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Chapter 2

Corrosion Control in Industry

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Additional information is available at the end of the chapter

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1. Introduction

The economic development of any region, state or country, depends not only on its natural resources and productive activities, but also on the infrastructure that account for the exploitation, processing and marketing of goods. Irrigation systems, roads, bridges, airports, maritime, land and air transport, school buildings, offices and housing, industrial installations are affected by corrosion and therefore susceptible to deterioration and degradation processes.

Corrosion is a worldwide crucial problem that strongly affects natural and industrial environments. Today, it is generally accepted that corrosion and pollution are interrelated harmful processes since many pollutants accelerate corrosion and corrosion products such as rust, also pollute water bodies. Both are pernicious processes that impair the quality of the environment, the efficiency of the industry and the durability of the infrastructure assets. Therefore, it is essential to develop and apply corrosion engineering control methods and techniques.

Other critical problems, that impact on infrastructure and industry are climate change, global warming and greenhouse emissions, all interrelated phenomena.

This chapter presents important aspects of corrosion in industrial infrastructure, its causes, impacts, control, protection and prevention methods.

2. Materials in industry

Metallic materials play a key role in the development of a country and its sustained growth in the context of the global economy. Table 1 shows a classification and the properties of dif-

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ferent types of materials used in the industry. During the course of the metal production it undergoes various types of processes: mining of minerals, manufacturing and application and generation of gases, liquids or solids that are released into the environment. In the industrial development, production and use of materials in general, economic cycles are due to take effect that influence the environment (Raichev et al., 2010). The selection of a predominant group of materials depends on the particular industries; they determine to a greater or lesser extent the pattern of consumption of a given product, inducing the market to adapt itself to this new reality. The materials industry follows two general strategies: research the materials and the available technology recommended for their. Recycled materials typically require less capital and energy consumption, but need more manpower, for primary processing. Also, the costs of pollution control are lower than those required for primary processing of minerals. Recycling becomes more intense, as economies tend to be more sophisticated, since viable quantities of recycled material must be available for reuse (Garcia, R., et al, 2012, Lopez, G. 2011, Schorr, M., 2010).

Material	Main properties	Uses
Metals and alloys (carbon and stainless steels, non ferrous alloys)	Mechanical resistance hardness	Cars, aircraft, tanks, infrastructure reinforcement.
Plastics (Synthetic polymers, rubbers)	Low density and corrosion resistance	Process components, tubes, vessels, coatings, paints.
Ceramics (Metallic carbides, silica, glass, alumina)	High hardness, high temperature and corrosion resistance	Cutting tools, motor components, refractory bricks, ovens, etc.
Composites (glass and carbon fibers reinforced plastics, plastic matrixes reinforced with metallic particles)	Light weight, high strength and hardness.	Car bodies, aircraft components, vessels, construction.

Table 1. Materials in industry: Types, main properties and uses.

In the production of a material waste is generated: for example, parts of material that was left aside, through the production steps. There are called effluent, which consist of waste that comes from the processes linked to the technology involved in each step of production, although not necessarily with the main material. Industrial processes for the recovery of ore from the mine to produce a metal, are related to technological development and therefore varies from one country to another, including regulatory laws, financial aspects etc.. Therefore, the environmental impacts vary widely. A low grade or poor quality of the ore, with low metal content, increase the cost of recovery, requiring large amounts of mineral raw material and energy invested for the recovery of small amounts of metal. Also important is the feasibility of the mineral that can be worked out e.g., the cost of physical removal of rock, accessibility to the mines, thickness and regularity of the ore zone, and its hardness. Figure 1, shows the material cycle, which involves processes from raw material, extraction from natural sources, processing

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and conversion into industrial materials, their processing and application, the deterioration rate effects, its mechanical properties, environmental behavior, corrosion, disposal and possible recovery of some of these through the use of recycling methods.

There are many examples of recovery of metals, which could help to describe step by step the various interactions with the environment itself. A mineral submitted to a production process will impact the environment, during four steps: extraction, processing, fabrication and manufacturing, of goods as seen in the cycle of materials. (Figure 1)

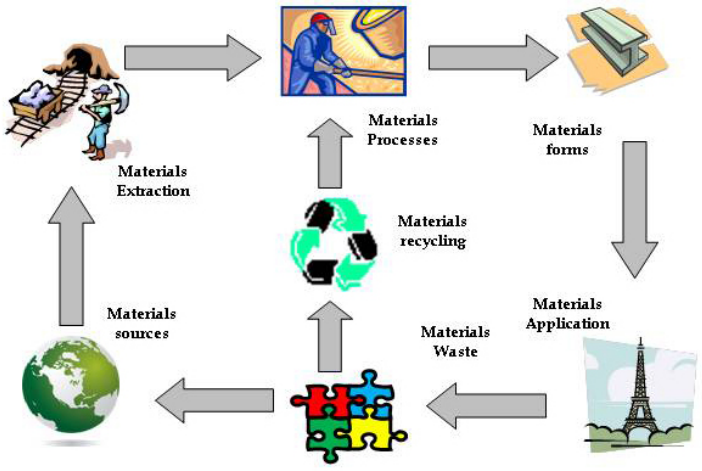


Figure 1. Materials production and use cycle.

In the mineral extraction step, the effluents of N, C, S, NO_x, SO_x and CO_x, from machinery and equipment, operation process water, particulate matter and ground movement in landfills.

The processing stage, chemical operations or extractive metallurgy for converting the concentrate into metal apply selected technologies. The effluents are gases such as SO_2, NO_2 and CO_2, water contaminated with heavy metals, and hazard sediments.

In the manufacturing step the material undergoes operations that transform it into rods, bars, sheets; losses are scrap metal, such as cuts, burrs, mill scale, which recycled with no net loss of metal. In the manufacturing stage the metal is formed by stamping, machining and forging.

Focus on good operations management involves control of air emissions, water management and treatment, solid waste disposal and good land use, will greatly help to maintain a good balance with the environment. It is also necessary to analyze the production area to identify what improvements or measures should be implemented. The role of hydrometalurgist is particularly important and so he is responsible for the design of environmentally friendly processes in each of his steps, to promote sustainable production.

2.1 Processes of materials biodeterioration in industrial systems

In addition to the common processes of deterioration of materials by chemical reactions and mechanical fracture, there are others who are concerned with the participation of various types of microorganisms that adhere in colonies or develop on their surfaces.

Biocorrosion and biodeterioration of metallic materials and nonmetallic materials are two important processes that cause serious problems to the infrastructure of various industrial systems. Generally, microorganisms do not deteriorate or corrode metals directly, but modify the conditions of interface material / environment and surroundings, favoring the degradation of these materials in such a way that induce or influence the development process.

Biofouling is a common term that indicates the presence of microbiological growth on the surfaces of structures built of different materials favoring the formation of biofilms with the colonies of various types of microorganisms.

In the case of metal, biocorrosion occurs due to corrosion electrochemical processes and biological agents due to the action of microorganisms and / or bacteria present in the system. The knowledge of these biological processes and their effects is necessary in order to establish preventive measures and control measures in industrial systems.

An industrial plant containing several biocorrosion environments is a potential risk:

In a heat exchangers system, usually dust accumulates biological waste; biocorrosion could occur, leading to corrosion film formation on walls surface. Therefore, it will be energy loss by increasing the resistance to fluid flow and heat transfer. Loss by evaporation of water favors the increase of the concentration of nutrients, the residence time, the water temperature and the surface / volume ratio, which leads to higher rate of microbial growth (Stoytcheva et al., 2010, Carrillo M. et al., 2010).

Until the early 80's of the twentieth century, we used mixtures of anodic and cathodic inhibitors, such as chromium, zinc and phosphates, to lessen the effects of corrosion in water systems. In some cases we added a polymer, as is still done to date, to avoid or eliminate the problems of fouling on the metal walls. On the other hand, to prevent microbiological growth, we added biocides such as chlorine and quaternary ammonium compounds under acidic conditions.

In the early 90's, the strategies for industrial water treatment changed because of pressure from laws inforcing for the preservation of the environment. Chromates and acid pH values are replaced by the use of organic phosphonates as corrosion inhibitors, while for the control of fouling polycarboxylate type polymers are used. However, this change brought about an increase in the amount of suspended solids, a greater number and variety of microorganisms and therefore a greater amount of inorganic deposits on the heat exchangers walls.

2.2. Biodeterioration of metallic and nonmetallic materials

The metal nature has an effect on the distribution and development of microbial films on its surface. These films influence on the wear and corrosion of the metal substrate. The lack of

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homogeneity in the biofilm is a precursor of differential aeration processes with formation of differential cell concentration, for example, stainless steels (SS) and nickel-copper (Ni-Cu) alloys in seawater. The oxides passive films or hydrated hydroxides (corrosion products) are a good place for the establishment and growth of bacteria, especially when these products are at a physiological pH values (pH ≈ 7.4)

- Carbon Steel (CS)

CS are very active metals in aggressive media, such as seawater. In this case, the action of microorganisms involves the dissolution of films of corrosion products, by processes of oxidation and reduction. This creates new metal active areas, exposed to the aggressive medium and suffers corrosion processes. In the case of sulfate-reducing bacteria (SRB), the species generated by their metabolism (sulfides) are corrosive to the metal. Figure 2 shows the final state pitting outside a CS pipe, which was affected by microbial growth inside, prompting a process of microbial corrosion with not uniform localized attack.

