

Study on the Vulnerability of Metals and Proposed Solutions to Prevent Corrosion of Structures in Salt - Brackish Water Environments

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ABSTRACT

This article studies the basis of metal corrosion process, corrosion rate, characteristics and factors affecting metal corrosion rate in salt water-brackish water environments, conducted in downstream areas of large rivers and coastal areas. Then, the study proposes anti-corrosion measures to increase the life of metal structures and reduce the destruction of steel reinforcement in concrete, thereby applying them to the design and manufacture of structures, equipment used in salt water-brackish water environments, projects on estuaries and coastal areas, including defense, transportation, construction, civil and industrial projects in areas vulnerable to intrusion salinity, climate change, etc. The process of metal destruction in saltwater-brackish water environments is analyzed through chemical reactions that destroy metals, reducing their load-bearing capacity, leading to destruction of works that use many metal structures. To tackle this situation, the authors have proposed effective solutions for practical application.

Keywords: Salt Water, Brackish Water, Metal Corrosion, Damage, Corrosion Rate

I. INTRODUCTION

Today, metal materials still occupy an important position in economic development. Due to their high activity, they are vulnerable to environmental impacts. Especially the increase in destructive climate change that destroy gradually from the outside in or the inside out (reinforced concrete

structures) and we call it the process of metal corrosion. Its consequences are common in everyday life and the huge damage is not only limited to the cost of regular maintenance and material replacement but also includes safety hazards and negative impact on the natural environment. In developed industrial countries, it is estimated that damage due to corrosion accounts for about 4.3% of

total national income. The damage will be even greater if it includes costs for maintenance, replacement of materials and consequences of corrosion, environmental pollution and ecological imbalance [1].

Vietnam is geographically located with a coastline of approximately 3,260 km, with many ports, wharves, offshore drilling rigs, defense and civil works along the coast. Therefore, the impact of corrosion of metal materials on water transport vehicles (ship hulls, rudders), reinforced concrete materials, building structures, and ports is huge. Therefore, the need of research of maintenance and anti-corrosion protection, prolonging the useful life of structures and works in salt-brackish water areas is a matter of practical significance, in terms of science, technology and economic aspects.

Anti-corrosion studies for construction components, including offshore constructions, are also given much attention to improve the longevity and performance of the components. Authors [2,3] used the electrochemical method (cathode protection using sacrificial anodes) with advantages in installation and monitoring. In recent years, with advances in equipment as well as inert anode materials, authors [4,5] have used the method of cathodic protection with external current. The outstanding advantage of this method is the voltage at the anodes is automatically adjusted depending on the corrosion rate of different sea areas, creating the most optimal anti-corrosion protection effect for steel structures. The author [6] has researched and developed a cathodic protection system using external current to prevent corrosion for marine ship hulls, and evaluated the properties of titanium-based inert anode electrode materials coated with rare mixed oxides (MMO). Thereby, the author designed, manufactured, installed and operated a cathodic protection system using external current. The results showed that the system was very effective in protecting against corrosion for the ship's hulls.

In the oil and gas industries, wharf, coastal roads and bridges construction, corrosion protection has been always extremely important. In all stages of exploration, exploitation, transportation, handling, and processing, specialized equipment often has to come into direct contact with the corrosive environment of salty-brackish water. The author [7] researched the application of a corrosion inhibitor chemical system based on Imidazolin for water injection pumps in the oil and gas exploitation industry, and the results showed high anti-corrosion effectiveness.

The corrosion in concrete structures such as bridge piers and coastal constructions is also of interest to scientists. Author [8] studied the corrosion prevention of steel reinforcement in concrete on a simulation model of coastal tide control. In their research, the authors proposed an anti-corrosion solution for concrete structures in rising and falling waters, which is to combine the method of applying epoxy to steel bars and the cathodic protection method. The results were very impressive.

Metal corrosion occurs in many different environments such as: atmospheric environment, soil environment, freshwater environment, saltwater-brackish water environment, dry corrosion, etc.

Within the scope of this article, it studies metal corrosion in saltwater-brackish water environments, characteristics and factors affecting metal corrosion rates, and provides solutions to prevent metal corrosion in this environment.

II. MATERIALS AND METHOD

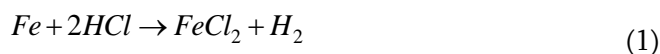
A. Metal corrosion process

Metal corrosion is an irreversible redox reaction that occurs between a metal and an oxidizing agent present in a corrosive environment. Oxidation of metals is associated with reduction of oxidants. The

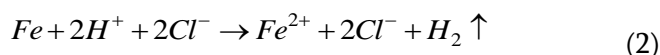
formula for metal corrosion can be expressed as follows:

Metal + oxidizing agent → oxidized metal + reducing agent

Considering the example of Fe immersed in HCl acid solution, the reaction occurs as follows [11]:



Equation (1) can be written in ionic form [11]:



In equation (2), the oxidant is H^+ ions, the products are oxidized Fe^{2+} ions and evaporated H_2 gas, Cl^- ions do not directly participate in the reaction, (2) is written more simply:



In alkaline and neutral environments, metal corrosion is a reaction that occurs between metal and oxygen. For example, in humid air, coastal structures made from iron corrode to form $FeOOH$ rust according to the reaction [11]:



During metal corrosion, the redox reaction always includes two separate reactions (partial reactions): the oxidation reaction is called anodic reaction, the reduction reaction is called cathodic reaction.

In equation (3), the $Fe \rightarrow Fe^{2+} + 2e^-$ is an anodic reaction, the $2H^+ + 2e^- \rightarrow H_2$ is a cathodic reaction. This is called the electrochemical corrosion of metals. In this process, anodic reactions and cathodic reactions always appear associated with the electron reactions of the oxidation reaction, this flow of electrons is transferred from the anode to the cathode and generates an electric current.

