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OVERVIEW OF CORROSION AND ITS PREVENTION: A CRITICAL REVIEW

Nelofar Tanveer
Assistant professor
Department of Chemistry,
Vivek College, Bijnor, (U.P) India.

Abstract: Corrosion is the destruction of materials usually metal owing to electrochemical reaction with the environment which result in a failure of component. Corrosion is a reverse of the process of extractive metallurgy and depends on the several factors such as environment, stress, erosion and the temperature. Every nation faces major economic losses ranges from 1% to 5% of GNP per year due to corrosion. Additionally, corrosion not only increases the costs of component butit also responsible for life losses and safety hazard. Hence, the aim of this review paper is to provide an overview of different types of corrosion and their preventive method. Corrective prevention action may be taken to minimize the effect of corrosion related problems.

Key words: **corrosion, types of corrosion, cathodic protection**

I. INTRODUCTION

Corrosion is an irreversible destruction of metal surface caused by chemical or electrochemical action of the surrounding environment. Corrosion is generally viewed as a universal phenomenon [1]. The most Common example of corrosion includes rusting, discoloration and tarnishing. The corrosive environment may be of any type i.e., may be solid, liquid or gas. These environments are generally known as electrolytes. These electrolytes allow the transfer of ions (cations and anions) and form two reactions (anodic and cathodic). If suppose, we have two different types of metals in a given electrolyte, then the less noble metal acts as anode and gets corroded whereas the more noble metal acts as cathode and gets protected. The electron flow is from anodic metal to cathodic metal. Among the two different metals present in a given environment, the metal with higher reduction potential (having higher position in electrochemical series) or less noble metal gets corroded. Corrosion is a surface phenomenon i.e.; it occurs at the surface of the materials. Corrosion takes place in several forms. First, an overall surface attack slowly reduces the thickness of the metal. Secondly, instead of an overall surface attack, only isolated areas are affected. Third, it also occurs along the grain boundaries or other lines of weakness because of a difference in resistance to corrosive environment [2]. It is a slow process that damages industrial machines, metallic equipment, and reduces the overall value of that product. On annual basis, total economic loss due to various types of corrosions in India is nearly US$ 6500 million. In the US, total direct wastage is estimated about 3.2% of domestic product [3]. The key to control the corrosion is its proper awareness and by adapting suitable and timely measures [4].

1.1 CAUSE OF CORROSION

Most of the metals found in nature are in the form of their compounds except the noble metals such as gold and platinum. This is due to the fact that the metals in their compound state are thermodynamically more stable than their elemental state [5]. As most of the metals exists in the form of oxides so during their extraction into free state, a lot of energy is provided to them. This provided energy enables them to rebound back to their combined state when they are exposed to external environment like moisture, oxygen etc. For example: when iron is exposed to external conditions, it undergoes corrosion and produces brown coloured hydrated ferrous oxide. This shows that corrosion is a process which is contrary to metal extraction [6].

1.2 FACTORS AFFECTING CORROSION

The rate of corrosion mainly depends on two factors:
1) Nature of metal
2) Nature of corroding environment.
Many other factors that affect corrosion are purity of metal, nature of surface film, nature of corrosive product, humidity of air, temperature and pH of electrolyte.

Nature of metal:

It further depends upon:
(a) Purity of metal
(b) Position in galvanic series
(c) Nature of surface film
(d) Nature of corrosive product.

(a) Purity of metal: The rate of corrosion increases with increase in addition of impurities. This is so because; impurities form tiny electrochemical cells where the anodic part gets corroded. For example: Zn containing impurities like Fe or Pb corrodes faster.

(b) Position in galvanic series: When we have two metals of different types and they are connected electrically in a given electrolyte, the metal which is present at a higher level in galvanic series or the metal with higher oxidation potential is corroded whereas the rest is protected. Further, the rate of corrosion also depends upon the difference of the positions of the two metals. Rate of corrosion is directly proportional to the difference of the position of the two metals i.e., more the difference, faster is the rate of corrosion.

(c) Nature of surface film: All the metals get covered with a thin surface film of the metal oxide in an aerated atmosphere. The ratio of volumes of metal oxide to the metal determines the effect of surface film. It is known as “specific volume ratio”. Greater the ratio, lesser is the oxidation rate.

(d) Nature of corrosive product: The corrosion comparatively proceeds at a faster rate if the product formed, is soluble in the corrosive medium. Also, if the corrosive product is volatile, it evaporates as soon as it is formed, thereby metal surface is exposed for further attack. In this way, corrosion further exceeds.