- Stainless steel

The presence of chromium and molybdenum as alloying elements, enable passive behavior of stainless steels in different environments. However, the passive surface of these SS provides an ideal location for microbial adhesion and therefore are susceptible to corrosion pitting, crevice corrosion under stress or in solutions containing chlorides, as sea water.



Figure 2. External pitting caused by biocorrosion on the internal surface of a carbon steel pipe in a fire extinguisher system.

In marine environments, the generation of peroxides during bacterial metabolism causes an ennoblement of the pitting potential of SS, thus promoting corrosion. Obviously, not all SS have the same behavior, but in general they tend to deteriorated in the presence of colonies of microorganisms.

- Copper and nickel alloys

Alloys of Cu with Zn, Sn and Al, brasses, bronzes, aluminum bronzes; also the nickel alloys: Monel, Hastelloy, nickel superalloys: Ni-Mo, Ni-Cr-Mo, Ni-Cr-Fe- Mo; the traditional nickel alloys: Ni-Cr-Fe, Ni-Fe-Cr, Fe-Ni-Cr-Mo), and the Cu-ni alloys CuNi\70/30, CuNi\90/10, have shown great corrosion resistance in different environments, so they have found a wide use in different industries and environments. However, despite these skills, there are reports that these alloys are colonized by bacteria after several months of exposure in seawater (Acuña, N. et al., 2004).

- Aluminum and its alloys

Al is an active metal which is passivated rapidly in some neutral and acid media, thus offering a good resistance to corrosion. Al alloys with copper, magnesium and zinc, are widely used in the aviation industry. However, there have been cases of biocorrosion on fuel tanks of jet aircraft made of Al alloys by microbial contaminants in turbo combustibles. The presence of water (moisture), even in minimal amounts, allows growth of microorganisms (typically fungi), when these are able to utilize hydrocarbons as a carbon source.

- Titanium

Ti is considered as the most resistant metal to biocorrosion, according to the results of tests carried in different conditions, due to its passive behavior that is reinforced in the presence of oxidizing agents. This is the reason why Ti is the material of choice, for example, for the manufacture of tubes in cooling systems that use seawater.

- Nonmetallic materials

Non-metallic materials such as fiberglass reinforced polyester (FGRP), concrete and wood, are also affected by biodeterioration processes in the presence of microorganisms

In the case of FGRP, bacteria and algae are able to use the polyester matrix as a carbon source, consuming and considerably reducing the mechanical strength of composite material, ultimately causing its failure. This is easily observable in screens of this material in cooling towers or tanks containing fresh water or salt water. Wood suffers biodeterioration by the presence of fungi in moist environments that promote the delignification of this material (Valdez B., et al., 1996, 1999, 2008).

2.3. Facing the problems of biodeterioration

The inevitable presence of microorganisms in the feed water causes a sequence of biofouling, biocorrosion and biodeterioration of the materials component of the structures. This sequence depends on the degree of microbial contamination and the system operating characteristics.

The most common methods of controlling these problems involve the application of continuous or metered biocides such as chlorine. Currently, we use substances more compatible with the environment, since the use of chlorine is limited to certain concentrations. Such is

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the case of ozone, which is also ascribed with passivating effects on certain metals and alloys commonly applied in industry, and also in antifouling action.

In order to tackle a biodeterioration problem it is required a prior analysis of the problem, to know when conditions are suitable for the development of this process. In industrial systems we need to know some parameters: temperature, pH, nutrients; carbon, phosphorus, nitrogen, sulfate ion levels and flow rates. The places where we find biodeterioration are: biofouling deposits, under any deposit, zones of localized metal corrosion. to check their presence it is necessary to utilize sampling techniques, isolation and identification of microorganisms. It is interesting to note that there are commercial devices for in situ measurements that are practical and useful for the plant engineer.

3. Corrosion in the electronics industry

Corrosion of device components, manufactured by the electronics industry, is a problem that has occurred during a long time. Often, especially corrosion of one or more of the metallic elements of an electronic component is the primary cause of failure in various electronic equipments. The high density of components required to reduce the size of electronic equipment, also for a better signal processing, leads to the generation of enclosed corrosion between thin metal sections. Furthermore, when electronic devices are in more severe environments such as tropical, subtropical, contaminated deserts, etc., they have high failure rates. Problems, due to the aggressiveness of the medium in electronic equipment for military use, have also occurred in aircraft and submarine guidance systems. Another common problem is corrosion damage suffered by components music players, when exposed to humid environments contaminated with chlorides, for example, during transport by ship, from the manufacture location to the consumer place. Thin layers of corrosion products on the surface of the metal component change their electrical characteristics: resistance, capacity and lead to partial or total failure of the electronic system. There are reported cases where small amounts of moisture have caused corrosion in tablets with printed circuits, nichrome resistors, fittings, electrical connectors and a wide range of components, and micro-electronic components, which have been coated with metallic films (Valdez B. et al., 2006, G. Lopez et. al., 2007)

Corrosion of metal components in the electronics industry may occur at different stages: during manufacture, storage, shipping and service. The main factors in the onset of corrosion and subsequent development are moisture and corrosive pollutants, such as chlorides, fluorides, sulfides and nitrogen compounds, organic solvent vapors, emanating from the resins used as label, or coatings formed during the curing process and packaging of microcircuits.

The sources providing aggressive pollutants are diverse, from flux residues used for welding processes, waste and vapors from electrolytic baths, arising volatile organic adhesives, plastics and acidification of their environment. Assays in artificial atmosphere, which simulates an indoor environment of an electronic plant have shown that the surface of the silver undergoes browning or tarnishing and the formation of dendrite whiskers due to corrosion (Figure 3).

The elemental chemical analysis of the surface (EDX - Scattered Electron Spectroscopy and XRD - X-rays) shows that the corrosion product formed on the silver surface is silver sulfide (Ag_2S), due to the action of pollutant gases such as SO_2 and H_2S present in a humid environment (Figure 4). Moreover, the micrograph of the silver surface (SEM) shows a dendritic growth of corrosion products, characteristic for silver components.

The design of electronics equipment requires a great variety of different metals, due to their different physical and electrical features. Metals and alloys used in the electronics industry are:

- Gold (Au) coating and / or foil in electrical connectors, printed circuits, hybrid and miniature circuits.;
- Silver (Ag) for protective coating in contact relays, cables, EMI gaskets, etc..;
- Magnesium (Mg) alloys for radar antenna dishes and light structures, chassis brackets, etc..;
- Iron (Fe), steel and ferroalloys for guide components, magnetic shielding, magnetic coatings memory disks, processors, certain structures, etc..;
- Aluminum (Al) alloys for armor equipment, chassis, mounting frames, brackets, trusses, etc..;
- Copper and its alloys for cables, tablets printed circuit terminals, nuts and bolts, RF packaging, etc..;
- Cadmium (Cd) for sacrificial protective coating on iron and safe electrical connectors;
- Nickel (Ni) coating for layers such as barrier between copper and gold electrical contacts, corrosion protection, electromagnetic interference applications and compatibility of dissimilar material joints;
- Tin (Sn) coating for corrosion protection of welding; for compatibility between dissimilar metals, electrical connectors, RF shielding, filters, automatic switching mechanisms;
- Welding and weld coatings for binding, weldability, and corrosion protection.

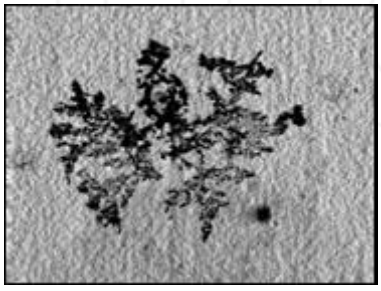


Figure 3. Silver sulfide whiskers corrosion products on silver exposed in an electronics plant atmosphere.

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Many of these metals are in contact with each other, so that in the presence of moisture, galvanic corrosion / bimetallic corrosion occurs. When using similar metals, due to design the following requirements must be taken into account.

- Designing the contact of different metals such that the area of the more noble cathodic metal should be appreciably smaller than the area of the more active anodic metal. The area of the cathode can be decreased by applying paint or coating.
- Coating the contact area of a metal with a compatible metal.
- Interpose between dissimilar metals in a metal compatible packaging.
- Sealing interfaces to prevent ingress of moisture.
- Set the electronic device in a hermetically sealed arrangement.

Other corrosion problems can occur due to the characteristics of electronic components such as electromagnetic interference, electromagnetic pulse, flux residues, finishes and materials component tips, organic products that are used for various purposes and emitting gases during curing, whiskers, embrittlement inter-metallic electrical contacts.

Metal components may corrode during manufacture and storage prior to assembly, needing protection against corrosion. In plants and warehouses, air conditioning systems must operate efficiently, removing moisture and suspended particulate matter. Filters and traps should be cleaned and replaced regularly. For closed containers, we recommend the installation of dryers with visual indicators, and the use of volatile vapor phase corrosion inhibitors. In the case of sealed black boxes, the temperature inside these drops should never be below the dew point (Veleva L. et al., 2008, Vargas L. et al., 2009, Lopez G. et al., 2010).