During the process of conduction, the electrons released by the corroded metal will move from the place of the anodic reaction to the place of the cathode reaction, while the ions move in the solution. So, when the metal is corroded, there will be cathode and anode areas.

We can represent the above process by the diagram in Figure 1a.

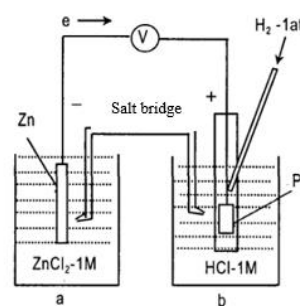


Figure 1a. Diagram of Zn electrochemical corrosion cell [1]

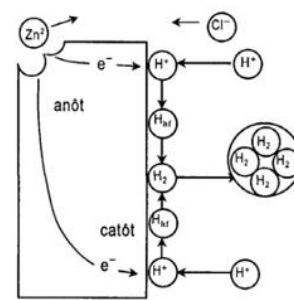


Figure 1b. Corrosion of Zn in acidic solution [1]

The process of corroding Zn in HCl acid solution is separated into: Zn rod anode dipped in $ZnCl_2$ -1M solution (cup a), cathode - hydrogen electrode (Pt dipped in HCl-1M solution) (cup b). Then in cup a, zinc will be corroded according to the reaction: $Zn \rightarrow Zn^{2+} + 2e^-$, while H^+ will perform the reduction reaction in cup b: $2H^+ + 2e^- \rightarrow H_2$. The salt bridge allows Cl^- anions to move from cup b to cup a to create a balanced ion.

When connecting two poles, an electric current will flow through. So, in the process of electrochemical corrosion, the metal acts like a battery, we call it a corrosive battery (electrochemical corrosion).

Metal corrosion has many forms such as: electrochemical corrosion, chemical corrosion, stress corrosion, abrasive corrosion, crevice corrosion, hole corrosion, interstitial corrosion, etc. Within the scope of the article, we study more clearly about a typical form of electrochemical corrosion which is galvanic corrosion.

B. Galvanic corrosion

Galvanic corrosion is a form of corrosion that occurs when there is a potential difference that creates a corroded battery. Galvanic corrosion occurs when two or more metals with different electrode potentials are assembled on the same structure. They can make conductive contact with each other in the

same corrosive environment, thus creating a battery corrode.

Because seawater contains many ions of NaCl and MgCl₂ salts, it is a good conductive medium suitable for galvanic corrosion. For example, when building ships, most parts are made of steel, but the propeller is made of copper alloy. There are also protectors made of zinc or aluminum alloy, all assembled on one ship.

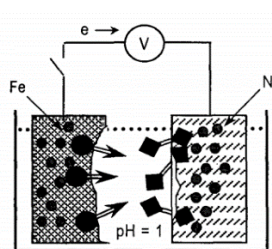


Figure 2. Fe - Ni galvanic corrosion batteries [1]

Galvanic corrosion also appears in multiphase alloys, when the phases in this alloy have different electrode potentials. For example, cast Cu parts are composed of two phases: Cu-rich α and Zn-rich β , which have very different electrode potentials.

Consider the mechanism of galvanic corrosion between metals. Figure 2 shows a diagram of a corrosion cell with Fe and Ni electrodes of the same shape and size immersed in an acid solution with reduced O₂, pH = 1.

Figure 3 shows the Fe - Ni polarization curve in a corrosive environment, assuming the hydrogen depolarization reaction rate at both electrodes is the same. Because the electrode potential of Fe is smaller than that of Ni, if both metals are left alone, the Fe electrode will corrode at a greater rate than the Ni electrode. When the Fe and Ni electrodes are connected by an electrical conductor, it is assumed that the solution has a small enough resistance so that both the Fe and Ni electrodes have the same corrosion potential $E_C^{a/m}$, with $E_{Fe}^{a/m} < E_C^{a/m} < E_{Ni}^{a/m}$. The

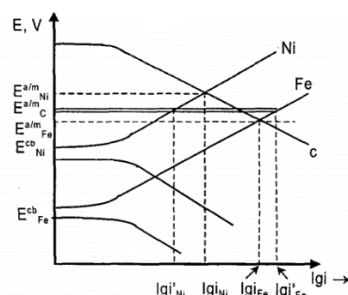


Figure 3. Polarization curve of Fe-Ni

general corrosion potential level $E_C^{a/m}$ corresponding to the corrosion density of Ni i_{Ni} is smaller than the corrosion current density without the Fe (i_{Ni}) electrode. On the contrary, the Fe corrosion current in the presence of Ni (i_{Fe}) is larger than the Fe corrosion current density in the absence of Ni (i_{Fe}). This is completely reasonable because Ni has a more positive electrode potential and can partly participate in the cathode reaction, thus reducing the corrosion rate; As for Fe, the corrosion rate increases. Factors affecting galvanic corrosion are diagrammed in Figure 4.

In Figure 4, we see:

The larger the potential difference, the stronger the galvanic corrosion: Between the Fe and Pt electrode ($E_{Fe}^0 = -0,44V$; $E_{Pt}^0 = +1,20V$) the potential difference is large, Fe is strongly corroded; There is a small potential difference between Fe and Ni electrodes ($E_{Fe}^0 = -0,44V$; $E_{Ni}^0 = -0,257V$), Fe corrosion increases slightly. Between the Fe and Zn electrode ($E_{Fe}^0 = -0,44V$; $E_{Zn}^0 = -0,76V$), $E_C^{a/m}$ can be smaller E_{Fe}^{cb} , then Fe is not corroded, Zn is strongly corroded.

The steeper the cathode polarization curve (large solution resistance, concentration polarity), the smaller the corrosion current and the lower the short-circuit connection efficiency, the metal with the more negative electrode potential will corrode strongly in the contact area.

