Mohamed Khider University of Biskra
Faculty of Science and Technology
Department of Industrial Chemistry

MASTER'S THESIS

Field: Science and Technology
Program: Process Engineering
Specialty: Chemical Engineering

Ref. : Enter the document reference

Submitted and defended by :
ZAOUCH Roufaida
On :02 /06 /2025

Synthesis of a corrosion inhibitor based on aromatic derivatives

---

Jury :

Dr	NOUIOUA Asma	Lecturer	University of Biskra	President
Dr	CHÉRIFI Nedjema	Lecturer	University of Biskra	Reviewer
Dr	ADAIKA Kaltoum	Lecturer	University of Biskra	Examiner

Academic Year : 2024 – 2025

ملخص

الهدف من هذا العمل هو ايجاد حل لمشكلة التآكل ,وذلك من خلال تخليق مثبط للتآكل يتمثل في مادة الهيدروكينون ,ودراسة تأثيره على الفولاذ في وسط مائي عدواني, وهو ماء الالبيان جامعة بسكرة

ينقسم هذا العمل الى قسمين رئيسيين :

في الجزء الاول , قمنا بتحضير مركب الهيدروكينون انطلاقا من الانيلين , وتمت دراسة تأثيره على نوع من انواع الفولاذ يعرف ب اكس 42 .

اما في الجزء الثاني , فقد تطرقنا الى دراسة النتائج وتحليلها بناءا على البيانات التي تم الحصول عليها .

اظهرت نتائج التجارب ان المثبط المستخدم يتمتع بكفاءة تثبيط عالية تجاوزة 70بالمئة في الوسط المائي المختار وذالك في تراكيزين 0.1و 0.02 جزء من المليون .

Résumé

L'objectif de ce travail est de proposer une solution au problème de la corrosion, en synthétisant un inhibiteur de corrosion, l’hydroquinone, et en étudiant son effet sur l'acier dans un milieu aqueux agressif, à savoir l'eau d’Albien, université de Biskra.

Ce travail est divisé en deux parties principales :

- Dans la première partie, nous avons synthétisé l’hydroquinone à partir de l’aniline, et nous avons étudié son effet sur l’acier de type X42.
- Dans la seconde partie, nous avons analysé et interprété les résultats obtenus.

Les résultats expérimentaux ont montré que l'inhibiteur présente une très bonne efficacité, dépassant 70 % dans le milieu aqueux étudié, aux concentrations de 0,1 et 0,02 ppm d’hydroquinone.

Abstract

The aim of this work is to find a solution to the problem of corrosion by synthesizing a corrosion inhibitor hydroquinone and studying its effect on steel in an aggressive aqueous medium, specifically the Albien water, Biskra university.

This work is divided into two main parts:

- In the first part, hydroquinone was synthesized from aniline, and its effect on X42 steel was investigated.
- The second part involved analyzing and interpreting the obtained results.

The experimental results showed that the inhibitor exhibits very good efficiency, exceeding 70% in the selected aqueous medium, at hydroquinone concentrations of 0.1 and 0.02 ppm.

Thanks

First and foremost, I thank Almighty Allah who blessed me with the gifts of intellect, faith, patience, and perseverance to complete this humble work. Praise be to Allah always and forever.

I extend my deepest gratitude and appreciation to my esteemed professor, **DR. CHÉRIFI Nedjema**, who enriched me with her knowledge and played a significant role in guiding me, allowing this work to take its present form .

I would also like to express my sincere thanks and appreciation to **Dr. NOUIOUA Asma** and **Dr. ADAIKA Kaltoum** for kindly agreeing to evaluate and discuss this work.

I pray to Allah to grant you all continued health and well-being.

إهداء

أهدي هذا التخرج لمن علمني أن اعطي و معنى ان اعيش من اجل الحق والعلم ولمن أحمل اسمه بفخر , الى **والدي العزيز** رحمه الله .

والى ملاكي وسعادتي وسر الوجود و ابتسامتي في الحياة **أمي الحبيبة** حفظها الله .

ولأولئك الذين لديهم ميزة كبيرة في تشجيعي وتحفيزي ,والذين اكتسبت بحضورهم قوة لاحدود لها ولمن تعلمت معهم معنى الحياة إخوتي وأخواتي الاعزاء .

ولأولئك الذين تمتعوا وتميزوا بالولاء والعطاء ,ولمن رافقتهم في دروب الحياة السعيدة والحزينة **أصدقائي الاعزاء** واخص بالذكر **صديقتي العزيزة رانيا .**

وجميع الزميلات والزملاء في قسم الكيمياء الصناعية حفظهم الله .

وفي النهاية قال الله تعالى **" رَبِّ إِنِّي لِمَا أَنْزَلْتَ إِلَيَّ مِنْ خَيْرٍ فَقِيرٌ "**... سورة القصص

أسأل الله أن أكون قد وفقت في إتمام هذا العمل ,فاللهم إن كنت قد أصبت فبتوفيق منك ثم بعون من حولي وإن كنت قد أخطأت,فالكمال لله وحده وتعالى إنك انت نعم المولى ونعم النصير ,وختامي بأن الحمد لله رب العالمين.

Summary

Chapter I : Generalities of corrosion 4

Conclusion

List of figures

Chapter I : Generalities of corrosion

Chapter II : Experimental staudy

Chapter III : Discussion of the results

List of tabels

Chapter I : Generalities of corrosion

Chapter II : Experimental staudy

List of schemas

General introduction

General introduction

The word corrosion is as old as the earth, but it has been known by different names. Corrosion is known commonly as rust, an undesirable phenomena which destroys the luster and beauty of objects and shortens their life. A Roman philosopher, Pliny (AD 23–79) wrote about the destruction of iron in his essay 'Ferrum Corrumpitar.' Corrosion since ancient times has affected not only the quality of daily lives of people, but also their technical progress. There is a historical record of observation of corrosion by many people , but there was little curiosity regarding the causes and mechanism of corrosion until Robert Boyle wrote his 'Mechanical Origin of Corrosiveness.' Philosophers, writers and scientists observed corrosion and mentioned it in their writings:

- Pliny the elder (AD 23–79) wrote about spoiled iron.
- Herodotus (fifth century BC) suggested the use of tin for protection of iron.
- Lomonosov (1743–1756).
- Austin (1788) noticed that neutral water becomes alkaline when it acts on iron.
- Thenard (1819) suggested that corrosion is an electrochemical phenomenon.
- Hall (1829) established that iron does not rust in the absence of oxygen.
- Davy (1824) proposed a method for sacrificial protection of iron by zinc.
- De la Rive (1830) suggested the existence of microcells on the surface of zinc [1].

Corrosion laboratories established in M.I.T., USA and University of Cambridge, UK, contributed significantly to the growth and development of corrosion science and technology as a multi disciplinary subject. In recent years, corrosion science and engineering has become an integral part of engineering education globally [1].

Corrosion protection involves a range of methods, including cathodic and anodic protection, as well as the use of corrosion inhibitors. Among these, inhibitors are often considered the most effective and economical solution due to their low cost and ease of synthesis. In this study, we aim to synthesize a corrosion inhibitor, hydroquinone, and evaluate its effectiveness in protecting X42 steel in an aqueous medium of Albien water, which is known for its aggressive and highly corrosive nature. The selection of hydroquinone is based on its high availability of free electrons due to its aromatic chemical structure, which enables interaction with metal surfaces and the formation of a protective layer. Its inhibitory performance was investigated in this aggressive medium using X42 steel as a representative substrate.

The field of corrosion protection holds particular importance in Algeria's oil industry, where companies such as Sonatrach society suffer from significant corrosion issues in petroleum pipelines. This is mainly due to the presence of water Albien an extremely aggressive medium mixed with crude oil during the extraction process.

This thesis start with general introduction and is divided into three main chapters. The first chapter presents general information about the phenomenon of corrosion, inhibitors, and steel. The second chapter focuses on the practical part, which includes the synthesis of a corrosion inhibitor and the study of its effectiveness in reducing the corrosion rate, as well as an analysis of the physical and chemical properties of the water and the steel used in the study. The third chapter is dedicated to discussing and analyzing the obtained results finally ,a conclusion on the results obtained .

Chapter Ⅰ: Generalities of corrosion

I . 1 . Introduction

There are four main reasons to study corrosion. Three of these reasons are based on societal issues regarding (i) human life and safety, (ii) the cost of corrosion, and (iii) conservation of materials. The fourth reason is that corrosion is inherently a difficult phenomenon to understand, and its study is in itself a challenging and interesting pursuit [2].

I . 2 . Corrosion and the conservation of materials

Corrosion deteriorates metals by transforming them into oxides or other corrosion byproducts. As a result, environmentalists aim to preserve metal resources not only to conserve natural mineral deposits but also to minimize the volume of solid waste sent to landfills or recycling facilities . Moreover, prolonging the lifespan of metal components or products delays the need for further manufacturing or processing, which in turn helps reduce greenhouse gas emissions **Fig. I.1** [2].

Fig.I.1. Oil pipeline corrosion [3] .

I . 3 . Challenges for today’s corrosion scientist

Several important timely challenges to the corrosion scientist can be listed. These are the following:

1. The development of protective surface treatments and corrosion inhibitors to replace inorganic chromates, which are environmentally objectionable.
2. An improved conservation of materials through the development of corrosion-resistant surface alloys which confine alloying elements to the surface rather than employing conventional bulk alloying.
3. The formulation of a new generation of stainless steels containing replacements for chromium and other critical metals.
4. An improved understanding of passivity so as to use our fundamental knowledge to guide the development of alloys having improved corrosion resistance.
5. Understanding the mechanism of the breakdown of passive oxide films by chloride ions and subsequent pitting of the underlying metal.
6. The development of “smart” organic coatings which can detect a break in the coating and automatically dispatch an organic molecule to the required site to both heal the coating and inhibit corrosion.
7. The ability to predict the lifetime of metals and components from short-term experimental corrosion data[2].

I . 4 . Definition of corrosion

According to American Society for Testing and Materials' corrosion glossary, corrosion is defined as "the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties"[4].

The word “rusting” applies to the corrosion of iron and plain carbon steel. Rust is a hydrated ferric oxide which appears in the familiar color of red or dark brown. See **Fig. I.2**. Thus, steel rusts (and also corrodes), but the non-ferrous metals such as aluminum, copper, and zinc corrode (but do not rust). The term “white rust” is often used to describe the powdery white corrosion product formed on zinc. The “white rusting” of sheets of galvanized steel (zinc-coated steel) is a frequent problem if the sheets are stacked and stored under conditions of high relative humidity. Condensation of moisture between stacked sheets will often lead to “white rusting”[2].

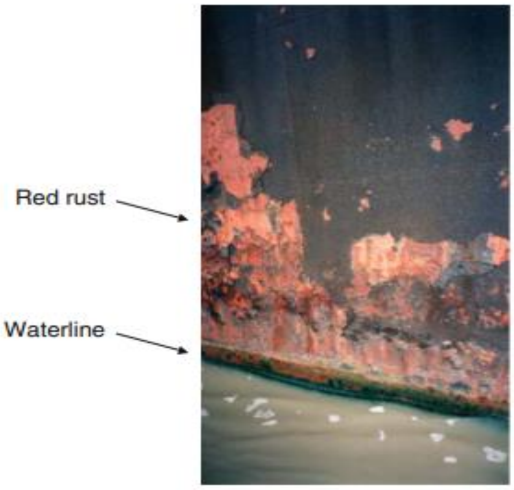


Fig.I.2. An example of red rust showing the corrosion of a ship near the waterline D [2].

I . 5 . Electrochemical reactions

Corrosion is an electrochemical process. That is, corrosion usually occurs not by direct chemical reaction of a metal with its environment but rather through the operation of coupled electrochemical half-cell reactions[2].

I . 5 . 1 . Half-Cell reactions

Ahalf-cell reaction is one in which electrons appear on one side or another of the reaction as written [2].

I . 5 . 1 . 1 . Anodic reactions

The loss of metal occurs as an anodic reaction. Examples are

$$\mathrm{Fe}_{(s)} \rightarrow \mathrm{Fe}^{2+}_{(aq)} + 2e^{-} \qquad \textbf{(I .1)}$$

$$\mathrm{Al}_{(s)} \rightarrow \mathrm{Al}^{3+}_{(aq)} + 3e^{-} \qquad \textbf{(I .2)}$$

$$2\mathrm{Cu}_{(s)} + \mathrm{H_2O}_{(l)} \rightarrow \mathrm{Cu_2O}_{(s)} + 2\mathrm{H}^{+}_{(aq)} + 2e^{-} \qquad \textbf{(I .3)}$$

Each of the above reactions in Eqs. (1), (2), and (3) is an anodic reaction because of the following:

(1) A given species undergoes oxidation, i.e., there is an increase in its oxidation number.

(2) There is a loss of electrons at the anodic site (electrons are produced by the reaction).

These ideas are illustrated schematically in **Figure I.3** [2].

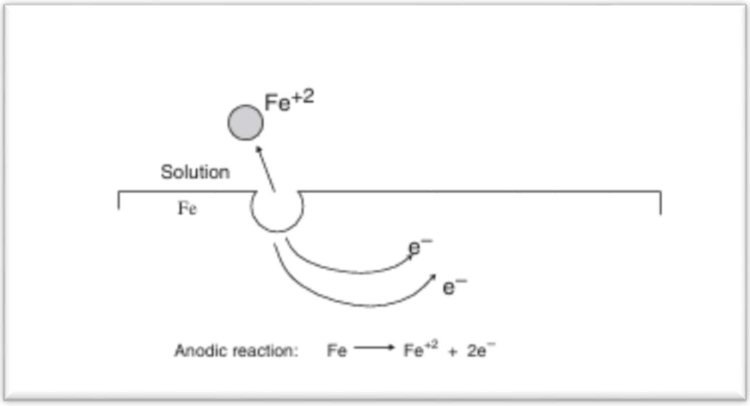


Fig.I.3. Example of an anodic reaction– the dissolution of iron [2] .

I . 5 . 1 . 2 . Cathodic reactions

In a cathodic reaction :

(1) A given species undergoes reduction, i.e., there is a decrease in its oxidation number.

(2) There is a gain of electrons at the cathodic site (electrons are consumed by the reaction).