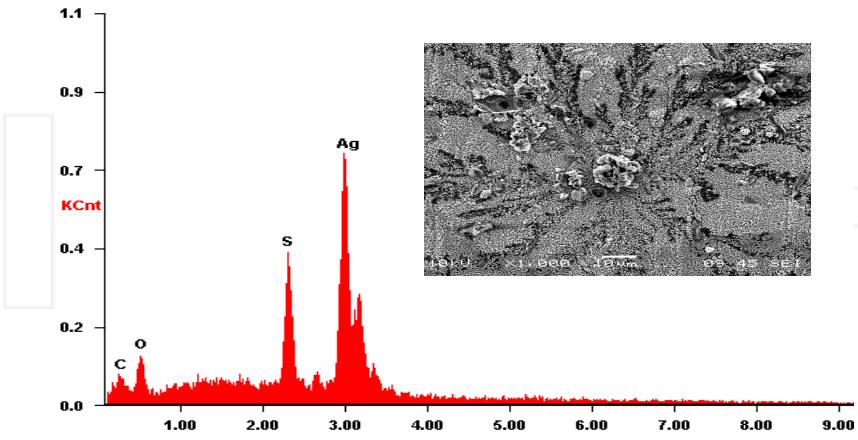


Figure 4. Scanning Electron Microscopy and EDS analysis of silver corrosion products at indoor conditions of an electronics plant contaminated with H_2S.

4. Corrosion in water

Abundant water sources are essential to a country's industrial development. Large quantities of this precious liquid are required for cooling products, machinery and equipment, to feed boilers, meet health needs and provide drinking water to humans. Estimates of water consumption for each country are different and depend on the degree of industrial development thereof. In first world countries like the United States, these intakes are as high as several hundred billion liters per day. These countries have implemented water reuse systems with certain efficiency due to the application of appropriate treatment for purification. Water, a natural electrolyte is an aggressive environment for many metals / alloys, so that they may suffer from corrosion, whose nature is electrochemical.

As raw water or fresh water we mean natural water from direct sources such as rivers, lakes, wells or springs. Water has several unique properties and one of these is its ability to dissolve to some degree the substances found in the earth's crust and atmosphere allowing the water to contain a certain amount of impurities, which causes problems of scale deposition on the metal surface, e.g. in pipelines, boiler tubes and all kinds of surfaces that are in contact with water (Valdez, B. et al., 1999, 2010).

Oxygen is the main gas dissolved in water, it is also responsible for the costly replacement of piping and equipment due to its corrosive attack on metals in contact with dissolved oxygen (DO). The origin of all sources of water is the moisture that has evaporated from the land masses and oceans, then precipitated from the atmosphere. Depending on weather conditions, water may fall as rain, snow, dew, or hail. Falling water comes into contact with gases and particulate matter in the form of dust, smoke and industrial fumes and volcanic emissions present in the atmosphere.

The concentrations of several substances in water in dissolved, colloidal or suspended form are low but vary considerably. A water hardness value greater than 400 parts per million (ppm) of calcium carbonate, for example, is sometimes tolerated in the public supply, but 1 ppm of dissolved iron should be unacceptable. In treated water for high pressure boiler or where radiation effects are important, as in nuclear reactors, impurities are measured in very small amounts such as parts per billion (ppb).

In the case of drinking water the main concern are detailed physicochemical analysis, to find contamination, and biological assays to detect bacterial load. For industrial water supplies it is of interest the analysis of minerals in particular salts. The main constituents of water are classified as follows:

- Dissolved gases: oxygen, nitrogen, carbon dioxide, ammonia and sulfide gases;
- Minerals: calcium, sodium (chloride, sulfate, nitrate, bicarbonate, etc.), Salts of heavy metals and silica;
- Organic matter: plant and animal matter, oil, agricultural waste, household and synthetic detergents;

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- Microbiological organisms: include various types of algae, slime forming bacteria and fungi.

The pH of natural waters typically lies within the range of 4.5 to 8.5; at higher pH values, there is the possibility that the corrosion of steel can be suppressed by the metal passivation. For example, Cu is greatly affected by the pH value in acidic water and undergoes a slight corrosion in water releasing small amounts of Cu in the form of ions, so that it's corroded surface because green stained clothing and sanitary ware. Moreover, deposition of the Cu ions on surfaces of aluminum or galvanized zinc corrosion cells leads to new bimetallic contact, which cause severe corrosion in metals.

The mineral water saturation produces a greater possibility of fouling on the metal walls, due to the ease with which the insoluble salts (carbonates) can be precipitated. To control this effect it is necessary to know and use the Saturation Indices. Water saturation refers to the solubility product of a compound and is defined as the ratio of the ion activity and the solubility product. For example, water is saturated with calcium carbonate when it is no more possible to dissolve the salt in water and then it begins to precipitate as scale. In fact, it is called supersaturated when carbonate precipitation occurs on standing the solution. The most common parameters that must be known to characterize the water corrosivity, be it raw or treated, for operation in an industrial facility are shown in Table 2.

Water properties	Corrosivity
Hardness	Source of scaling that promotes corrosion
Alkalinity	Produces foam and motion of solids
pH	Corrosion depends on its value
Sulphates	Produces scaling
Chloride	Increases water corrosivity
Silica	Generates scaling in hot water. Condensers and steam turbines
Total Dissolved Solids (TDS)	Increases electrical conductivity and corrosivity
Temperature	Elevated temperatures increases corrosion rates

Table 2. Water properties and corrosivity.

There six formulas to calculate Saturation Indices and embedding: Langelier index (LSI), Ryznar stability index, Puckorious index of scaling, Larson-Shold index, index of Stiff- Davis and Oddo-Tomson index. There is some controversy and concern for the correlation of these indices with the corrosivity of the waters, particularly regarding the Langelier (LSI).

A LSI saturation index with value "0" indicates that the water is balanced and will not be fouling, while the positive value indicates that the water may be fouling (Table 3). The negative value of the LSI suggests that water is corrosive and can damage the metal installation, increasing the content of metallic ions in water. While some sectors of the water manage-

ment industry uses the values of the indices as a measure of the corrosivity of the water. Corrosion specialists are alerted and are very wary of issuing an opinion, or extrapolate the use of indices to measure the corrosivity of the environment.

Langelier Index	Water corrosivity and scaling
-5.0	Severe corrosion
-4.0 to -2.0	Moderate corrosion
-1.0 to -0.5	Light corrosion
0.0	No corrosion / no scale (balance)
0.5 to 2.0	Light incrustation
3.0	Moderate incrustation
4.0 to 5.0	Severe incrustation

Table 3. Langelier index for water corrosivity and scaling.

Sometimes the raw water is contaminated with chemicals such as fertilizers and other chemicals coming from agricultural areas (Figure 5).

In these cases, ionic agents such as nitrites, nitrates, etc., in water causes an accelerated process of localized corrosion to many metals and the consequent failure of equipment.



Figure 5. Corrosion on the gates dam on the Colorado River, Baja California, Mexico

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Raw water contaminants can be quite varied, including both heavy metals and organic chemicals, referred to as toxic pollutants. Among the heavy metals may be mentioned arsenic (As), mercury (Hg), cadmium (Cd), lead (Pb), zinc (Zn) and cadmium (Cd), which are sometimes at trace levels, but they tend to accumulate over time, so that priority pollutants are to be treated.

Pesticides, insecticides and plaguicides comprise a long list of compounds, for which we should be concerned: DDT (insecticide), aldrin (an insecticide), chlordane (pesticide), endosulfan (insecticide), diazinon (insecticide), among others.

Contaminants, such as polycyclic aromatic organic compounds, include what is known as volatile organic compounds such as naphthalene, anthracene and benzopyrene. There are two main sources of these pollutants: petroleum and combustion products found in municipal effluents. On the other hand, there are polychlorinated biphenyls or PCBs, which are mainly used in transformers for the electrical industry, heavy machinery and hydraulic equipment. This class of chemicals is extremely persistent in the environment and affects human health.

From the viewpoint of corrosion, these contaminants which are present even at low concentrations or trace in the raw water, favor the corrosivity the metals which are in contact with. The combination of the corrosive effects of these contaminants together with the oxidation by oxygen, minerals and other impurities, leads to consider raw water as a natural means capable of generating corrosion of metals. It is recommended at least, to carry out a process of treating raw water, to reduce significantly the hardness and remove suspended solids, which will help greatly in preventing subsequent problems of corrosion and fouling on metal surfaces, curbing economic losses and maintaining the industrial process in good operating condition.

