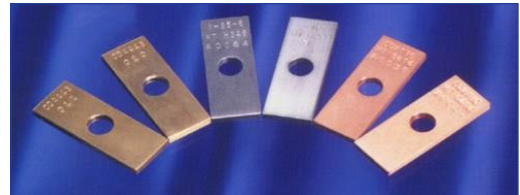
Of the techniques listed above, corrosion coupons, ER, and LPR form the core of industrial corrosion monitoring systems. The four other techniques are normally found in specialized applications which are discussed later.

These corrosion monitoring techniques have been successfully applied and are used in an increasing range of applications because:

- The techniques are easy to understand and implement.
- Equipment reliability has been demonstrated in the field environment over many years of operational application.
- Results are easy to interpret.
- Measuring equipment can be made intrinsically safe for hazardous area operation.
- Users have experienced significant economic benefit through reduced plant down time and plant life extension.

Corrosion Coupons (Weight Loss)

The Weight Loss technique is the best known and simplest of all corrosion monitoring techniques. The method involves exposing a specimen of material (the coupon) to a process environment for a given duration, then removing the specimen for analysis. The basic measurement which is determined from corrosion coupons is weight loss; the weight loss taking place over the period of exposure being expressed as corrosion rate.



The simplicity of the measurement offered by the corrosion coupon is such that the coupon technique forms the baseline method of measurement in many corrosion monitoring programs.

The technique is extremely versatile, since weight loss coupons can be fabricated from any commercially available alloy. Also, using appropriate geometric designs, a wide variety of corrosion phenomena may be studied which includes, but is not limited to:

- Stress-assisted corrosion
- Bimetallic (galvanic) attack
- Differential aeration
- Heat-affected zones

Advantages of weight loss coupons are that:

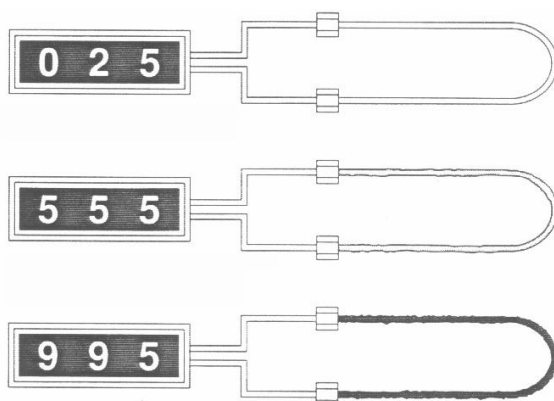
- The technique is applicable to all environments - gases, liquids, solids/particulate flow.
- Visual inspection can be undertaken.
- Corrosion deposits can be observed and analyzed.
- Weight loss can be readily determined and corrosion rate easily calculated.
- Localized corrosion can be identified and measured.
- Inhibitor performance can be easily assessed.

In a typical monitoring program, coupons are exposed for a 90-day duration before being removed for a laboratory analysis. This gives basic corrosion rate measurements at a frequency of four times per year. The weight loss resulting from any single coupon exposure yields the “average” value of corrosion occurring during that exposure. The disadvantage of the coupon technique is that, if a corrosion upset occurs during the period of exposure, the coupon alone will not be able to identify the time of occurrence of the upset, and depending upon the peak value of the upset and its duration, may not even register a statistically significant increased weight loss.

Therefore, coupon monitoring is most useful in environments where corrosion rates do not significantly change over long time periods. However, they can provide a useful correlation with other techniques such as ER and LPR measurements.

Electrical Resistance (ER) Monitoring

ER probes can be thought of as “electronic” corrosion coupons. Like coupons, ER probes provide a basic measurement of metal loss, but unlike coupons, the value of metal loss can be measured at any time, as frequently as required, while the probe is in-situ and permanently exposed to the process stream.