An example :

$$2\mathrm{H}^{+}_{(\mathrm{aq})} + 2e^{-} \rightarrow \mathrm{H}_{2\,(\mathrm{g})} \qquad \textbf{(I .4)}$$

See **Fig**. **I.4.** for a schematic representation of this reduction reaction . [2]

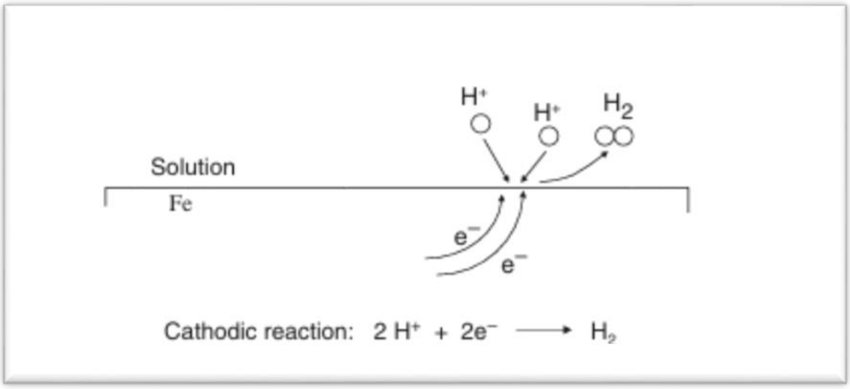


Fig.I.4. Example of a cathodic reaction– hydrogen evolution on iron immersed in an acid solution [2].

I . 6 . Corrosion types based on mechanism

I . 6 . 1 . Uniform (or general corrosion)

Uniform corrosion refers to a type of corrosion that spreads relatively evenly across the surface of a material, resulting in a uniform reduction in thickness. This form of corrosion commonly affects metals that do not exhibit strong passivation behavior in their operating environment such as iron. It is considered the most widespread form of corrosion and accounts for the majority of material loss. However, it is not regarded as particularly dangerous, as the rate of material degradation can be easily estimated through basic testing. This predictability allows for the design of appropriate corrosion allowances, taking into consideration the required strength and intended service life of the component [4] .

I . 6 . 2 . Pitting

Pitting is a form of localized corrosion in which the attack is confined to a small fixed area of the metal surface. Pitting occurs due to localized breakdown of a passive film, usually by chloride ions. **Fig I.5** shows a cross section of a corrosion pit formed on Al alloy 6061 (Al-1% Mg) in 0.1M NaCl by anodic polarization . Pitting is a dangerous form of corrosion attack for several reasons. Pits can result in the perforation of a metal component while the rest of the metal piece remains unattacked.In the presence of an applied stress, pits can serve as sites to initiate stress-corrosion cracking, another catastrophic form of corrosion attack. Finally, the presence of pits can be difficult to detect if they are covered with corrosion products [2].

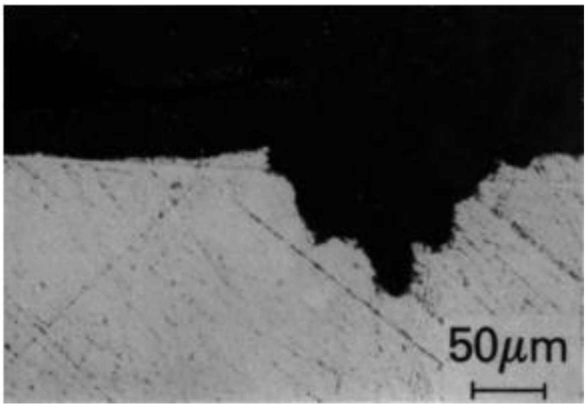


Fig. I.5. SEM image presente cross-sectional view of a corrosion pit on Al 6061 formed by anodic polarization in 0.1 M NaCl [2] .

I . 6 . 3 . Crevice corrosion

Crevice corrosion is a form of localized corrosion that occurs in confined spaces where oxygen supply is limited. It typically develops in narrow gaps that are wide enough to allow fluid entry but too tight to permit proper fluid flow, creating stagnant conditions [2] .

This type of corrosion can occur in geometrical crevices such as:

- Beneath gaskets or seals
- Under bolt heads
- Between overlapping metal surfaces
- Within threaded connections
- Inside wire rope strands

Crevice corrosion can also develop under various deposits, including:

- Corrosion products
- Dust particles
- Marine growths like barnacles (especially in seawater environments) [2]

Fig. I.6 shows crevice attack on an alloy 625 specimen after crevice corrosion testing in natural seawater [2].

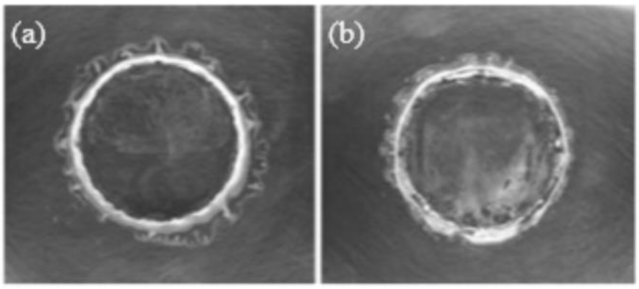


Fig.I.6 Alloy 625 after crevice corrosion testing at 65◦C in natural seawater . (Left) +200 mV vs. Ag/AgCl for 24 h, (Right) +400 mV vs. Ag/AgCl for 24 h. The crevice (removed in the photographs) was provided with a compressed gasket [2] .

I . 6 . 4 . Galvanic corrosion

Galvanic corrosion occurs when two dissimilar metals with different electrochemical potentials or varying tendencies to corrode come into direct metal-to-metal contact in the presence of a conductive electrolyte, as illustrated in **Fig. I.7**.

Examples of galvanic corrosion include the following :

1. Copper pipes connected to steel storage tanks.
2. Boats with nickel alloy hulls and steel rivets.
3. Zinc-coated screws used in copper sheets.
4. Tin-plated electrical connector pins mated with gold-plated sockets.
5. A stainless steel screw in contact with a cadmium-plated steel washer [2] .

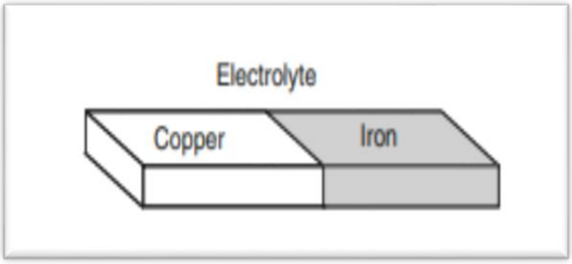


Fig .I.7. Two dissimilar metals in a galvanic couple[2].

I . 6 . 5 . Intergranular corrosion

Intergranular corrosion is the pronounced localized attack that occurs in narrow regions at or immediately adjacent to grain boundaries of an alloy. Type 304 stainless steel (which contains 18% Cr and 8% Ni as well as small amounts of carbon) is subject to intergranular corrosion if the stainless steel is heated to the temperature range of 425–790◦C (and then cooled). The stainless steel is said to be sensitized and is susceptible to intergranular corrosion. During sensitization, carbon diffuses tothe grain boundaries where it combines with chromium to form chromium carbide precipitates (such as $Cr_{23}C_6$). This process depletes chromium from the areas in and adjacent to the grain boundaries so that these regions locally contain less than the 12% Cr required for a stainless steel. Thus, localized corrosion occurs in certain aqueous environments in the form of intergranular corrosion, as depicted in **Fig.I.8** [2] .

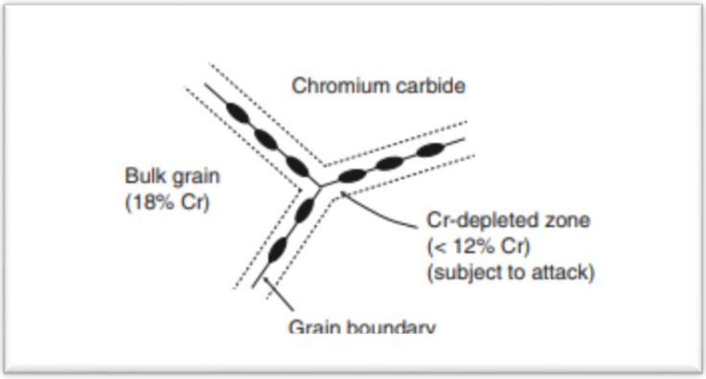


Fig. I.8. Schematic representation of sensitized stainless steel. After Myers. Chromium-depleted zones adjacent to grain boundaries are susceptible to intergranular corrosion [2].

I . 6 . 6 . Selective corrosion

Selective corrosion, also known as selective leaching, occurs in alloys where one element is significantly less noble than the others. In this process, the less noble metal is preferentially removed, resulting in a porous structure with drastically reduced strength and ductility. In some cases, the corroded regions become covered with corrosion products or other surface deposits, allowing the component to retain its original shape. This often makes the corrosion difficult to detect [4].

I . 6 . 7 . Erosion or abrasion corrosion

Erosion or abrasion corrosion arises when there is relative motion between a corrosive fluid and a metal surface submerged in it. This movement causes mechanical wear on the surface, stripping away protective layers and exposing fresh, reactive metal underneath. Materials that typically rely on passive oxide films especially those with weak adherence or mechanical strength such as lead, copper, steel, and certain aluminum alloys, are particularly vulnerable.

When particles move parallel to the metal surface, the process is known as abrasion corrosion. In contrast, if the particles strike the surface at an angle, the phenomenon is referred to as erosion corrosion [4].

I . 6 . 8 . Cavitation corrosion

Cavitation corrosion refers to the combined mechanical and chemical damage that occurs when vapor bubbles in a liquid collapse and strike a metal surface. This phenomenon is commonly observed in areas with high-velocity fluid flow and frequent pressure fluctuations, such as ship propellers, pump interiors, turbine blades, hydrofoils, and similar surfaces. **Fig I.9.** illustrates an example of cavitation corrosion. [2]

Fig. I.9. Cavitation damage on the outer edge of a propeller on a personal watercraft. Figure courtesy of Erik Axdahl, who took this photograph while he was an undergraduate research assistant at the University of Minnesota and who is now a Graduate Research Assistant at the Georgia Institute of Technology [2].

I . 6 . 9 . Fretting corrosion

Fretting corrosion occurs at the contact surface between two tightly fitted components when they are subjected to repeated, slight relative motion. This motion can range in amplitude from less than a nanometer to several micrometers. Commonly affected elements include press fits, bolted joints, and other assemblies where the interface is under load[4].

I . 6 . 10 . Stress corrosion cracking

Stress Corrosion Cracking is the formation of cracks resulting from the combined influence of static tensile stress and a corrosive environment. The tensile stress can arise from various sources, such as external loads, centrifugal forces, temperature fluctuations, or internal stresses introduced by processes like cold working, welding, or heat treatment. Typically, cracks develop perpendicular to the direction of the tensile stress and may propagate either along grain boundaries (intergranularly) or through the grains themselves (transgranularly), often displaying a branched pattern **Fig. I.10** , **Fig. I.11 .** [4].

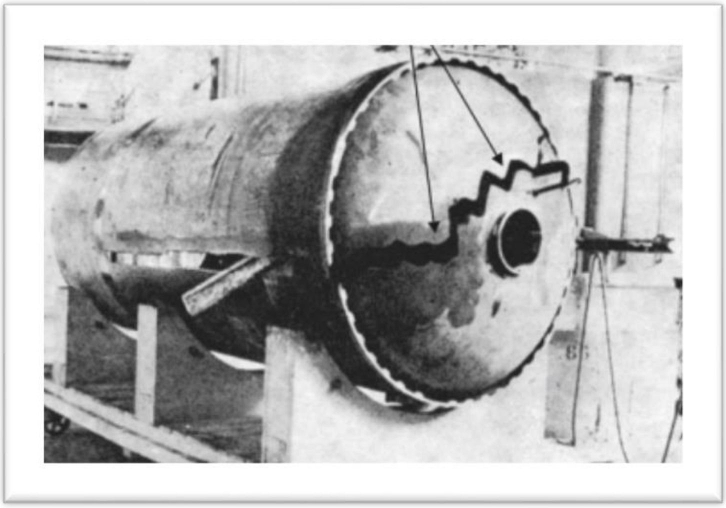


Fig. I.10 . Fracture of a high-strength steel rocket case due to stress-corrosion cracking . The arrows indicate the location of the stress-corrosion crack [2].

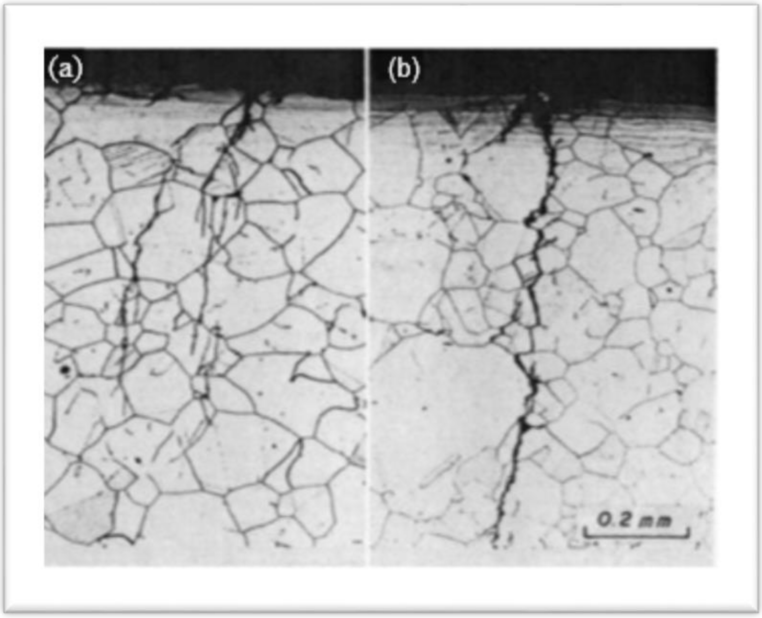


Fig. I.11 . SEM image presente the stress-corrosion cracking of sensitized type 304 stainless steel in (a) boiling 45% magnesium chloride solution and (b) in boiling 20% magnesium chloride solution [2].

I . 6 . 11 . Microbial corrosion

Another type of corrosion occurs when organisms produce an electron flow, resulting in modification of the local environment to a corrosive one. **Fig. I.12 .** [4].