Nature of corroding environment:

It further depends on:

(a) Temperature

(b) Humidity of air

(c) Effect of pH

(a) Temperature: The rate of corrosion increases with the rise in temperature. The rate of corrosion is expected to be almost double for every 100 rises in temperature [7]. This increase is usually represented by an exponential curve. However, one encounters not only the simple dependence upon temperature given by exponential curves.

(b) Humidity of air: It also plays a great role in deciding the rate of corrosion. The rate of corrosion increases sharply above a special point of relative humidity. This is called critical humidity. The reasons for this increase of corrosion with humidity are that the oxide film has the tendency to absorb moisture thus creating another electrochemical corrosion. Also, the moisture present in the atmosphere will furnish water to the electrolyte which is essential for setting up of an electrochemical cell and corrosion to occur.

(c) Effect of pH: It is the most important factor to determine the rate of corrosion. Generally, lower is the pH, greater is the corrosion. This shows that acidic media having pH less than 7 are more corrosive than alkaline or neutral media.

1.3 CORROSION COST TO SOCIETY

Corrosion as being one of the most serious problems in our society is resulting into losses each year in hundreds of billions of dollars [8]. Some major losses due to corrosion are enlisted below:
(i) It damages industrial machines and unpredictable machinery failure, which could lead to loss of life.
(ii) It damages metallic equipment such as boiler tubes in thermal power plants [9-11].
(iii) It reduces the overall value of that product and wastes the valuable resources.
(iv) Some metallic properties such as conductivity, ductility, malleability, luster etc. are lost due to corrosion.
(v) About 20% of the total production of iron is wasted annually every year due to corrosion.
(vi) It also contaminates portable water.
Hence, to minimize the effects of corrosion, we must carefully observe its mechanism.

1.4 EFFECT OF CORROSION ON HUMAN HEALTH

Exposure to extreme pH values result in irritation to the eye, skin and mucous membrane. Eye irritation and exacerbation of skin disorder have been associated with pH values greater than eleven. In addition, solutions of pH 10-12.5 have been reported to cause hair fibres to swell. Exposure to low pH values can also result in similar effect. Below 2.5 pH can affect the degree of corrosion of metals as well as dissection efficiency, it may have an indirect effect on health. All material compounds are toxic and they affect many organ systems both during pre-metal and post metal development and in adulthood. Mercury compounds are neurotoxic. Same are immunologically active. The main toxicity stems from the binding of mercury to salt dry groups of enzymes and other proteins, there by disruption their structure and function. This interferes with basic cellular process and damages or kills cell. The different forms of mercury differ in their ability to penetrate membranes and gains the neuron toxicity, that is of greatest importance although same forms of mercury damage the kidneys and same compounds are highly corrosive to skin and mucous membrane [12].

II CORROSION MECHANISM

Corrosion involves exchange of electrons from anode to cathode in a given conductive electrolytic solution. The metal at anode undergoes liberation of free electrons (oxidation) whereas the cathodic metal accepts the electrons (reduction). The metal which has the higher reduction potential acts as anode whereas the other at lower potential acts as cathode, so the anodic metal gets corroded. For corrosion, these conditions must be fulfilled:

1. There must exist separate regions (cathodic and anodic) between which current might flow through conducting medium.
2. At anode, oxidation of metal occurs due to which the metal surface is depleted due to combination with oxygen. Hence, corrosion always takes place at anode.

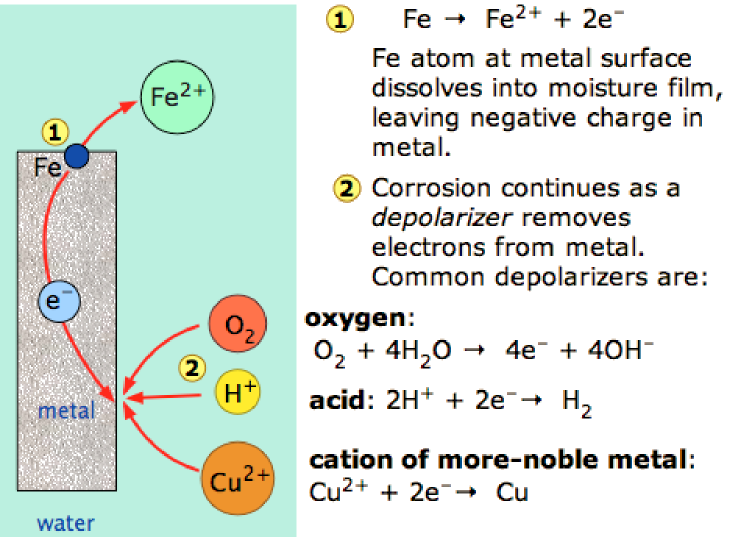

Figure 1. Mechanism of Corrosion

III TYPES OF CORROSION

The various types of corrosion are classified into following categories as shown in Figure. 2