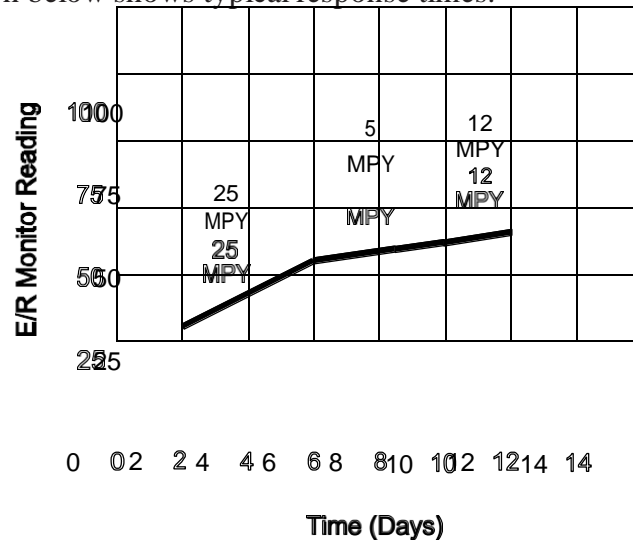


In this diagram, a standard ER instrument is connected to a 40 mil wire loop element which has a useful life of 10 mils. The instrument still reads close to zero because the element is new.

Here the instrument reads around half-scale, indicating that the element has experienced about 5 mils of metal loss or about half of its useful life. The instrument’s reading is increasing proportionally with the resistance of the element, which increases as a result of metal loss.

Here the instrument reads almost full scale, indicating that the element has experienced 10 mils of metal loss and requires replacement.

The ER technique measures the change in Ohmic resistance of a corroding metal element exposed to the process stream. The action of corrosion on the surface of the element produces a decrease in its cross-sectional area with a corresponding increase in its electrical resistance. The increase in resistance can be related directly to metal loss and the metal loss as a function of time is by definition the corrosion rate. Although still a time averaged technique, the response time for ER monitoring is far shorter than that for weight loss coupons. The graph below shows typical response times.



ER probes have all the advantages of coupons, plus:

- Direct corrosion rates can be obtained.
- Probe remains installed in-line until operational life has been exhausted.
- They respond quickly to corrosion upsets and can be used to trigger an alarm.

ER probes are available in a variety of element geometries, metallurgies and sensitivities and can be configured for flush mounting such that pigging operations can take place without the necessity to remove probes. The range of sensitivities allows the operator to select the most dynamic response consistent with process requirements.

Linear Polarization Resistance (LPR) Monitoring

The LPR technique is based on complex electro-chemical theory. For purposes of industrial measurement applications it is simplified to a very basic concept. In fundamental terms, a small voltage (or polarization potential) is applied to an electrode in solution. The current needed to maintain a specific voltage shift (typically 10 mV) is directly related to the corrosion on the surface of the electrode in the solution. By measuring the current, a corrosion rate can be derived.

The advantage of the LPR technique is that the measurement of corrosion rate is made instantaneously. This is a more powerful tool than either coupons or ER where the fundamental measurement is metal loss and where some period of exposure is required to

determine corrosion rate. The disadvantage to the LPR technique is that it can only be successfully performed in relatively clean aqueous electrolytic environments. LPR will not work in gases or water/oil emulsions where fouling of the electrodes will prevent measurements being made.

Galvanic Monitoring

The galvanic monitoring technique, also known as Zero Resistance Ammetry (ZRA) is another electrochemical measuring technique. With ZRA probes, two electrodes of dissimilar metals are exposed to the process fluid. When immersed in solution, a natural voltage (potential) difference exists between the electrodes. The current generated due to this potential difference relates to the rate of corrosion which is occurring on the more active of the electrode couple.

Galvanic monitoring is applicable to the following electrode couples:

- Bimetallic corrosion
- Crevice and pitting attack
- Corrosion assisted cracking
- Corrosion by highly oxidizing species
- Weld decay

Galvanic current measurement has found its widest applications in water injection systems where dissolved oxygen concentrations are a primary concern. Oxygen leaking into such systems greatly increases galvanic currents and thus the corrosion rate of steel process components. Galvanic monitoring systems are used to provide an indication that oxygen may be invading injection water through leaking gaskets or deaeration systems.

Specialized Monitoring

Biological Monitoring

Biological monitoring and analysis generally seeks to identify the presence of Sulphate Reducing Bacteria - SRB's. This is a class of anaerobic bacteria which consume sulphate from the process stream and generate sulphuric acid, a corrosive which attacks production plant materials.