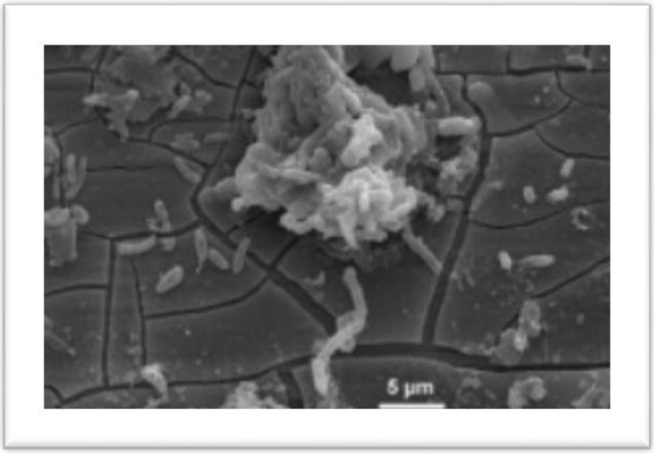


Fig. I.12. SEM image presente the microbial Corrosion [5].

I . 7 . Corrosion types of based on the media

Corrosion types can also be categorized based on what type of environment they take place. Accordingly major corrosion types are atmospheric corrosion, corrosion in fresh water, cor rosion in seawater, corrosion in soils, corrosion in concrete and corrosion in the petroleum industry [4].

I . 7 . 1 . Atmospheric corrosion

In general for atmospheric corrosion, dusts and solid precipitates are hygroscopic and attract moisture from air. Salts can cause high conductivity, and carbon particles can lead to a large number of small galvanic elements since they act as efficient cathodes after deposition on the surface. The most significant pollutant is SO_2, which forms H_2SO_4 with water. Water that is present as humidity bonds in molecular form to even the cleanest and well-characterized metal surfaces[4].

I . 7 . 2 . Corrosion in water

Second only to atmospheric corrosion is corrosion in water. The rate of corrosion is highest when the water is soft and acidic, leading to the formation of bulky corrosion products on the metal surface, as commonly seen with iron. Localized corrosion can significantly reduce the structural integrity and flow capacity of pipes. In severe cases, iron oxide can contaminate the water, resulting in complaints about "red water" [4].

Fig. I.13 . Corrosion in Water [6].

I . 7 . 3 . Corrosion in soil

Particle size of soils is an important factor on corrosion in addition to the apparent effect of acidity levels. Gravel contains the coarsest and clay contains the finest particles, with a 2 mm. diameter for the former and a 0.002 mm diameter for the latter. Sizes of sand and silt are in between gravel and clay. While clay prevents the supply of oxygen but not water, gravels allow oxygen supply as well [4] .

Fig. I.14 . Corrosion in Soil [7].

I . 8 . Consequences of corrosion

Some key consequences of corrosion can be outlined as follows :

■ **Facility shutdowns :** Halting operations at nuclear power plants, industrial facilities, or refineries can cause major disruptions for both industries and consumers .

■ **Product loss :** Leaks from containers, storage tanks , pipelines for water, oil, and fuel can result in significant material loss and pose serious safety and environmental risks. It's estimated that at least 25% of water is lost due to leakage.

■ **Reduced efficiency :** Corrosion deposits on heat exchanger tubes and pipelines hinder heat transfer and decrease pipeline capacity, leading to reduced operational efficiency.

■ **Contamination:** Corrosion by-products can contaminate chemicals, pharmaceuticals, dyes, and packaged goods, posing serious threats to consumer safety.

■ **Nuclear hazards :** The Chernobyl disaster remains a stark example of how radioactive corrosion products carried through water can be deadly to humans, animals, and the environment[1].

I . 9 . Corrosion protection

Corrosion protection methods are based on the principle that corrosion involves two half-reactions, and preventing either one can effectively stop the overall process. One of the most common methods for protecting metals from corrosion is applying a protective coating, such as paint. However, such coatings are rarely perfect and may have defects or become damaged over time, exposing the underlying metal to corrosion.Another widely used method involves coating susceptible metals with a thin layer of a more corrosion resistant metal, such as silver, copper, or nickel.These metals have more positive reduction potentials, which helps minimize or eliminate the likelihood of corrosion. However, it is essential that the coating remains intact and free from pinholes or cracks.If the coating is damaged, the exposed metal underneath can corrode rapidly, especially in the presence of dissimilar metals, as shown in **Fig. I.15**.For example, if iron is coated with tin, any small damage in the tin layer can expose the iron beneath, leading to galvanic corrosion due to the potential difference between the two metals. As a result, tin cans tend to corrode quickly when exposed to air [8].

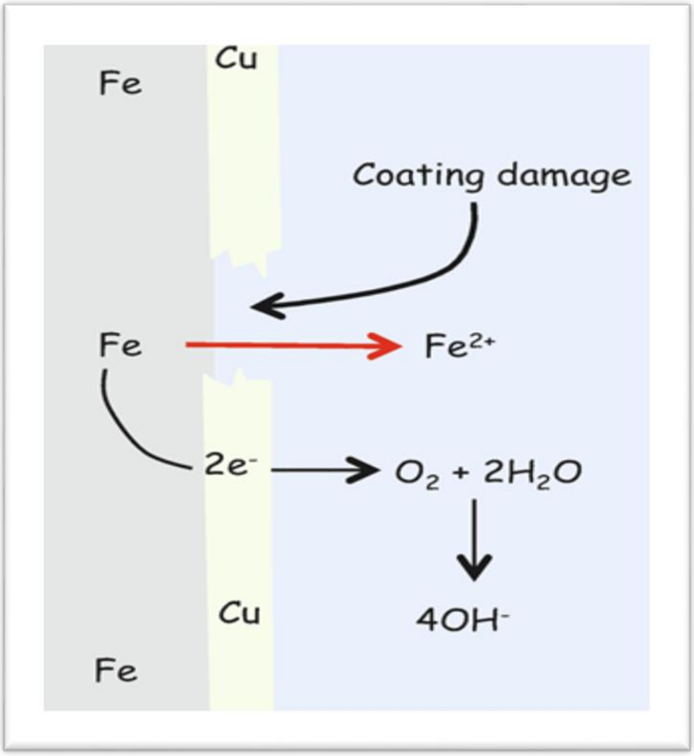


Fig. I.15. Schematic diagram of noble metal coating failure[8].

Coating can also be less noble. Such coatings undergo oxidation and, therefore, prevent oxidation of the protected metal. An example is the protection of iron with zinc coating, a process called galvanizing. Zinc exhibits a more negative reduction potential than iron and will be oxidized first while protecting iron. The coating of less noble metal does not have to be perfect as an imperfection in coating does not change the fact that the more electronegative element, the coating, oxidizes first.

The damage to such coating will not affect the metal to be protected as the oxidation reaction will still take place on the protective coating metal, e.g., zinc **.**The cathodic reduction of oxygen takes place on the exposed area of iron. In this corrosion protection method, the less noble metal is called a sacrificial anode. The most commonly used sacrificial anodes in industrial corrosion protection are zinc and magnesium **Fig. 16** .

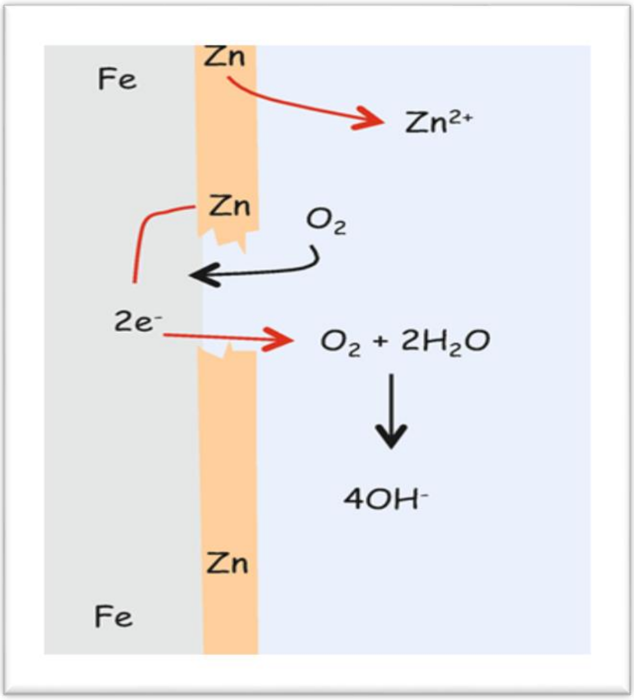


Fig. I. 16. Corrosion coating of a less noble metal [8].

$$\mathrm{Zn}^{2+}_{(\mathrm{aq})} + 2e^- \rightarrow \mathrm{Zn}_{(\mathrm{s})} \qquad \mathrm{E}^{\circ}_{\mathrm{red}} = -0.76\ \mathrm{V} \tag{I .5}$$

$$\mathrm{Fe}^{2+}_{(\mathrm{aq})} + 2e^- \rightarrow \mathrm{Fe}_{(\mathrm{s})} \qquad \mathrm{E}^{\circ}_{\mathrm{red}} = -0.44\ \mathrm{V} \tag{I .6}$$

Besides coatings for corrosion protection, an electrical method can be used to apply negative voltage to the metal and prevent anodic reaction ($M \rightarrow M^+ + 2e^-$). This method is known as cathodic protection. An external power supply is used to apply cathodic protection. The method is very commonly used to protect oil pipelines and other buried structures **Fig I. 17**.

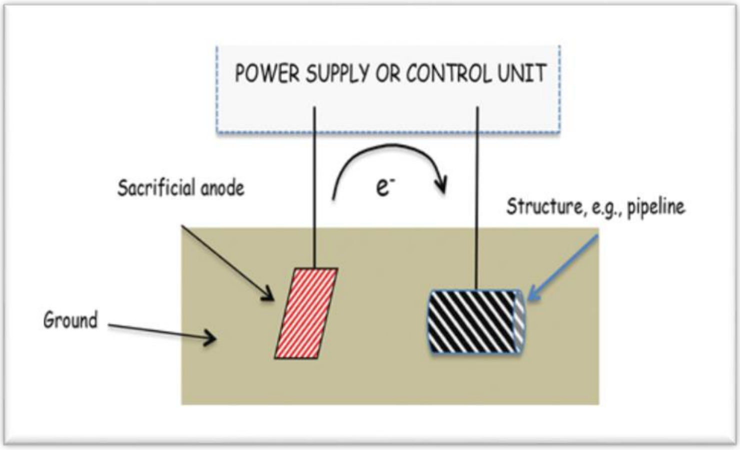


Fig I. 17. Cathodic corrosion protection[8].

An alternative method is to connect a more active (i.e., more negative) piece of metal to the structure that needs to be protected, making it therefore a dissimilar metal corrosion **Fig I. 18**. The more negative or more active metal is the sacrificial anode, typically zinc or aluminum.

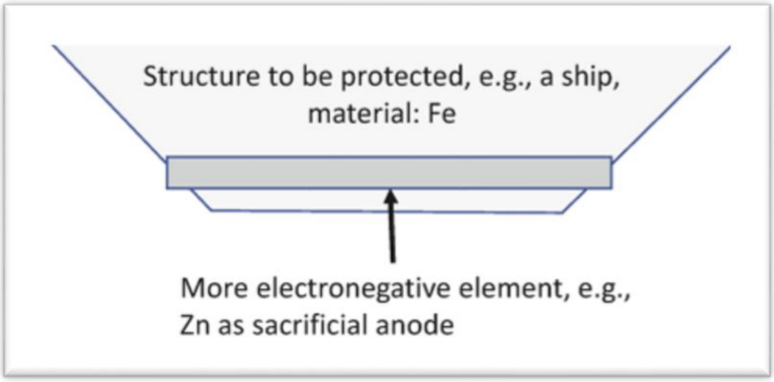


Fig I.18. Depiction of a sacrificial anode concept[8].

Other methods for corrosion protection and prevention include anodization (increasing the thickness of the oxide coating using constant anodic current), organic coatings, and inhibitors [8] .

I . 10 . Corrosion inhibitors

I . 10 .1 . Definition

A corrosion inhibitor is a chemical compound that, when introduced into a solution(usually in small quantities) helps improve a material's resistance to corrosion. It functions by altering electrochemical reactions at the metal/solution interface from the solution side. The effectiveness of the inhibitor can be assessed through various evaluation parameters. [2]

I . 10 .2 . Application of inhibitors

Corrosion inhibitors are used in various industrial applications, including potable (drinking) water, cooling water systems, automobile engine coolants, acid pickling (cleaning) solutions, to protect reinforcing steel bars in concrete, and in oil recovery and storage. Various applications and the inhibitors used are listed in **Table I.1.** Inhibitors are also used in the surface treatment of metals to improve the corrosion resistance (chromates on aluminum alloys or galvanized steel) or to improve their paint adhesion (phosphates on autobody steel sheet). Corrosion inhibitors can also be incorporated into paints or organic coatings [2].

Table I.1 Some industrial applications of corrosion inhibitors [2].

Application	Inhibitors
Potable (drinking) water	CaCO3 deposition Silicates Polyphosphates
Recirculating cooling water	Chromates Nitrates Polyphosphates Silicates Zinc salts Benzotriazole (for copper)
Automotive engine coolant systems (ethylene glycol/water)	Borax–nitrite mixtures Sodium mercaptobenzothiazole Benzotriazole
High-chloride solutions (seawater, refrigerating brines)	Chromates Sodium nitrite Chromate–phosphate mixtures
Acid pickling (cleaning mixtures)	Various amines Pyridine Quinoline Mercaptans Phenylthiourea
Oil recovery	Primary, secondary, tertiary amines Diamines Amides Polyethoxylated amines
Steel-reinforced concrete Surface treatment of metals Aluminum aircraft components and galvanized steel Autobody steel sheet	Calcium nitrite Sodium benzoate Chromates Phosphates

I . 10 . 3 . Types of inhibitors

Inhibitors can be classified in several different ways. The two main types are :

I . 10 . 3 . 1 . Adsorption inhibitors

Adsorption inhibitors form a chemisorptive bond with the metal surface and impede ongoing electrochemical dissolution reactions. Most organic inhibitors are chemisorption-type inhibitors. For example**, Fig. I. 19. a.** shows schematically that an aliphatic organic amine has an electron pair on the nitrogen atom which is available for donation to the metal surface. In addition, the hydrocarbon tails of the molecule are oriented away from the interface toward the solution so that further protection is provided by the formation of an array of hydrophobic hydrocarbon tails located on adjacently adsorbed amines. This hydrophobic network serves to keep water molecules and aggressive anions, such as Cl^-, away from the metal surface, as shown in **Fig. I.19.b.** [2].