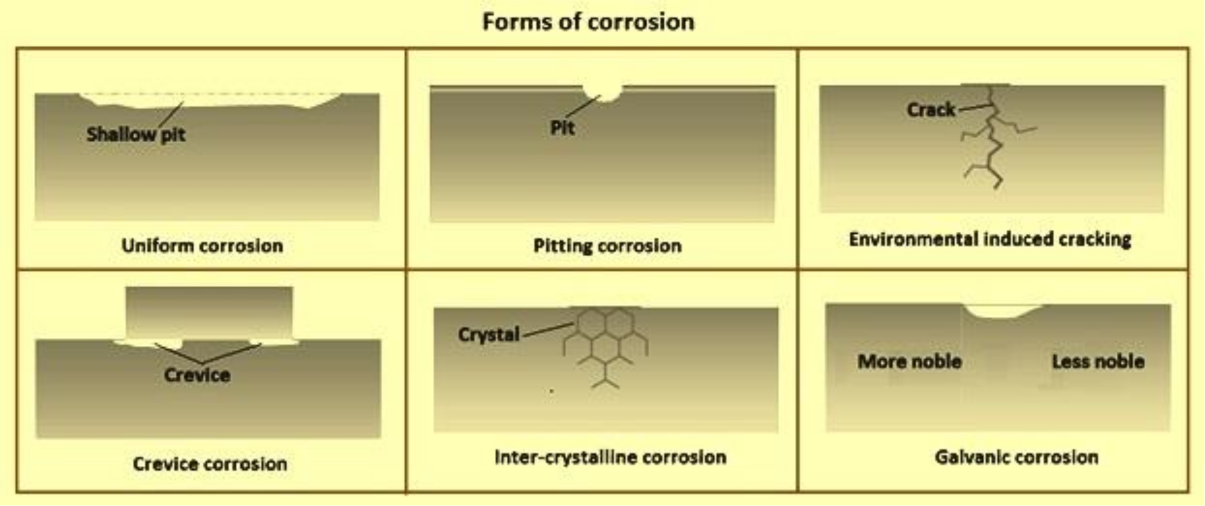

Figure 2. Forms of Corrosion

3.1 Uniform Corrosion

It is also known uniform corrosion or dry corrosion; it is the type of corrosion which perishes the barren metal surface more or less, uniformly. It can also be defined as a type of corrosion which proceeds at same rate over the entire surface area. Oxygen acts as a main cause of this corrosion. The most common materials which show general corrosion are cast iron and steel. When they are exposed to moist atmosphere, they give rust-like appearance.

3.2 Pitting Corrosion

Pitting corrosion is well known type of localized corrosion. This type of corrosion initially occurs in a comparatively small area on a material. After sometime, the area gets larger and deeper, which forms pits in the surface. In this type of localized corrosion, pits (or holes) are established on the surface of material. The growing rate of pitting depends upon the corrosivity of the surrounding environment. An area covered by impurity or water has lower concentration of oxygen so it acts as anode while the other acts as cathode. It is supposed that electrochemical mechanism is responsible for the dissolution of the metal [13]. Till now, two theories are widely used: One is suggested by Hoar. He linked the emergence and growth of the pits with the effect of increase of acidity level of the solutions at active sections [14-15]. Another is suggested by Russian investigators. They linked the formation of pits with the displacement from the metal surface by anions [16-18]. The ratio of deepest pit to the average penetration is known as pitting factor. Pitting factor can be used to check the intensity of pitting corrosion. It is much harmful type of corrosion as it is strenuous to detect, foretell and design against. It is usually observed in passive materials. The presence of non-uniformities adds fuel to the rise of this corrosion. The reaction may proceed as:

