ENHANCING OF PIVOT IRRIGATION MANAGEMENT BY MINIMIZING CORROSION OF FERROUS BASED PIPE ALLOYS TREATED IN MAGNETIZED AQUEOUS MEDIUM

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Bilal Ali Abbas AL-HALBOOSI

Thesis Advisor
Assoc. Prof. Dr. İsmail Hakkı KARA

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Bilal Ali Abbas AL-HALBOOSI

Thesis Advisor
Assoc. Prof. Dr. İsmail Hakkı KARA

T.C.
Karabuk University
The Institute of Graduate Programs
Department of Metallurgical and Materials Engineering
Prepared as
PhD Thesis

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I certify that in my opinion the thesis submitted by Bilal Ali Abbas AL-HALBOOSI titled "ENHANCING OF PIVOT IRRIGATION MANAGEMENT BY MINIMIZING CORROSION OF FERROUS BASED PIPE ALLOYS TREATED IN MAGNETIZED AQUEOUS MEDIUM" is fully adequate in scope and in quality as a thesis for the degree of PhD.

Assoc. Prof. Dr. İsmail Hakkı KARA ....
Thesis Advisor, Department of Metallurgical and Materials Engineering

This thesis is accepted by the examining committee with a unanimous vote in the Department of Metallurgical and Materials Engineering as a PhD thesis. July 5,2024

Examining Committee Members (Institutions)		Signature
Chairman	: Assoc. Prof. Dr. İsmail Hakkı KARA (KBU)	....
Member	: Prof. Dr. Hayrettin AHLATCI (KBU)	....
Member	: Assoc. Prof. Dr. Harun ÇUĞ (KBU)	....
Member	: Prof. Dr. Yunus TÜREN (NEU)	....
Member	: Assoc. Prof. Dr. Muhammet Hüseyin ÇETİN (KTUN)	....

The degree of PhD by the thesis submitted is approved by the Administrative Board of the Institute of Graduate Programs, Karabuk University.

Assoc. Prof. Dr. Zeynep ÖZCAN ....
Director of the Institute of Graduate Programs

“All information in this thesis has been obtained and presented by academic rules and ethical principles; I also declare that I have made all references that do not originate from this work, as required by these rules and principles.”

Bilal Ali Abbas AL-HALBOOSI

ABSTRACT

Ph. D. Thesis

ENHANCING OF PIVOT IRRIGATION MANAGEMENT BY MINIMIZING CORROSION OF FERROUS BASED PIPE ALLOYS TREATED IN MAGNETIZED AQUEOUS MEDIUM

Bilal Ali Abbas AL-HALBOOSI

Karabük University
Institute of Graduate Programs
The Department of Metallurgical and Material Engineering

Thesis Advisor:
Assoc. Prof. Dr. İsmail Hakkı KARA
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Iron pipes are widely used in irrigation systems but are susceptible to corrosion, leading to deterioration. Magnetized water has gained popularity as a potential anti-corrosion solution, but its effectiveness on iron pipes in irrigation systems is still unclear. This research investigates the effect of magnetized water on the corrosion rate of iron pipes commonly used in irrigation systems. This research methodology involves exposing iron pipe samples to magnetized and non-magnetized water under controlled conditions that simulate different irrigation scenarios (such as flow rate, temperature, and water quality). Three types of water were used: regular river water, sulfuric water, and well water. These waters were also magnetized. The scanning electron microscopy (SEM) technique is employed to determine the morphology of corroded surfaces, enabling a deeper comprehension of the interplay between magnetized water and iron. This investigation aims to deliver valuable insights into the potential of magnetized water to reduce corrosion of iron pipes within irrigation systems. Furthermore, it seeks to highlight the influence of water quality and operational conditions on the effectiveness of magnetized water and elucidate the mechanisms through which magnetized water interacts with iron, consequently influencing its corrosion behaviour. The outcomes of this study will also contribute to the enhancement of improved strategies for designing and maintaining irrigation systems. It can diminish infrastructure damage and replacement expenses, bolster water utilization efficiency and resource sustainability, and enhance agricultural productivity and food security. In conclusion, river water, particularly when magnetized, delivers the most favourable outcome on steel by reducing the occurrence of chemical reactions that lead to corrosion. Conversely, magnetized sulfate water exhibits the most adverse effect as corrosion intensifies with elevated carbon and oxygen concentrations.

Key Words : Magnetized water, Iron pipes, Corrosion.
Science Code : 91513

ÖZET

Ph. D. Thesis

MIKNATISLI SULU ORTAMDA KULLANILAN DEMİR ESASLI BORU ALAŞIMLARININ PASLANMASINI EN AZA İNDİREREK PİVOT SULAMA YÖNETİMİNİN GELİŞTİRİLMESİ

Bilal Ali Abbas AL HALBOOSI

Karabük Üniversitesi
Lisansüstü Eğitim Enstitüsü
Metalurji ve Malzeme Mühendisliği Bölümü

Tez Danışmanı:
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Demir borular sulama sistemlerinde yaygın olarak kullanılmaktadır, ancak korozyona karşı hassastır ve bu durum da korozif etkilere neden olur. Mıknatıslanmış su, potansiyel bir korozyon önleyici çözüm olarak giderek daha fazla tercih edilmektedir, ancak sulama sistemlerindeki demir borular üzerindeki etkinliği tam olarak belirsizdir. Bu çalışma, mıknatıslanmış suyun, yaygın olarak kullanılan sulama sistemlerindeki demir boruların korozyon hızına etkisini araştırmaktadır. Çalışmanın metodolojisi, demir boru örneklerini, akış hızı, sıcaklık ve su kalitesi gibi farklı sulama senaryolarını simüle eden kontrollü koşullar altında hem mıknatıslanmış suya hem de mıknatıslanmamış suya maruz bırakmaktır. Üç farklı su türü kullanılmıştır: normal nehir suyu, kükürtlü su ve kuyu suyu. Bu sular da mıknatıslanmıştır. Korozyona uğramış yüzeylerin morfolojisi, mıknatıslanmış su ve demir arasındaki etkileşimin ardındaki mekanizmaları anlamak için taramalı elektron mikroskobu (SEM) kullanılarak belirlenmiştir. Bu çalışma, mıknatıslanmış suyun, sulama sistemlerindeki demir boruların korozyonunu azaltma potansiyeline, su kalitesi ve çalışma koşullarının mıknatıslanmış suyun etkinliği üzerindeki etkisine, ayrıca mıknatıslanmış suyun demirle etkileşime girdiği mekanizmalara dair değerli bilgiler sunacaktır. Elde edilen sonuçlar, altyapı hasarını ve yenileme maliyetlerini azaltabilme, su kullanım verimliliğini ve kaynak sürdürülebilirliğini artırabilme, tarımsal üretkenliği ve gıda güvenliğini artırabilme amacıyla sulama sistemlerinin tasarımı ve bakımı için iyileştirilmiş stratejilerin geliştirilmesine katkı sağlayacaktır. Nehir suyunun, özellikle mıknatıslanmış suyun, reaksiyonlara ve dolayısıyla korozyona neden olan kimyasalları azalttığı için çelik üzerinde en iyi etkiye sahip olduğu, manyetize sülfatlı suyun ise C ve O arttıkça korozyonun artması nedeniyle en kötü etkiye sahip olduğu sonucuna varılmıştır.

Anahtar Kelimeler : Manyetize su, Demir boru, Korozoyon.
Science Code : 91513

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SYMBOLS AND ABBREVIATIONS INDEX

SYMBOLS

W : weight difference
w_0 : basic sample weight
w_1 : sample weight
A : the surface area of the sample
d : sample density
t : ımmersion time a: plot area
B : weight difference
R : effective instantaneous resistance estimated in ohms
V : rated applied voltage in volts
P : polyvinyl chloride

ABBREVIATIONS

NAS : National Aeronautics and Space Administration
LPR : Liner Advantages of Polarization Resistance Technique
SCC : Stress-Corrosion-Cracking
MIC : Microbially Induced Corrosion
pH : A numerical Measure of The Acidity or Alkalinity
MWT : Magnetic water treatment
EIS : Electrochemical Impedance Spectroscopy
USNA : United States Naval Academy
EDS : Energy-dispersive X-ray spectroscopy

PART 1

INTRODUCTION

1.1. LITERATURE REVIEW

We rely on metallic structures to support our everyday activities, be it getting to work, transporting goods worldwide, storing and preserving food, or using it to move water to many uses, for example, in agriculture, especially pivot irrigation. Metals are everywhere. However, when most metals encounter water, they are subject to sustained and continuous attack, leading to the metal corroding and failing to do its job. It is, therefore, essential to understand when corrosion will occur, how fast it will proceed and what can be done to slow down or stop it. As we know, corrosion is the process of destroying or corrosion of a substance due to interaction with the surrounding environment. Corrosion can occur in metals, plastics, and other materials, such as corrosion in iron pipes used in pivot irrigation systems. As we know, Iron pipes are the most common type of pipe used for pivot irrigation. However, these pipes can be corroded by water, leading to damage or even collapse. Many ways to reduce corrosion include coatings, varnishes, and chemical additives. One of the methods being studied is magnetized water. Magnetized water is water that has been exposed to strong magnetic fields. Some people believe that this exposure changes the properties of water and makes it more corrosion resistant. There are many theories about how magnetized water works to reduce corrosion. One theory is that magnetic fields can rearrange water molecules, making them less vulnerable to chemical attack. Another theory is that magnetic fields can inhibit the formation of molecular oxygen, which can cause metal corrosion. There is some evidence to suggest that magnetized water can reduce corrosion. For example, a study found that magnetized water can reduce the rate of corrosion in steel pipes. However, some studies have not found any effect of magnetized water on corrosion. Research into the use of magnetized water to reduce corrosion is ongoing. More studies are needed to confirm the effectiveness of this method. Some scientists believe magnetic fields can rearrange water molecules, making them less vulnerable to chemical attack. Water molecules consist of two hydrogen atoms and one oxygen atom joined by covalent bonds. When water molecules are exposed to magnetic fields, they can be rearranged to make them more stable. Some scientists believe this added stability makes water molecules less likely to react with oxygen, reducing the corrosion rate. Some scientists also believe that magnetic fields can inhibit molecular oxygen formation, which can cause metal corrosion. Molecular oxygen consists of two oxygen atoms bonded together by a double bond. Molecular oxygen can react with iron to form iron oxide, which can cause metal corrosion. Some scientists also believe magnetic fields can inhibit molecular oxygen formation by holding oxygen atoms in place. That makes it difficult for oxygen atoms to interact to form molecular oxygen. However, the initial results are promising and may lead to the development of new and effective ways to reduce corrosion. There are many theories about how magnetized water works to reduce corrosion in iron. Some evidence suggests it could be effective, but more studies are needed to confirm this [1].