Sand / Erosion Monitoring

These are devices which are designed to measure erosion in a flowing system. They find wide application in oil/gas production systems where particulate matter is present.

Hydrogen Penetration Monitoring

In acidic process environments, hydrogen is a by-product of the corrosion reaction. Hydrogen generated in such a reaction can be absorbed by steel particularly when traces of sulphide or cyanide are present. This may lead to hydrogen induced failure by one or more of several mechanisms. The concept of hydrogen probes is to detect the amount of hydrogen permeating through the steel by mechanical or electrochemical measurement and to use this as a qualitative indication of corrosion rate.

Instrumentation

There exists a variety of instrument options associated with the various corrosion monitoring techniques. Three classifications are:

- Portable Meters and Data Loggers
- Field-Mounted Data Loggers
- Field-Mounted Transmitters

In some applications such as those experienced in oil/gas production and refining, instrumentation is required to be certified for use in “hazardous areas”. For portable instruments this is most often achieved by having the equipment certified as “intrinsically safe” by a recognized authority such as BASEEFA (U.K.), U.L. (U.S.A.), ITS (U.S.A.), or CENELEC (Europe). For hardwired continuous monitoring electronics, isolation barriers can be used to ensure that, in the event of a fault condition, insufficient energy is transmitted to the hazardous field area for an explosive spark to be produced.

Probe Fitting Styles

There are two fundamental fitting styles for corrosion probes: fixed and removable under pressure.

Fixed styles of probes/sensors have typically a threaded or flanged attachment to the process plant. For fixed styles of sensors, removal can only be accomplished during system shut down or by isolation and depressurization of the sensor location.

From time to time, corrosion coupons and probes require removal and replacement. It is sometimes more convenient to be able to remove and install sensors while the process system is operational. To facilitate this, there are two distinct systems which permit removal/installation under pressure.

In refinery and process plant environments where pressures are normally less than 2000

psi, a Retractable System is used. This consists of a packing gland (stuffing box) and valve arrangement. For environments such as those experienced in oil/gas production where pressures of several thousand psi are experienced, a special High Pressure Access System is used. This permits the safe and easy installation/removal of corrosion monitoring devices at working pressures up to 3600 psi.

Applications of Corrosion Monitoring Techniques

Corrosion monitoring is typically used in the following situations:

- Where risks are high - high pressure, high temperature, flammable, explosive, toxic processes.
- Where process upsets can cause high corrosivity.
- Where changes in operating conditions can cause significant changes in corrosion rate.
- Where corrosion inhibitors are in use.
- In batch processes, where corrosive constituents are concentrated due to repeated cycling.
- Where process feedstock is changed.
- Where plant output or operating parameters are changed from design specifications.
- In the evaluation of corrosion behavior of various alloys.
- Where induced potential shifts are used to protect systems and/or structures.
- Where product contamination due to corrosion is a vital concern.

Corrosion monitoring may be used in virtually any industry where corrosion prevention is a primary requirement. Some examples of industries and specific areas of interest include, but are not limited to:

Oil/Gas Production

- Flowlines
- Gathering Systems
- Transport Pipelines
- Water Injection Facilities
- Vessels
- Processing
- Water Systems
- Chemical Injection Systems
- Drilling Mud Systems
- Water Wash Systems
- Desalters

Refining

- Crude Overheads
- Visbreakers
- Vacuum Towers
- Sour Water Strippers
- Amine Systems
- Cooling Systems

Pulp and Paper

- Digesters
- White Liquor
- Boiler Systems

Utilities

- Cooling Systems
- Effluent Systems

Petrochemicals/Chemicals/Processing

- Process Systems
- Cooling Systems

- Make-Up Water Systems
- Boiler Water Systems

In any corrosion monitoring system, it is common to find two or more of the techniques combined to provide a wide base for data gathering. The exact techniques which can be used depend on the actual process fluid, alloy system, and operating parameters.

Corrosion monitoring offers an answer to the question of whether more corrosion is occurring today as compared to yesterday. Using this information it is possible to qualify the cause of corrosion and quantify its effect. Corrosion monitoring remains a valuable weapon in the fight against corrosion, thereby providing substantial economic benefit to the user.