The larger the ratio of the surface areas of the two electrodes: Ni cathode and Fe anode, the closer $E_C^{a/m}$ will be with $E_{Ni}^{a/m}$, then the Fe corrosion rate increases.

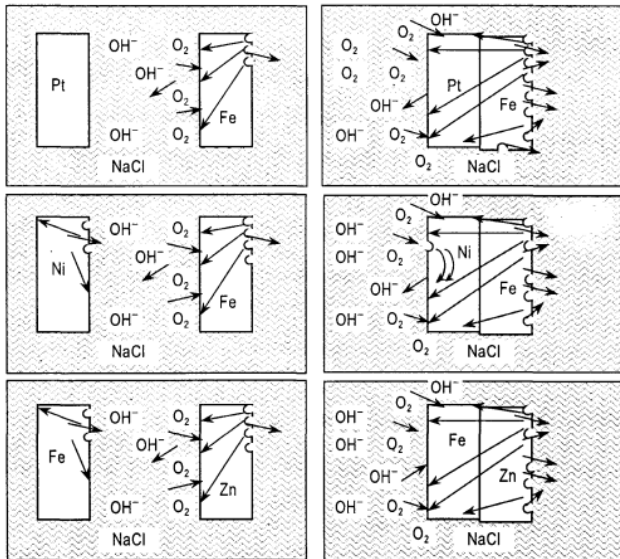


Figure 4. Galvanic corrosion between metals [1]

In the case of galvanic corrosion batteries between crystal grains and grain boundaries, the difference in composition and structure of the alloy at different locations can be the cause of corrosion. Galvanic corrosion batteries can form between crystal grains and grain boundaries, between crystal grains or between metals and impurities. For most metals and alloys, the grain boundaries are usually more chemically reactive than the metal matrix and thus corrode. The reason is that at the grain boundaries there are many lattice dislocations, many impurities and component residues (Figure 5).

On the contrary, there are also some metallic materials whose grain boundaries are less chemically active, because at the grain boundaries, the pyrolysis phenomenon concentrates more elements with more positive electrode potentials. This phenomenon causes corrosion in the vicinity of grain boundaries (Figure 6).

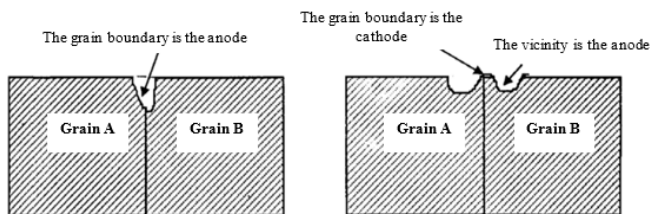


Figure 5. Corrosion at

Figure 6. Corrosion in

crystal grain boundaries [1] the vicinity of crystal grain boundaries [1]

Comparing single-phase alloys and multi-phase alloys, we see that single-phase alloys are more corrosion resistant than multi-phase alloys, because in the case of multi-phase, galvanic corrosion cell pairs can be formed between phases with different electrode potential stability. Corrosion of gray cast iron is a case. The typical structure of pearlite gray cast iron consists of black graphite on pearlite base. We know that the equilibrium electrode potential of graphite is higher than pearlite, thus forming a corrosion galvanic battery that has a graphite cathode and anode a pearlite metal base. The pearlite base is corroded and dissolved into the solution leaving behind graphite (Figure 7).



Figure 7. Structure of gray cast iron [1]

C. Metal corrosion rate

To determine the metal corrosion rate, quantities are given to determine which are mass corrosion rate, penetration rate and polarization curve.

Mass corrosion rate (P_{khl}):

Mass corrosion rate is considered as the mass lost due to corrosion per unit surface area, per unit time [1].

$$P_{khl} = \frac{m_1 - m_2}{S \cdot t}; \quad [\text{g/cm}^2 \cdot \text{day}] \quad (5)$$

In which: m₁, m₂ are the mass of sample metal before and after corrosion, g; S is the metal surface area, cm²; t is time, day.

Penetration rate (P_{tn}):

Penetration rate is the average depth calculated from the original surface of the corroded metal after one year, we have [1]:

$$P_m = \frac{P_{kil} \cdot 365}{\rho}; \quad \text{cm/year (or mm/year)} \quad (6)$$

In which: ρ is the density of the metal, g/cm^3 ; 365 is the number of days in a year.

Based on the Ptn penetration rate, we can determine whether the metal is durable or corrosive. Specifically, it can be divided into 3 groups as follows:

- + Group of metals with $P_{tn} < 0.125$ mm/year, considered very resistant to corrosion.
- + The group of metals with P_{tn} in the range of $(0.125 \div 1.25)$ mm/year are considered medium corrosion resistant metals.
- + The group of metals with $P_{tn} > 1.25$ mm/year are considered corrosion resistant.

In addition, the corrosion rate can be measured by the corrosion current density $i_{a/m}$ or by the volume of hydrogen gas released.

We can illustrate the mass corrosion rate through the corrosion current density according to Faraday's law [1]:

$$P_{kil} = \frac{i_{a/m}}{nF} \cdot M \cdot t; \quad [\text{g/dm}^2 \cdot \text{day}] \quad (7)$$

where: $i_{a/m}$ is the corrosion current density, A/dm^2 ; t is the time in a day and night (s); M is the atomic mass of the metal; n is the number of electrons exchanged by a metal atom; F is Faraday's constant.

Determine the corrosion rate using the polarization curve:

The case where both cathode and anode are inhibited by activation polarity. Let's consider the example of corrosion of zinc in acid solution, then the cathodic and anodic processes occur as follows:

- + Cathode process: $2H^+ + 2e \leftrightarrow H_2$
- + Anode process: $Zn \leftrightarrow Zn^{2+} + 2e$

Oxidized zinc has no charge accumulation, meaning that all the electrons produced by the zinc dissolution reaction are consumed by the dehydrogenation reaction. Then the oxidation rate and reduction rate must be equal.