At Anode: $Fe \longrightarrow Fe^{2+} + 2e^-$

At Cathode: $\frac{1}{2}\, 0_2 + H_2O + 2e^- \longrightarrow 2OH^-$

Overall: $Fe^{2+} + 2OH^- \longrightarrow Fe(OH)_{2\,(ppt)}$

$Fe(OH)_{2\,(ppt)} \longrightarrow Fe(OH)_3$

3.3 Crevice Corrosion

Crevice corrosion usually occurs in crevices, splits, and gaps or cracks present in metal structures. It mainly affects Stainless Steels. Presence of chloride adds more difficulties while handling with crevice corrosion [19-21]. It is a restricted space corrosion to which the approach of working fluid from the corrosive environment to the space (crevices) is inadequate. The joint area has comparatively lower content of oxygen as compared to the outer area, so joint area acts as anode whereas the outer area acts as cathode. This corrosion is started by concentration gradients. The grouping up of chlorides ions inside a crevice will begin it. It occurs at comparatively lower temperature than pitting corrosion. Various factors that impact crevice corrosion are as follow.
(i) The type of material i.e. alloy, metal.
(ii) Geometric characteristics of crevices such as surface roughness
(ii) Environmental conditions such as pH level, temperature, etc.

3.4 Inter Granular Corrosion

It is also called Inter granular attack (IGA) this corrosion occurs when the margins of the metal surface are more prone to corrosive environment than at the core. This corrosion helps to veil the material's corrosion resistance under many circumstances. This is known as IGA Test. The Inter granular corrosion of aged Al-4%Cu alloys has been the subject of numerous investigations. Inter-granular Corrosion is not affected with the addition of impurities like C, N, O, Mn and S whereas addition of Si and P affects the corrosion [22].

3.5 Galvanic Corrosion

According to electrochemistry, the galvanic corrosion reaction is caused at discrete portions on the metallic surface by an anodic part and a cathodic part [23]. The preferential corrosion of one metal (in presence of a suitable electrolyte) over the other, when both are having an electrical contact is known as galvanic corrosion. It is also known as bimetallic corrosion. It is an electrochemical phenomenon of two unlike metals electrically connected and placed in a suitable electrolyte. The metal at cathode is protected while the metal at anode is corroded. Only unlike metals show galvanic corrosion. The less reactive metal is assigned as cathode while the other is assigned as anode. The rate of galvanic corrosion is directly proportional to the potential difference between the two metals. It increases with the increase in potential difference between the two metals. The reaction of galvanic corrosion is represented in Fig.3.

This potential difference can be calculated by using this equation

$$P.d. = -dG/nF$$

Where; dG is the Gibbs free energy of the reaction, n is the number of moles of electrons transferred and F is the Faraday constant whose value is 23.06kcal/volt. Let us have an example in which Zn and Cu are electrically connected. Since, in electrochemical series, Zn lies at a higher position than Cu, so Zn acts as anode whereas Cu acts as cathode. This means that Zn undergoes loss of electrons whereas Cu accepts electrons. Due to lesser noble nature of Zn as compared to Cu, Zn undergoes corrosion. In Acidic solution,

$$Zn + 2H^+ \longrightarrow Zn^{2+} + H_2$$

In neutral or slightly alkaline solution,

$$\frac{1}{2}\, 0_2 + H_2O + 2e^- \longrightarrow 2OH^-$$

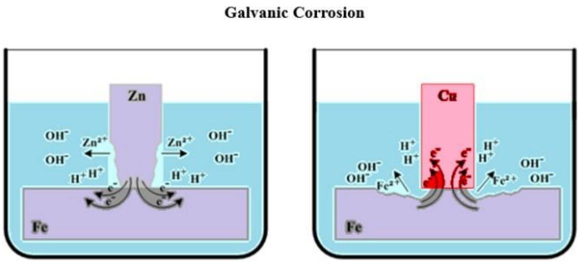

Figure 3. Schematic diagram of Galvanic Corrosion

IV CORROSION PREVENTION

Generally, there are several methods for prevention of corrosion. Different types of corrosion prevention method depicted in Fig. 4.

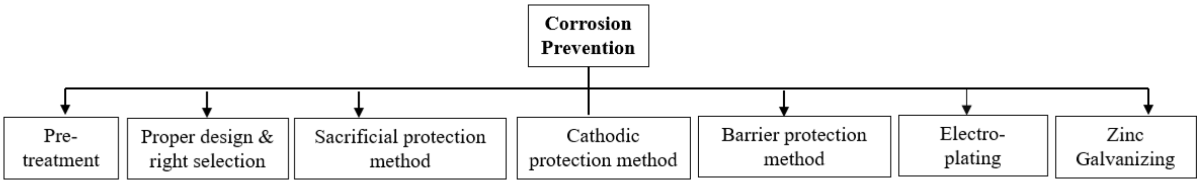

Figure 4. Corrosion prevention methods

4.1 Pre-treatment of Metals

Before the adaptation of any protective measures, the surface of the metal should be properly cleaned. Degreasing is one of the most widely adopted methods for the pre-treatment. A volatile organic solvent like trichloroethylene helps to dissolve the oily as well as greasy surface films [24]. Acid pickling is also an important method of pre-treatment of metals.