Research (2009) Rifay-al. H.S in the effect of corrosion of graphite cast iron as a composite material under local conditions, including drinking water, and indicated that the slatted shape of graphite causes higher corrosion rates than the shape of graphite spherical or pink and pointed out that the reason for this is the association and overlap of graphite strips in grey casting iron, which forms a network Continuous graphite allows the penetration of the corrosion medium. Still, In the case of graphite cast iron and graphite spherical cast iron, the graphite forms a continuous network, which works to keep the corrosion medium isolated, reducing the wear rate compared to grey cast iron. It may make the metal less active with the corrosive medium or due to the formation of protective layers that reduce the interaction of the metal surface with the corrosive medium [2].

As the researcher. Sancy. M (2009) and his colleagues studied corrosion in the drinking water pipe network made of cast iron, where the study included corrosion in water and soil saturated with the same water, and the inner surface of the pipe showed a low rate of corrosion relative to the outer surface, where the rate of erosion of the outer surface exposed to water-saturated soil as a corrosive medium was about ten times the rate of corrosion of the inner surface exposed to water as a corrosive medium. Because a porous corrosion layer is formed on the inner surface of the tube, this layer is conductive, reducing the presence of oxygen on the pipe's inner surface. Still, this layer is present on the outer surface. Still, it is non-conductive, as it works to reduce the rate of oxygen diffusion [3].

Researchers S.A.Ajeel and S.M.Hasoni (2007)When studying the microstructure properties and chemical analysis of both grey cast iron and iron cast malleable for use in analyzing the results of the microstructure after immersion and polarization tests of cal bimetals in different concentrations of sodium chloride (3.5%,0.58%,0.01%). The corrosion resistance of both metals is excellent, the corrosion resistance of ductile casting iron is better than grey casting iron, and the decrease in the corrosion rate in the bimetals is related to the sediment barrier layer (layer Barrier). Which is more homogeneous in ductile iron? Electrochemical tests were also carried out, which included measuring the corrosion potential in the open circuit and for both metals. The corrosion efforts measured using an open circuit in all solutions of grey cast iron showed that their values were more noble than those calculated for the forging casting iron. As for the results of the microstructure during corrosion, it was proven that a homogeneous barrier layer was obtained on the surface of the cast iron, and the grey casting iron process occurred [4].

Yadav. P. A (2003) studied the effect of electrochemical corrosion of galvanized steel under the conditions of the cycle dry-wet, where the results were presented for alternating conditions of wetting and drying, and the time is different (11,7,3) hours at a temperature of 298K and a humidity of 60%. It was concluded that corrosion is rapid in the first period of this cycle and decreases at the end and that the short drying time of the cycle leads to an increase in the rate of corrosion, and the reason for this is due to the breakage of the oxide layer formed by air and to the effective increase in the decrease in the protective coating due to the rise in the concentration of chloride ions during the drying period [5].

S.R Abdeltwab. (2011) investigated the effect of industrial magnetized water devices on dissolved salts in water, mainly calcium ions, magnesium ions, and pH. He used four different groups of water (drainage water, swamp water, drinking water, and salt water), and each sample of water used a particular device for magnetization and a pipe made of plasticity (PVC) with a length of 5.1 meters to transport it, where water was pumped from a tank with a capacity of 25 liters. It was found that it reduces the percentage of dissolved salts in water and increases the pH value, as the pH is related to the concentration of hydrogen ions, so the less hydrogen ions, the less acidity of the medium and the higher the pH and thus reduces the percentage of corrosion [6].

H. H Ge. (2010) and colleagues studied the inhibition scale of electromagnetically treated water and the corrosion of carbon steel in this water. They found that corrosion is inhibited when carbon steel is exposed to this water for some time, and carbon steel corrosion decreases as the water is exposed to the electromagnetic field [7].

Research G. Bikulchyus and colleagues in the corrosion behavior of low carbon steel in magnetized water where the research included the passage of water and circulation in a magnetic field of magnitude 05.0 ask and was used heater to heat water to (40º or 70ºC) where the development of standard rings of steel that contains (0.15% wtC) and a surface area of $132cm^2$ directly above the heater and the experiment took two hours and then was weighed rings to know the rate of corrosion also measured the proportion of the presence of oxygen and electrical conductivity of water and concluded that magnetization Water reduces corrosion by 14% whatever the temperature[8]. Study on water treatment magnetically that it prevents the internal sedimentation of the tube because the magnetization of water reduces the presence of calcium ions and thus reduces the formation of calcium carbonate NASA tested the corrosion of steel in magnetized water and compared it with chemical corrosion inhibitors in which the rate of corrosion of (1-50 mpy) (where the rate of corrosion four mpy is acceptable) while recorded a corrosion rate of 0 mpy for magnetized water and the researcher considered that although the research It was conducted in NASA laboratories, magnetized water can't show an effect of corrosion, it has been proven. It is very successful in reducing the rate of corrosion [9].

PART 2

CORROSION

2.1. DEFINITION OF CORROSION

Corrosion is the most significant failure of metal parts and equipment, which may reach more than 70% of all other failures that affect metal parts. This failure is caused by metal surface corrosion in the medium in which it operates. The corrosion dilemma is due to electrochemical reactions, and this happens when the medium exposed to the metal is a carrier medium called catabolite. So, this type of failure is known as wet or electrochemical corrosion because the reactions leading to its occurrence require aqueous media and may occur at average temperatures. As for rust, which is the other type of surface failure resulting from the interaction of the metal surface with the medium in which the metal operates, it is not caused by electrochemical reactions. Still, by a direct union between this surface and the oxygen in the medium it works, this usually happens for many metals at average and high temperatures [1].

2.2. ECONOMIC EFFECTS OF CORROSION

The study of the phenomenon of corrosion and its causes to reduce it is of great importance from an economic point of view because of the possibility of prolonging the life of the metal part. The material damage caused by rapid damage to the metal part due to corrosion is often much higher than the material damage resulting from the disbursement of money to protect the metal part from prolonging its life, in addition to the high economic cost of controlling corrosion. This comes from several reasons, the most important of which is the choice of alloys, especially corrosion resistance. Corrosion prevention methods have their costs, including those related to unique designs, cathode protection, elevator protection, the use of inhibitors, and coating with various materials [1].

The greater the economic cost of erosion is, the greater the degree of industrial progress of a country. The losses resulting from erosion and prevention work amount to about 3% of the national income in developed countries, which is not negligible. For example, the loss of the United States in 1998 was approximately 672 billion dollars, and the following are the most critical losses as follows;Losses due to production interruption, repair and maintenance costs, loss of product due to leakage or contamination, low operating efficiency due to the accumulation of corrosion products on the pipes and the blockage that occurs in them, loss of production time, which delays the development of the product and its marketing at the planned time, costs of design precautions, protection methods, and corrosion control, loss of safety and security due to disasters such as explosions, fires and loss of life environmental pollution [2].

2.3. CORROSION MEASUREMENT

Corrosion is measured using two different techniques: weight loss measurement and linear polarization.

2.3.1. Weight Loss Measurement

Weight loss measurement is a classic non-electrochemical method that is effective for accurately determining corrosion rate. The method gives more accurate results than electrochemical techniques because the experimental conditions are more realistic. Weight difference tests depend on immersing the sample in the test solution according to three-time stages. Each stage takes 15 days, so the period for the study is 45 days. Weight loss Measurement is one of the best-known corrosion control techniques. The primary measurement that is renewed is the weight change, which expresses the weight difference that occurs during a certain period of exposure to the corrosion medium[10].

2.3.2. Electrochemical Method of Measuring Corrosion

The polarization curves method is an electrochemical technique that uses a small voltage to measure current density through the metal/liquid contact zone. This technique involves changing the potential of the electric path and monitoring the output current as a function of time or potential difference [11].

The electrical conductivity of the solution is related to its corrosivity. Two or three electrodes are used during the work of LPR technology, and the electrodes are electrically isolated. A small voltage of about 20mV (which does not affect the normal corrosion process) is applied between the elements, and the intensity is measured inversely to the corrosion rate[11].

The study of linear polarization technique is one of the effective electrochemical methods used to measure corrosion. Studying the relationship between electrochemical potential difference and the current generated between electrically charged electrodes helps calculate the corrosion rate. The main benefit of LPR technology is that it allows the corrosion rate to be determined quickly. Because you can notice changes in the percentage of corrosion within minutes. A significant benefit is the observability of corrosion by metal necrosis.