Prevention Of Corrosion:

Since corrosion weakens the metal and reduces its strength. It is important to prevent the metal from corroding easily. The process of corrosion can be prevented by the following measures.

Coating

The process of corrosion can be prevented by applying a layer or a coat of non-corrosive metal on the surface of metals which must be protected. The metals can be coated with epoxy and acrylic to reduce their corrosion.

Cathodic Protection

Corrosion takes place when the metal is in contact with water for a long period of time. Pipelines which are situated inside the sea and saltwater are more prone to corrosion as oxides are easily deposited in salty water. With this method, DC current is applied to metals. The impressed current method, also known as cathodic protection, is used for the protection of large ships which are constantly underwater.

Sacrificial Method

The sacrificial method is yet another method to prevent metal from being corroded. A metal of higher reactivity is placed beside the metal to be protected. Thus, the higher reactivity metal sacrifices itself to prevent the main metal from corroding. This method is used with pipelines which are fitted underground.

Galvanisation

With the help of galvanisation, the corrosion of metals can be prevented. It is the most efficient method in terms of corrosion prevention. The electroplating of zinc metal takes place in the process of galvanisation over the metal which is used to prevent corrosion. This technique is usually used in preventing bicycles and motorcycles from being corroded.

Oiling The Surface

The corrosion of metal can be prevented when their surfaces are oiled or greased. When the surface is oiled, then a protective film is formed between the metal and its surroundings, preventing direct contact between them. Thus, this prevents corrosion for long periods of time. The oiling of metal surfaces is the most common and cost efficient method of preventing corrosion.

Alloying

Metals can avoid corrosion when they are not used in their pure forms. The metal gets mixed with another metal and the alloy is used. The alloy which is so formed does not get corroded easily. The alloy of iron and chromium is stainless steel which does not corrode easily when it comes in contact with its surroundings even for long periods of time.

Painting

Paint can help in the prevention of corrosion. Paint must be applied regularly to do this. When the paint surface gets scratched from any sides, then it must be repainted again. The process is also cost efficient and commonly used in homes. The quality of paint must be good to ensure that it helps the metal maintain its appearance. The metal oxide commonly known as primer is used to coat the iron surface to prevent rusting. Multiple layers of paint can prevent the surface from corrosion.

Hot Dip Galvanisation

Corrosion can also be prevented when metals are dipped in the hot molten metal of zinc or chromium to electroplate their surface. This ensures that the metals are coated and helps avoid contact with its surroundings. The plated layer can be applied multiple times depending on the nature of metals which is used to prevent it. The dipping of metal increases the equality and cost of the metal as well.

Protection against corrosion

- Corrosion of metals/alloys: not desirable
- It tarnishes the metals/alloys & reduces its strength, ductility, malleability, electrical conductivity etc.
- Protection against corrosion means not allowing corrosion reaction to take place

METHODS OF CORROSION PREVENTION

- Proper designing
- Proper selection of materials for the environment concerned
- Cathodic protection
- Modification of the environment
- Corrosion inhibitors
- Protective coatings.

PROPER DESIGNING & MATERIAL SELECTION

- Selecting the proper material is essential for long term corrosion control
- There is no material that withstands corrosive attack in all environment
- Materials must match to the environment that they will encounter in service

Avoid galvanic corrosion by following methods:

- Dissimilar metal contact can not always be avoided because of weight, cost & functional issues.
- Never join different metals & alloys, if not possible, insulate them with efficient moisture resistance electrical insulator.
- Greater the separation, more rapidly anode will corrode
- Never use a design, if relative sizes of the cathode & anode are widely different.
- (area of anode/area of cathode > 1)

- Manufacture bolts, screws, nuts & riveting from a more noble materials than the members to be joined, [a small anode (the less noble metal such as Al) joined to a large cathode (the more noble metal such as SS)] will result in a high current density on Al & hence a high rate of corrosion
- No problem occurs, if the area of the anode is large compared to the cathode
- Continuous welds should be preferred, not intermittent (responsible for crevice corrosion)