4.1. Corrosion in potable water systems

Corrosion is a complex phenomenon that arises as a result of the interaction between water and the surface of metallic pipes or the equipment of storage and handling. The process is invariably a combination of oxidation and reduction, as already described in previous chapters. In drinking water, it should be noted that the corrosion products which are partially soluble in water in ionic form are toxic at certain concentrations, e.g. copper and lead. The existence of high concentrations of lead in water carried by copper tubing, indicate that the source of lead may be tin-lead solder at the junctions of the copper pipes. The consumption of domestic water contaminated with toxic metal ions (Pb^{+2}, Cu^{+2}, Zn^{+2}, Cr^{+3}), gives rise to acute chronic health problems. The regulations have set the following limits allowable concentration in drinking water: Cr (0.05 ppm), Cu (0.01 ppm), Pb (0.05 ppm) and Zn (5 ppm). These regulations are made in order to protect the public user and consumer of drinking water and are continuously striving for a reduction in the maximum allowable limits. Some concentrations reach zero as is the case of Pb in the United States due to the concerns Pb about poisoning of children. Still, many sources such as wells and springs are outside the control of law and toxic substances, bacteria and pathogens. Damage caused by corrosion of household plumbing may be accompanied by unpleasant aesthetic problems such as soiled

clothing, unpleasant taste, stains and deposits in the toilets, floors of bathrooms, tubs and showers. To prevent corrosion of pipes, we recommend the use of PVC pipes for drinking water, replacing the metal, as a preventive measure.

Corrosion can occur anywhere on the pipes that carry drinking water, mainly at sites of contact between two dissimilar metals, thus forming a corrosion cell. In general, the metals will corrode to a greater or lesser degree in water, depending on the nature of the metal, on the ionic composition of water and its pH. Waters high in dissolved salts (water hardness), favor the formation of scale, more or less adherent, in different parts of the equipment (Figure 6). These deposits may be hard or brittle, sometimes acting as cement, creating a physical barrier between the metal and water, thereby inhibiting corrosion. Calcium carbonate ($CaCO_3$) is the most common scale; its origin is associated with the presence of carbon dioxide gas (CO_2) in water. Sometimes these deposits are filled with pasty or gelatinous hydrated iron oxides or colonies of bacteria (Valdez, B. et al., 1999, 2010).



Figure 6. Corrosion in potable water pipes.

Usually, groundwater $CaCO_3$ saturated (calcareous soils), due to the presence of dissolved CO_2, whose content depends on its content in the air in contact with the water and on temperature. These waters are often much higher in CO_2 content, so they may dissolve substantial amounts of calcium carbonate. These waters are at pressures lower than they had in the ground, so CO_2 gas lost with consequent supersaturation of carbonates. If conditions are appropriate, the excess of $CaCO_3$ can precipitate as small agglomerates deposited in muddy or hard layers on solid surfaces, forming deposits. An increase in temperature is an important factor and also leads to supersaturation of carbonates, with the consequent possibility of fouling. To a lesser extent fouling can precipitate more soluble Mg carbonates ($MgCO_3$) and Mn ($MnCO_3$), and also oxides / hydroxides, dark colored and gelatinous. Except in very exceptional cases in sulfated water, it is normal to find deposits of gypsum ($CaSO_4 \bullet ½\ H_2O$) because their solubility is high, but decreases with increasing temperature. Hard silica scale (SiO_2) may appear with oversaturated waters or appear as different silicates (SiO_4^{4-}) trapped in the carbonate deposits. Generally, the silica appears trapped in other types of scale and it is not chemical precipitation.

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Waters often carry considerable amounts of iron (ferrous ion, Fe^{+2}), which may be often precipitated by oxidation upon contact with air as hydrated iron oxide (ferric, Fe^{+3}) but sometimes can be Fe^{+2} form black sludge, more or less pasty or gelatinous and sometimes very large. The voluminous precipitate occupies the pores, significantly reducing the permeability of the fouling. Sometimes the Fe ions can come from corrosion of the pipe giving rise to simultaneous corrosion and scaling (Figure 6). Common bacteria of the genera Gallionella, Leptothrix Cremothrix are known as Fe bacteria, can give reddish-yellow voluminous precipitate and sticky ferric compounds from ferrous ion, which drastically reduce the permeability of the deposit, in addition to trap other insoluble particles.

The cost for impairment of domestic water systems and the impact on health, involves several consequences: premature corrosion and failure of the pipes and fittings that carry water in a house or building, a low thermal efficiency (up to 70%) of water heaters (boilers), which can cause their premature failure. High levels of metals or oxides, which usually are not properly, treated in drinking water cause red or blue-green deposits and stains in the toilets sinks. In addition to concerns about the aesthetic appearance, a corrosion process can result in the presence of toxic metals in our drinking water. For evaluating water quality and their tendency corrosive and / or fouling, LSI can be used. This analysis must be accompanied by measurements of water pH and conductivity, and corrosion tests applying international standards.

4.2. Anticorrosive treatment of water

Corrosion control is complex and requires a basic knowledge of corrosion of the system and water chemistry. Systems can be installed for water pretreatment, using non-conductive connections, reducing the temperature of hot Cu water pipes employed and copper installing PVC or other plastic materials. It is important to note that the corrosiveness of water can be increased by the use of water softeners, aeration mechanisms, increasing the temperature of hot water, water chlorination, and attachment of various metals in the water conduction system. A proper balance between the treatment systems and water quality, can be obtained with acceptable levels of corrosivity. Thus, the lifetime of the materials that make the water system in buildings, public networks, homes and other systems will be longer.

5. Soil corrosion

A large part of steel structures: aqueducts, pipelines, oil pipelines, communications wire ropes, fuel storage tanks, water pipes, containers of toxic waste, are buried, in aggressive soils. Large amounts of steel reinforced concrete structures are also buried in various soil types. In the presence of soil moisture it is possible to have humid layer on the metal surface, whose aggressiveness depends on soil type and degree of pollution (decaying organic matter, bacterial flora, etc.). Thus, the soil can form on the metal surface an electrolyte complex with varying degrees of aggressiveness, a necessary element for the development of an underground electrochemical corrosion. The corrosion process of buried structures is ex-

tremely variable and can occur in a very fast, but insignificant rate, so that pipes in the soil can have perforations, presenting localized corrosion attack or uniform.

Metal structures are buried depending on their functionality and security. Most often they traverse large tracts of land, being exposed to soils with different degrees of aggressiveness exposed to air under atmospheric conditions (Figure 7).



Figure 7. Valve system of a desert water aqueduct.

When pipes or tanks are damaged by corrosion, the formation of macro-and micro-cracks can lead to leaks of contained products or fluids transported, causing problems of environmental pollution, accidents and explosions, which can end in loss of life and property (Guadalajara, Jalisco, Mexico, 1992). In the case of pipes used to carry and distribute water, a leak may cause loss of this vital liquid, so necessary for the development of society in general and especially important in regions where water is scarce, so the leakage through aqueducts pipes should be avoided. An important tool needed to prevent the most serious events, is the knowledge of the specific soil and its influence on the corrosion of metal structures.

5.1. Types of soils and their mineralogy

A natural soil contains various components, such as sand, clay, silt, peat and also organic matter and organisms, gas, mineral particles and moisture. The soils are usually named and classified according to the predominant size range of individual inorganic constituent particles. For example, sandy soil particles (0.02 - 2 mm) are classified as fine sand (0.02 - 0.2 mm) or thick (0.20 -2.00 mm). Silt particles (0.002 to 0.02 mm) and clay, which have an average diameter 0.002 mm, are classified as colloidal matter. A comparison of the sizes of these typical soils is done in Figure 8.

Currently exists in the U.S. and in over 50 countries worldwide, a detailed classification for soils, which includes nine classes with 47 subgroups.

The variation in the proportion of the groups of soil with different sizes, determines many of its properties. Fine-textured soils due to high clay content, have amassed particles, so they have less ability to store and transport gases such as oxygen, that any ground-open e.g. san-

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dy soil. The mineralogy of both clay types and their properties, are closely related to the corrosivity of the soil. Silica (SiO_2) is the main chemical constituent of soils type clay, loam and silt, also in the presence of Al_2O_3. Common species in moist soil are dissolved ions H^+, Cl^-, SO_4^{2-}, HCO_3^-. The chemical composition and mineralogy of the soil determine its corrosive aggressiveness; poorly drained soils (clay, silt and loam) are the most corrosive, while soils with good drainage (gravel and sand type) are less aggressive to metals. Vertically homogeneous soils do not exist, so it is convenient to consider the non-uniformity of ground, formed of different earth layers. To understand the corrosion behavior of a buried metal is very important to have information about the soil profile (cross section of soil layers). The physicochemical and biological nature of soil, corrosive aggressiveness and dynamic interactions with the environment, distinguishes the ground like a very complex environment and different from many others. Climate changes of solar radiation, air temperature and relative humidity, amount of rainfall and soil moisture are important factors in corrosion. Wind, mechanical action of natural forces, chemical and biological factors, human manipulation can alter soil properties, which directly affects the rate of corrosion of metals buried in the ground. Conditions may vary from atmospheric corrosion, complete immersion of the metal, depending on the degree of compactness of the soil (existence of capillaries and pores) and moisture content. Thus the variation in soil composition and structure can create different corrosion environments, resulting in different behavior of the metal and oxygen concentrations at the metal / soil interface.