The polarization curve is defined as a latency curve (or vice versa) expressed by the following equation in (2.1):

$$I=f(E) \tag{2.1}$$

Where this curve is used to illustrate the process of granting and receiving electrons. When the metal surface is polarized by applying current in the positive direction, it is called anosmatic polarization. In contrast, the opposite direction refers to cathode polarization, whether the current changes as a subject of voltage or vice versa. It allows the researcher to study the effect of concentration and effective processes on the metal at which anode and cathode reactions can be hindered.

When the metal is subject to a potential difference at first, the metal is the cathode. It is in a cathode protection state, after which the metal passes through the inert zone. In this area, the corrosion speed is significantly low despite the great tendency to dissolve the metal due to the formation of a protective layer of corrosion products. We notice from the curve starting from the potential corrosion of the metal. The higher the latency applied, the faster the current density increases as the curve passes through the so-called effective zone through which the metal is analogically dissolved [11]

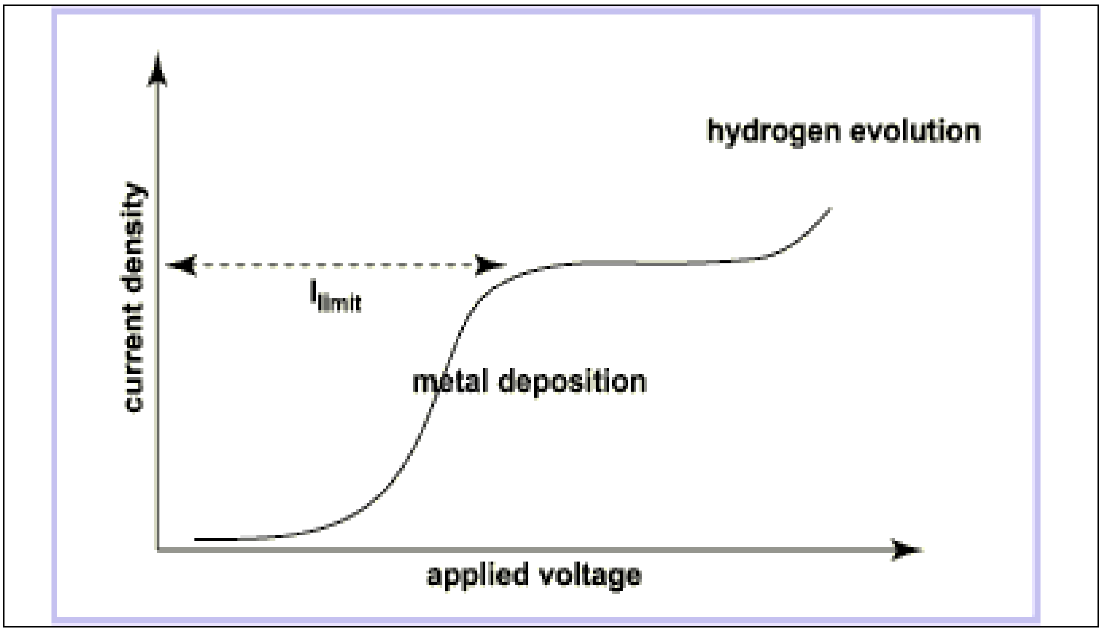


Figure 2. 1. Polarization Curve [11].

To determine the value of the corrosion current corresponding to the corrosion potential value, we draw a tangent to the curve representing the elevator reaction and a tangent to the curve representing the cathode reaction, then determine the value of the corrosion potential and create a line from it until it intersects with the point of convergence of the two tangents, then we project this point on the represented axis (log I).

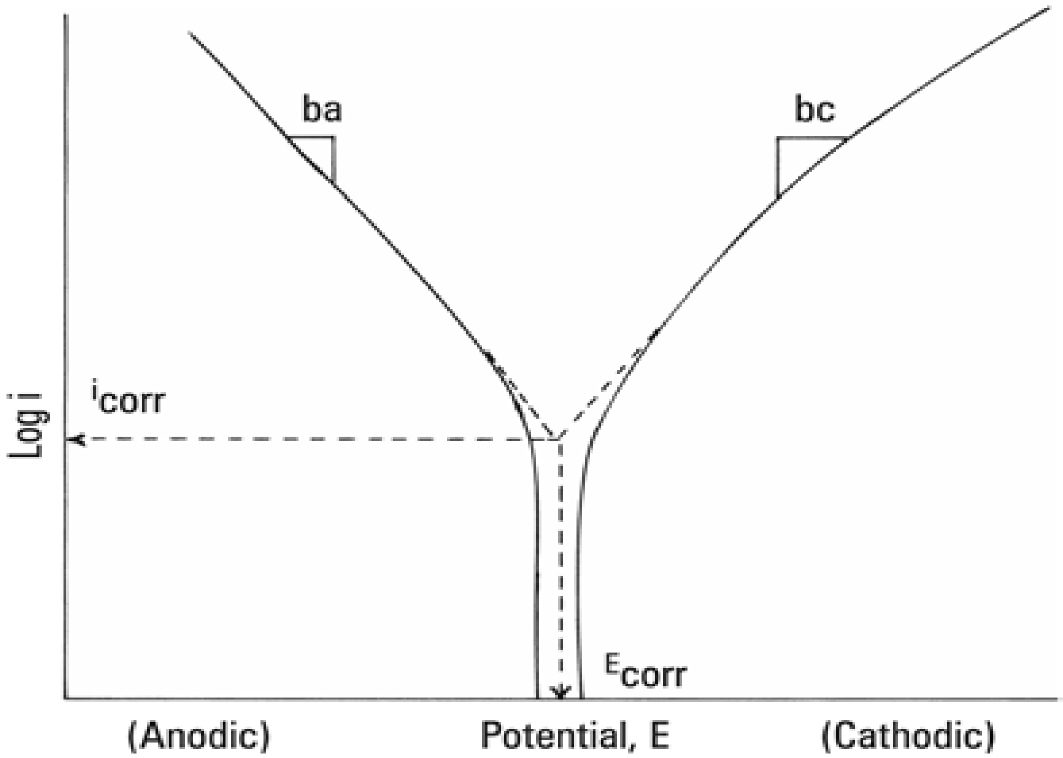


Figure 2. 2. Relationship between potential and current logarithm (Tafel curve) [11].

2.3.3. External Factors Affecting the Corrosion Process

The concentration of the solution can increase the corrosion speed of the metal. For example, iron corrodes in an aqueous solution of a nitrogen acid concentration of 1M. In comparison, it does not rust in a solution of concentration 12M due to forming an inert protective layer that protects the metal in concentrated and expanded sulfuric acid. The temperature affects thermodynamics and the driving forces of metal corrosion. The increase in temperature usually increases the ascendant and cathode reactions, where the decomposition of gaseous oxygen in the media decreases and accelerates the spread of electrolytes. The temperature also changes the decay and transfer of corrosion products formed on the surface of the metal. For example, it is expected that an increase in temperature accelerates the corrosion of steel in aqueous media, but experiments will appear because the rate of iron corrosion increases at the beginning of the temperature rise and then reaches the highest limit at 80-60 and then decreases as in the figure (3).

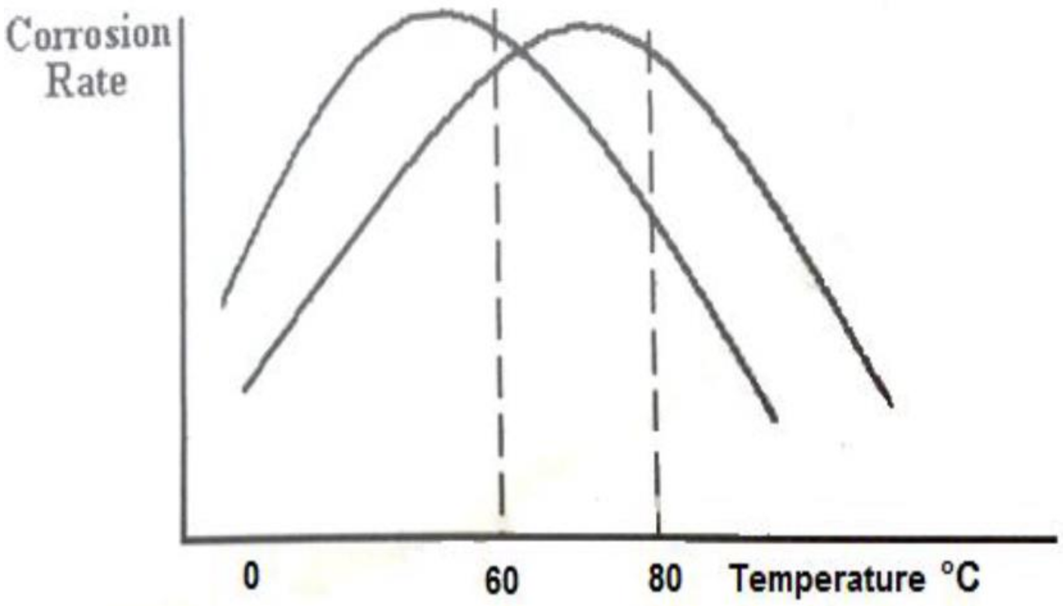


Figure 2. 3. Relationship of the rate of corrosion with temperature [12].

The temperature increases at first, which accelerates the reaction on the surface of the metal. Thus, the dissolution of metal electrolytes and the decrease of oxygen electrolytes, and this temperature rise also results in a reduction of the solubility of oxygen in the water, and at a temperature of approximately 100 ° C, all dissolved oxygen disappears to remove the dissolved oxygen in the water is heated to 100 °C at normal atmospheric pressure [12].

Temperature affects corrosion in two different ways; accelerates the escalating and cathode reactions and reduces the concentration of dissolved oxygen.