4.2 Proper Design and Selection of Right Material

The design of material should be that corrosion is minimum.

(a) Proper Design:

- In the presence of a corroding environment, avoid the contact of two dissimilar metals.
- In case it is necessary to make a contact of two different metals, the metal to be made anode must have as large area whereas the other metal have small area.
- If two dissimilar metals in contact have to be used, they should be as close to each other as possible in the electrochemical series.
- Whenever, the direct contact of dissimilar is unavoidable, an insulating material may be applied in between them to avoid direct metal-metal electrical contact.
- Sharp corners must be avoided as they favor the gathering up of solids.
- The metal should never be painted or coated because any break in coating would result inrapid localized corrosion.

(b) Selecting the Right Material: The properties for the construction of right materials are:
Tensile strength, highly resistant to corrosion and cheap.
The selection of the material is carried as following

- Prior selection: This type of selection is made on the basis of past experience and safety aspects.
- Testing in lab: In this, the suitable material is re- evaluated under the given conditions
- Explanation of laboratory results: In this, the results likeeffect of impurities, excess temperature, pressure, etc [25].

4.3 Sacrificial Method

Sacrificial protection means protecting the metal by covering its surface with a layer of another metal which is more active or more electropositive than it [26]. The metal surface which is more active loses electrons in preference to the other and converts itself into an ionic state by losing electrons. As the time passes, the more active metal gets fully used up. As an example, Zn is usually coated over Fe to prevent it from rusting. This process iscalled Galvanization. Zn being more electropositive than Fe acts as anode and gets corroded whereas Fe is protected till the Zn is present.

4.4 Cathodic Protection

This is a widely used method for the prevention of corrosion. It is mostly used to prevent the pipes from rusting. It is performed by providing an electric current to the pipes (which is to be protected) from outside source. The iron object, which has to be protected, is connected with a more active metal. The iron object becomes cathode whereas the metal used for protecting becomes anode. Due to oxidation, the anode is slowly used up to its ions due to loss of electrons. The iron metal is free from rust only till the protective metal is present and only till the electrode potential ismaintained below -0.62 V. Metals often used for rusting are Mg, Zn and Al which are alsoknown as sacrificial anodes.

It is usually of two types:
(a). Sacrificial anode method: In this method, the anode corroded sacrificially to protect the material. That’swhy, it is known as sacrificial anode method. Usually zinc or magnesium is used for making galvanic anodes because they have higher oxidation potential than the steel. The schematic diagram of internal and external protection of water pipe using sacrificial anodic methods is shown in Fig. 5 (a, b).

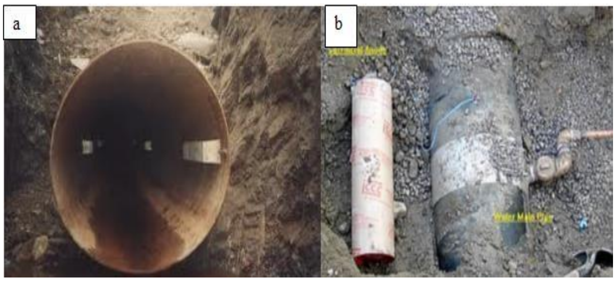

Figure 5. (a) Internal protection of water pipe-line using sacrificial anodic method (b) External protectionof water pipe-line using sacrificial anodic method

(b) Impressed current method: In Impressed current method, both the anode and the material (which is to be protected) are joined by an insulated wire internally and so the path of current is from the anode, through the electrolyte, to the material. It is much similar to the galvanic system. The onlydifference is that the galvanic system depends on the difference in oxidation potential between the anode and the material whereas in impressed current method, the external supply is provided for the current to flow.