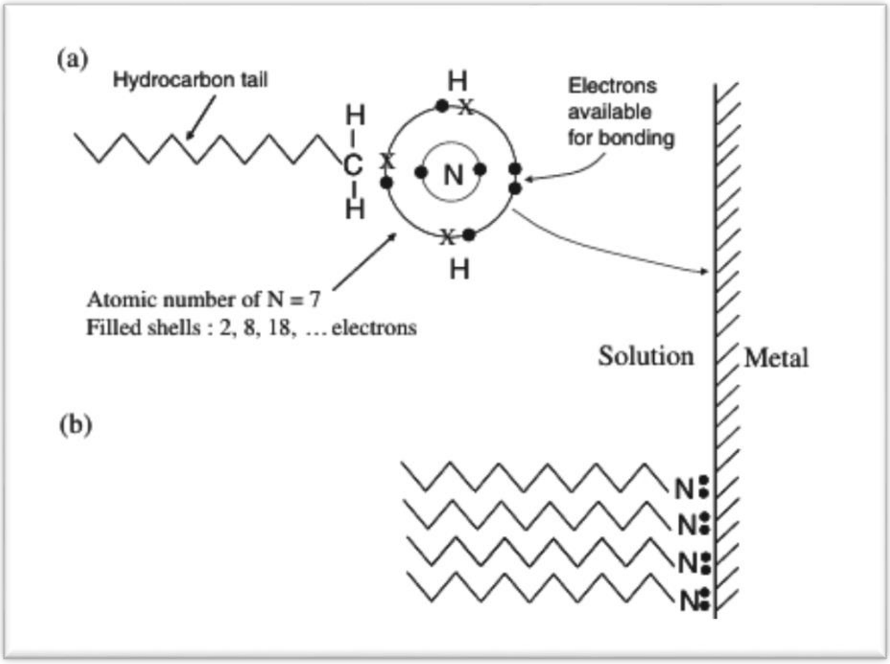


Fig .I.19.(**a**) Chemisorption of amines at a metal surface. The solid black dots denote electrons belonging to the N atom, whereas the Xs refer to electrons from H or C atoms. (The size of the nitrogen atom is exaggerated relative to the rest of the molecule.) (**b**) Formation of a close-packed monolayer on the metal surface [2].

I . 10 . 3 . 2 . film-forming inhibitors

There are two types :

I . 10 . 3 . 2 . 1 . Passivating inhibitors

As implied by their name, passivating inhibitors function by promoting the formation of a passive film on the surface. Passivating inhibitors may be oxidizing or non-oxidizing agents. (Oxidizing agents themselves are reduced in the process of oxidizing another molecule). Chromates are typical oxidizing inhibitors, and with iron or steels, the chromate ion is reduced to Cr_2O_3 or $Cr(OH)_3$ on the metal surface to produce a protective mixed oxide of chromium and iron oxides . Adsorption is also important with oxidizing inhibitors because they are usually adsorbed on the metal surface prior to their reduction and formation of the passive film. Non-oxidizing passi vators like benzoates, azelates, and phosphates also first adsorb on the surface before forming the passive film. [2]

I . 10 . 3 . 3 . 2 .Precipitation inhibitors

With precipitation inhibitors, a precipitation reaction between cations of the corroding metal and the inhibitor deposits a three-dimensional barrier film on the metal surface. Such a film is formed when the solubility product is exceeded for the salt formed between the cations of the metal and the anions of the inhibitor. Phosphates and silicates are examples of precipitation-type inhibitors.

From another point of view , inhibitors can be classified as : inorganic and organic shown in **Fig I.20.** [2]

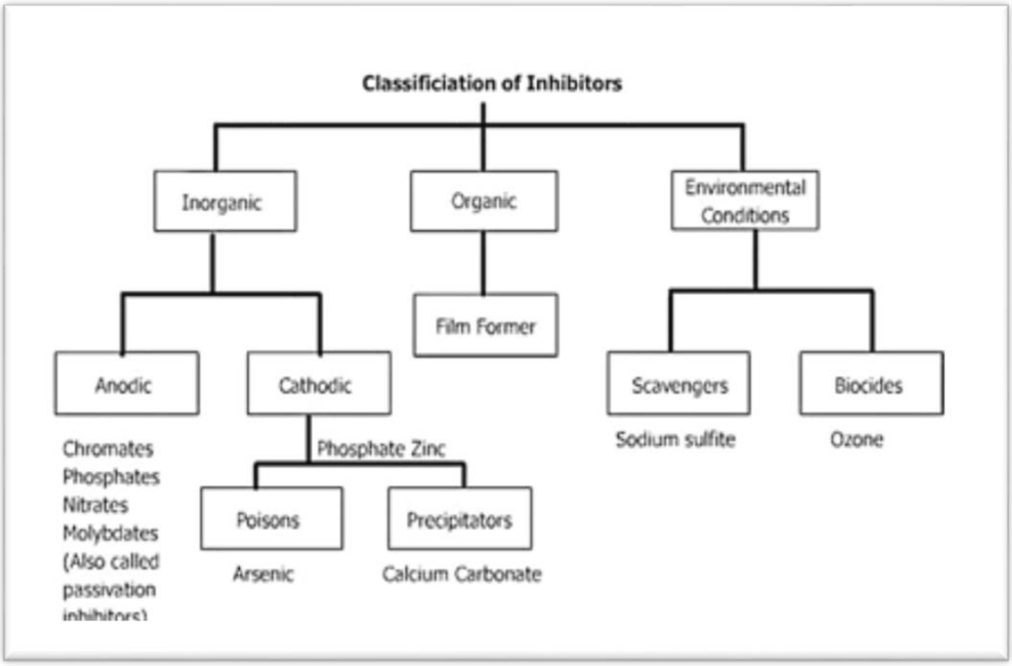
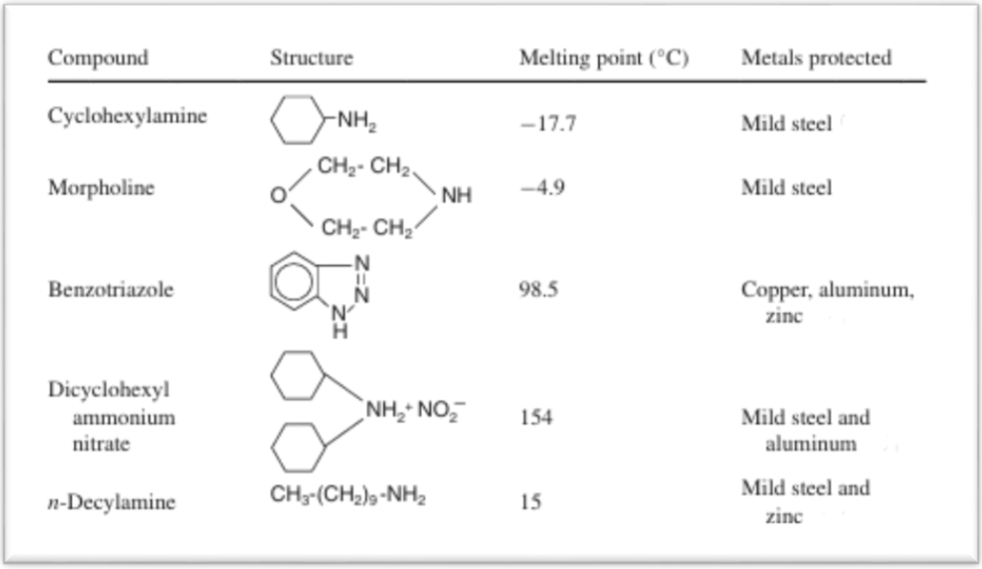


Fig I.20. Classification of inhibitors [1].

I . 10 . 3 . Vapor-phase inhibitors

Inhibitors can be used to protect against atmospheric corrosion in gaseous atmospheres that contain moisture or other corrosive agents, such as Cl^-,H_2S, SO_2, and others. In such applications, the inhibitor is applied from the vapor phase and is called a vapor-phase inhibitor (VPI) or volatile corrosion inhibitor (VCI). These inhibitors volatilize and adsorb on all surfaces located in an enclosed space. Vapor-phase inhibitors are used to protect metal surfaces in storage or transport, as well as to protect electronic materials, such as circuit boards. Vapor-phase inhibitors can provide corrosion protection for periods ranging from months to years . Vapor-phase inhibitors can be either liquids or solids and are very often volatile amines. Some examples of VPIs are given in **Table I.2**. [2].



Compound	Structure	Melting point (°C)	Metals protected
Cyclohexylamine	$-NH_2$	−17.7	Mild steel
Morpholine	CH_2- CH_2 O NH CH_2- CH_2	−4.9	Mild steel
Benzotriazole	N N N H	98.5	Copper, aluminum, zinc
Dicyclohexyl ammonium nitrate	NH_2^+ NO_2^-	154	Mild steel and aluminum
n-Decylamine	CH_3-$(CH_2)_9$-NH_2	15	Mild steel and zinc

Table I.2.Some examples of vapor-phase inhibitors [2].

I . 10 . 4 . Chemisorption of inhibitors

Chemisorption involves an actual charge transfer or charge sharing between the inhibitor molecule and the metal surface. By interacting with metal surface atoms, the chemisorbed inhibitor interferes with metallic dissolution. The simplest picture is one of a blockage of active surface sites, but this view is not quite complete. Like all adsorbed species, chemisorbed molecules have a certain residence time at the surface and thus play a dynamic role by participating in a number of adsorption–desorption steps.

The main characteristics of chemisorption are the high heats of adsorption, persistence, and specificity. **Table I.3** compares the process of chemisorption with physisorption (i.e., physical adsorption), a more general type of adsorption but one involving weaker interactions[2] .

Table .I.3 Comparison of chemical adsorption (chemisorption) and physical adsorption (physisorption) [2].

	Physisorption	**Chemisorption**
Type of electronic interaction	Van der Waals or electrostatic forces	Charge transfer or charge sharing
Reversibility	Adsorbed species readily removed by solvent washing	Adsorption is irreversible, more persistent
Energetics	Low heat of adsorption, <10 kcal/mol (40 kJ/mol)	Higher heat of adsorption, >10kcal/mol(40kJ/mol)
Kinetics	Rapid adsorption	Slow adsorption
Specificity	Adsorbed species relatively indifferent to identity of surface	Specific interaction, strong dependence on identity of surface

I . 11 . Steel

Steel is an alloy of iron with a carbon content of less than 2%. Carbon plays a key role in increasing the mechanical strength of steel, but it also makes the material more brittle. As carbon content rises, the weldability of steel decreases due to the risk of forming martensite during cooling. In stainless steel, welding may lead to "weld decay," where chromium carbides form at the grain boundaries, reducing corrosion resistance by depleting chromium in those areas.[9]

I . 11 . 1 . Classification of steel

According to carbon percent (max 2%) [9].

Table .I.4. Classification of steel according to carbon percent (max 2%) [9]

Steel			
Low steel	**Medium steel**	**High steel**	**Very high steel**
• Called mild steel • Contain less than 0.3% carbon • More ductile than high carbon steel	• Contain carbon from 0.3 to 0.45% • Increased carbon means increases hardness and tensile strength, decrease ductility and more difficult machinery	• Contain carbon from 0.45 to 0.75%	• Up to 1.5% carbon content • Used for hard steel products • E.g. metal cutting tool

According to additives [9].

Table .I.5. Classification of steel according to additives [9].

Steel	
Plain carbon steel	**Alloy steel or (stainless steel)**
• Contain Fe and carbon only	• Contain Fe , carbon and other alloy elements e.g. (Cr, Ni, Si, Mn) • Purpose of alloy elements . - Cr «chromium » to improve corrosion resistance specially to oxidizing solution e.g.HNO_3 - Ni «nickel » to improve mechanical property 1. As Ni increase ductility . 2. As Ni decrease brittleness of stainless steel at low temp . - Mo (molybdenum) 1. To increase heat resistance .

Table .I.6. Classification of Alloy steel or (stainless steel)[9].

Alloy steel or (stainless steel)	
Low alloy steel	**High alloy steel**
• Carbon content less than 0.25% • Contain low %of alloy elements .	• Contain at 12%Cr with high Ni content • Carbon content high than 0.25%

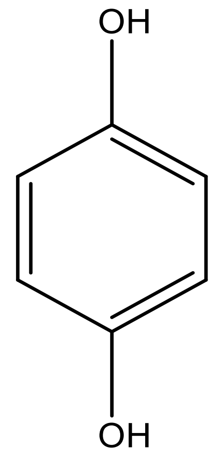
Chapter II : Experimental staudy

II . 1 . Generalities

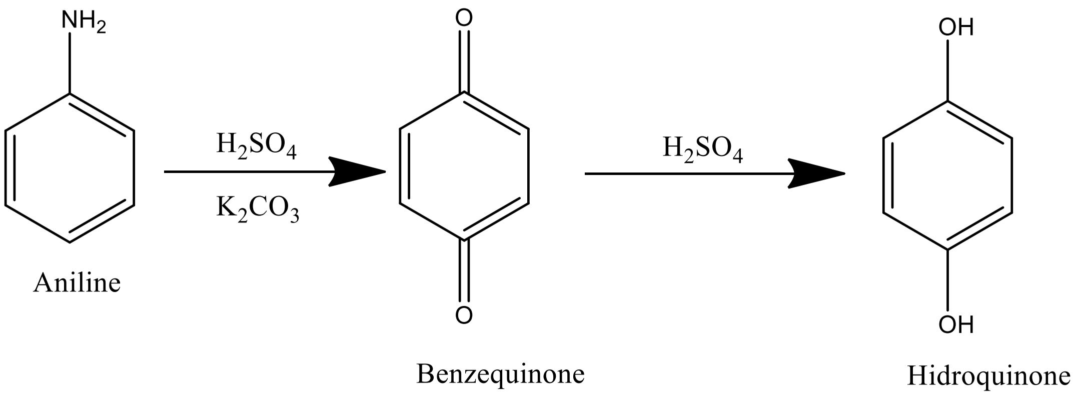
Hydroquinone (HQ), also known as benzene-1,4-diol or quinol, is an aromatic organic compound and a type of phenol. The name "hydroquinone" was first coined by Friedrich Wöhler in 1843. It is a derivative of benzene with the chemical formula $C_6H_4(OH)_2$, consisting of two hydroxyl groups attached to a benzene ring in the para position, classifying it as a type of dihydroxybenzene. It is one of the three diatomic alcohols of benzene and can be obtained through the dry distillation of quinic acid and oxysalicylic acid. Hydroquinone may also be produced by adding lead oxide to an aqueous solution of quinic acid or by treating arbutin with diluted sulfuric acid[10]. Industrially, hydroquinone is used as a corrosion inhibitor due to its antioxidant properties, which help prevent oxidation reactions that contribute to metal corrosion. Additionally, it is widely used in dermatology to lighten the skin and treat hyperpigmentation disorders.