Figure 2.4 shows the effect of temperature on the dissolution of oxygen in water. These two factors are achieved at some temperatures so that corrosion reaches the maximum value. With high temperatures, oxygen dissolved in water decreases and increases ascendant and cathode reactions. When dissolved oxygen disappears, the rate of corrosion decreases [12].

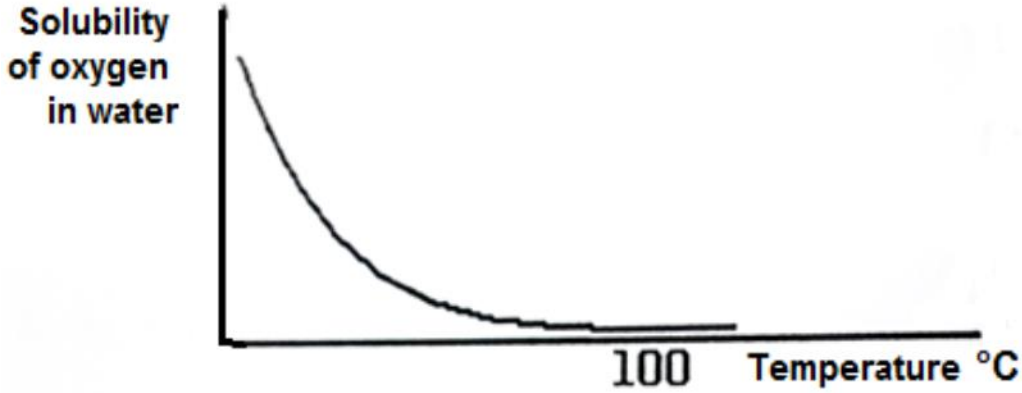


Figure 2. 4. Oxygen decay changes with temperature change [12].

pH is a measure of the acidity or alkalinity on a scale of 1 to 14. pH 7 is neutral. In neutral sea water, the pH is around 7.5, meaning the hydrogen ions (acid) and hydroxyl ions (alkali) are almost in balance. Under such circumstances, the reaction that balances the iron dissolution is the reduction of dissolved oxygen to form hydroxyl ions. If the environment becomes more acidic and the pH falls closer to 1, the solution has a greater quantity of hydrogen ions than hydroxyl ions. The excess hydrogen ions can become involved in the balancing (cathodic) reaction, which results in the evolution of hydrogen gas. Steel can rust faster as hydrogen ions and gas diffuse rapidly. This is common when carrying pet coke, sulphur and sour crude oils. Under alkaline conditions, where excess hydroxyl ions and the pH levels tend towards 14, steel cannot rust and remains unaffected. Many blisters in ballast tanks, particularly in the double bottoms, are filled with high-pH fluid. When the blister caps are removed, the steel is bright underneath. However, it will begin to rust once the cap is removed, so once one or two of a group of blisters have been checked, and the liquid found to be alkaline, the remainder of the blisters should be left intact [13].

Oxygen is another crucial factor for corrosion, whether in the air or aqueous media, and oxygen plays a significant role in chemical reactions that occur in localized galvanic cells. These two factors (air and water) are sufficient for corrosion to occur, even if the metal is pure. Metals absorb air on their surface, so if the concentration of oxygen around a certain point of the metal is higher than around another point, this leads to the formation of galvanic cells in which the metal is the elevator and oxygen is the cathode [14].

The salts and electrolytes in the solution can have a harmful or beneficial effect. For example, in alkaline solutions, aluminum is not corroded; it is corroded in an aqueous electrolyte containing copper electrolytes. Chlorides are one of the catalysts in the process of metal corrosion, as they help form the electrolytic solution that helps form galvanic cells. They can be seen in aluminum facilities adjacent to marine areas. Dry hydrogen chloride gas is not considered a corrosive agent, but if it is found at a certain degree of humidity, it becomes a strong catalyst for corrosion.

The role of carbon dioxide in corrosion is secondary, and most natural water contains this gas, as it dissolves to form carbon acid, which is displaced according to the following two equations (2.2) and (2.3):

$$\mathrm{H2O + CO2 \rightarrow H2CO3} \tag{2.2}$$

$$\mathrm{H2CO3 \rightarrow HCO3\ - + H+} \tag{2.3}$$

It thus increases the acidity of the water, and the increase in the concentration of positive hydrogen electrolytes increases corrosion.

As for sulfur dioxide gas SO2, it dissolves strongly in water, forming cretantic acid, which is displaced according to the following (2.4) and (2.5):

$$\mathrm{SO2 + H2O \rightarrow H2SO3} \tag{2.4}$$

$$\mathrm{H2SO3 \rightarrow HSO3- + H+} \tag{2.5}$$

Its danger comes not only in its ability to increase the concentration of hydrogen electrolytes in the solution but also in the amount of it helps to return dissolved oxygen in water and the formation of sulfate ions with the most substantial effect.

$$\mathrm{SO2 + O2 + 2e- \rightarrow SO42-} \tag{2.6}$$

As for hydrogen sulfide gas, it is one of the chemically active gases, as it can interact directly with many metals, leading to their eating.

Corrosion increases in the presence of mechanical factors such as stresses, where cracks are formed from the surface under the dual effect of both the irritating medium and the applied stress force, and cracks grow either between the granules or through the granules, and this is accompanied by a deterioration in the mechanical properties of the metal if the metal is subjected to repeated stresses we get the phenomenon of fatigue corrosion. Corrosion occurs associated with erosion when the movement or flow of a liquid contains solid abrasive particles, which leads to the removal of the protective oxide layer, so electrical solutions are formed between the rest of the oxide layer and the surface of the bare metal, which increases the speed of corrosion [14].

2.4. TYPES OF CORROSION

2.4.1. Uniform Corrosion

This corrosion results from the continual shifting of anode and cathode regions of the surface of a metal in contact with the electrolyte. It leads to a nearly uniform corrosive attack on the entire surface. An example of such corrosion is the rusting of steel plates in seawater.

If the rate of metal loss is known, allowances can be made in design and maintenance to accommodate the corrosion. Although it is termed uniform corrosion, it is characterized by average surface loss [15].

2.4.2. Galvanic Corrosion

An electrical potential difference will exist when two metals are exposed to a corrosive environment. If the two metals are electrically connected, the more active metal will become the anode in the resulting galvanic cell, and its corrosion will increase. An example of such a corrosion cell is using steel bolts to hold copper plates together. Not all galvanic corrosion is detrimental. Zinc-coated steel, or galvanizing, is used to protect steel, not because the steel is resistant to corrosion, but because the zine, being anodic to the steel, corrodes preferentially. Hence, the steel is protected cathodically by making any exposed steel areas into cathodes [16].

2.5.3. Crevice Corrosion

Crevice corrosion is a localized attack when crevices, formed by lapped joints or areas of partial shielding, are exposed to corrosive environments. Such resulting cells are referred to as concentration cells. Two typical cases are oxygen cells and metal-ion cells.

Oxygen concentration cells occur when the shielded area becomes depleted in oxygen, and the area acts as an anode relative to the oxide region. The corrosion becomes relatively rapid because of the small, shielded area compared to the unshielded area. Please do not get confused with the concentration polarization that we previously discussed. In the case of an oxygen cell, we have an oxygen "gradient" that forces the formation of the anode and cathodes for the oxygen levels. The initial driving force of such corrosion is the oxygen cell. The continued growth is fostered by the accumulation (often caused by the same factors that produced the low oxygen level) of acidic, hydrolyzed salts within the aperture. Alloys, such as 18-8 stainless steel, are subject to corrosion of oxygen cell crevices.

Metal-ion cells are formed mainly with copper alloys. The shielded area accumulates corrosion products and becomes cathode to the regions outside the crevice where corrosion products are washed away [16].

Another example of metal-ion cell corrosion occurs when relative speeds of electrolyte over the metal surface are more incredible at one point than at another, thus resulting in metal-ion crevice corrosion. A good example is when a metal disc rotates rapidly in seawater. Corrosion occurs near the edge where linear velocities ($v=\omega r$) are the highest, and the metal-ion concentration is low (since the ions are repeatedly swept away). The high velocity, higher than in regions closer to the disc's hub, sweeps away the metal ions, thus forming anode regions. At the center of the disc, where velocities are lower, the metal acts as a cathode. It is protected (Do not confuse this with the discussion on "immunity" from corrosion where the low ion concentration was one of the entering arguments. That was equilibrium concentration. In this case, metal ions continue to form because we can't reach an equilibrium concentration).

However, the two concentration cells corrode at different regions of the aperture. The oxygen cell corrodes under the shielded area, while the metal-ion cell corrodes outside. As stated before, the initial driving force behind the corrosion is either the oxygen or the metal-ion cell. Its continued growth is governed by accumulating corrosion products, calcareous deposits, and salts within the aperture.

2.5.4. Pitting Corrosion

Pitting is a highly localized attack that eventually results in holes in the metal. It is one of the most destructive and insidious forms of corrosion. The alloys subject to pitting rely on an oxide film for protection, such as stainless steel. The initiation of a pit can be the result of any of the following: Chemical attacks, such as ferrous chloride or aerated seawater on stainless steel, mechanical attack such as an impact or scratching that removes small areas of the protective film, crevice corrosion resulting from tiny deposits on the surface, especially in stagnant seawater. Some theories state that pitting is just a particular case of crevice corrosion.