Avoid L, T & U shaped profiles in constructions:

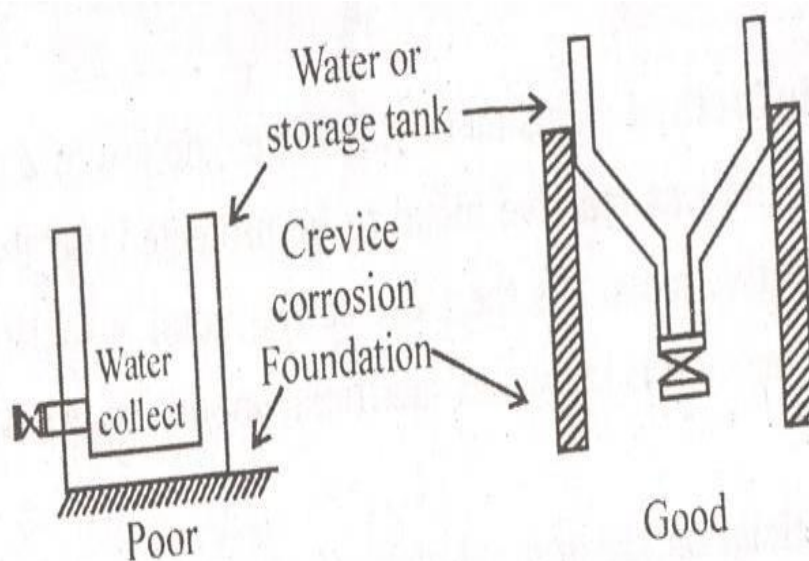
- greater the no. of angles, corners & edges, it becomes more difficult for efficient surface treatment.

Avoid improper insulation:

- leakage of current can take place which causes anodic corrosion.

Avoid the contact of metallic object with moisture:

- water can not be avoided but can be controlled with drain paths, drain holes, sealants & corrosion inhibiting compounds.
- Design should be such that retention of moisture is as low as possible
- Design the storage containers should be such that they can be completely drained & cleaned.



Using of pure metal:-

- Purity increases the corrosion resistance.
- The rate & extent of corrosion increases with increase in impurities.
- Viz.-the corrosion resistance of Al depends on its oxide film formation, which is highly protective only on the high purity of metal

Using of metal alloys:-

- Suitable alloying increases corrosion resistance.
- Use of various types of SS such as AISI:301, 304 (Austenitic); AISI: 409 M & 3Cr12 grade of IRS-M-44 (Ferritic)
- Use of HSLA (IRS:M-41 i.e. cor-ten steel (Weather resistant steel/ Atmospheric corrosion resistant steel): (C-0.10% Min, Mn-0.20-0.50, Si-0.25-0.75, Cu-0.25-0.55%, Ni-0.65% max, Cr-0,50-1,25%,P-0.075-0.145%) & Cu-bearing steel (IS:2062 WC).
- HCS are not widely used for structural work due to its lack of ductility & weldability
- For this purpose HSLA steels are used which has excellent ductility, YS & weldability which is obtained by decreasing C-content & adding alloying elements

Elimination of tensile stress:-

- – Internal stresses & corrosion can be reduced by heat treatment like annealing.

CATHODIC PROTECTION

Definition:-

“Cathodic protection is defined as the control of electrolytic corrosion by forcing the structure to be protected to behave like a cathode”.

- One of the most effective & economical method of preventing corrosion
- Can be effectively applied to control corrosion of surfaces that are immersed in water or exposed to soil
- Most commonly used system to protect steel, water or fuel pipe lines, ships, etc

SACRIFICIAL ANODE METHOD

The method involves the use of a more reactive metal as sacrificial anode along with the less reactive metal to be protected

- – Sacrificial anodes are pieces of metal usually electrically connected by a conductive wire (usually Cu wire) to the surface to be protected
- CP with galvanic anodes uses the corrosion of an active metal such as Mg or Zn or Al or their alloys (available in variety of blocks, rods or wire form) to provide the required electrical current
- In this method, the active metal is consumed in the process of protecting the surfaces where corrosion is controlled
- The anodes must be periodically checked & replaced, if consumed completely

MODIFICATION OF ENVIRONMENT

Deaeration:

Deaeration is done to prevent corrosion due to oxygen, dissolved oxygen from water is removed by physical or chemical means.