- **Physical and chemical properties**

Table II.1. Physical and chemical properties .

Formula	$C_6H_4(OH)_2$	**Chemical stracture of (HQ)**
Molar mass	110.11 g/mol	
Melting point	170-285 °C	
Boiling point	285-287 °C	
Solubility	In water at 15°C : 59g /l	
Volumic mass	1.358g $/cm^3$	
Auto-ignition temperature	515°C	
Density	1.358 at20°C 1.33 at15°C	

II . 2 . The synthesis of hydroquinone



Scheme .II.1. Chemical reaction of the synthesis of HQ

- **Physicochemical characteristicsof hydroquinone synthesis**

Table II.2. Physicochemical characteristics of the elements of hydroquinone synthesis .

Pruducts	Molar mass	Density	Melting point	Solubility(water)
Aniline	93g/mol	1.02	-6.3°C	Soluble in water
Benzequinone	108.049g/mol	1.32	115.7°C	10g/l at 25°C
Sulfuric acid	93.07g/mol	1.83	10.31°C	Soluble in water
Potassium carbonate	138.205 g/mol	2.428	891°C	Soluble in water

II . 2 . 1 . Procedure

Preparation of Hydroquinone from Aniline

Step 1: Oxidation of Aniline to Quinone

1. In a sufficiently large container, measure 1500 ml of water.
2. Slowly add 250 ml of concentrated sulfuric acid to the water while stirring (always add acid to water, not the reverse).
3. Allow the resulting acidic solution to cool completely.
4. Gradually add 60 ml of aniline (m = 61.2 g) to the cooled acidic solution while stirring continuously.

5. Slowly add finely pulverized potassium dichromate to the reaction mixture, a little at a time, until the greenish precipitate formed initially has completely redissolved.
- About 160 g of potassium dichromate is required to complete the oxidation.
6. This process produces quinone as the oxidation product.

Step 2: Extraction of Quinone

1. Stir the reaction mixture vigorously with approximately 600 ml of methyl ether or ethyl ether for 15 to 20 minutes to extract the quinone.
2. Allow the mixture to stand and separate.
3. Decant the upper ethereal layer carefully.
4. Evaporate the ether solution in the open air using a porcelain dish to obtain crystals of quinone.

Step 3: Reduction of Quinone to Hydroquinone

1. Meanwhile, prepare a sulfurous acid solution:

Option 1: Use 80 ml of commercially available anhydrous, liquefied sulfurous acid dissolved in approximately 400 ml of water.

Option 2: Prepare sulfurous acid by distilling a mixture of 100 g of copper turnings and 120 ml of sulfuric acid in a small flask:

- Seal the flask with a pierced cork and insert a glass tube into a separate flask containing about 200 ml of water.
- After 30 minutes of distillation, a solution of sulfurous acid is obtained.

2. Pour the prepared sulfurous acid solution over the quinone crystals left in the dish after ether evaporation.
3. Place the dish on a boiling water bath and allow the liquid to evaporate to dryness.

Step 4: Purification of Hydroquinone

1. The crystalline mass remaining after evaporation is crude hydroquinone.
2. To purify it:
- Dissolve the crude hydroquinone in ether or alcohol.
- Slowly crystallize it by allowing the concentrated solution to stand.

A yield of approximately 85% is expected, corresponding to about 52.0g of pure hydroquinone .

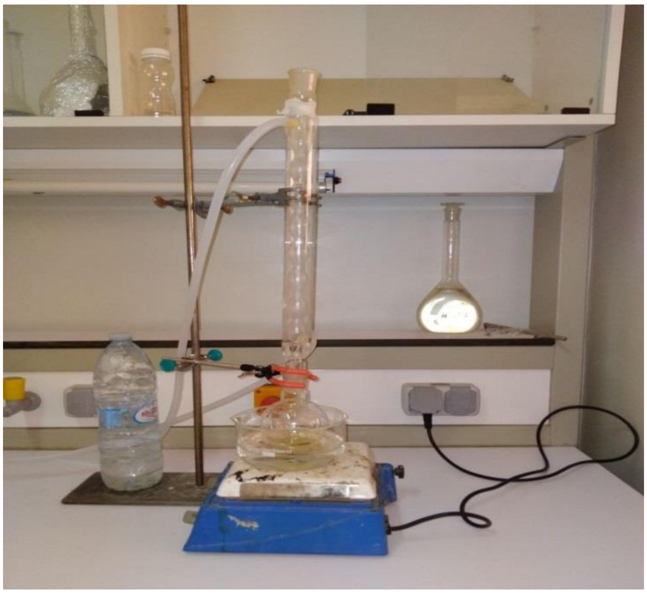


Fig II.1. The synthesis of hydroquinone **.**

Fig II.2. Hydroquinone in crystal form .

II . 2 . 2 . Analysis and confirmation methodes used

II . 2 . 2 . 1 . Infrared Spectroscopy (IR)

Vibrational transitions occur in the IR spectral region. Because the location of the peaks depends on the molecular structure, the IR is often referred to as a ``fingerprint" region because the pattern of the spectrum can be used to identify the associated species**[11].**

Fig II.3. Photograph of the IR device used .

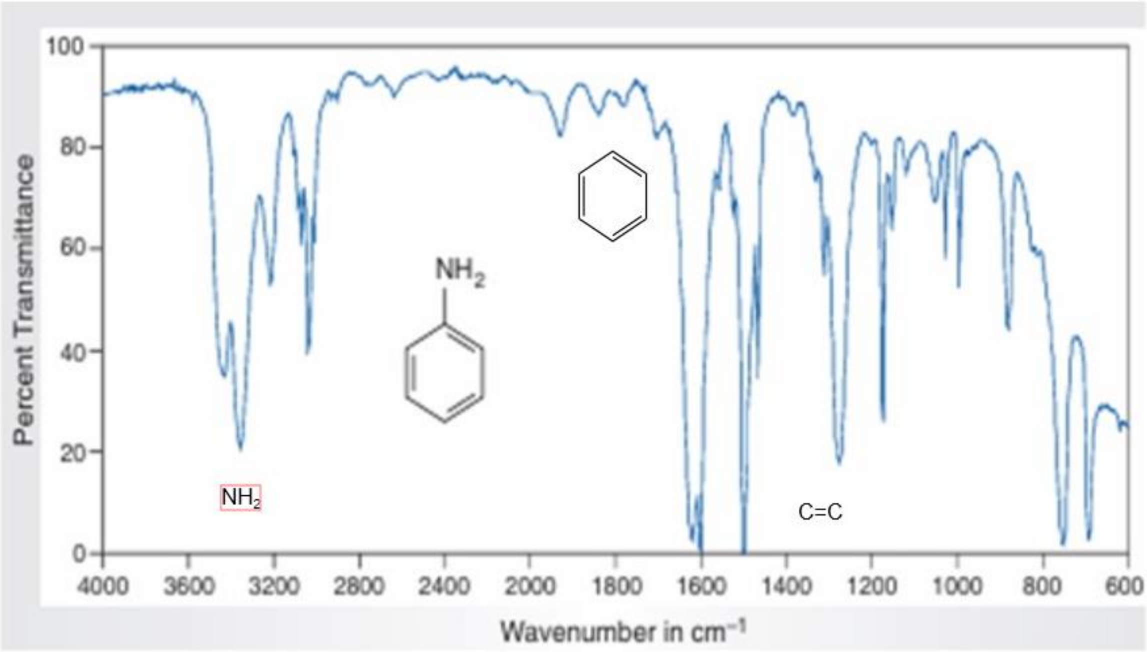


Fig II.4. IR spectrum of aniline (neat)[12].

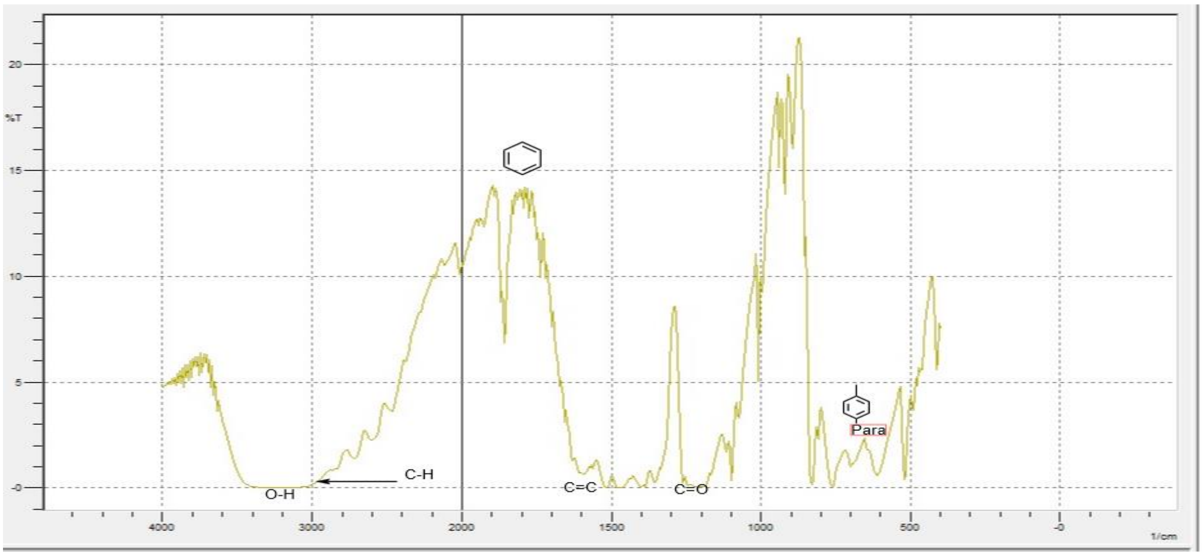


Fig II.5. IR spectrum of hydroquinone .

II . 2 . 3 . 2 . Treatment procedure

Corrosion inhibitor treatment is performed through continuous injection into the first sleeve downstream of the nozzle holder, using a metering pump calibrated to deliver the optimal inhibitor concentration. This continuous treatment is conducted in two stages:

- **Stage One**: A shock treatment aimed at forming a protective inhibitor film. This stage can last up to 24 hours.
- **Stage Two**: Maintenance of the protective film. During this stage, the inhibitor concentration is reduced to a lower dosage. The operator must ensure the metering pumps are functioning properly and that the corrosion inhibitor remains consistently available[13].

Fig II.6. Corrosion inhibitor injection point at the well [13] .

II . 2 . 3 . 3 . Principle of an industrial test

The inhibitor provided by the supplier must undergo a series of tests known as "industrial testing" before it can be used in the field. This testing process consists of several stages and is designed to ensure a shelf life of six months or more. The key steps include:

- A monitoring period of the process, along with chemical analyses, conducted prior to inhibitor injection.
- A filming phase lasting 24 to 48 hours, during which the inhibitor is injected at a rate of 20 to 50 g/m²/day to form a protective layer on the metal surface.
- Optimization of the injection rate based on the results obtained.
- A subsequent monitoring period and chemical analyses following inhibitor injection.

This extended testing period allows for effective evaluation of the inhibitor’s performance, its impact on the process, and confirmation of its corrosion protection capabilities[13].

II. 3 . Physicochemical characteristics of Albien water

Table II.3. Physicochemical characteristics of Albien water from the University of biskra (Februry 2025).

Parameter	Result	Standard
T(C°)	24	25
pH	7.30	6.5-8.5
Cond(µs/cm)	5760	2800
TH(°F)	117	500
Ca^{2+}(mg/l)	272	200
Mg^{2+}(mg/l)	184	150
Cl^{-}(mg/l)	757	500
Na^{+}(mg/l)	247	200
K^{+}(mg/l)	15	12
Total Fe (mg/l)	0.02	0.3
SO_4^{2-}(mg/l)	327	250
NO_3^{-}(mg/l)	10.2	50
TDS(mg/l)	2400	/
Sal%	2.4	/

II. 4 . Calculation of pean miser’s aggressiveness rate

II. 4 . 1 . Hardness test (HT)

In French its means (Titre Hydrométrique) in English (Hydrometric titer or Water Hardness Test) . This chemical analysis is used to determine the concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in water. It involves titrating the water sample with a standard solution of a chelating agent such as EDTA (ethylenediaminetetraacetic acid), which reacts with the calcium and magnesium ions to form stable complexes.

The indicator Eriochrome Black T is used in this process, changing the solution’s color from red to blue upon completion of the reaction.

II. 4 . 2 . Chloride determination (Cl^-)

Chloride analysis (Cl^-) is a chemical process used to determine the concentration of chloride ions in a sample, such as water. Several methods are available for this analysis, with the Mohr method being one of the most common. This method involves titrating chloride ions (Cl^-) with silver nitrate ($AgNO_3$), using potassium chromate (K_2CrO_4) as an indicator. Initially, a white precipitate of silver chloride ($AgCl$) forms. When all the chloride ions have reacted, a red-brown precipitate of silver chromate (Ag_2CrO_4) appears, indicating the endpoint of the titration .

II. 4 . 3 . Sulfate (SO_4^{2-})determination

The dosage is measured using a PALINTEST photometer set to a wavelength of 520 nm, with a measurement range spanning from 0 to 200 mg/L.