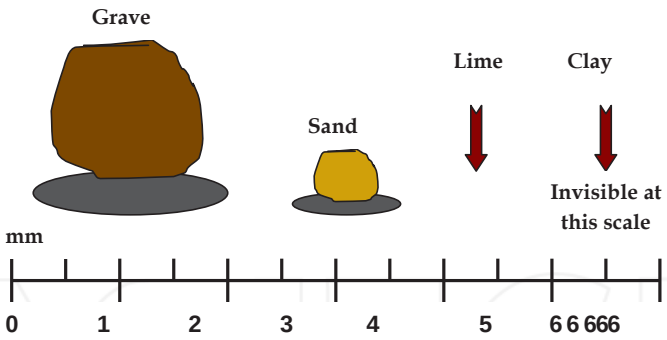


Figure 8. Size of soil particles.

Two conditions are necessary to initiate corrosion of metal in soil: water (moisture, ionic conductor) and oxygen content. After startup, a variety of variables can affect the corrosion process, mentioned above, and among them of importance are the relative acidity or alkalinity of the soil (pH), also the content and type of dissolved salts.

Mainly three types of water provide moisture to the soil: groundwater (from several meters to hundreds below the surface), gravitational (rain, snow, flood and irrigation) and capillary (detained in the pores and capillary spaces in the soil particles type clay and silt). The moisture content in soils can be determined according to the methodology of ASTM D 2216

("Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass"), while its permeability and moisture retention can be measured the methods described in ASTM D2434 and D2980. The presence of moisture in soils with a good conductivity (presence of dissolved salts), is an indication for high ion content and possible strong corrosive attack.

The main factors that determine the corrosive aggressiveness of the soil are moisture, relative acidity (pH), ionic composition, electrical resistance, microbiological activity.

5.2. Corrosion control of buried

Given the electrochemical nature of corrosion of buried metals and specific soils, this can be controlled through the application of electrochemical techniques of control, such as cathodic protection. This method has been universally adopted and is appropriate to protect buried metallic structures. For an effective system of protection and cheaper maintenance, pipelines must be pre-coated, using different types of coatings, such as coal tar, epoxies, etc. This helps reduce the area of bare metal in direct contact with the ground, lowering the demand for protection during the corrosion process. The purpose of indirect inspection is to identify the locations of faulty coatings, cathodic protection and electrical Insufficient shorts (close-interval, on/off Potential surveys, electromagnetic surveys of attenuation current, alternating current voltage gradient surveys, etc..), interference current, geological surveys, and other anomalies along the pipeline.

6. Corrosion under thermal insulation

One of the most common corrosion problems in pipes, ducts, tanks, preheaters, boilers and other metal structures, insulated heat exchange systems, is the wear and corrosion occurring on metal (steel, galvanized steel, Al, SS, etc.), below a deposit or in its immediate neighborhood. This corrosion is known as corrosion under deposit. The deposit may be formed by metal corrosion products and / or different types of coating applied for protection. For example, in the case of a calcareous deposit, formed in the walls of galvanized steel pipes which carry water with a high degree of hardness (dissolved salts), it might develop corrosion under deposit. These shells may be porous, calcareous deposit and / or partially detached from the metal surface, so that direct contact between metal, water and oxygen (the oxidizing agent in the corrosion process) allows the development of metal corrosion. For this reason the pipes could be damaged severely in these locations up to perforation, while in parts of the installation corrosion might occur at a much lower level.

There is a considerable amount of factors in the design, construction and maintenance, which can be controlled to avoid the effects of deterioration of metal by corrosion under deposit. In general, under these conditions the metal is exposed to frequent cycles of moisture, corrosivity of the aqueous medium or failure in the protective coatings (paint, metal, cement, fiberglass, etc.). Figure 9 shows a conductor tube steam in a geothermal power plant, where CS corrosion happened beneath the insulation.

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Figure 9. Corrosion of a carbon steel pipe under insulation.

Seven factors can be controlled on the ground, to prevent this type of corrosion: design of equipment, operating temperature, selection of the insulation, protective coatings and paints, physical barriers from the elements, climate and maintenance practices of the facility. Any change in any of these factors may provide the necessary conditions for the corrosion process to take place. The management knowledge of these factors help explain the causes of the onset conditions of corrosion under deposits, and it will guide a better inspection of existing equipment and the best design.

6.1. Equipment design

The design of pressure vessels, tanks and pipes, generally includes accessories for support, reinforcement and connection to other equipment. Details about the installation of accessories are the responsibility of the engineers or designers, using building codes to ensure reliability of both insulated and non insulated equipment. The protective barrier against the environment surrounding the metal structure in such designs often breaks donor due to an inappropriate insulation, loss of space for the specified thickness of insulation or simply by improper handling during installation of the equipment. The consequence of a rupture or insulation failure means greater flow water ingress to the space between metal and coating hot-cold cycle, generating over time a buildup of corrosive fluid, increasing the likelihood of corrosive damage. Moreover, wet insulation will be inefficient and also cause economic losses. The solution of this factor is to meet the thickness specifications and spacing, as indicated in the code or equipment-building specifications and characteristics of the coating used.

The operating temperature is important for two reasons: a high temperature favors the water is in contact with the metal for less time, however, also provides a more corrosive environment, causes fast failures of coatings. Usually a team operating in freezing temperatures is protected against corrosion for a considerable life time. However, some peripheral devices, which are coupled to these cold spots and operating at higher temperatures, are exposed to moist, air and steam, with cycles of condensation in localized areas, which make them more vulnerable to corrosion. For most operating equipment at freezing conditions, the corrosion occurs in areas outside and below the insulation. The temperature range where this type of corrosion occurs is 60 °C to 80 °C; however, there have been failures in zones at temperatures up to 370 °C. Also, in good water-proof insulation, corrosion is likely to occur at points where small cracks or flaws are present, so that water can reach the hot metal and evaporate quickly. On the other hand, in machines where the temperature reaches extreme values, as in the case of distillation towers, it is very likely to occur severe corrosion problems.

6.2. Selection of insulation

The characteristics of the insulation, which have a greater influence on the corrosion processes deposits, are the ability to absorb water and chemical contribution to the aqueous phase. The polyurethane foam insulation is one of the most widely used; however, in cold conditions they promote corrosion due to water absorption present. The coatings of glass fiber or asbestos can be used in these conditions, always when the capacity of absorbing water do not becomes too high. Corrosion is possible under all these types of coating, such insulation. The selection of insulation requires considering a large group of advantages and disadvantages regarding the installation, operation, cost, and corrosion protection, which is not an easy task. The outside of the insulation is the first protective barrier against the elements and this makes it a critical factor, plus it is the only part of the system that can be readily inspected and repaired by a relatively inexpensive process. The durability and appearance, melting point fire protection, flame resistance and installation costs are other important factors that must be taken into account together with the permeability of the insulation. Usually the maintenance program should include repairs to the range of 2 to 5 years. Obviously the weather is important and corrosion under thermal insulation will more easily in areas where humidity is high. Sometimes conditions of microclimate can be achieved through the use of a good design team.

7. Corrosion in the automotive industry

One of the most important elements of our daily life, which has great impact on economic activity, is represented by automotive vehicles. These vehicles are used to transport people, animals, grains, food, machinery, medicines, supplies, materials, etc. They range from compact cars to light trucks, heavy duty, large capacity and size. All operate mostly through the operation of internal combustion engines, which exploit the heat energy generated by this process and convert it in a mechanical force and provide traction to these vehicles.

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The amount and type of materials used in the construction of automotive vehicles are diverse, as the component parts. They are usually constructed of carbon steel, fiberglass, aluminum, magnesium, copper, cast iron, glass, various polymers and metal alloys. Also, for aesthetic and protection against corrosion due to environmental factors, most of the body is covered with paint systems, but different metal parts are protected with metallic or inorganic coatings.

Corrosion in a car is a phenomenon with which we are in some way familiar and is perhaps for this reason that we often take precautions to avoid this deterioration problem.

A small family car, with an average weight of 1000 kg, is constructed of about 360 kg of sheet steel, forged steel 250 kg, 140 kg cast iron mainly for the engine block (now many are made of aluminum), 15 kg of copper wires, 35 kg and of plastic 50 kg of glass that usually do not deteriorate, and 60 kg for rubber tires; which wear and tear. The remaining material is for carpets, water and oil. Obviously, that is an advanced technology in the car industry, with automobiles incorporating many non-metallic materials into their structure. However, the problem of corrosion occurs at parts where the operation of the vehicle is compromised. Corrosion happens in many parts of the car (mostly invisible) it is not only undesirable for the problems it causes, but also reduces the vehicle's resale value and decreases the strength of the structure. To keep the car in good condition and appearance, its high price, it is necessary to pay attention to the hidden parts of the vehicle.

The main cause of corrosion of the car body is the accumulation of dust in different closed parts, which stays for a long time by absorbing moisture, so that in these areas metal corrosion proceeds, while in the clean and dry external parts it does not occur (Figure 10).

The corrosion problem that occurs in the metal car body has been a serious problem that usually arises most often in coastal environments, contaminated with chlorides and rural areas with high humidity and specific contaminants. Many countries use salt (NaCl, $CaCl_2$ or $MgCl_2$) to keep the roads free of ice; under these conditions these salts, in combination with the dust blown by the car, provide conditions for accelerated corrosion. Therefore, it is recommended as a preventative measure, after a visit on the coast or being on dirty roads, to wash the car with water, and also the tires and the doors, especially their lower parts. In urban environments, the corrosion problem has been reduced due to the new design and application of protective coatings, introduced by major manufacturers in the early nineties of the twentieth century. The areas most affected are fenders, metal and chrome bumpers views which are used in some luxury vehicles as well as areas where water and mud are easily accumulated e.g. auctions of funds windshield and doors (Figure 11).