*In modern practice, this is accomplished through the use of oxygen scavengers [sodium sulphite & hydrazine (N_2H_4)]

Dehumidification:

Moisture from air is removed by dehumidification using silica gel to prevent corrosion.

Neutralisation of acids:

Corrosive environment due to presence of acids (HCl , SO_2 , CO_2 , H_2S , etc) can be minimised by injecting alkaline neutralisers (NH_3 , $NaOH$, Lime, etc)

CORROSION INHIBITORS

“Reduce corrosion rate when added in small quantity”

Types of inhibitor:

ANODIC: inhibits corrosion of anode

Some inorganic salts like metal silicate & borates

CATHODIC: “inhibits corrosion of cathode” Some reducing agents like sodium thio sulphate & some salts of Ni, Mg etc

PROTECTIVE COATINGS

- Protective coatings are means for separating the surface that are susceptible to corrosion from the factors in the environment which cause corrosion to occur
- Most widely used corrosion control technique
- Coating of oil, grease can be used to give a temporary protective coating
- Organic polymers or rubber latex can be applied to give coatings which can be stripped off when required
- Paint: The most common coating
- Any protective coatings can never provide 100% protection of 100% of the surface

Types of coating applied on the metal surface:-

- Metallic coatings
- Chemical conversion coating
- Organic coating

METALLIC COATINGS

- The metallic coatings used are:- Zn, Sn, Ni, Cu, Cr, Al & Pb.
- Coating separates the base metal from the corrosive environment & acts as an effective barrier.

GALVANISING

A corrosion protection process for steel or iron, in which the substrate is thinly coated with zinc.

Process:

Surface preparation

Degreasing/ caustic cleaning:

- Immersing in acid degreasing bath or caustic solution to remove dirt, oil & grease

Pickling:

- Immersing in acid tank filled with either dil HCl or H₂SO₄ at 60 -90°C for 15-20 mts to which removes oxides & mill scale & rinse with water

Fluxing:

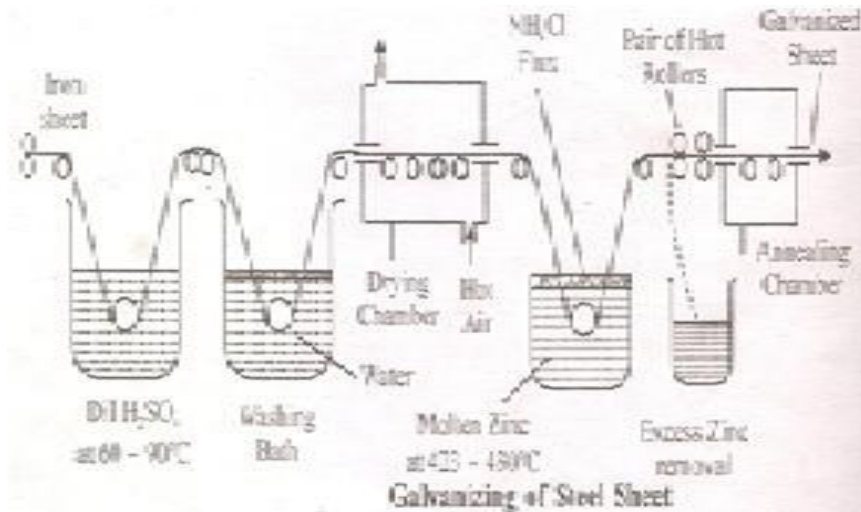
- Pass through a tank containing a combination of ZnCl₂ & NH₄Cl (flux-slightly acidic) which cleans the steel from all oxidation products & to create a protective coating

Galvanising:-

- Passing the well washed dried metals through a molten bath of Zn maintained at 425- 430°C covered with the flux (to inhibit oxidation of the cleaned surface upon exposure to air)
- The iron reacts with molten Zn to form tightly bonded alloy coating that provides superior corrosion protection.