Fig II.7. The methode for determining sulfates **[13].**

Table II.4. The reference dosage of sulfates .

mg/l		SULPHATE SULFAT		SULPHATE SULFAT			SULFATOS		520 nm	
%T	9	8	7	6	5	4	3	2	1	0
90	3	5	7	8	9	10	12	13	14	15
80	16	17	18	19	20	21	22	24	25	26
70	27	28	29	30	31	32	33	34	35	36
60	37	38	39	40	42	43	45	46	48	49
50	50	52	53	54	56	57	59	60	62	64
40	65	67	68	70	72	74	75	77	79	81
30	83	85	87	90	93	95	97	100	103	107
20	110	113	116	120	124	128	133	138	143	148
10	155	162	170	178	185	192	200	-	-	-

II. 5 . Materials used

II. 5 . 1 . The metal used

The base metal used in this work is supplied by the Algerian company COSIDER, in the form of steel plates of grade X42.

Base Metal Identification:

API 5L X42 is a carbon steel commonly used in the construction of pipelines. It is classified according to its mechanical properties, such as yield strength and tensile strength. The meaning of each part of the designation is as follows:

- API: Stands for American Petroleum Institute, the organization that sets the standards.
- 5L: Refers to the specification for line pipe used in pipeline transportation systems.
- X42: Indicates the steel grade. Other grades include A, B, X60, X70, etc.
- 42: Refers to the minimum yield strength, which is 42,000 psi (pounds per square inch).

Chemical Composition:

The chemical composition of X42 steel is presented in the following table :

Table II.5. Chemical composition of X42 steel **.**

Elements%	C	Si	Mn	S	P	Cr	Ni	MO	Cu
Min	-	-	-	-	-	-	-	-	-
Max	0.200	-	1.30	0.030	0.030	-	-	-	-
Product	0.18	0.29	0.85	0.003	0.010	0.06	0.06	0.013	0.015

Elements%	V	Al	Ti	Sn	Ca	N	B	Nb	CE
Min	-	-	-	-	-	-	-	-	-
Max	-	-	-	-	-	-	-	-	-
Product	0.001	0.026	0.001	0.009	0.0013	0.0056	0.0006	0.0010	0.35

II . 5 . 2 . Experimental conditions

II . 5 . 2 . 1 . Mechanical polishing

This operation is performed in the Mechanics Laboratory , Faculty of Science and Technology , Mouhammed Khider University ,Biskra .

Using a polishing machine and sandpaper, we polish the interface of the samples to obtain a mirror-like surface .

Fig II.8. Polishing machine.

Fig II.9. Sandpaper used .

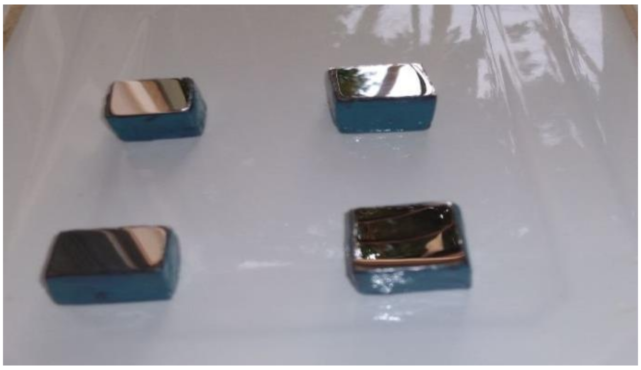


Fig II.10. Sample interface after polishing .

II . 5 . 2 . 2 . Sample isolation

We used nail polish on all sides except the interface for staudy purposes .
Nail polish are not biodegradabel in corosive aqueous environments .

Fig II.11. The coating used .

II . 5 . 2 . 3 .Corrosive solution

The corrosive solution chsen is Albien water (tap water) from the Mohammed Khaider University fodder spring in Biskra .

II . 5 . 2 . 4 .Choice of flow velocity

In our work , we chose a flow velocity($V_{ecoul} = 121\ t / \mathrm{min}$) .

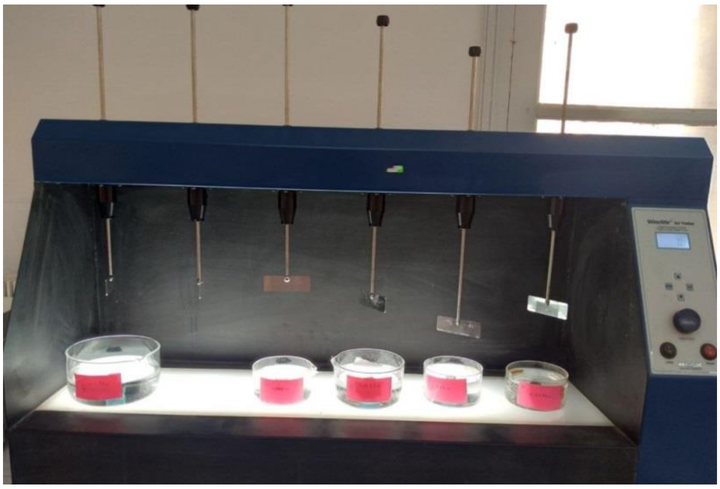


Fig II.12. Jar test apparatus .

II . 5 . 2 . 5 . Duration of immersion experimental

In order to study the phenomenon of inhibitory adsorption and its effectiveness in reducing corrosion in the environment , through the formation of an inhibitory layer on the surface of the sample and below room temperature .

We chose the following soaking times : 24h ,18h ,6h et 3h .

II . 6 . Electrolytic solutions

II . 6 . 1 . Preparation of solutions

We prepare aqueous solutions consisting of (water Albien + inhibitor (hydroquinone)) . First, we prepare the mother solution. We weigh 0.2 mg of the inhibitor and put it in a beaker containing a little water. We stir a little, then we put the contents of the beaker in a 1L fiole . We leave it until the inhibitor dissolves in the water .

using the dilution law, we prepare secondary solutions with the following concentrations : 0.1ppm ,0.05 ppm , 0.02 ppm et 0.01 ppm . dilution law:

$$\mathbf{C_1V_1 = C_2V_2} \qquad (II.1)$$

Fig II.13. The solutions used

II . 6 . 2 . Corrosive media

Five corrosive baths of an aqueous tap water medium were prepared, the first without inhibitor, and four with the inhibitor (hydroquinone) at concentrations of 0.1 ppm, 0.05 ppm, 0.02ppm and 0.01. They are presented in the following table :

Table II.6. Corrosive environmentes .

Bath 1	Tap water
Bath 2	Solution of 0.1 ppm concentration of hydroquinone
Bath 3	Solution of 0.05 ppm concentration of hydroquinone
Bath 4	Solution of 0.02 ppm concentration of hydroquinone
Bath 5	Solution of 0.01 ppm concentration of hydroquinone

II . 7 . Immersions with flow

The samples were immersed in crystallizing dishes containing solutions prepared in the Jar test apparatus shown in the following figure :

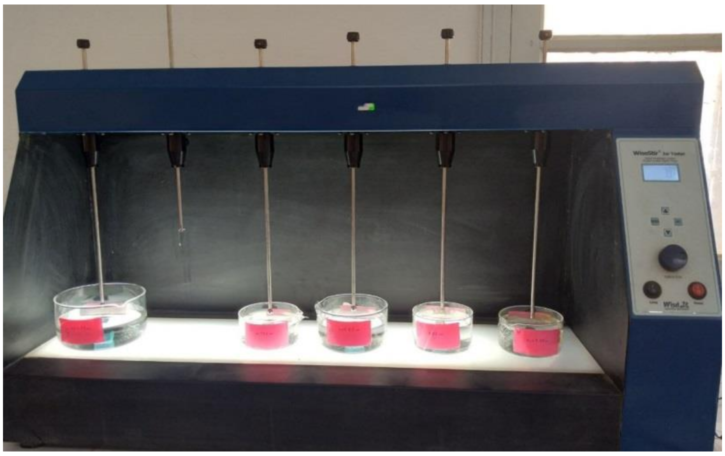


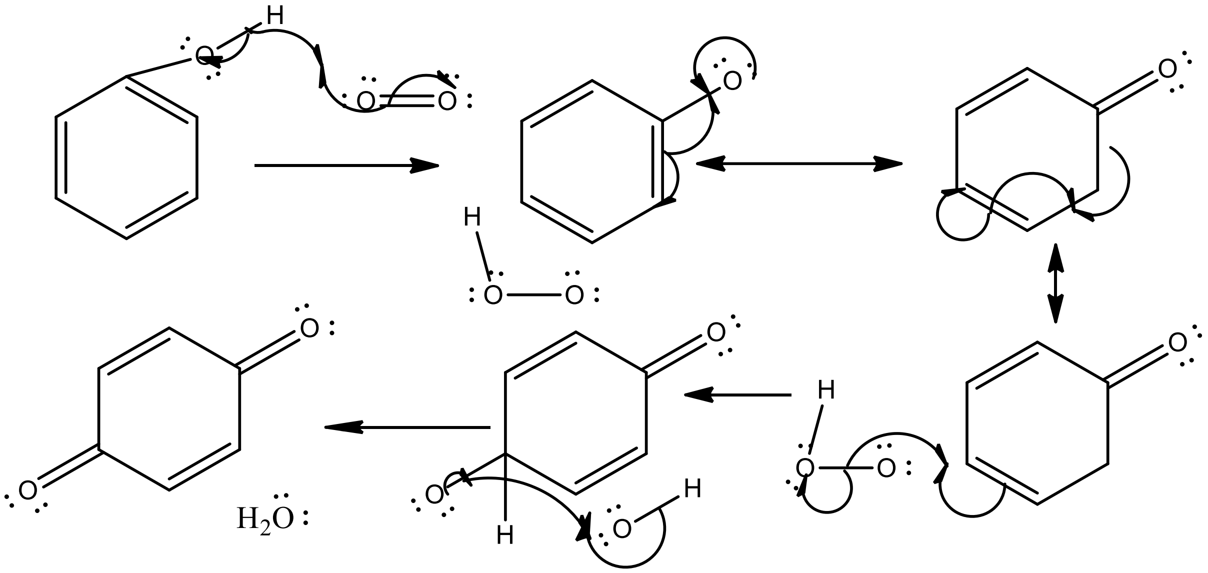
Fig II.14. The immersion experiment with stirring .

Chapter III : Discussion of the results

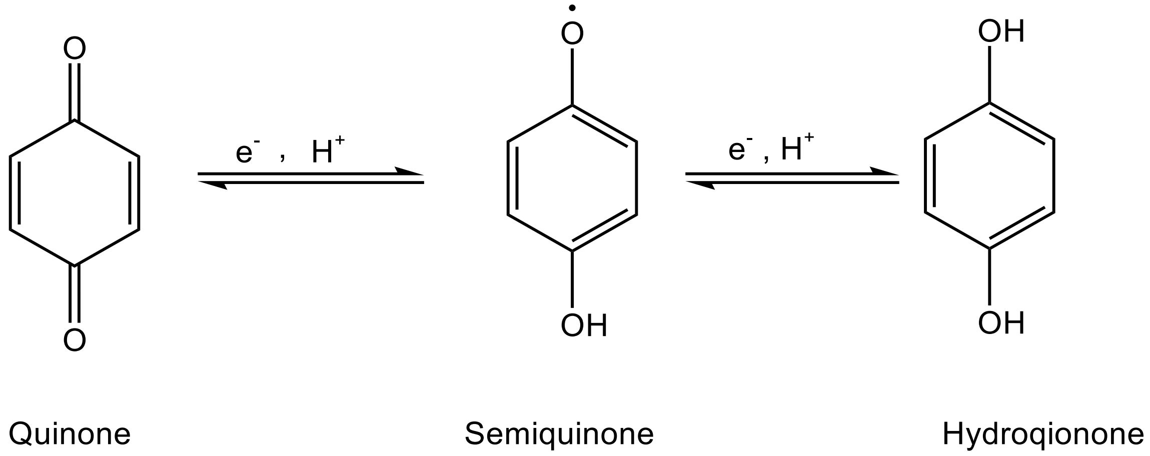
III . 1 . Introduction

In this chapter, we presented and analyzed the results obtained during the study, which included the synthesis of the chemical compound and the evaluation of its inhibitory efficiency in reducing the corrosion rate of X42 steel in an aqueous medium.

III . 2 . Synthesis of hydroquinone



Scheme III.1. Reaction mechanism for the synthesis of quinone .



Scheme III.2. Reaction mechanism for the synthesis of hydroquinone from quinone .

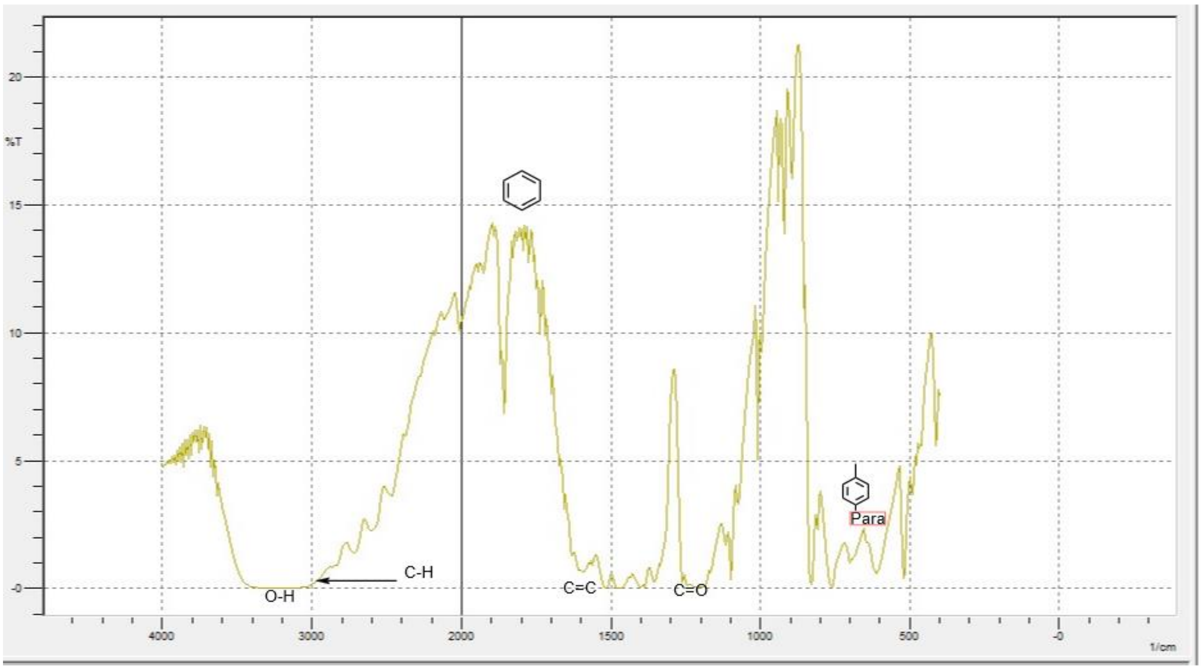


Fig III.1. IR spectrum of hydroquinone .