In regions with high incidence of solar radiation and the presence of abrasive dust, paint vehicles deteriorate rapidly. The hot, humid weather, combined with high levels of SO_2 and NO_x emissions that come from burning oil, chlorides salt. In the Gulf of Arabia, the blowing sand from the nearby desert, creates a very aggressive environment; statistics reveals that one in seven cars is damaged and due to corrosion the car life is estimated to an average of 8 months, also the car corrosion resistance decreases in the following order: manufactured in Europe, USA and Japan. White paints generally have shown a significantly better corrosion

protection than other colors. Initially, corrosion defects appear as a kind of dots and spots of corrosion products formed under the paint and subsequently emerge from the steel sheet, leaving a free entry for moisture and air (oxygen), accelerating the corrosion process; in these cases reddish metal corrosion products.



Figure 10. Corrosion on a bodywork exposed to the Gulf of Mexico tropical coast.



Figure 11. Corrosion on a car door and bottom of the bodywork

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7.1. Corrosion in the cooling system

The cooling system of a car combustion engine consists of several components, constructed of a variety of metals: radiators are made of copper or aluminum, bronze and solder couplings with tin water pumps; motors are made of steel, cast iron or aluminum. Most modern automobiles, with iron block engine and aluminum cylinder head, require inhibitor introduced into the cooling water to prevent corrosion in the cooling system. The inhibitor is not antifreeze, although there are in the market solutions which have the combination of inhibitor-antifreeze. The important thing is to use only the inhibitor recommended in the automobile manual and not a mixture of inhibitors, since these may act in different ways and mechanisms. The circulating water flow should work fine without loss outside the system. If the system is dirty, the water should be drain and filling the system with a cleaning solution. It is not recommended to fill the system with hard water, but with soft water, introducing again the inhibitor in the correct concentration. If there exhaust at the water cooling system, every time water is added the inhibitor concentration should be maintained to prevent.

In small cars, it is common for water pumps; constructed mainly of aluminum, to fail due to corrosion, cavitation, erosion and corrosion, making it necessary to replace the pump (Valdez, B. et al., 1995). Accelerated corrosion in these cases is often due to the use of a strong alkaline solution of antifreeze. On the other hand, in heavy duty diesel trucks, the cooling system is filled with tap water or use filters with rich conditioner chromates that can cause the pistons jackets to suffer localized corrosion. After 12 or 15 months, the steel jackets are perforated and the water passes into the cavity through which the piston runs, forcing to carry out repair operations (Figure 12).



Figure 12. Corrosion in a carbon steel jacket on the water face in a diesel combustion engine truck.

Corrosion causes great economic losses to the transport industry, since it must stop to repair the truck and abandon to provide the service with all the consequences that this entails. Furthermore, the use of chemical conditioning is now controlled by environmental regulations, so chromates and phosphates are restricted and novel mixtures of corrosion inhibitors have been produced to control the problem of corrosion in automobile cooling systems.

7.2. Corrosion in exhaust pipes and batteries

Exhaust pipes made of SS (0.6 - 0.8 mm thick) have a better resistance to chemical corrosion at high temperatures, which is why we are now using SS in many popular models. This SS resists corrosion much more than conventional CS and thus their long life covers the higher price. Another alternative is to use conventional CS tube, zinc coated or aluminum (Figure 13). These exhaust pipes are less expensive than stainless steel, but less resistant to corrosion.



Figure 13. Corrosion on carbon steel exhaust pipes coated with aluminum.

The acidic environment which is generated on the surface of accumulators supplying the energy necessary for starting the engine, favors conducting corrosion processes in the lead terminals, where the cables are connected by bronze or steel clamps. Thus, this environment and these contact zones predispose cells to a process galvanic corrosion, which gradually deteriorates the contact wires, generating bulky corrosion products. This phenomenon is called sulfation of the contacts due to the sulfuric acid containing the battery, thus forming white sulfates on the corroded metal surface. These products introduce high resistance to current flow and cause failure to the engine ignition system, and impede the battery charge

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process. This problem has been eliminated in batteries that have airtight seals, or are manufactured with new technologies as well as bases covered with organic coatings that prevent corrosion.

Some years ago it was common for starters to fail, because the moisture or water penetrated into the gear area preventing it sliding motion and causing burning of the electric motor. Currently, new designs avoid contact with moisture and other foreign agents, preventing the occurrence of corrosion problems in these devices. As a preventive measure is recommended to prevent spillage of battery acid, to periodically clean the battery terminals (with a brush of wire or a special instrument), also coat them with petroleum jelly to prevent corrosion in these contact areas. A fat based composition which contains several components: alkaline salts and oxides of lithium, sodium bicarbonate and magnesium oxide are applied to the terminals and the connector. In general, in wet weather, the contacts of the accumulators have a tendency to more accelerated corrosion, thus requiring greater care to disconnect the terminals when not being used.

7.3. Corrosion prevention

To keep the vehicle for a longer time without the appearance of corrosion, it always requires washing with running water and, the use of very soft brush or cloth-like material, with a special detergent (not household detergents, which are very corrosive) and finally wash the vehicle with plenty of water. The floor carpet should be maintained clean and dry. A car should not be left wet in a hot garage, since under these conditions accelerated corrosion takes place since the water does not dry and can condense on the cold parts of the vehicle. In these cases, it is best not to close the garage door or use a roof space, to protect it from rain, and not allow moisture condensation. However, if the vehicle is left unused for a long time in a closed garage, it should be protected from dust, moisture and contaminants.

8. Corrosion control in thermoelectric plants

Electricity is a key element in ensuring economic growth and social development of a country. Many conventional power plants in recent years are being installed in combined cycle power plants, also called cogeneration. The latter, simultaneously generate electricity and / or mechanical power and useful heat, sometimes using thermal energy sources that are lost in conventional plants.

A power station is a thermoelectric energy conversion system, starting with the chemical energy of fuel that during combustion is converted into heat energy accumulated in the steam. This thermal energy generates mechanical energy from the hot steam, which expands in a turbine, turning on electricity in the generator. In this process of low energy thermal efficiency is lost in the hot gases that escape through the chimney and the cooling steam in the condenser.

Electricity generating plants burn fossil fuels such as coal, fuel oil and natural gas. These fuels containing as minor components sulfur compounds (S), nitrogen (N), vanadium (V)

and chloride (Cl^-). These are corrosive chemicals attacking the metal infrastructure; and polluting the environment by becoming acid gas emissions, also affecting the health of the population.

The three central equipment of a thermoelectric plant are the boiler, which converts the water into steam, the steam turbine to whom the pressure imparts a rotary motion and the condenser that condenses the vapor released by the turbine and the condensed water is returned to the boiler as feed water. The turbine itself transmits rotary motion to the generator of electricity, which will be distributed to industrial, commercial and homes in cities.

Corrosion in steam plant equipment occurs in two parts of the boiler: on the water side and the steam side, with the fire temperature up to 700 ° C, depending on the type, size and capacity of the boiler. The boiler feedwater must be treated to eliminate the corrosive components: salts such as chlorides and sulfates dissolved oxygen (DO); silicates and carbonates, producing calcareous scale on the boiler walls, regarded as precursors for the formation of corrosion under deposits. The water is softened by eliminating salts and treated to remove oxygen; the pH is controlled by addition of alkaline phosphate to reach a pH range of 10 to 11, and inhibitors are added to the feedwater to prevent corrosion.



Figure 14. Stress corrosion cracking, in a combustion gases pipe of a thermoelectric station.

The flue gases and ash solid particles reach temperatures up to 1000 to 1200 °C, impinging on the outer surface of the boiler water tubes and preheater, creating an atmosphere for aggressive chemical corrosion. The damaged tubes lose its thickness generating metal corrosion products; they often are fractured, suffering a stress corrosion due to the combined effects of mechanical stress and corrosion (Figure 14). Since the tubes lose steam and pressure, the operation of the plant is interrupted and the tubes or its sections should be

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changed incurring severe economic losses. For example, in the United States has been concluded that the costs of electricity are more affected by corrosion than any other factor, contributing 10% of the cost of energy produced.

A study reveals that in 1991 there were more than 1250 days lost in nuclear plants operating in the United States, due to failure by corrosion, which represented an economic loss of $ 250.000 per day. Such statistics indicate that the power generation industry needs to obtain a balance between cost and methods for controlling effectively corrosion in their plants. It is sometimes advisable to add additives to the fuel, for example, magnesium oxide which prevent the deposition of the molten salts on the boiler tubes. Corrosion occurs also in the combustion air preheater, by sulphurous gases which react with condense and form sulfuric acid. Metal components of the turbine rotor: disks and blades suffer from corrosion by salts, alkalis and solid particles entrained in the vapor. In these cases, it is common to observe the phenomena of erosion-corrosion, pitting and stress corrosion fracture; their damage can be ameliorated through a strict quality control of boiler water and steam.

