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## Overview of Electrochemical Corrosion at Pipe Supports Causes and Solution

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**Abstract-** The paper discusses inspection strategy and provides a simplified visual screening method that has proven useful in mechanical integrity programs also the various corrosion mechanisms that occur at pipe supports. Rusting of steel and cast iron in water, including humid air, as occurs with domestic and industrial water tanks and supply piping, automobiles, and exposed steel structures.

**Keywords:** Corrosion, Thermo-plastic, Environment

### I. INTRODUCTION

The need to control corrosion almost always reduces to considerations of safety and economics. Machines, equipment, and functional products may fail due to corrosion in such a manner as to result in personal injury. Because the choice of materials, enforcement of manufacturing procedures, and control of products to minimize personal injury all involve economic considerations, implementation of safety measures not only involves humanitarian concerns but also economics. With all economic decisions, the basis for action is a compromise between the benefits generated by a certain level of corrosion control versus the costs that would result if that level of control were not maintained. Corrosion at pipe supports is one of the leading causes of process piping failure. This paper will discuss the various corrosion mechanisms that occur at pipe supports. A proven method of prevention with a 15-year experience will be presented. The paper also discusses inspection strategy and provides a simplified visual screening method that has proven useful in mechanical integrity programs.

The internal wall of the steel pipe exposed to aqueous environment (flow water) usually suffers more severe corrosion (so called internal corrosion) than the external wall exposed to indoor conditions (Wang et al., 2012). Many water distribution systems begin to experience pinhole leaks caused by pitting corrosion on the internal surfaces of the piping. Corrosion of zinc in flow water is a complex process controlled largely by water chemistry and temperature. Relatively small differences in water chemistry can produce relatively substantial changes in corrosion products and rate. Polymeric and ceramic materials generally do not support electron conduction and hence corrode by either direct chemical or physical mechanisms. Chemical attack of polymers breaks bonds responsible for the properties of these materials, resulting in changes of molecular structure, possible transfer of material to the environment, and degradation of properties. In the case of chemical attack of ceramic materials, the composition of the environment may cause the ceramic or components in the ceramic to either become soluble or to be changed into soluble corrosion products. An example is the attack of sulphurous and sulphuric acid on limestone. Corrosion by direct chemical attack often results in the material being transported into the environment-polymers in certain organic solvents or metals in liquid metals. Direct physical attack often is the result of the mechanical action of the environment, which can remove protective films or actually disintegrate the material by intense local forces. Thus, cavitation corrosion results from the forces of collapsing vapour bubbles in a liquid impinging on the surface of the material. If the environment contains suspended matter, abrasive wear may cause a form of failure classified as erosion-

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corrosion. In the present treatment, the fundamental mechanisms involved in aqueous electrochemical corrosion of metals and alloys and the effects of direct chemical and physical processes will be emphasized.

## II. Electrochemical Corrosion- Causes and Variables

To develop qualitatively the major phenomena involved. The following sections review several general types of metal/corrosive-environment combinations, the chemical reactions involved, idealised mechanisms for the transfer of metal ions to the environment, and the electrochemical processes occurring at the interface between the metal and the aqueous environment.

Thus, the metal passes from the metallic state to ions of valence  $m$  in solution with the evolution of hydrogen. The reaction is considered to be directly with hydrogen ions in acid solution and progressively with water molecules as the pH increases to neutral and alkaline conditions. Two processes are involved in the reaction, with each involving a change in charge:  $M \rightarrow M^{m+}$  and  $mH^+ \rightarrow m/2 H_2$  (in acid solution). The changes in charge are accomplished by electron transfer from  $M$  to  $H^+$ . Because the metallic phase is an electron conductor, it supports the electron transfer, allowing the two processes to occur at separate sites on the metal surface. In limiting cases, these processes occur within a few atom diameters on the surface with the sites constantly changing with time, thus producing uniform corrosion. Otherwise, the corrosion is non-uniform. Uniform corrosion supported by pH is represented schematically in Fig. 1.1. In this example, oxygen is excluded by a nitrogen gas purge and over blanket.