4.5 Barrier Protection

The metal surface may be coated for protection against corrosion. Most of these coatings perform as a barrier between the metallic surface and corrosive environment and therefore, this method is called barrier protection [27]. This is one of the simplest methods to prevent corrosion. In this method, a suitable barrier is placed between the metal surface and atmosphere. Thus, the metal surface remains protected by the action of air, water and carbon dioxide and does not corrode. The barrier protection can be attained by using any of the following methods:

- By coating paints, oils or grease over the metal surface
- By coating the metal surface with non-corroding metals
- By coating the metal surface with certainchemicals

Graphene is widely used in barrier protection method because of its inert nature, unique structure and electrical properties Graphene contains carbon atoms that are strongly bonded to form a hexagonal like structure. It acts as inert under that condition also where other would undergo chemical reactions [28].

4.6 Electroplating

The Italian chemist Luigi Brugnatelli invented electroplating in 1805. After multiple attempts and failures, he successfully plated a thin layer of gold onto silver [29]. It is the method of coating one metal over another by passing electricalcurrent through a solution Fig.6. It is used for multiple purposes such as decorative purposes,appearance and protection. Chromium plating can be used to coat over the vehicle wheel rims, gas burners to resist corrosion. Nickel plating is used for decorative purposes and also for various machinery parts. For electroplating following procedure is used.

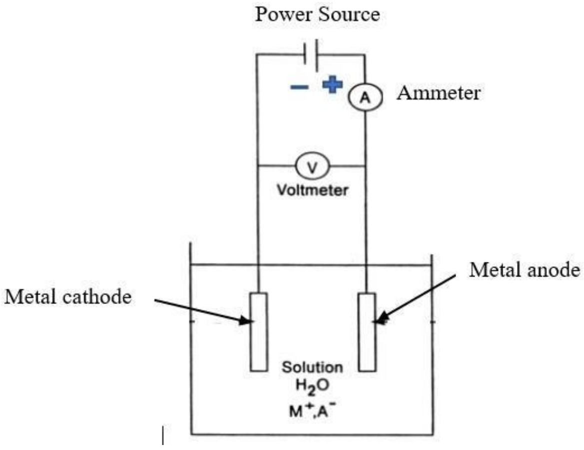

Figure.6 Electroplating Process

The foremost step is to prepare a clean work piece. This is done by dipping the work piece in various solutions such as alkaline cleaners, degreasers, etc. This helps in removal of dirt, grease and contaminants from the piece.After having a pure work piece, it is connected to the negative terminal (cathode) of the dc power supply. Themetal, which is to be plated over the work piece, is connected to the positive terminal (anode) of the dcpower supply. An ammeter is connected in series and a voltmeter is connected in parallel to the cell in order to measure the current and voltage of the cell. The work piece is then polished thoroughly. The Faraday's Law is helpful in determining the thickness of the coating. The coating quality depends onuniformity of thickness and continuity.

4.7 Zinc Galvanizing by Hot Dipping Method

It is a process in which the cleaned steel is dipped in molted zinc. Temperature is maintained at near about 445-450^{0}C, that's why it is known as hot dipping method Fig. 7. As compared to electro-plating, hot dipping method is much better and is most often used. This is so because the coating of hot dipping method provides greater corrosion protection to the metal ascompared to the electroplating [30].

The two folded protection nature of the coating is the reason for the boundless use of hot dip galvanization. This coating is formed when a ferrite substrate is immersed into molten zinc, so this coating is a mixture of different stages, which are formed due to reactions between iron and zinc [31]. During hot dip galvanization, the steel is immersed in a container which must contain a minimum of 98% pure molten zinc [32]. The zinc metal then reacts with the iron on the steel surface to form a zinc/iron intermetallic alloy. The excessive zinc is removed by the process of centrifuging.

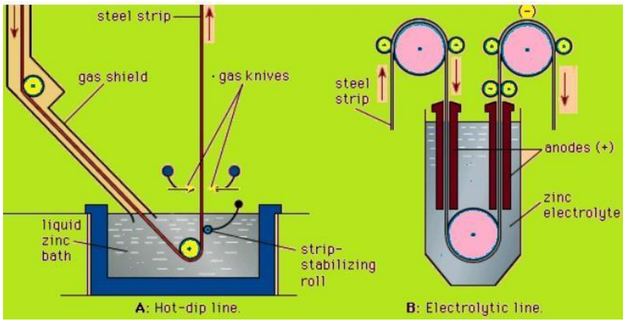

Figure 7. Galvanization of steel by hot dipping and electroplating

V CONCLUSION

Corrosion is the natural phenomena that cause degradation and failure of component. Although, the general or uniform attack leads to maximum destruction of metal component. However, other types of corrosion such as intergranular or stress corrosion are very destructive for industrial components. All types of corrosion have impact on environment, economy and human life. It has been concluded that timely preventive measures could resist corrosion.

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