Efficient maintenance and corrosion control in a power plant is based on the following:

- Operation according to mechanical and thermal regime, indicated by the designer and builder of the plant;
- Correct treatment of fuel, water and steam;
- Chemical cleaning of the surfaces in contact with water and steam, using acidic solutions containing corrosion inhibitors, passivating ammoniacal solutions and solutions;
- Mechanical cleaning of surfaces covered with deposits (deposits), using alkaline solutions and water under pressure;
- Perform an optimum selection of the materials of construction for the components of the plant, including those suitable as protective coatings.
- The installation of online monitoring of corrosion in critical plant areas will be one of the most effective actions to control corrosion. In addition, it is recommended same use and document to use corrosion expert system software and materials databases for the analysis of the materials corrosion behavior.

Corrosion in power plants can be controlled by applying the knowledge, methods, standards and materials, based on corrosion engineering and technology.

9. Corrosion in geothermal environments

The development of alternative energy sources represents one of the most attractive challenges for engineering. There are several types of renewable energies already in operation, such as wind, solar and geothermal. Geothermal environments can lead to aggressive environments, e.g. the geothermal field of "Cerro Prieto", located in Baja California, Mexico.

The physical and chemical properties of the vapor at "Cerro Prieto" make it an aggressive environment for almost any type of material: metal, plastic, wood, fiberglass or concrete. The typical chemical composition of a geothermal brine, is shown in Table 4. Many engineering materials are present as components of the infrastructure and field equipment, required for the steam separation, purification and posterior operations for the generation of electricity. This entire infrastructure is a costly investment and therefore, failure or stoppage of one of them, means economic losses, regardless of how vital it is to maintain constant production of much-needed electricity.



Figure 15. Corrosion in concrete structures used to separate steam from water and to operate steam silencers.

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In the process of the geothermal fluid exploitation, corrosion of metal structures occurs from the wells drilling operation, where the drilling mud used, causes corrosion of pumping and piping equipment. Subsequently, when the wells pipes are in contact with the steam, they can also suffer from corrosion-erosion problems, where the corrosive agent is hydrogen sulfide. Steam separators and the pipes are exposed to problems of fouling and localized corrosion due to the presence of aggressive components such as H_2S and chloride ions (Cl^-), present in the wells fluid. These agents lead to the deterioration of reinforced concrete foundations supporting steel pipes, or other concrete structures used to separate steam from water and to operate steam silencers. The reinforced concrete deterioration due to steel corrosion in this aggressive environment, and the steam pressure mechanical forces lead to concrete damage with formation of cracks and fractures.

Component	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	SO_4^{2-}	SiO_2	HCO^{3-}
Ppm, mg/kg	6429	1176	18.6	347	11735	15	1133	303

Table 4. Typical chemical composition of typical "Cerro Prieto" geothermal brine

In the power plants, the observed corrosion affects components of the steam turbines, condensers and pipelines, and also the cooling towers and concrete structures inside and outside the building that houses the plant. In these cases, the effects of corrosive attack appears in the form of localized corrosion in metal walls and gas piping) or as corrosion fatigue or stress corrosion, caused by cyclic mechanical forces or residual stresses, in turbines and other metal equipment. Table 5 shows a list of equipment and materials used for construction, which are part of the infrastructure of a geothermal power (Valdez, B. et al., 1999, 2008)

Equipment	**Materials**
Pipelines	Concrete, steel
Vertical and centrifugal pumps	Steel, copper alloys
Valves	Steel
Flanges and fits	Steel
Silencers	Concrete, steel, FRGP
Brine canals	Reinforced concrete
Evaporation ponds	Plastics
Control and safety instruments	Metals and plastics

Table 5. Equipment and materials used to build infrastructure in a geothermal field

The combination of an aerated moist environment with the presence of hydrogen sulfide gas (H_2S) dissolved in water provides a very aggressive medium (Figure 16), which promotes the corrosion of metals and alloys, such as CS and SS. The presence of dust, from the geo-

thermal field and condensation cycles favor the failure of protective coatings applied to steel, so that developed corrosion leads to constant repairs and maintenance of metal installations: pipes, machinery, cooling towers, vehicles, tools, fences, warehouses, etc.

Cooling towers constructed of wood, steel and fiberglass in the presence of flowing and stagnant water and air currents (induced to complete cooling fans), suffer a serious deterioration of the steel by corrosion and biodeterioration, involving a variety of microorganisms. The timber is subjected to oxygen delignification under the effect of colonies of fungi and algae, as well as fiberglass reinforced polyester screens, which deteriorate due to colonies of aerobic and anaerobic bacteria e.g. sulfate reducers.

Furthermore, carbon steels corrode in the form of delamination due to sulfate reduction processes which induce the oxidation of iron, while the SS nails and screws undergoes localized corrosion, forming pits (Figure 17)



Figure 16. A humid corrosive environment in a geothermal field caused by steam and gases emission.

The deterioration by microorganisms capable of living in these conditions is one of the processes that have provided more information to the study of corrosion induced by microorganisms. In "Cerro Prieto", for example, have been isolated and studied various bacteria capable of growing even at temperatures of 70 ° C under conditions of low nutrient concentrations, while in the geothermal field of "Azufres" bacteria have been isolated to survive at temperatures of 105 °C and pressures of downhole (Figure 18).

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Figure 17. Corrosion in a cooling tower of a geothermal power plant.

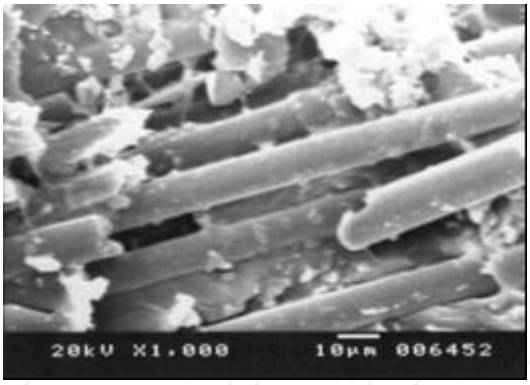


Figure 18. Biodeterioration of polyester polymeric matrix in a fiberglass screen exposed at geothermal temperatures.

10. Corrosion in the paper industry

Corrosion of the infrastructure used in the pulping and paper industry, is another serious problem for corrosion specialists. The wide experience, gathered from cases of corrosion in the various infrastructure components of the paper industry, has provided an extensive literature on mechanisms, types and control of corrosion in this environment.

In the early 60's of last century, when the continuous digester process was adopted, the paper industry had limited knowledge about caustic embrittlement. Currently, it is known that

the digesters are subjected to caustic levels and temperatures too close to the fracture caustic range where the total relieves of stresses in the material are essential. To elucidate the mechanism of this phenomenon, it was necessary to conduct serious investigations, which subsequently provide solutions to the problem of corrosion and caustic embrittlement. Technology in the paper industry has evolved over the last forty years and in parallel we can talk about the solution of corrosion problems in different parts of its infrastructure. Components with high failure rate due to corrosion are those built of bronze, SS, cast iron. Corrosion occurs in the papermaking machinery, where the white water equipment is subjected to an aggressive environment. The metal surfaces are exposed to immersion in this water; to steam that promotes the formation of cracks, which favor the deposit of pulp and other compounds. CS undergoes rapid uniform corrosion, while the copper alloys and SS (austenitic UNS S30400 L: 18% Cr8% Ni, UNS S31600 L: 16% Cr10% Ni 2% Mo) develop localized pitting corrosion. In the mill bleach plants the pulp equipment has traditionally been made of SS which has good general corrosion resistance and weldability. The use of chlorine gas (Cl_2) and oxygen in the bleach plant and pulp bleaching, favors a very aggressive oxidant and SS, as type 317 L (18% Cr14% Ni3.5% Mo). However, in the last 25 years the environment in these plants has become much more corrosive due to the wash systems employed for the paper pulp, which increased the emission of oxidizing and corrosive gases; so type "317 L" SS is not resistant and has a shorter service life. Many mills in the paper industry have opted for the use of high-alloy SS, nickel (Ni) and titanium (Ti), for better corrosion resistance in these particular environments. In general, SS exposed to corrosive environment of bleach plants are benefited by the share of chromium, nickel and molybdenum as alloying elements, which increase their resistance to the initiation of pitting and crevice corrosion. The addition of nitrogen (N) increases its resistance to pitting corrosion, particularly when it contains molybdenum (Mo). Furthermore, to avoid waste of elements such as carbon (C), where a concentration greater than 0.03%, can cause sensitization at affected by heat areas in the solder, causing the SS to be less resistant to corrosion. Other waste elements, such as phosphorus (P) and sulfur (S) can cause fractures in the hot steel, formed in the metal welding area. The corrosive environment of bleach plants contain residual oxidants such as chlorine (Cl_2) and chlorine dioxide (ClO_2), these are added to resists the effects of temperature and acidity, maintaining a very aggressive environment.

Corrosion also occurs in the pulping liquor facilities by sulfites, chemical recovery boilers, suction rolls and Kraft pulping liquors. The Kraft process is the method of producing pulp or cellulose paste, to extract the wood fibers, necessary for the manufacture of paper.