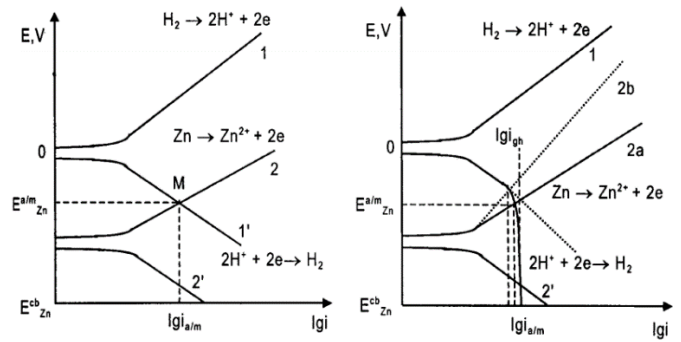


Figure 8. The polarization curves of two pairs of zinc and hydrogen

Line 1'01 is the polarization line of hydrogen in both directions of the reaction: $2H^+ + 2e \leftrightarrow H_2$

Line 2'02 is the polarization line of Zn in two directions of the reaction: $Zn \leftrightarrow Zn^{2+} + 2e$

Branches 1' (cathodic polarization of hydrogen) and 2 (anode polarization of Zn) represent the corrosion process of zinc in acidic environments. During corrosion, the rate of oxidation equals the rate of reduction, which occurs when branches 1' and 2 intersect. In the figure, two branches 1' and 2 intersect at M, respectively on the vertical axis is the corrosion potential and the horizontal axis is the corrosion current density $i_{a/m}$.

Similarly, we can determine the corrosion potential and corrosion current density when there is mixed polarity (activation polarity and concentration polarity), in which Zn has activation polarity, hydrogen has mixed polarity. Thus, the dehydrogenation process (cathodic process) has both activation polarity and concentration polarity; Metal oxidation (anode process) only has activation polarity.

In Figure 9, we see that the corrosion current is always less than or equal to the limiting current even though the anode polarization curve of zinc is changed from 2a to 2b: $i_{a/m} < i_{gh}$

D. Characteristics and factors affecting metal corrosion rate in saltwater - brackish water environments

According to research by scientists around the world, factors affecting the corrosion rate in seawater and brackish water include the following: salt concentration, oxide scale on the steel surface, hole corrosion, oxygen concentration, influence of temperature, water velocity, galvanic corrosion.

1) Effect of salt concentration

We know that salt water is a relatively homogeneous solution containing many salts, mainly NaCl and MgCl₂. In addition to the corrosive effects of NaCl and MgCl₂ salts, there are many other minerals in seawater that speed up corrosion to the extent that it can be considered that seawater contains up to 0.5N of NaCl salt. Studies showed that, with a concentration of 0.5N NaCl salt, the corrosion rate in seawater reaches its maximum value; any concentration higher or lower will have the corrosion rate less than the maximum value.

TABLE 1
STEEL PENETRATION RATE IN SEAWATER
CHANGES OVER TIME [1]

Year	1	2	3	...	8	9	10	11	...
P _{max} , μm/ year	130	130	130	130	130	105	80	55	55

The corrosion rate of steel in seawater is often expressed as the penetration rate P_{tn}. The penetration rate of carbon steel in seawater is about 0.13mm/year. This rate remains constant for about 8 years. After 8 years, the corrosion rate decreases steadily by about 25 μm per year for several years and then is relatively stable (table 1).

The results of research on the corrosion rate in seawater of many types of HSLA steel during the first five and ten years are similar to carbon steel, at about 130 μm/year. It can be said that common carbon steel as well as low-alloyed HSLA steel with

Cr and Cu are not resistant to corrosion in seawater. Table 2 shows that only steel containing Mo is relatively resistant to corrosion in seawater, while other materials corrode quite quickly.

TABLE 2
CORROSION RATE OF SOME MATERIALS IN
SEAWATER [1]

Materials	Corrosion rate, μm/year, in			
	1,5 years	2,5 years	4,5 years	8,5 years
Construction carbon steel	120	105	85	70
HSLA steel	105	110	95	80
HSLA containing Mn - 0.75Ni - 0.45Cu	110	95	75	65
HSLA containing 1.8Ni - 0.81Cu	135	115	90	80
HSLA containing 2.6Cr - 0.52Mo	35	40	40	33

In estuaries or brackish water, it also contains salt but is completely different from sea water. Depending on the characteristics of each location, brackish water may have lower salinity but may contain sulfate, phosphate and nitrate salts. Normally, low salinity has a small corrosion rate, but it also depends on other factors such as water temperature, pollution, oxide layer erosion, etc.

2) Effect of oxide scale on steel surface

Statistical results of corrosion rates in many parts of the world showed that the penetration rate of steel in seawater is almost similar worldwide, but the depth of penetration is different between carbon steels that have and do not have an oxide scale layer (Table 3). The main reason is that under the metal oxide scale layer, there is a more stable negative electrode potential than steel without scale layer. Therefore, the steel under the oxide scale layer is cathodic, the area under the scale layer is dug deeper.

TABLE 3
CORROSION RATE AND MAXIMUM DEPTH OF
CORROSION HOLES IN SEAWATER AFTER 10
YEARS [1]

Locations	Without oxide scale layer		With oxide scale layer	
	P _{tn} , μm/year	Deepest, mm	P _{tn} , μm/year	Deepest, mm
Halifax	120	1.9	110	1.7
New Zealand	75	1.1	85	3.7
Anh	60	1.65	60	4.0
Colombo	90	1.6	100	6.1

3) Effects of hole corrosion

Research showed that alloy steels are more resistant to corrosion than carbon steel; the hole corrosion rate of alloy steel is only half of carbon steel's. Studies on corrosion of 2% Ni steel in seawater after 6 years showed that the depth of the corrosion hole is about 2mm. Under the same conditions, carbon steel corrodes with a hole depth of 5mm.