The infrared (IR) spectrum shows the following features:

- **Region 3200–3600 cm⁻¹:**

A broad peak due to O–H stretching (hydrogen bonding).

- **Region 3000–3100 cm⁻¹:**

Weak to medium peaks resulting from aromatic C–H stretching (in the benzene ring).

- **Region 1600–1500 cm⁻¹:**

Peaks corresponding to C=C stretching vibrations in the aromatic ring.

These peaks are clearly observed since hydroquinone contains an aromatic nucleus.

- **Region 1200–1300 cm⁻¹:**

A strong peak due to C–O stretching (alcohol).

Two peaks are expected for the two OH groups.

III . 3 . Discussion of the immersion test results

III . 3 . 1 . Corrosion rate

Prepared samples of X42 steel were immersed in Albien water both in the absence and presence of the hydroquinone inhibitor at varying concentrations: 0.1 ppm, 0.05 ppm, 0.02ppm, and 0.01ppm. The immersion was carried out for different time intervals: 3 hour, 6.30 minutes , 18 hours, and 24 hours, all at room temperature.

The corrosion rate was determined using the following equation:

$$V = \frac{\Delta m}{St} \qquad \text{(III . 1)}$$

V: Corrosion rate ($g/mm^2 \cdot h$).

Δm: Mass loss, expressed as $\Delta M = m_1 - m_2$ (g).

m_1: Mass of the sample before the test (g).

m_2: Mass of the sample after the test (g).

S: Surface area of the exposed sample (mm^2).

t: Immersion time (hours).

- **Corrosion study in the absence of the inhibitor**

The corrosion rate **V** without inibitor as a function of time is presented in the following table :

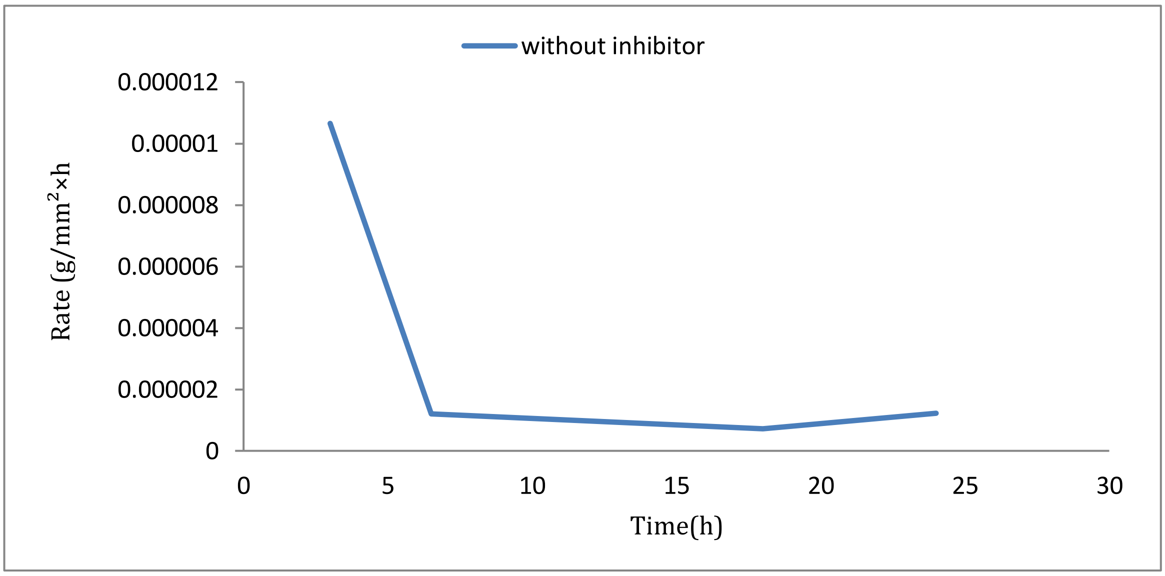


Fig III .2. Corrosion rate as a function of time without inhibitor .

- **Corrosion study in the presence of the inhibitor**

The corrosion rate **V** with inibitor as a function of time is presented in the following table :

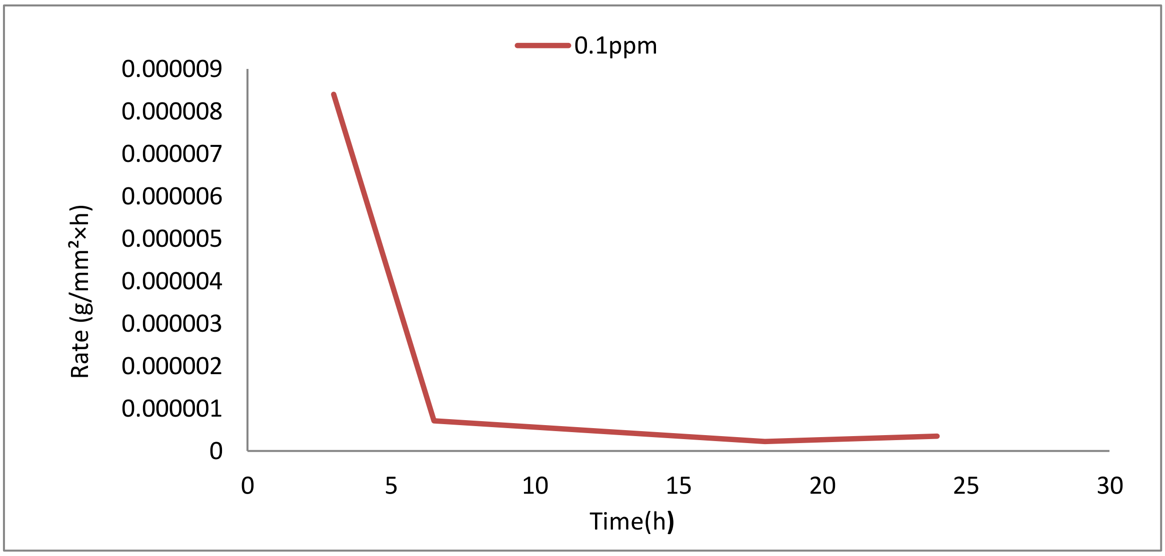


Fig III .3. Corrosion rate as a function of time at 0.1ppm .

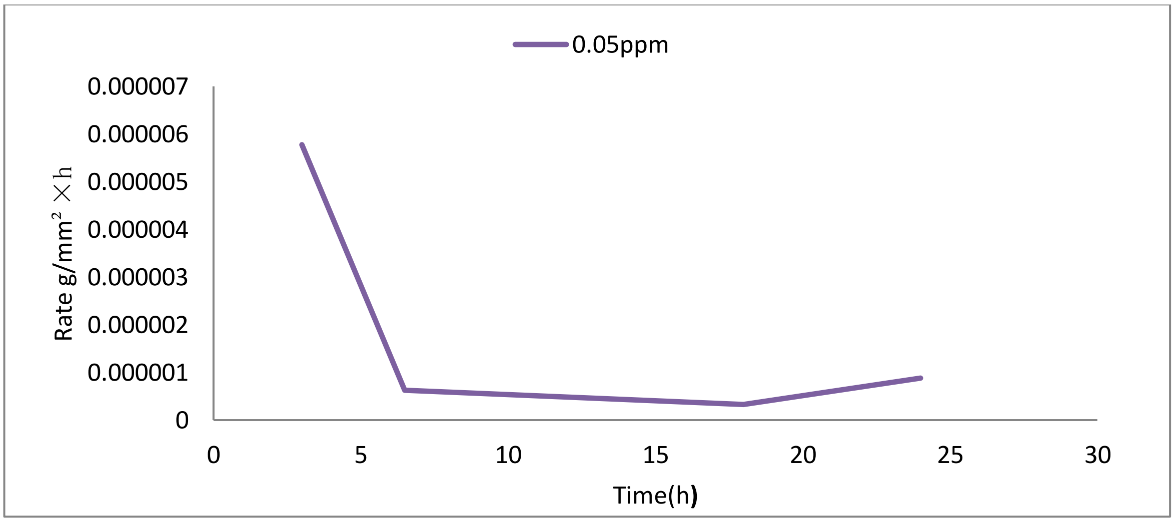


Fig III .4. Corrosion rate as a function of time at 0.05ppm .

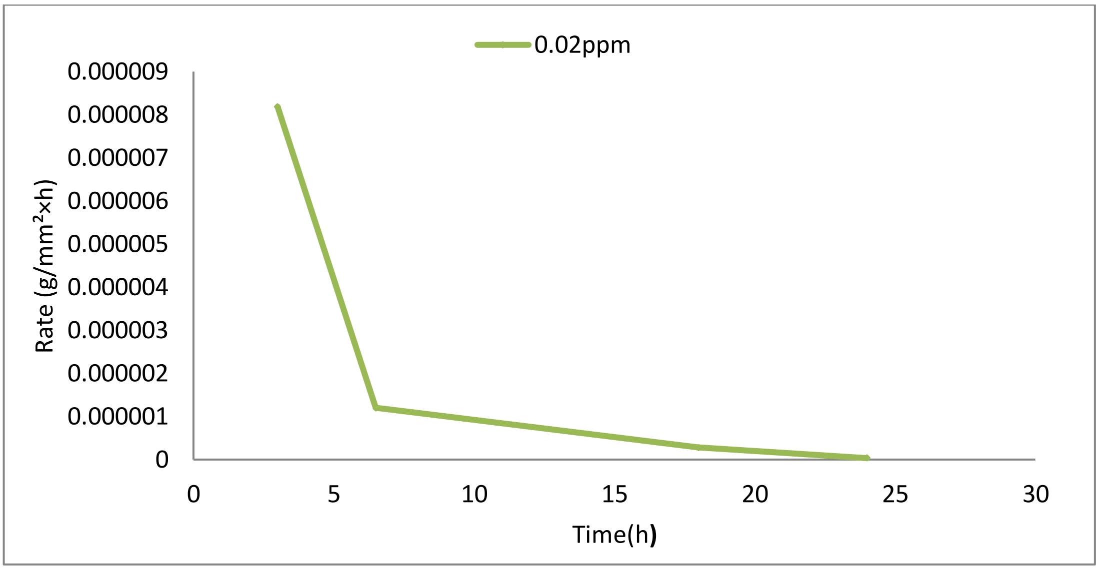


Fig III .5. Corrosion rate as a function of time at 0.02ppm .

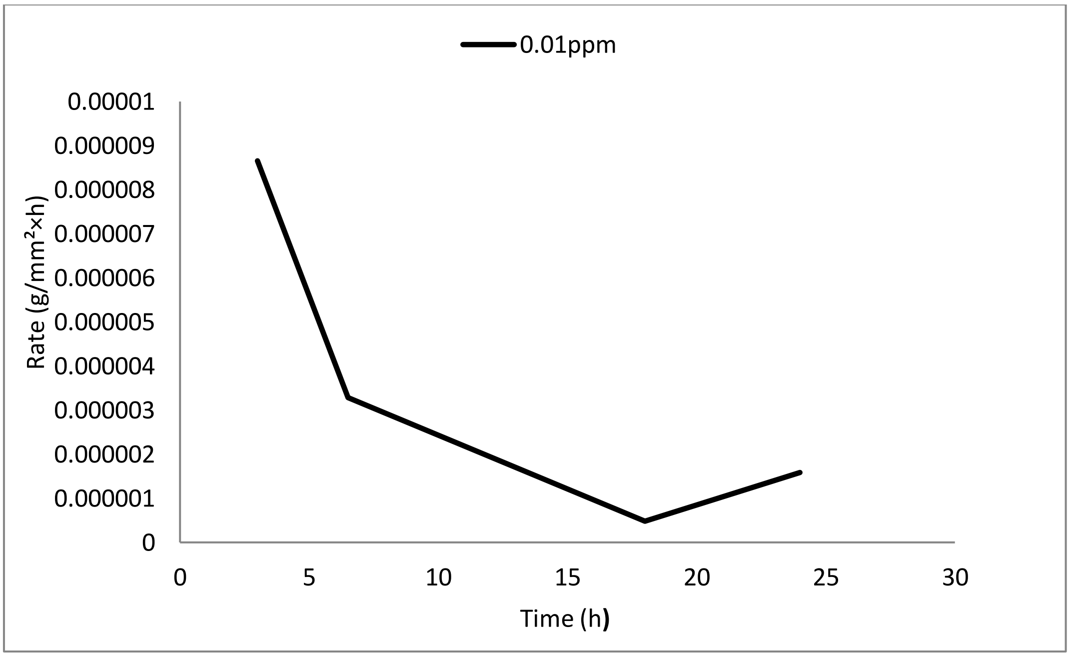


Fig III .6. Corrosion rate as a function of time at 0.01ppm .