The process involves the use of sodium hydroxide (NaOH) and sodium sulfite (Na_2SO_3) to extract the lignin from wood fibers, using large high pressure digesters. High strength is obtained in the fiber and methods for recovery of chemicals explain the popularity of the Kraft process. The black liquor separated, is concentrated by evaporation and burned in a recovery boiler to generate high pressure steam, which can be used for the plant steam requirements for the production of electricity. The inorganic portion of the liquor is used to regenerate sodium hydroxide and sodium sulfite, necessary for pulping. Corrosion of metals in the facilities used in this process may occur during the acid pickling operation for the

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removal of carbonate incrustations on the walls and black liquor pipe heaters. It has been found that SS 304 L presents fracture failure and stress corrosion. In the recovery processes of chemical reagents, known as stage re alkalinization, metals can fail due to caustic embrittlement or corrosion-erosion under conditions of turbulent flow. Corrosion also occurs in the equipment used for mechanical pulping, such as stress corrosion cracking, crevice corrosion, cavitation and corrosion-friction.

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References

[1] Acuña, N., Valdez, B., Schorr, M., Hernández-Duque, G., Effect, of., Marine, Biofilm., on, Fatigue., Resistance, of., an, Austenitic., & Stainless, Steel. Corrosion Reviews, United Kingdom (2004). , 22(2), 101-114.

[2] Carrillo, M., Valdez, B., Schorr, M., Vargas, L., Álvarez, L., Zlatev, R., Stoytcheva, M., In-vitro, Actinomyces., israelii's, biofilm., development, on. I. U. D., copper, surfaces., & Contraception, Vol. (2010). (3), 261-264.

[3] Carrillo Irene, Valdez Benjamin, Zlatev Roumen, Stoycheva Margarita, Schorr Michael, and Carrillo Monica, Corrosion Inhibition of the Galvanic Couple Copper-Carbon Steel in Reverse Osmosis Water, Research Article, Hindawi Publishing Corporation, International Journal of Corrosion, Volume(2011). Article ID 856415

[4] 2010, Garcia, A., Valdez, B., Schorr, M., Zlatev, R., Eliezer, A., Haddad, J., Assessment, of., marine, , fluvial, corrosion., of, steel., aluminium, Journal., of, Marine., Engineering, , & Technology, Vol. (18), 3-9.

[5] Garcia Inzunza Ramses, Benjamin Valdez, Margarita Kharshan,Alla Furman, and Michael Schorr, ((2012). Interesting behavior of Pachycormus discolor Leaves Ethanol Extract as a Corrosion Inhibitor of Carbon Steel in 1M HCl. A preliminary study. Research Article, Hindawi Publishing Corporation, International Journal of Corrosion, Article ID 980654, 8 , 2012, 2012.

[6] Lopez, B. G., Valdez, B., , S., Zlatev, R., , K., Flores, J., , P., Carrillo, M., , B., Schorr, M., & , W. Corrosion of metals at indoor conditions in the electronics manufacturing industry. Anti-Corrosion Methods and MaterialsUnited Kingdom, N0. 6, Noviembre (2007). , 54, 354 EOF-359 EOF.

[7] Lopez, B. G., Valdez, B., , S., Schorr, M., , W., Rosas, N., , G., Tiznado, H., , V., Soto, G., & , H. Influence of climate factors on copper corrosion in electronic equipment and devices. Anti-Corrosion Methods and MaterialsUnited Kingdom, N0. 3, (2010). , 57, 148 EOF-152 EOF.

[8] Lopez, Gustavo, Hugo Tiznado, Gerardo Soto Herrera, Wencel De la Cruz, Benjamin Valdez, Miguel Schorr, Zlatev Roumen,(2011). Use of AES in corrosion of copper connectors of electronic devices and equipments in arid and marine environments. Anti-Corrosion Methods and MaterialsIss: 6, , 58, 331-336.

[9] Lopez, Badilla Gustavo, Benjamin Valdez Salas and Michael Schorr Wiener, Analysis of Corrosion in Steel Cans in the Seafood Industry on the Gulf of California, Materials Performance, Vol.April (2012). (4), 52-57.

[10] Navarrete, M., Ballesteros, M., Sánchez, J., Valdez, B., Hernández, G., Biocorrosion, in. a., geothermal, power., plant, Materials., & Performance, April. (1999). USA., 38, 52-56.

[11] Schorr, M., Valdez, B., Zlatev, R., Stoytcheva, M., Erosion, Corrosion., in, Phosphoric., Acid, Production., Materials, Performance., & Jan, . (2010). USA, 50(1), 56-59.

[12] Stoytcheva, M., Valdez, B., Zlatev, R., Schorr, M., Carrillo, M., Velkova, Z., Microbially, Induced., Corrosion, in., The, Mineral., Processing, Industry., Advanced, Materials., & Research, . (2010). Trans. Tech publications, Switzerland, 95, 73-76.

[13] Raicho Raichev, Lucien Veleva y Benjamín Valdez, Corrosión de metales y degradación de materiales.Principios y prácticas de laboratorio. Editorial UABC, 978-6-07775-307-0(2009). pp

[14] Santillan, S. N., Valdez, S. B., Schorr, W. M., Martinez, R. A., Colton, S. J., Corrosion, of., the, heat., affected, zone., of, stainless., steel, weldments., Anti-Corrosion, Methods., Materials, United., & Kingdom, Vol. (2010). (4), 180 EOF-184 EOF.

[15] Schorr, M., Valdez, B., Zlatev, R., Stoytheva, M., Santillan, N., Phosphate, Ore., Processing, For., Phosphoric, Acid., Production, Classical., And, Novel., Technology, Mineral., Processing, , Extractive, Metallurgy., & Vol, . (2010). (3), 125-129.

[16] Valdez, B., Guillermo Hernandez-Duque, Corrosion control in heavy-duty diesel engine cooling systems, CORROSION REVIEWS Vol.Nos. 2-4, (1995). , 245-260.

[17] Valdéz, Salas. B., Miguel, Beltrán., Rioseco, L., Rosas, N., Sampedro, J. A., Hernandez, G., & Quintero, M. Corrosion control in cooling towers of geothermoelectric power plants. Corrosion Reviews, (1996). England., 14, 237-252.

[18] Valdez, B., Rosas, N., Sampedro, J., Quintero, M., Vivero, J., Hernández, G., Corrosion, of., reinforced, concrete., of, the., Rio, Colorado., Tijuana, aqueduct., Materials, Performance., & May, . (1999). USA., 38, 80-82.

[19] Valdez, B., Rosas, N., Sampedro, J., Quintero, M., Vivero, J., Influence, of., elemental, sulphur., on, corrosion., of, carbon., steel, in., geothermal, environments., Corrosion, Reviews., & Vol, . Nos. 3- 4, October (1999). England, 167-180.

[20] Valdez, S. B., Zlatev, R., , K., Schorr, M., , W., Rosas, N., , G., Ts, Dobrev. M., Monev, I., Krastev, Rapid., method, for., corrosion, protection., determination, of. V. C. I., Films-Corrosion, Anti., Methods, , Materials, United., & Kingdom, Vol. Noviembre (2006). (6), 362-366.

[21] Valdez, B., Carrillo, M., Zlatev, R., Stoytcheva, M., Schorr, M., Cobo, J., Perez, T., & Bastidas, J. M. Influence of Actinomyces israelii biofilm on the corrosion behaviour of copper IUD, Anti-Corrosion Methods and Materials, United Kingdom, N0. 2, 55-59, (2008). , 55

[22] Valdez, B., Schorr, M., Quintero, M., Carrillo, M., Zlatev, R., Stoytcheva, M., Ocampo, J., Corrosion, , scaling, at., Cerro, Prieto., Geothermal, Field., Anti-Corrosion, Methods., Materials, United., & Kingdom, Vol. N0. 1, (2009). , 28 EOF-34 EOF.

[23] Valdez, B., Schorr, M., Corrosion, Control., in, The., Desalination, Industry., Advanced, Materials., & Research, . (2010). Trans. Tech publications, Switzerland, 95, 29-32.

[24] Valdez, B., Schorr, M., Quintero, M., García, R., Rosas, N., The, effect., of, climate., change, on., the, durability., of, engineering., materials, in., the, hydraulic., & infrastructure, . An overview. Corrosion Engineering Science and Technology(2010). , 45(1), 34-41.

[25] Valdez, B., Schorr, M., So, A., Eliezer, A., Liquefied, Natural., Gas, Regasification., Plants, Materials., Corrosion, M. A. T. E. R. I. A. L. S. P. E. R. F. O. R. M. A. N. C. E., & Vol, . December (2011). (12), 64-68.

[26] Vargas, O. L., Valdez, S. B., Veleva, M. L., Zlatev, K. R., Schorr, W. M., Terrazas, G. J., Corrosion, of., silver, at., indoor, conditions., of, assembly., processes, in., the, microelectronics., industry-Corrosion, Anti., Methods, , Materials, United., & Kingdom, Vol. N0. 4, (2009). , 218 EOF-225 EOF.

[27] Veleva, L., Valdez, B., López, G., Vargas, L., Flores, J., Atmospheric, Corrosion., of-Electronics, Electro., Metals, in., Urban-Desert, Indoor., & Environment, . Corrosion of Electro-Electronics Metals in Urban-Desert Indoor Environment. Corrosion Engineering Science and Technology(2008). , 43(2), 149-155.

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