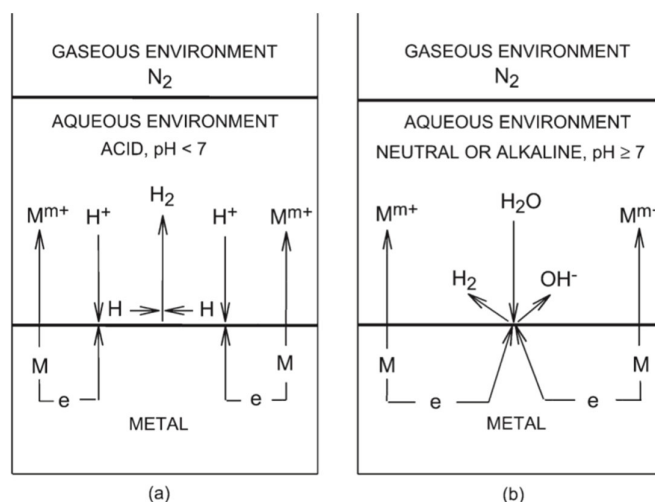


Fig. 1.1 Uniform corrosion supported by controlled pH (oxygen excluded, deaerated). (a) Acid,  $pH < 7$ . (b) Neutral or alkaline,  $pH \geq 7$

The basic corrosion process is represented in Fig. 1.3. In the simplest case, the corrosion reaction is the transfer of metal atoms from the solid to the solution where they exist as ions (i.e.,  $M \rightarrow M^{m+} + me$ ). Because there is a loss of electrons from the metal atom in this transfer, the metal has undergone oxidation. The oxidation is sustained by the consumption of the electrons by another reaction, generalized in this case as  $X^{x+} + xe \rightarrow X$ . The oxidation occurs at a site on the metal surface referred to as the anodic reaction site and is the location of the loss of metal by corrosion. The electrons are picked up at a cathodic reaction site. The areas over which the anodic and cathodic reactions occur individually vary greatly and may extend from positions a few atom distances apart on the surfaces to microscopic areas, and even to macroscopic areas extending to hundreds of square meters. When the sites are so close together that they cannot be distinguished, and when the sites undergo changes and reversals with time, uniform corrosion is said to occur. With resolvable areas and/or with anodic and cathodic sites that do not change with time, the corrosion will be largely identified by the anode areas only, and localized corrosion is said to occur. Obviously, there are large differences in interpretation between uniform corrosion and localized corrosion. It frequently depends on the scale of observation, or the magnitude of the difference in corrosion rate between areas that are predominantly anodic and areas that are predominantly cathodic because both reactions often occur over the entire surface. If the two processes are occurring on a micro scale, then the anodic and cathodic areas are considered the same and equal to the total area,  $A$ . If the two processes are occurring over separate areas, an anodic reaction area,  $A_a$ , is distinguished from a cathodic reaction area,  $A_c$ .

To show that these reactions actually proceed to the right (i.e., to show that corrosion actually occurs), it is necessary to calculate the Gibbs free-energy change and find that it is negative. To make this calculation requires quantitative information on the activity or

effective concentration of iron ions ( $a_{\text{Fe}^{2+}}$ ) in the solution, the acidity, or pH, and the concentration of dissolved oxygen that is related to the partial pressure of the oxygen,  $P_{\text{O}_2}$ , in contact with the solution. It is demonstrated in the following chapter that the change in the Gibbs free energy is negative for these reactions at all values of pH, and hence, iron tends to corrode at all pH values. The rate of corrosion, however, depends on factors influencing the kinetic mechanisms of the several processes involved in the transport of ions from metal to solution and in the supporting cathodic reactions. In addition to the species in solution relating directly to the above reactions ( $\text{Fe}^{2+}$ ,  $\text{H}^+$ , and  $\text{O}_2$ ), other species in solution can affect both the tendency to corrode in terms of thermodynamic driving forces and the kinetics of the several steps involved. For example, complexing agents reacting with metal ions in solution reduce the concentration of free metal ions and make it more favorable thermodynamically for metal ions to pass into solution, thereby increasing the corrosion rate. Conversely, if species in solution can form precipitates with metal ions and form protective diffusion barriers at the interface, corrosion rates may be decreased significantly.