Comparison of corrosion rates in seawater and fresh water in the tropics [1] also showed that in seawater, the rate of hole corrosion increases faster than in fresh water. Especially, steel without Ni has the highest rate of hole corrosion.

4) Effect of oxygen concentration

The role of oxygen concentration also has a great influence on the corrosion rate of metals. We know that oxygen is the most important oxidizing element and at the same time the most important passivation factor for steel surfaces. The effects of depth, salinity, temperature and pH on the corrosion rate in seawater have been studied. The results confirmed that the corrosion rate is proportional to the oxygen content.

The relationship between corrosion rate P_{tn} (μm/year) with oxygen CO_2 content (ml/l) and temperature T (°C) is determined according to formula [1]:

$$P_{tn} = 21.3 + 25.4CO_2 + 0.356T \quad (8)$$

5) Effect of temperature

According to formula (8), we see that temperature also significantly affects the metal corrosion rate. For each metal, the difference in temperature creates a potential difference that causes galvanic corrosion.

6) Effect of water speed

Water speed also affects the corrosion rate of metals. In general, as the water speed increases, the corrosion rate increases. Studies have shown that the corrosion rate of carbon steel and low-alloyed steel with Cu is the same and is about 70 μm/year. But when the flow rate is high, the corrosion rate increases to 380 μm/year for carbon steel, and for low-alloyed steel with Cu, the corrosion rate is 120 μm/year. This proves that low-alloyed steel with Cu has good anti-corrosion properties in moving seawater.

In case the ship runs in a river mouth, the water flow speed is high, the oxide layer is eroded away. So the corrosion rate is faster than in still sea water. Survey results showed that erosion caused by alluvial soil in the estuary, causing the loss of the protective oxide layer on the surface, is an important factor affecting the corrosion rate of structures and metal structures in the estuary area.

With galvanic corrosion, when the C/A area ratio remains constant, the greater the water movement speed, the greater the corrosion rate (Table 4).

TABLE 4
CORROSION RATE DEPENDS ON WATER SPEED
[1]

Corrosive pair	Water speed of 0,15m/s		Water speed of 2,4m/s	
	P _{tn} , μm/year	Coefficient	P _{tn} , μm/year	Coefficient
Carbon steel - carbon	280	1	785	1

steel				
Carbon steel - stainless steel 8Cr8Ni	655	2.34	905	1.15
Carbon steel - Ti	645	2.30	1040	1.32
Carbon steel - Cu	555	1.98	2440	3.10
Carbon steel - Ni	545	1.95	2820	3.59

increases. For example, in the Fe - Cu corrosion pair, the Fe corrosion rate is proportional to the Cu surface area. The results recorded in Table 5 show the relationship between the mass of Fe lost in P, g/cm² after 20 hours of immersion in a solution containing 3% NaCl, changing according to the ratio of Cu cathode and Fe anode areas (C/A).

Table 5 shows that the larger the C/A area ratio, the higher the corrosion rate.

TABLE 5
CORROSION RATE DEPENDS ON C/A AREA
RATIO [1]

C/A	1/1	2/1	5/1	8/1	12/1
P_{khl} , g/cm ²	0.23	0.57	0.79	0.94	1.09

7) Effects of garvanic corrosion

Galvanic corrosion in seawater is more important than in other environments because seawater conducts electricity relatively well. According to the data in table 7.6 [1], it shows that the materials Mg, Mg alloy, Zn, Be, Al alloy, steel (cast iron), HSLA steel, austenitic iron Ni, Cu and Cu alloy,... in increasing order of Ea/m; the materials standing above are anodes during the corrosion process.

The stable voltage value depends significantly on seawater composition, ocean waves, seawater temperature, metal purity, surface corrosion products, biological activity, etc. When forming galvanic battery pair, the metals on top are polarized, the anode is corroded; the metals standing below are cathodes that do not corrode.

The relationship of the surface area ratio between the two metals in a galvanic corrosion cell pair has a great influence on the corrosion rate, because the number of electrons exchanged between the two metals in the galvanic corrosion cell pair must be equal. Normally, the corrosion reaction rate is determined by the cathode reaction rate, so when the cathode area increases, the corrosion rate

increases. Table 6 shows that when carbon steel is left alone, the corrosion rate in seawater is about 5.5mg/m².day. When assembling carbon steel on the same structure with HSLA steel, although the electrode stability of these two types of steel is only 0.05V different, the corrosion rate of carbon steel is up to 8.2mg/m².day. When assembling carbon steel with 410 stainless steel, due to the large potential difference of about 0.35V, the corrosion rate of carbon steel increases by 2.36 times. This shows that materials that are nearly the same or have nearly the same stable electrode potential, but are assembled to work in seawater, the corrosion rate increases.

TABLE 6
GALVANIC CORROSION RATE IN SEAWATER [1]

Pair of galvanic corrosion batteries	Corrosion rate, mg/m ² . day		
	C/A=1/1	C/A=1/8	C/A=8/1
Carbon steel- carbon steel	5.5	-	-
Carbon steel - HSLA steel	8.2	6.7	17
Carbon steel -	13	7.0	47

410 stainless steel			
HSLA steel - HSLA steel	4.5	-	-
HSLA steel - 410 stainless steel	9.5	6.2	35

The results presented in Table 6 also show that: if the area ratio is increased to 8/1, the carbon steel-HSLA pair has a corrosion rate increased by 3.1 times, while the carbon steel-410 stainless steel pair has a corrosion rate of 3.1 times. Corrosion increases 8.5 times compared to carbon steel. When reducing the C/A ratio, the corrosion rate decreases.