2.5.9. Intergranular Corrosion

On a microscopic level, metals and their alloys have small, distinguishable regions called grains. Within an individual grain, the orientation of the atomic arrangement (called a lattice) is the same. Individual grains have different orientations, and the boundary between them is called the grain boundary. Usually, grain boundaries are no more reactive in corrosion than the grain itself. Under certain conditions, however, the grain boundaries are altered. Not all grain boundaries are equally susceptible to corrosion. Those enriched with second-phase particles are particularly vulnerable to impurities and enrichment (or depletion) of one of the alloying elements. Heat treatment and welding can change metal composition, possibly inciting intergranular corrosion. In severe cases, intergranular corrosion can lead to a marked decrease in mechanical properties and can, in extreme cases, turn the metal into a pile of individual grains. One of the most common examples of intergranular corrosion occurs in stainless steel. During welding of the alloy or heating in the 950F to 1450F, the alloy becomes sensitized or susceptible to intergranular corrosion. The chromium carbide (Cr23C6) is not soluble in this temperature range and sediments from the grain into the grain boundary. As a result, the grain area adjacent to the grain boundary is depleted, and chromium becomes anodic to the rest of the grain and the grain boundary. The corrosion of this depleted grain boundary area is very severe and occurs in environments and acids where the alloy would not normally corrode. The simplest solution to the stainless-steel intergranular corrosion problem is to cast alloys with carbon contents below 0.03%. (This prevents chromium carbide formation, and the chromium stays in solution) [16].

2.5.11. Biological corrosion

Biological organisms can play a significant role in mental attacks. This attack is usually categorized in the following two headings: Microbially induced corrosion (MIC) - aerobic and anaerobic bacteria and other microorganisms contain enzymes and can produce metabolites which accelerate corrosion. Pitting-type corrosion of the metal surface is a possible manifestation (or consequence) of this phenomenon. Macrofouling effects - barnacles, oysters, and other macrofoulers produce by-products that are often acidic and can accelerate corrosion. These organisms also create crevices at their attachment points, which can lead to crevice corrosion.

PART 3

PIVOT IRRIGATION

3.1. INTERDICTION

The irrigation pipes are an essential component of irrigation systems, moving water from their source to agricultural areas. However, irrigation tubes are vulnerable to erosion, which can lead to several problems, including reduced flow of water, which can cause erosion and make the surface of the pipes coarse and pierced, thus reducing the water flow. It also results in leaks that cause deterioration and leaks in pipes, resulting in water waste and reduced irrigation system efficiency. Also, in extreme cases, erosion can lead to complete failure of pipes, resulting in crop damage and costly repairs. Corrosion can be caused by a variety of factors, including Water chemistry: The pH, salinity, and mineral content of water used for irrigation can affect the rate of pipe wear. For example, acidic water is more aggressive than alkaline water, and water with high salinity levels can also accelerate erosion. Tube material: The pipe material used can also affect the wear rate. For example, iron pipes are more susceptible to corrosion than steel or plastic pipes. Environmental factors: The environment in which irrigation pipes are installed can also affect the corrosion rate. For example, hot, humid, or saline pipes are more corrosion resistant. Since irrigation pipes are susceptible to corrosion, it may lead to significant economic losses. Some of the financial losses from corrosion in irrigation pipes are as follows: Reduced agricultural productivity: Erosion can reduce crop water flow, resulting in lower productivity.

Increased irrigation costs: Corrosion can increase irrigation costs due to the need to repair or replace damaged pipes. Water Pollution: Water leaking from damaged pipes can contaminate ground and surface water.

Corrosion of irrigation pipes is a serious problem that can lead to significant economic losses. Farmers, businesses and governments can protect their investments and ensure the continuity of water supplies by taking steps to prevent or mitigate erosion.

3.2. DEFINITION OF PIVOT IRRIGATION

Pivot irrigation is a form of overhead sprinkler irrigation consisting of several parts of pipes (usually galvanized steel or aluminum) with sprinklers placed along them, connected and supported by supports, and mounted on towers with wheels. The machine moves in a circular pattern and is fed water from the focal point in the circle's center [15].

3.3. CENTER PIVOT DESIGN CONSIDERATIONS

The sprinklers' arrangement (or design) in a center-pivot irrigation system is crucial. Components would include (as shown in Figure 3.1) the pivot point, control panel (user interface), spans between towers, tower drive wheels, truss system supporting the water supply lateral, sprinklers, and often an end gun (with or without an end gun booster pump). For most electric systems, a one-minute timer is used to control the “walk” (i.e., travel) speed of the end tower. The speed of the end tower around the circle controls the application depth (assuming a constant water supply to the pivot point). A 50% timer setting would correspond to the end tower moving for 30 seconds and then remaining stationary for 30 seconds since the end tower drive motor is a constant velocity design. Thus, the center pivot system's maximum travel (or “walk”) speed would be when the timer is set to 100%. All interior towers have switches that energize the respective tower drive motor to start that tower walking whenever the next tower has walked ahead such that the two towers are misaligned. Once re-aligned, the switches stop the drive motor.

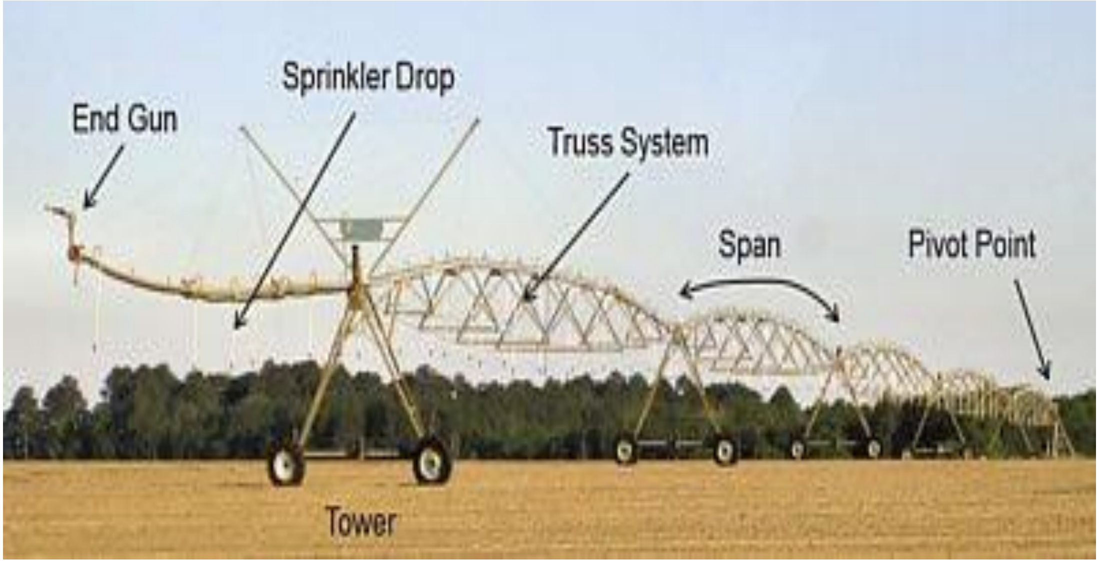


Figure 3. 1. Components of a typical center pivot irrigation system [17].

3.4. CORROSION OF WATER PIPES

The water distribution system is a critical public health battlefield of the 21st century. Iron and steel pipes have been used in water distribution systems for over five centuries. The water distribution network cannot be considered an inert system; it is a reactor interacting with the interior aqueous environments. During the interaction, unwanted deposits form. The primary source of deposit is particulate matter transported by water, dissolved oxygen, microbial activity, chlorides, sulphates and physicochemical reactions both at the pipe wall interface and within the water bulk. Most water distribution systems have a buildup of iron corrosion products inside the iron pipes. Corrosion scale/deposits restrict the flow of water and degrade water quality. The scales are porous deposits that are comprised of iron hydroxide phases. Corrosion inhibitors aim at the protection of metals and alloys, preventing or retarding corrosion reactions through the formation of a monomolecular film-adsorbed surface exposed to a corrosive medium. The modified polymers in the form of solids can be used as corrosion inhibitors. Still, they must possess, interalia, the following features: anticorrosion protection capability, proper consistency to use controlled dissolution rate and chemical compatibility with the material, corrosive medium and other additives used in petroleum industry operations. This work aims to present a corrosion inhibitor in solid form for use in the hydrochloric acid solutions commonly used in oil well stimulation and propose solid inhibitor application techniques for use in segments of the petroleum industry such as oil and gas pipelines [18]

3.5. CORROSION CAUSES OF IRRIGATION WATER PIPES

Here are a few of the main reasons why water pipes corrode. Some are simple and easy to remedy; others are complex and hard to diagnose. Often, more than one of the following contributes to the breakdown of pipes.

3.5.1. Galvanic

Galvanic corrosion is common with metal pipes. It occurs when pipes made of different metals are joined. A small electrical current flows from one to the other. Galvanic corrosion is easily prevented by installing a dielectric union when joining the pipes, but dielectric connectors are often left out to save money.

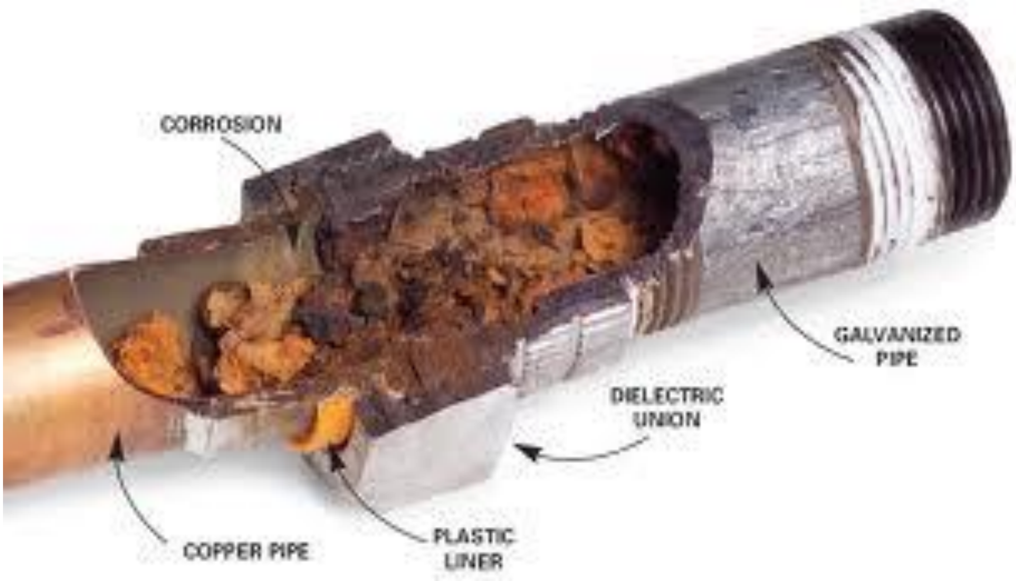


Figure 3. 2. Galvanic corrosion [1,11,19].