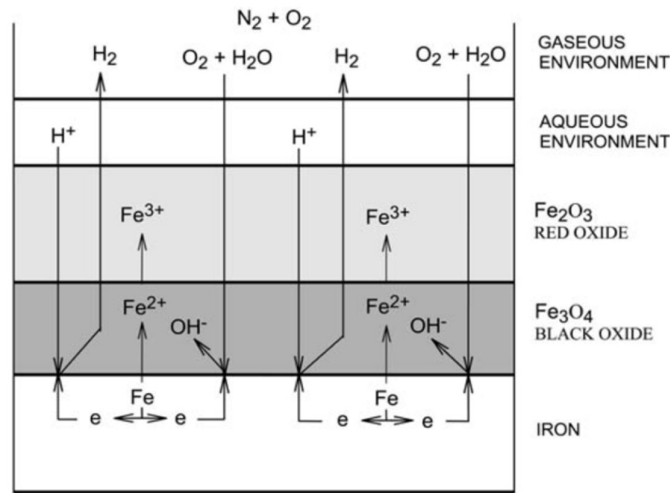


Fig. 1.2 Uniform corrosion with solid corrosion product deposit. Details of the formation of oxide species are not considered at this point.

A simple example demonstrates the impact of corrosion in everyday life on human health. This example was contributed by Prof. Lucien Bonou from Burkina Faso, Africa, at the WCO workshop during the 17<sup>th</sup> International Corrosion Congress in September 2008. He examined the metal composition of cooking pots produced in his country from recycled aluminium alloys. He found that the material consisted of 32% iron and 10% copper. In addition, considerable amounts of other heavy metals were present (10% zinc, 2.5% lead, and 0.12% cadmium).



Fig 1.3: Corrosion-susceptible cooking pots from scrap containing aluminium alloys.

Establishing a healthy environment and guaranteeing sound nutrition in every country is a huge, so far unsolved problem. The most important component to this is water, its abundant availability, and its healthy distribution. Water is a basic factor in nutrition. Therefore, distribution of water with defined purity and hygienic properties is an essential contribution to health and nutrition worldwide.



Fig 1.4: Aluminum containing scrap used for cooking pots.

### III. Deterioration of Steel Pipes in Water Distribution System

It is a common misconception that metal-to-metal contact coupled with water entrapment is the major cause of corrosion at these points. This is not the case; the sequence of events is as follows. Water is trapped the very nature of the supports allows water to be held in contact with the painted pipe surface as well as the paint on the support element. The paint system fails even if the paint on the pipe and support beam is perfect; the paint system is designed for atmospheric exposure and not immersion service. The longer the paint surface is continuously exposed to water, the more it softens. As the pipe softens it is inevitable that the steel substrate will be directly exposed to the water. Corrosion is initiated. The small area of steel now exposed to oxygenated water (often with high chlorides) starts to corrode. Corrosion undercuts paint film. The initial corrosion soon undercuts and spreads. Soon the whole support area is bare steel. Crevice corrosion starts. From this point on the crevice corrosion driven by differential aeration takes over from the general corrosion mechanism that initiated the corrosion. As corrosion products build they further restrict oxygen diffusion and the oxygen concentration gradient gets steeper. Pitting now becomes the main problem with corrosion rates acceleration by an order of magnitude. Pipe fails if the inspection program is not set up to detect this mostly concealed wall loss the pipe will fail.

The important features of one successful solution that is in widespread use throughout the offshore community are as follows:

1. The crevices at the pipe surface and the ability to trap and hold water in contact with the pipe surface must be eliminated.
2. As a secondary concern, metal - to - metal contact should be eliminated.
3. The solution should allow easy maintenance and inspection of the pipe at the support point.
4. The system must provide complete support to the piping system.
5. The system will ideally be non size- specific.
6. Must be applicable to new construction and retrofits, and should require no hot work to install.
7. Must be cost effective.

The half round, high strength thermo-plastic rod, meets all of the above requirements. The half round configuration minimizes the crevice at the pipe and allows no water accumulation. The standoff provided allows easy inspection and maintenance at the support.

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The metal-to-metal contact is eliminated, and if used with an insulated bolt, the pipe can be totally isolated from the support structure. The low cost material has been selected and configured to optimize compressive strength while exhibiting very low creep, excellent u.v. stability is also a material feature. The material can be deployed as a continuous dressing to the top of a pipe support beam (Fig.1.5), or can be integrated with a stabilizing U-bolt. Either way allows cold work installation for new construction or retrofit applications.