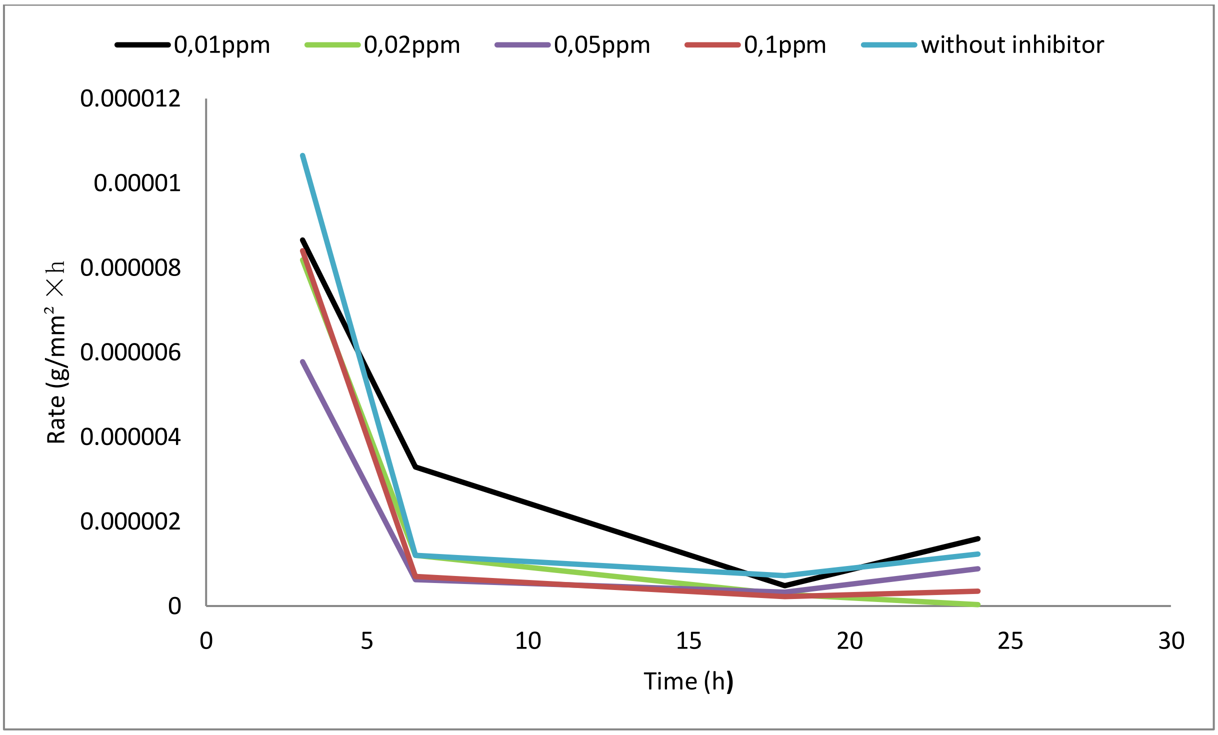


Fig III .7. Comparison betwenn corrosion rares as a function of immersion time in an aqueous medium .

- The results indicate that the corrosion rate was minimal at all selected concentrations (0.1 ppm, 0.05 ppm, 0.02 ppm, and 0.01 ppm) after approximately 18 hours of immersion. It was observed that the maximum corrosion rate recorded was 0.000008655099 g/mm^2.h , which gradually decreased over time to a minimum of 0.000000324786 g/mm^2.h .
- All obtained results were satisfactory; however, the most notable performance was observed at the concentrations of 0.1 ppm and 0.02 ppm during the 18-hour immersion period .
- The addition of the corrosion inhibitor (hydroquinone) to the corrosive medium significantly contributed to the reduction of the corrosion rate of X42 steel. This decrease in corrosion rate is attributed to the chemical adsorption of the inhibitor onto the metal surface, indicating the initial formation of a protective layer during the early hours of immersion, which explains the effectiveness of the synthesized inhibitor.

III . 3 . 2 . Study of inhibitory effecacety

- The inhibitory efficiency is measured by the following relationship :

$$\mathbf{IE} = \frac{\mathbf{V_s} - \mathbf{V_a}}{\mathbf{V_s}} \times \mathbf{100} \qquad \textbf{(III . 3)}$$

$\mathbf{V_s}$, $\mathbf{V_a}$ Corrrosion rates of the sample after immersion in the solution respectively without and with the inhibitor .

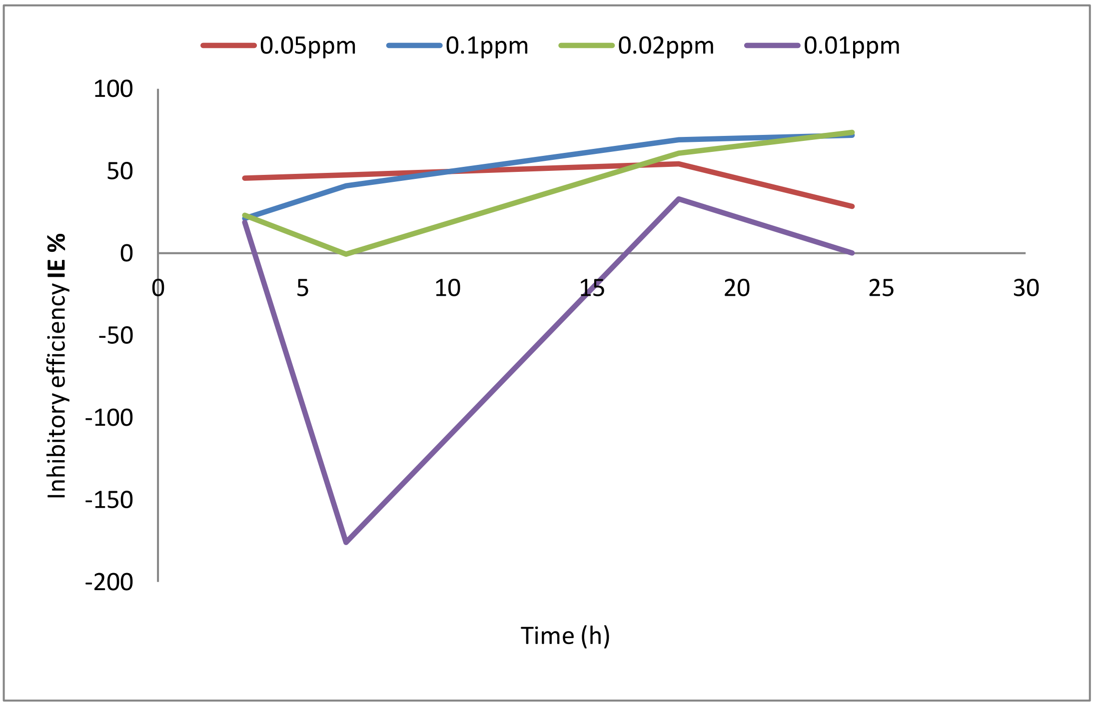


Fig III .8. Comparison of inhibitory efficiency as a function of time .

- ❖ We observed that the inhibitor showed relatively good efficiency at these concentrations in all cases.
- ❖ It was observed that the highest inhibitor efficiency was recorded at a concentration of 0.02 ppm, reaching 73.47% after 24 hours of immersion.
- ❖ Negative values were observed after 24 hours at a concentration of 0.01 ppm, as well as after 6.5 hours at concentrations of 0.01 and 0.02 ppm. This is attributed to the degradation of the protective film.

III . 3 . 3 . The yield

The inhibitor yield is determined after these immersion times at room temperature given by the following relationship :

$$R = \frac{m_{af}}{m_{be}} \times 100 \qquad (III.3)$$

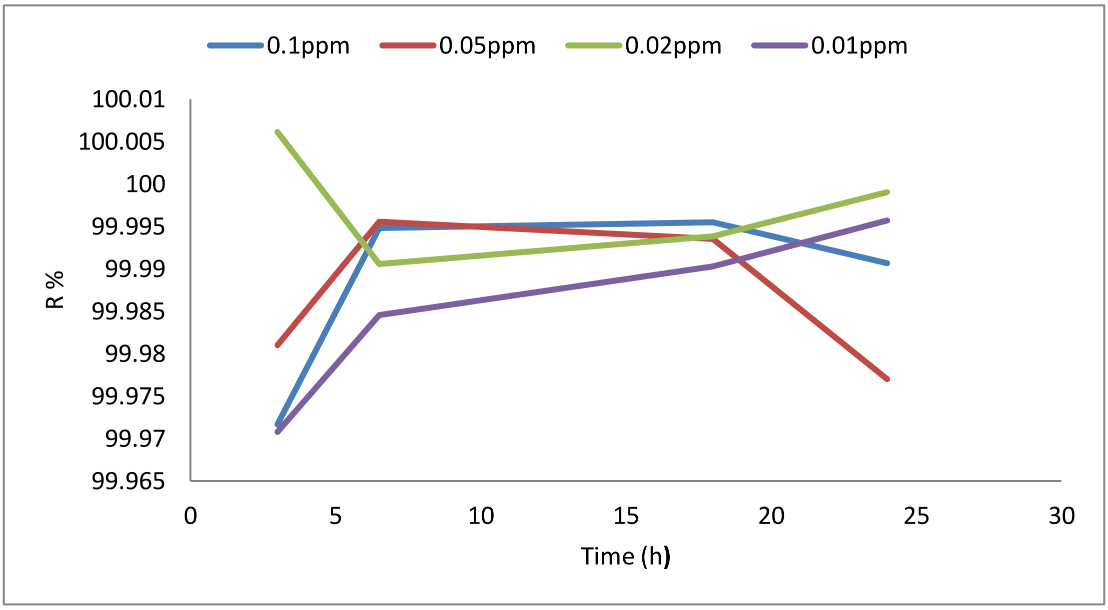


Fig III .9. Comparison of hydroquinone inhibitor yields as a function of time .

It is observed that the yield exceeds 99.97% across all selected concentrations and immersion durations, indicating the high efficiency of the synthesized inhibitor.

Conclusion

Conclusion

Given the significant issue posed by corrosion, this work was undertaken to synthesize of hydroquinone a corrosion inhibitor and study its effect on the corrosion behavior of X42 steel in an aqueous medium specifically,albien water from Biskra University. The study focused on evaluating the corrosion rate of X42 steel over immersion time, with the aim of identifying the optimal conditions to minimize corrosion based on both inhibitor concentration and immersion duration.

Most results showed good performance, with the best inhibition observed at concentrations of 0.1 ppm and 0.02 ppm after 18 hours of immersion. Additionally, hydroquinone achieved 100% inhibition efficiency during the first few hours at 0.02 ppm. The synthesized inhibitor demonstrated excellent effectiveness, reaching an inhibition efficiency of 73.47% at the same concentration after 24 hours of immersion.

From these findings, we conclude that our synthesized inhibitor has a strong effect in reducing the corrosion rate, making it a promising candidate for industrial applications.

References

[1] Ahmad Z. *Principles of Corrosion Engineering and Corrosion Control*. 1st ed. Great Britain: Elsevier; 2006.

[2] McCafferty E. *Introduction to Corrosion Science*. Business Media; 2010.

[3] Youm7. الصدأ والتآكل الذي يصيب الحديد [Internet]. 2019 Mar 1. Available from: https://img.youm7.com/ArticleImgs/2019/3/1/66606. Accessed 23 May 2025 at 12:03.

[4] Cicek V, Al-Numan B. *Corrosion Chemistry*. USA: John Wiley & Sons; 2011.

[5] Kherbiche D, Kemer Y. Study of the Causes of Corrosion in Petroleum Storage Tanks. National Higher School of Mines and Metallurgy – Amar Laskri – Annaba.

[6] American Water College. Pipe corrosion. Available from: https://www.americanwatercollege.org/pipecorrosion/. Accessed 3 Apr 2025 at 05:36.

[7] Land Development 101. Watch out for corrosive soil. 2019 Dec 1. Available from: https://landdevelopment101.com/2019/12/01/watchoutforcorrosivesoil/. Accessed 3 Apr 2025 at 06:32.

[8] Petrovic S. *Electrochemistry Crash Course for Engineers*. 1st ed. Switzerland: Springer Nature; 2021.

[9] Aljohani, T. A., Alateyah, A. I., El-Sanabary, S., & El-Garaihy, W. H. Corrosion of weldments. In *Welding of Metallic Materials* (pp. 565-588). Elsevier. 2023.

[10] Hadji A. *Influence of an Aniline-Derived Inhibitor on the Corrosion Rate of X42 Steel in an Aqueous Medium*. Univ. of Biskra, 2024.

[11] HELAL, Mohamed Atef (ed.). *Solitons*. Springer, 2022.

[12] *Experimental Organic Chemistry: A Miniscale and Microscale Approach*. 5th ed. USA; 2011.

[13] Haimer S. *Synthesis of a corrosion inhibitor and the study of its effect on X42 steel in an aqueous medium* [Master's thesis]. Biskra (DZ): Mohamed Khider University of Biskra, 2016.

الجمهورية الجزائرية الديمقراطية الشعبية

وزارة التعليم العالي والبحث العلمي

جامعة محمد خيضر-بسكرة

كلية العلوم والتكنولوجيا

قسم الكيمياء الصناعية

بسكرة في: ....

إذن بإيداع مذكرة الماستر بعد التصحيحات

أنا الممضي أسفله الأستاذ: شريفي زهية

الرتبة: أستاذ محاضر "أ"

أستاذ مشرف على مذكرة ماستر-للطالب (ة): زاوش رفيدة

الشعبة: هندسة الطرائق

التخصص: هندسة كيميائية

بعنوان: Synthesis of a corrosion inhibitor based on aromatic derivatives

أرخص بإيداع المذكرة المذكورة.

الأستاذ المشرف

Dr Chérifi

رئيس لجنة المناقشة

ملحق القرار رقم: 933 المؤرخ في: 28 جويلية 2016
الذي يحدد القواعد المتعلقة بالوقاية من السرقة العلمية ومكافحتها

الجمهورية الجزائرية الديمقراطية الشعبية

مؤسسة التعليم العالي:

نموذج التصريح الشرفي

خاص بالالتزام بقواعد النزاهة العلمية لانجاز بحث

أنا الممضي أدناه،

السيد: زاوش رفيدة الصفة: طالب، أستاذ باحث، باحث دائم: طالب

الحامل لبطاقة التعريف الوطنية رقم: 110020232003500008 والصادرة بتاريخ 19 - 05 - 2025

المسجل بكلية العلوم والتكنولوجيا قسم الكيمياء الصناعية

و المكلف بإنجاز أعمال بحث (مذكرة التخرج ، مذكرة ماستر، مذكرة ماجستير ، أطروحة دكتوراه)، عنوانها: Synthesis of a corrosion inhibitor based on aromatic derivatives

أصرح بشرفي أني ألتزم بمراعاة المعايير العلمية والمنهجية ومعايير الأخلاقيات المهنية والنزاهة الأكاديمية المطلوبة في انجاز البحث المذكور أعلاه.

التاريخ 24 - 06 - 2025

إمضاء المعني