Table 7 also shows that the galvanic corrosion rate in seawater is about 3 to 5 times that in fresh water with the ratio C/A=7/1.

TABLE 7
GALVANIC CORROSION RATE IN SEAWATER
AND FRESH WATER [1]

Galvanic corrosive pair	Corrosion rate, mg/m ² . day		
	Sea water	Fresh water	Coefficient
Carbon steel - CuP	26.8	9.3	2.88
Carbon steel - 316 stainless steel	23.6	6.6	3.57
Carbon steel - Monel	24.7	8	3.1
Aluminum - carbon steel	21.5	4	5.37

E. Corrosive zones in seawater

In the seawater environment, each structure is divided into six different corrosion zones in the

direction normal to the sea surface. Corrosion rates in these areas are depicted in Figure 10.

Atmospheric area: This zone is influenced by sea air. It has relatively high humidity but does not get wet due to ocean waves.

Water area caused by waves splashing water: Depending on the altitude or time of survey, this area may only be wet; there may be a thin layer of water rubbing on the surface.

Tidal area: The area sandwiched between the highest and lowest levels of tidal water. This area is sometimes in the air environment, sometimes submerged in sea water.

The area below the low tide level (low tide area): This area is narrow, ranging from 0.3 to 1 meter below the low tide level. This is the strongest corrosion area. The corrosion process occurs continuously because it is always submerged in sea water.

Area deeply submerged in sea water (gray area): The structure ranges from below the low water area to the turbid water area.

Burial area (black area): This zone is below the turbid water level, where the structure is located on the ocean floor.

In Figure 10, we see that the order of corrosion rate from largest to smallest is as follows: Water splashing area, low tide area, gray area, tidal area, atmospheric area and black area. In which, the water splashing area and low tide area have the highest corrosion rate, the least corrosive areas are the tidal area and the black area. This is the basis for choosing appropriate materials to limit the impact caused by metal corrosion.

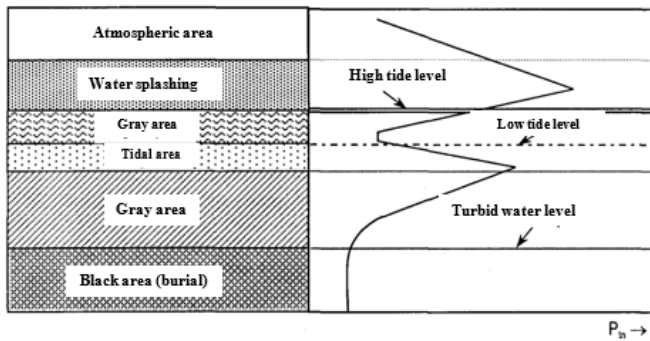


Figure 10. Corrosion rate changes with sea level depth [1]

Comparing carbon steel and alloy steel (HSLA), through research, HSLA steel (especially those containing Ni, Cu and P) is more resistant to corrosion in the atmospheric area and in the water splashing area than carbon steel. In the tidal area, low tide area and black area, the corrosion resistance of these two types of steel is equivalent.

Test results after 5 years show that HSLA steel with 0.5Ni-0.5Cu-0.1P is durable in areas exposed to sea water, and in areas submerged in sea water, the corrosion rate is 115 $\mu\text{m}/\text{year}$.

III. ANTI-CORROSION SOLUTION SYSTEM FOR STRUCTURES IN SALT WATER - BRACKISH WATER ENVIRONMENTS

Based on research on factors affecting metal corrosion in seawater-brackish water environments, we realize that there is a need for metal corrosion prevention solutions with the aim of improving the lifespan of structures and components of marine and coastal projects, contributing to the economic efficiency to the country.

There are many different solutions to prevent corrosion of metal structures, depending on the level of economic and industrial development of each country at each time as well as the importance of the structure and the need to produce one product at a time. Within the scope of the article, based on the mechanism of metal corrosion, the authors offer a

system of general solutions, from which each specific solution is applied to prevent metal corrosion for other structures and works, and evaluate its advantages and disadvantages.

General solutions to prevent metal corrosion are presented according to the following diagram:

General solutions to prevent metal corrosion are presented according to the following diagram in Figure 11.

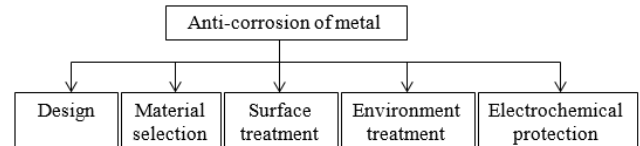


Figure 11. Metal anti-corrosion solutions

A. Design solution

In a saltwater - brackish water environment, before manufacturing a steel structure or constructing a reinforced concrete project, a reasonable structural design is the first important thing to do for anti-corrosion. The designer must analyze the working conditions of each module and each detail in the structure, thereby selecting materials with requirements for mechanical, technological, electromagnetic, and heat properties satisfying the economic and environmental requirements. Specifically, the following principles need to be met: The structure must be reasonable, meeting production requirements, and be easy to apply anti-corrosion protection methods such as easy to paint, maintain, or apply other protective layers of good and uniform quality and no water stagnation.

Avoid creating sudden bends in the pipeline so that the flow does not create vortices and does not cause corrosion.

Replace riveted joints with welded joints to eliminate joint corrosion. If rivets must be used, we should choose a material with a stable electrode potential higher than the material to be joined.

This is a general solution, applicable to most structures and construction works, especially wharves in saltwater-brackish water environments.

B. Material selection

Choosing the right metal material is considered the most optimal solution to prevent corrosion for construction projects exposed to saltwater and brackish water.