3.5.2 Dissolved Gases and Chemicals

High levels of dissolved gases, like oxygen or carbon dioxide, can corrode metal pipes and cause pinhole leaks. High chlorine levels can be corrosive to pipes, and high fluoride levels corrode stainless steel. Chloramine is associated with the leaching of lead from inner pipe surfaces [20].

3.5.3 Low pH

Water with low pH attacks copper pipes and causes pinhole leaks. Copper is subject to corrosion when the water is below 7.0 pH. Corrosion caused by high acidity or mineral content in water is usually not a problem with city water. However, it can be a significant issue for well-owners [10].

3.5.4. Low alkalinity.

Alkalinity is related to pH, but it isn’t the same. Low alkalinity leaves pipes vulnerable to acids [13].

3.5.5. High Temperature and High Flow Rates.

Hot water is much more corrosive than cold. The faster water flows through a pipe, the more it breaks down the pipe.

Figure 3. 3. A pinhole leak in a copper pipe caused by corrosion[11].

3.5.6. Microbiological

If given a food supply and oxygen, microbes can corrode pipes, causing interior buildup and subsequent leaks. Corrosion in a water distribution system can cause health issues and damage water leaks. When pipes are corroded, some of the metal from the pipe enters the drinking water and is consumed. Pipes and fixtures containing copper, lead, and brass (brass contains lead) can cause various health problems. While the municipal supplier regulates such contaminants as lead at the water plant, no one checks the amount of lead or copper in the kitchen tap. Pipe corrosion is a compelling justification for having a drinking water system under the kitchen sink. A comprehensive treatment system like reverse osmosis takes care of virtually any contamination that enters the water from the water plant [11].

3.6. REDUCE CORROSION OF GALVANIZED WATER PIPES

Galvanized water pipes are a common type of water pipe used worldwide. It is made of galvanized iron coated with a thin layer of zinc. Zinc protects pipes from corrosion but can also rust over time. Corrosion of galvanized water pipes can lead to many problems, including Waterproofing, low water pressure, water pollution, and hardware damage Water treatment can reduce corrosion to acceptable levels, but generally, it will not eliminate it. The method of treatment depends on the cause of the erosion[21].

3.6.1. Acidity Treatment

If acidity is the problem, installing an equalizer filter works better. These filters contain flakes of calcium carbonate (limestone), marble, magnesia (magnesium carbonate), or other alkaline substances that dissolve while neutralizing water. Acid-neutralizing filters are usually installed after the pressure tank. When water flows through the filter, the pH increases, which reduces corrosion. This process makes water more difficult. It may also reduce water pressure. The neutralizing material must be refilled when it dissolves. Flakes can last from weeks to months, depending on the type of material, how corrosive the water is, and how much water you use. Filters should usually be washed to remove suspended particles and oxidizing metals. Another way to neutralize acidic water is to add a sodium hydroxide or sodium carbonate (soda ash) solution. They are usually done by installing a chemical feed pump before the pressure tank. If you're on a low-sodium diet, consider using potassium hydroxide instead of sodium salts. This treatment regimen is superficial and ineffective. It does not increase water hardness and does not reduce water pressure. The injection rate should be adjusted to produce water with a pH of 7.5 to 8.0 [1,11].

3.6.2 Reduce Salts

Removing high concentrations of dissolved salts from water requires a reverse osmosis system. This method can require pre-treatment of water, and systems of the entire house require large storage tanks. Reverse osmosis systems increase water use by 30 to 200 percent and generate wastewater with concentrated salts. Reverse osmosis can remove 80 to 95 percent of the salt from the water entering the system. In some cases, treated water may be so low in total dissolved salts that it corrodes plumbing components. Generally, reverse osmosis water must be transported and distributed through non-metallic pipes and fittings. In general, it is not worthwhile to remove high levels of dissolved salts from the water systems of the whole house. Polyphosphate or food silicate compounds can be added to the water system to control corrosion[1,11,21].

3.6.3. Reduce Dissolved Oxygen

Often, you cannot do much to reduce dissolved oxygen in small water systems. Installing an elastic membrane or floating disk in the pressure tank will reduce water contact with air. This reservoir type also reduces waterlogging, which is common in highly ventilated water. However, injecting polyphosphate or silicate compounds may be necessary to protect the water system in the long term [14,18].

A large, semi-open storage tank can allow air to escape, like bubbles in a drinking cup. Requires a tank twice the size of daily use and chlorination because the water is no longer pressurized.

PART 4

MAGNETIZED WATER

4.1. DEFINITIONS

There are some ways to reduce corrosion, including the use of corrosion-resistant materials, the application of protective coatings, and the use of anti-corrosion chemicals. One of the new ways to reduce corrosion is to use magnetized water. It is done by passing water through a magnetic field. This magnetic field is thought to change the structure of water molecules, making them less susceptible to corrosion. Many studies support the effectiveness of magnetized water in reducing corrosion. For example, a 2016 study found that magnetized water can reduce the corrosion rate of galvanized pipes by up to 50%. However, more studies are needed to confirm the effectiveness of magnetized water in reducing corrosion in various conditions. Here are some suggested mechanisms by which magnetized water can lower corrosion. Firstly, by Changing the structure of water molecules, it is believed that the magnetic field can change the structure of water molecules, making them less susceptible to corrosion. For example, a magnetic field can cause smaller clusters of water molecules to form, which may be less corrosion resistant. Secondly, in the Deoxygenation of water, it is believed that the magnetic field can help remove oxygen from water, which can accelerate corrosion. Also, in metal surface activation, it is thought that the magnetic field can help activate the surface of the metal, making it more corrosion resistant. The mechanisms of action of magnetized water are still not fully understood, but evidence suggests that it could effectively reduce corrosion.

4.2.1. Definition Of Magnetized Water

Magnetized water is scientifically defined as "water whose atoms have been exposed to magnetic fields of different frequencies and adversities." it can be done using special magnetic devices or by-passing water through natural magnetic fields, such as Earth's.

4.2.2. Origin of Magnetized Water

The origin of magnetized water dates to the nineteenth century when it was discovered that passing water through a magnetic field could alter some of its properties. In 1822, French scientist Antoine Boissay discovered that magnetized water could help speed up the process of metal decay. The study on magnetized water increased vastly since T. Fer Mylan of Belgium had designed the magnetic treatment device to remove scales, which acquired the patent for commercialization in 1945. Its study flourished out of the result that proved its validity in removing scales and, in several other cases, through full-scale experiments, investigation, and surveys among researchers in the Soviet Union. In the twentieth century, more research was conducted on the properties of magnetized water, and many claims emerged about its health and therapeutic benefits. However, strong scientific evidence has not supported many of these claims.

4.2.3. Principle of Magnetized Water

Magnetized water does not mean Water itself does not retain a magnet. The magnetic field changes the role of water molecules to form a peculiar water molecule structure. Such a characteristic is maintained for a certain period and returned to its original condition. Accordingly, the water is called ‘magnetized water’, which is in a state after the change to the peculiar structure of water molecules by the magnetic field.

Giant cell membrane structures or enzyme molecules will be directly involved in metabolism as magnetized water is concentrated with clusters of small molecules. When magnetic solid energy is formed, the hydrogen atom with plus polarity (+) in the water molecule binds with the hydrogen atom with minus polarity (-) to cause the rotation, contraction and vibration for atomization and activation. At this time, while the cluster of water molecules decreases by its number, nearby clusters pull each other to form a structure. The following shows the meaning of diminishing and concentrating clusters of water [22,23].

4.2.4. Factors That Affect the Degree of Magnetization

There is a relationship between the velocity of water flow, the amount of water to be treated, and the density of the magnetic field, as he determined the factors on which the degree of magnetization depends, namely: The amount of liquid prepared for magnetization, the strength of the magnet used and the contact time between the liquid and the magnet [24] .

4.2.5. Water and Magnetism

The magnetic treatment of water does not magnetize water, as is commonly mistaken. Water is unlike magnetized materials when exposed to a strong magnetic field [28]. However, as is the case with all liquids, it possesses the properties of magnetic materials. When exposed to a magnetic field, water will produce a weak magnetic field in the opposite direction. On the contrary, modified or conditioned water or magnetically treated water is the correct expression to avoid confusion. The magnetic treatment of water does not magnetize water, as is commonly mistaken. Water is not like materials that can be magnetized when exposed to a strong magnetic field, except that, as with all liquids, it has magnetic properties. Materials are magnetic. When exposed to a magnetic field, water will produce a weak magnetic field in the opposite direction. Therefore, modified air-conditioned or magnetically treated water is the correct expression to avoid interference [9,25].