Post treatment:-

- Zn layered metal is passed through a pair of hot rollers to produce a thin film of uniform thickness & quenched in water added with some chemicals to create a passivation layer & to enhance the galvanised coating
- *when exposed to the atm, the pure zinc reacts with O₂ to form ZnO, which further reacts with CO₂ to form ZnCO₃, usually dull grey, fairly strong that stops further corrosion



TINNING

“Coating of tin on ferrous or non-ferrous articles”

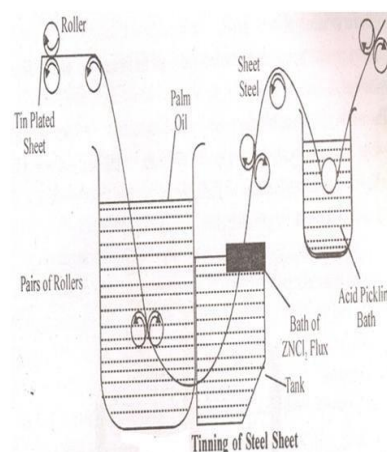
Tinning process:

Surface preparation:

- Cleaning of metals by pickling with dil H_2SO_4 to remove any scale, etc

Tinning:

- Pass the sheet through a tank of molten tin covered with Zinc chloride flux & finally through a series of rollers.
- More resistant to corrosion & wear
- *Does not protect iron/steel when the coat is scratched/porous because of iron is anodic to Sn



CEMENTATION

- Base metal (steel) is heated with fine powdered coating metal (Zn, Cr & Al)

The process is called:

Sheradising, if Zn is used;

Chromising, if Cr is used;

Calorising or Alonising, if Al is used.

- Very good bond is produced
- The process is limited to relatively small objects.

ELECTROPLATING

Process:

- The freshly cleaned metal is made cathode in a suitable electrolyte bath containing:-

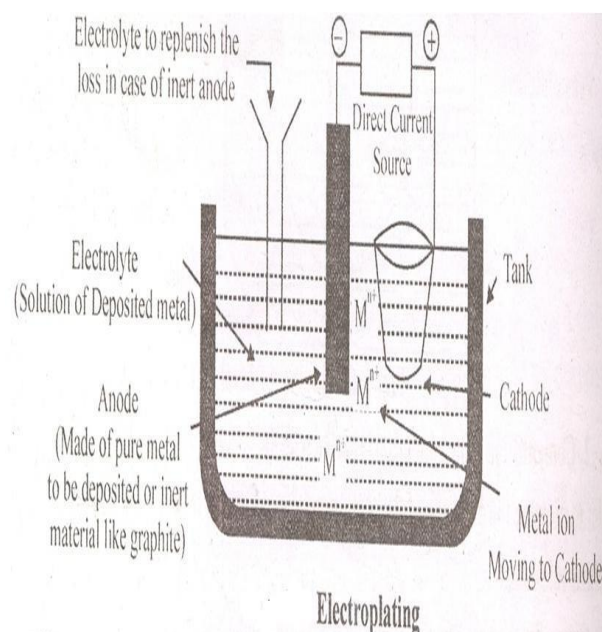
A soln of the salt of the metal (electrolyte) to be electroplated

Buffer solution to maintain pH.

- Extra reagents to increase conductivity & to aid the formation of smooth, dense & coherent coating
- The concentration of the salt solution is controlled by the addition of metal salt at regular intervals.

Different electroplating:-

- Chromium plating
- Nickel plating
- Copper plating



Chemical conversion coating

- Anodising
- Phosphating (Bonderising)

Anodising:

- Al develops an oxide surface layer in air which offers some CR. This can be improved by thickening through an electrolytic process. This treatment is known as Anodising. The freshly formed anodic layer is porous & has to be sealed by immersion in boiling water to give max protection against atmospheric corrosion. This anodic layer increases surface hardness, abrasion resistance & CR.

Phosphating :

- In this process, steel surfaces are treated with phosphoric acid or solutions containing phosphate ions
- The treatment results in the removal of surface rust & the steel surface is converted to metallic phosphate (protective).
- The coatings do not provide appreciable corrosion protection.
- They are useful mainly as a base for paints, ensuring good adherence of paint to steel.