Due to their corrosion resistance properties, the following materials are often used in seawater environments: copper and copper alloys; types of steel,...

Application range:

- Copper and copper alloys: this material is quite resistant to corrosion in freshwater and seawater environments. Even when the water flow speed is high, and has the ability to prevent wear and tear caused by all kinds of organisms in the water, copper and copper alloys are often used to make rudders for ships, seawater pipelines, petroleum and chemical distribution pipelines, water systems, etc.

Disadvantage: this material is quite expensive.

- Steels:

- + Carbon steel: This is the most common metal material. Due to its durability, ductility, good technological properties, cheapness and popularity, steel is used in most construction structures on land and at sea. The disadvantage of carbon steel is that it is less resistant to corrosion in most environments, so to use it effectively in saltwater-brackish water environments, it must combine anti-corrosion protection measures such as: zinc coating, painting and Anode protection in acidic environments, etc.

- + High-strength alloy steel (HSLA) has higher mechanical and chemical durability and hardness than carbon steel. HSLA steel resists corrosion better, especially stress corrosion, which is one of the forms of corrosion. Corrosion causes great damage, so in important structures (ports, drilling rigs), HSLA steel

should be used in combination with cathodic protection with protectors.

- + Peritone stainless steel (chromium content from 20% to 30%), has good corrosion and pitting resistance, so it can be used in seawater environments and petrochemical industry.

- +Austenitic stainless steel with the composition of (17-19)Cr – (7-12)Ni, is very resistant to corrosion in the atmosphere, fresh water and seawater; so, this material is commonly used in chemical industry, especially in the acid production industry, petrochemical industry and food industry. Disadvantages of austenitic stainless steel are that it is expensive and corrodes in seawater.

C. Surface treatment

This is a solution that is used a lot in practice, with the technology of creating protective layers on metal surfaces, which prevent corrosion by creating a protective film on structures and metal works, helping to limit the impact of the environment and corrosive chemicals on metal.

A protective layer is simply the use of a layer of preservative grease, chemicals or paint on the surface of metal parts, in which coating is an effective measure that is often applied to all projects and boats (Figure 12). In addition, coatings can be created using technologies such as immersion technology in molten metal, plasma spraying, thermochemical technology, electrochemical technology, etc. Metals are often used for surface coating. These are: Nickel, Zinc, aluminum, tin, lead.

Composite materials are new with many outstanding features, especially the ability to not rust and resist corrosion when operating long-term in marine climate and sea water environments. They are now increasingly widely applied in many different fields. Composite materials have been used to produce small ships or cover layers of composite materials on the surface of metal ship-boat hulls, inland waterway warning signs, etc. The results are very positive in

prevents metal corrosion, increases usage time for ships, boats, waterway warning systems, etc.



Figure 12. An engineer applying coating to a ship's hull

Coating layers of composite materials or using grease cloth wrapping technology (Xunda T900) on the outside of oil pipelines, chemical pipelines, hydraulic pipes placed in seawater and along the coast has also been applied effectively, increasing the life of the structures.

To protect the legs of offshore drilling rigs due to the erosion of marine microorganisms (fouling), which affects the longevity of the structure, an effective protection solution is to use anti-fouling rings (MGP-I), designed in circles to install on rig bases, horizontal bars, risers, etc., with the aim of eliminating and preventing barnacles and marine organisms from sticking to metal surfaces (Figure 13). In addition, in the transportation construction industry in estuaries and coastal areas, this solution is also applied to steel structures that are quickly corroded by saltwater and brackish water environments.

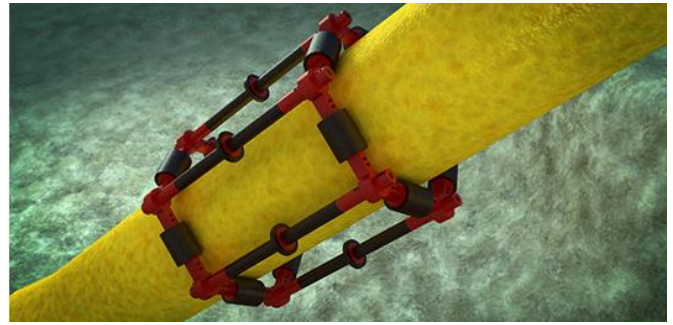


Figure 13. An equipment to protect barnacles from adhering to the structure

The above solutions have brought good results, preventing and slowing down the corrosion process of metals. However, in terms of economics, they also cost a lot to implement, operate, and periodically maintain those structures and works.

D. Environment treatment

The environment plays an important role in the corrosion process. A fairly effective solution is to use inhibitors to slow down the metal corrosion process. Inhibitors are substances that, when introduced into a corrosive environment in very small amounts, have the effect of slowing down corrosion or reducing the rate of corrosion.

Of the three processes that occur when metals are corroded: anode process, cathode process and conduction process, using corrosion inhibitors to affect these processes is to inhibit them. When restrained, the polarity increases, the polarization curve becomes steeper, so the corrosion rate decreases.

In saltwater-brackish water environments, some of the following inhibitors are often used to prevent corrosion of metals: NaNaO_2 , Na_2SiO_3 , $\text{Ca}(\text{HCO}_3)_2$. However, one of its disadvantages is its short protection time.

E. Electrochemical protection

To protect metal structures in saltwater-brackish water environments, the commonly used solution is cathodic protection, with the principle of reducing

or completely eliminating the metal corrosion process thanks to metal cathode polarization by protector (sacrificial anode) or by external current.

- Protecting the metal with a protector: The metal to be protected is connected to a protector with a more negative electrode potential and placed in the same environment. Then the metal becomes a cathode and does not corrode, while the protector corrodes more strongly. (Figure 14).

Protectors are often made from Zn, Al, Mg or their alloys.