4.2.6. The Effect of Magnetic Field on Molecules

A water molecule contains one oxygen and two Hydrogen atoms covalently bound. The molecule resulting is stable, does not carry a net electrical charge, and has no unpaired electrons [31]. The molecules of substances are of two types: polar, such as water and N - 2 o, or non-polar, such as O - 2 and H 2. The passage of non-polar particles through the magnetic field will lead to their charge and transform them into a bipolarity [26].

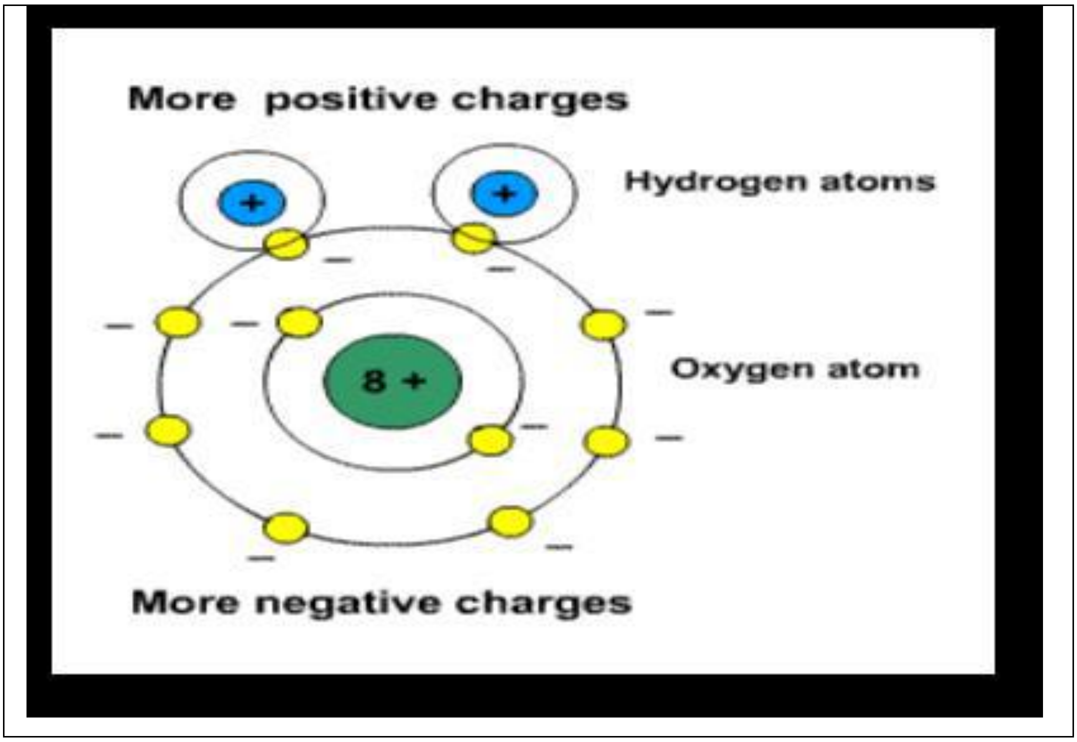


Figure 4. 1. The molecule of water [9].

The molecule possesses a positive charge on one end and a negative charge on the other Because the two hydrogen atoms share electrons on one end. The dipole moment is a vector quantity responsible for solubility, one of water's most important properties. Figure 4.2 shows how the dipole moment of a water molecule is like a magnet.

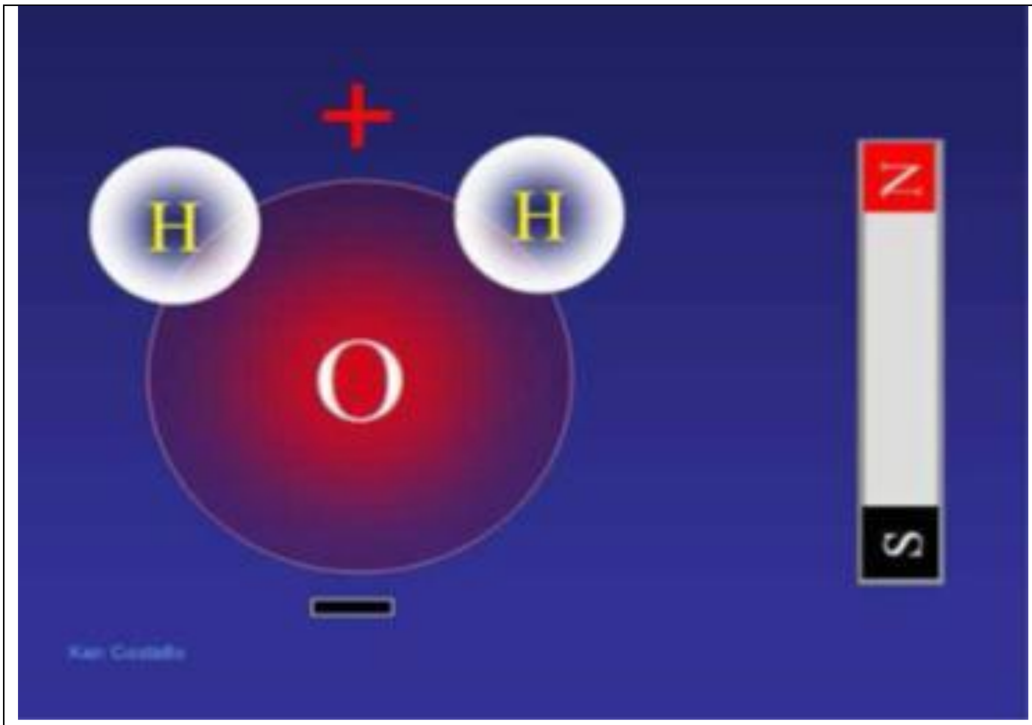


Figure 4. 2. The dipole moment of a water molecule is like a magnet [9].

When using the magnetic field for water treatment, the covalent bond will be broken, leading to more energy absorbed, thus reducing the boundary between the water molecules and increasing electrical decay, which affects crystal decay. The molecules of water could be either not polar or polar. Under the influence of the magnetic field, we can change the molecules of water from non-polar to polar, and a non-polar molecule becomes polarized. They will be charged, and this charge will be pulling them together. The magnet also reduces the bond angle between hydrogen-oxygen within the water molecule from 104.45˚ to 103˚. Figure 4.3 shows the water molecules before and after magnetic treatment. Many researchers confirm that total fruit yield, like that of tomatoes, increases the health of the human body, or the effect on weight and the number of sunflower plants is due to the magnetic field. The constant magnetic field's effect was studied to determine its direct impact on the properties of wastewater modification [9,25].

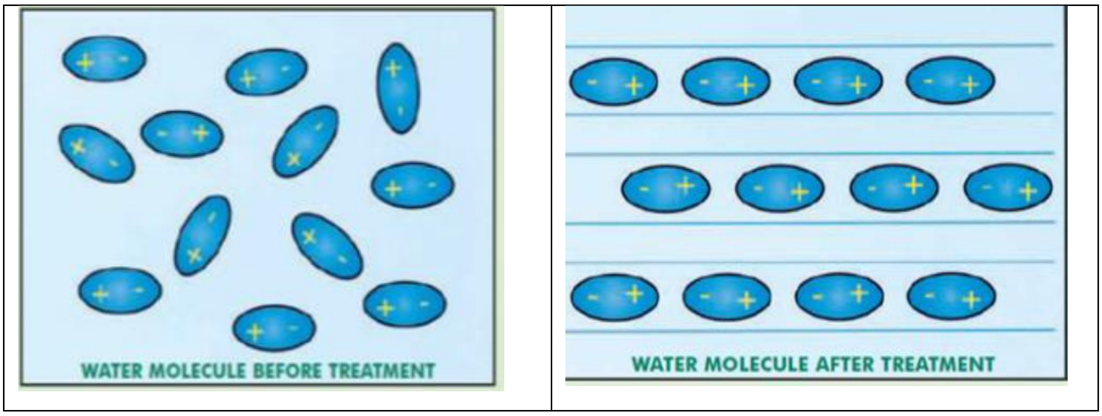


Figure 4. 3. Water molecules before and after magnetic treatment [9].

Consequently, the activity of the water molecules increases. The magnetic fields were reported to weaken the intraclusters' hydrogen bonds, breaking the larger clusters and forming smaller clusters with stronger intracluster hydrogen bonds [27].

The effect of the magnetic field in enhancing the hydrogen bonding was confirmed. The impact of the magnetic field on water molecules is schematically shown in Figure 4.4.

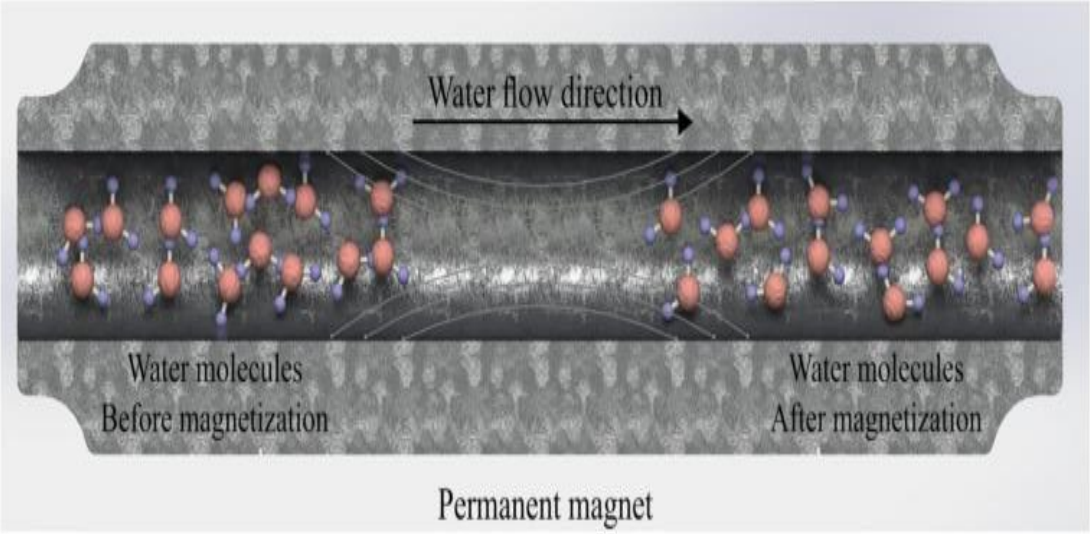


Figure 4. 4. Effect of magnetic field on water molecule clusters [28].