When using U-bolts it is important to apply a polyolefin sleeve over the shank of the bolt. This reduces the risk of cracking the paint film around the pipe as the bolt is torqued down. The olefins provide the right combination of hardness and durability to protect the pipe paint but avoid setting up a capillary crevice around the circumference of the pipe.



Fig 1.5 U-Bolt Stabilized Beam Supports.

#### IV. The Premature Deterioration of Zinc Coated Steel Pipes

The pipe samples which forms a part of two hot water distribution systems exposed approximately: first one for 2 years (region I) and second one for 5 years (region II) to flow water delivered by two public supplied sources in the city has been considered for the study. After this short service life galvanized pipes experiencing pitting failures, as it shown in Figure 1 (after 2 years of service) and Figure 2 (after 5 years of service).

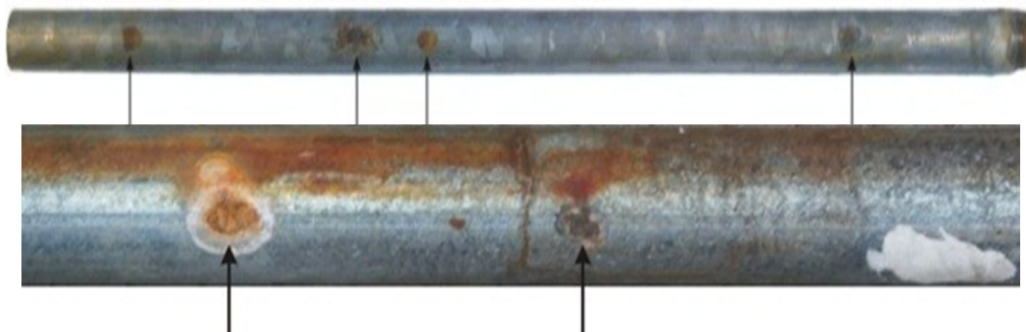


Fig 1.6. Magnified Image of pitting perforation along the weld seam, 5/4" Pipe after 5 years of Service.

Installation Technology Research & Development Centre COBRTI Instal, there are conditions under which galvanised steel pipes will sustain corrosion damage. One of the main factors influencing corrosion of zinc-coated pipes is the water composition. The influence of chloride, nitrate and sulphate ions on pitting corrosion is determined by the so called concentration ratio S1 calculated from the equation.

According to EN 12502 (Euro Norm, 2005) pitting corrosion of zinc-coated steel pipes is extremely unlikely with S1 values below 0.5 and very likely with S1 values above 3.

Elaborated by the Polish Installation Technology Research & Development Centre COBRTI Instal recommendations for materials selection (COBRTI, 2002) provide a list of region in Poland in which water chemistry (including concentration ratio S1) may cause premature deterioration of piping in water distribution system, depending of used materials (iron, steel, copper, plastics and related).

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Both studied in present work hot water distribution systems use water supplied from two different sources in two separate distribution networks listed in work (COBRTI, 2002) as sources of high concentration ratio S1 where use of zinc-coated steel pipes is strongly not recommended. Above mentioned recommendations are based on long term chemical analyses of distributed water.

Similar long term study of water chemistry was performed for the two transit lines carrying water to above mentioned region I (Niedziolek et al., 2011). It was stated, that this water is characterised by low buffering capacity, which adversely affect its corrosion properties. UN favourable in this respect was the Ryzner's index value (variations from 7.9 to 9.1 in the four year period 1998 -2001).

The premature corrosion failure of zinc-coated steel pipes in both examined hot water distribution systems was due to the loss of the internal protective zinc layer as most probably the result of inadequate water chemistry, which will be discussed later. An example of the break in zinc coating on the inner pipe surface which promotes further pit initiation and growth is presented in figure.

## V. Conclusion

Thus corrosion becomes an important phenomenon to be considered while any mechanical setup or fluid transmission is constructed. It can be initially prevented through pure casting of materials that constitute the mechanical elements. Even the pure materials is capable of being corroded after the construction which can be prevented at feeble degree through normal techniques such as painting, coating of non corrosive metals and electrochemical techniques.

While cataloging the extent and severity of the problem, it was necessary to develop inspection strategies that would allow high risk items to be addressed before failure. In recent years improvements in guided wave ultrasonic inspection have allowed a more quantitative approach to this type of inspection, but this is a costly inspection and it is relatively time consuming. It was necessary to have a visual guideline that would help to screen the supports requiring further inspection.

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