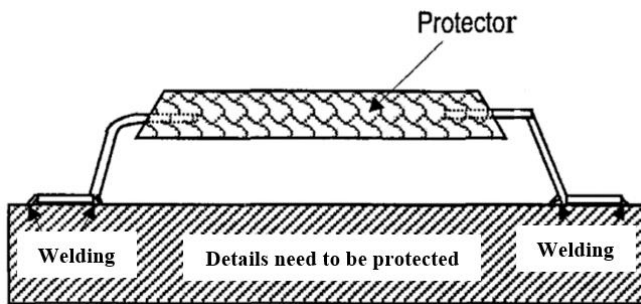


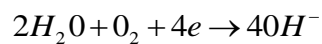
Figure 14. Diagram of protection by protector in water environment [1]

Scope of application of some alloys as protector:

+ Use zinc Zn as protector to protect steel hulls of ships and barges that are frequently exposed to seawater. The zinc plate is installed on the stern of the ship to form an electrochemical battery, with the ship's hull is the positive pole, the zinc plate is the negative pole, acting as an anode, so it corrodes according to the mechanism:

at the anode (negative pole): $Zn \rightarrow Zn^{2+} + 2e^-$

at the cathode (positive pole):



Then electrochemical corrosion will occur. Zinc is a more active metal than iron, so it corrodes, while iron does not. After a period of time, the zinc plate will corrode and will be replaced periodically (Figure 15).

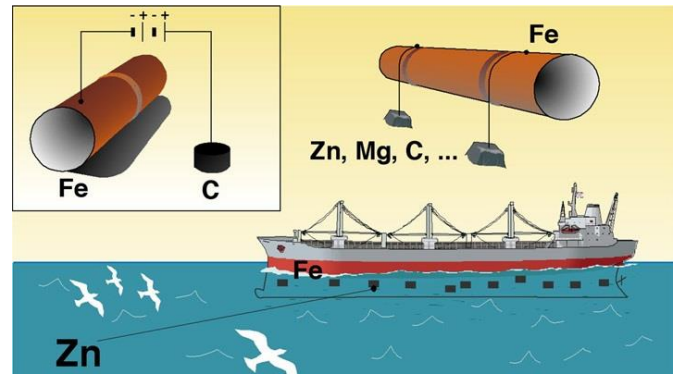


Figure 15. Using zinc plate to protect ship hulls

+ Al-Zn-Sn alloy is used to protect wharves and coastal traffic bridges, with a protection period of 5 to 10 years.

+ Al-Zn-Ln and Al-Zn-Hg alloys are used to protect drilling rigs and gasoline tanks in soil and seawater, with a protection period of 10 to 20 years.

- *Cathode protection by external current:*

The diagram of cathodic protection by external current is shown in Figure 15. When connecting the metal to be protected to the cathode of the power source to lower the metal's potential below the equilibrium potential of the metal oxidation process, the speed Corrosion is zero. The metal is completely protected, while the anode surface has corrosive reactions.

Depending on specific conditions, the anode material can be used as fast-dissipating, slow-dissipating or inert material. Steel anodes are of the fast consumable type; anodes made of graphite, Fe-Si alloy or lead-based alloy are of the slow consumable type and Titanium or Platinum coated anodes are of the inert type.

When protecting underground structures in water, wide anodes should be used. Large structures (underground pipes, long wharves, etc.) should have multiple anodes installed. Each anode has its own path so checking must be performed for each anode separately.

Note that during the cathodic protection process, reduction reactions occurring on the surface of the

metal structure can produce hydrogen gas and create an alkaline environment. If protection with a negative potential shift is too large, too much hydrogen can escape, causing hydrogen embrittlement.

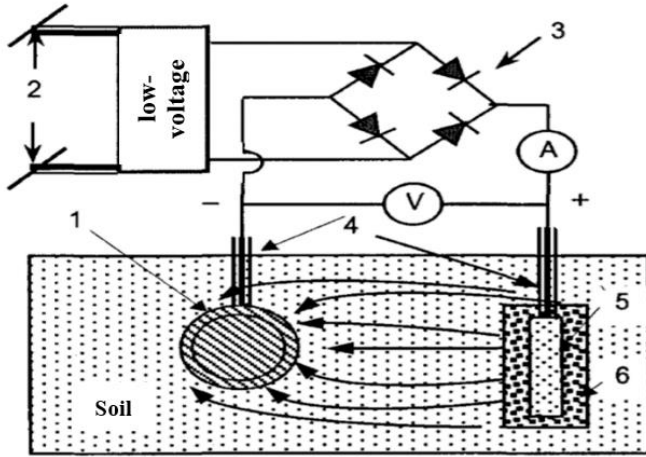


Figure 16. Diagram of cathodic protection by external current [1], with 1- metal that needs protection; 2- power source net; 3- two half cycle rectification; 4- conductor bars have insulating covers; 5- anode; 6- conductive filler

IV. CONCLUSIONS

The article has researched the basis of metal corrosion process, corrosion rate, characteristics and factors affecting metal corrosion rate in salt water - brackish water environment; researching metal corrosion zones in seawater and brackish water. Finally, we see that:

Metal corrosion depends on many different influencing factors, especially in seawater environments that contain a lot of salt and easily form galvanic corrosion, significantly affecting the metal corrosion rate.

Metal corrosion also depends on each different corrosion area, in which the water splashing and low tide are the areas with the highest corrosion rate.

The article has proposed a system of appropriate solutions to prevent corrosion of metal structures and structures in saltwater-brackish water

environments, in order to increase the life of boats and port structures at sea, civil defense works and reinforced concrete wave and flood protection dikes along coasts and estuaries.

Depending on the purpose of use, importance and economic efficiency of each structure and project, we choose each appropriate solution or can combine many different solutions to bring best value, practicality and optimal efficiency.

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