4.2.7. Magnetic Water Treatment (MWT)

Magnetic water treatment exposes water to a magnetic field to induce changes in water's chemical and physical properties. MWT is a type of water treatment used in many fields, such as medicine, environmental, industrial, and agriculture. The magnetic treatment method has been applied in water and wastewater systems, industrial and domestic, to control corrosion. Attention has been paid to magnetic treatment during the last few years. The objective of this study comes from the fact that such a simple technology has a beneficial effect on many applications and impacts industries that utilize water. The technology of MTW is cheap, requires no energy to run, and creates no pollutants. Besides, the magnetic treatment method of water requires no chemical reagents and is, therefore, environmentally friendly. (MWT) it is a relatively new technique in environmental management. When water is exposed to a magnetic field, it will change the chemical and physical properties of water molecules, resulting in unique characteristics. Magnetized water has shown different properties and applications in various fields of environmental management. Some applications include scale prevention, plant growth, soil enhancement, water saving, crop yield, and wastewater treatment. After the magnetic treatment of water, the structure of the water molecules will change into a small, uniform, and hexagonally structured group that can easily pass through the passages in plant and animal cell membranes. These features make MW a bio-friendly compound for human, animal, and plant cells. Magnetic water treatment changes the transition character of the electrons in the water molecules due to the alteration of the polarization properties of the molecules and their distribution in magnetized water.

Classification of the hypotheses of the MWT mechanism the effects of MWT have a complex dependence on the MWT parameters. It does not increase in proportion with the increase in the intensity of the magnetic field (magnetic induction). A large amount of MWT data, their volatility, and practical relevance have led to different hypotheses of the MWT mechanism, and they can be roughly classified into three groups (see Table 4.1)

Table 4. 1. Classification of The Hypotheses of The MWT Mechanism [28].

Group of approaches	Colloidal	Ionic	Water
Impact object	Colloidal particles, including ferromagnetic	Ions that are present in water	Water molecules
Mechanisms	Such particles' surface properties change and act as crystallization centres under the influence of the magnetic field. This group explains the anti-scale effect.	Under the influence of a magnetic field, polarization and deformation of ions occur, which are accompanied by their hydration decrease, which affects the course of physicochemical processes in aqueous systems.	This group combines ideas about the possible influence of a magnetic field on the water structure. This influence on the one hand can cause changes in the aggregation of water molecules, and on the other hand, etc.

4.2.8. Characteristics of Magnetized Water

The magnetized water changes the arrangement of water molecules without the help of salts or other minerals to form and concentrate the clusters, which activates the cell structures inside the body to promote metabolism. Magnetized water has the following characteristics that are different from general water.

Characteristics: Oxygen radicals with free electrons are decreased in magnetized water, it does not mean high oxygen concentration but instead reduced oxygen concentration, the magnetized water has higher activation to reinforce the resistance of the body, and the magnetized water maintains a long viscosity. (not evaporated), the molecular structure of the magnetized water is concentrated for slow freezing and fast melting. Viscosity increases, solubility increases, and conductivity increases.

4.2.9. Safety Feature of Magnetized Water

Magnetized water has been known as biologically nonhazardous. After a certain period, it converts to regular water, so there is no suspicious allergic action or toxicity. The magnetized water maintains its characteristics for a short period after intake. After the metabolism reaction, it rapidly converts to regular water, so there is no concern about the side effects of accumulating long hours of using the magnetized water. In modern cultural society, water molecules experience the deformation of their arrangement by the polluted drinking water and physical-chemical water treatment, so there is a decline in the activation of drinking water in the living body. Therefore, it is necessary to rearrange water molecules by magnetization. It's called MT (magnetic treatment) [26,28,29].

PART 5

MATERIALS AND METHODS

5.1. PREPARING TEST MODELS

Six galvanized iron models were prepared, and mechanical operations were carried out, which included cutting, scraping, and grinding, and after completing the manufacture of the models in the required shape and measurements with a size of 1 cm2. The samples were then distributed to selected corrosion media, including ordinary and magnetized water. The models were distributed over six plastic basins of equal size. Samples of different water solutions (river water, salt well water, and sulfur water) were also brought from the river water taken from the Euphrates River in the city of Fallujah, and well water was taken from the town of Amriya south of Fallujah. Sulfur water was taken from a well in Anbar University, west of Fallujah. The aqueous medium was analyzed, which included the most essential elements within 24 hours of taking the sample, to avoid the loss of the magnetization property of the water, and the most critical aspects are PH, NACL, TDS and EC. These analyses were taken for magnetized and non-magnetized water for each type. As shown in Table 5.1

Table 5. 1. Analysis of Elements in Magnetized and Non-Magnetized Water.

Sample	EC	TDS	NACL %	PH
	ds.m	ppm		
River water	1.46	737	2.9	7.44
Magnetize	1.40	703	2.8	7.81
Wells water	4.1	2070	8.1	7.6
Magnetize	4.15	2100	8.2	7.66
Sulfate water	6.11	3070	12.1	7.43
Magnetize	6.14	3080	12.1	7.52

5.2. CHEMICAL ANALYSIS OF WATER

Water was analyzed in the laboratory to identify and measure the chemical elements and properties of water, including pH, cations, key anions, trace elements, and isotopes. Water chemistry analysis is widely used to determine the possible uses of water or to study its interaction with its environment. This research used three types of water as a corrosion medium—river water, sulfur water, and well water. The elements in the water were comprehensively analyzed in the laboratory. As in Table 5.2.

Table 5. 2. Chemical Analysis of Water.

sample	Positive ions				negative ions			EC	TDS	NACL	PH
	meq.L^{-1}				meq.L^{-1}			Ds.m^{-1}	PPm	%	
	Ca	Mg	Na	K	Cl	HCO_3	SO_4				
Wells water	32.5	33.5	12.9	0.15	10	10	22.3	4.1	2070	8.1	7.6
Magnetize	37.5	4.5	13	0.15	10	9	26.4	4.15	2100	8.2	7.66
Sulfate water	36	26.5	21.5	0.7	18.5	15	27	6.11	3070	12.1	7.43
Magnetize	45	11.5	20.9	0.73	17.5	4.5	25.3	6.14	3080	12.1	7.52
River water	15	20	4.7	0.13	10	6.5	4.9	1.46	737	2.9	7.44
Magnetize	10	4.5	4.6	0.08	4.5	10	5.7	1.4	703	2.8	7.81

The most important devices used for analysis are the PH measuring device, as in Figure 5.1, and the device of salinity in water, as in Figure 5.2. The Flame Photometer device was used to measure sodium and potassium as shown in Figure 5.3, the centrifuge was used to measure sulfate as in Figure 5.4, and the device.

Figure 5. 1. PH measuring device.

Figure 5. 2. TDS salinity meter.

Figure 5. 3. Flame photometer device

Figure 5. 4. Burette device to measure cations and anions

5.3. WATER MAGNETIZATION

The process of magnetization of the wastewater in the study using a magnetic device of 1500 Kaos locally made, where the magnets and the number 4 were placed inside a pipe with a diameter of 1 inch made of copper, and the tube consists of two pieces intended to be able to put magnets inside the pipe to become in contact with water. The Gauss meter produced by Hirst Magnetic Jntrument measured the magnetic intensity under serial number 4977GM at the Ministry of Science and Technology, Department of Water Technology and Treatment / Research and Laboratories Section.

Figure 5. 5. Water magnetization device used in the research experiment.

5.4. METAL SPECIMEN PREPARATION

Galvanized iron samples were placed in special plastic troughs. The basins were full of water. The basins are divided into two types: the first type contains ordinary water, and the second type contains magnetized water. The basins were named for the water used; for example, sulfur water contains two basins, a basin with ordinary water and a basin with magnetized water. Iron samples were placed in plastic ponds for the same period. A sample in ordinary water and a sample in magnetized water for all types of water were used, as in Fig. 27, for more than 190 hours and with different drying periods.

Figure 5. 6. Iron samples in different aqueous solutions.

5.5. CORROSION / EIS MEASUREMENT

The Corrosion/EIS measurement set-up includes a Host computer, thermostat, magnetic stirrer (Vertex one, Ivium Technologies, Netherlands), Potentiostat/Galvanostat/EIS as shown in Fig. (6.8). The cell is (100 ml) capacity made of Pyrex consist of internal and external bowls. The electrochemical cell consisted of three electrodes: carbon steel as a working electrode used to determine the potential according to the reference electrode, an auxiliary electrode is platinum with an area (1 cm^2), and saturated calomel (Hg/Hg_2Cl_2 sat.KCl) as a reference electrode. The working electrode was immersed in the test solution for 15 min to establish steady state open circuit potential (Eocp). All tests were carried out at K using a cooling-heating circulating water bath. The electrochemical measurements were performed in a potential range of (± 250) mV according to the OCP value for corrosion. For EIS measurement, ten mV of amplitude was used in impedance, and the frequency range was between 0.1Hz and 100KHz.

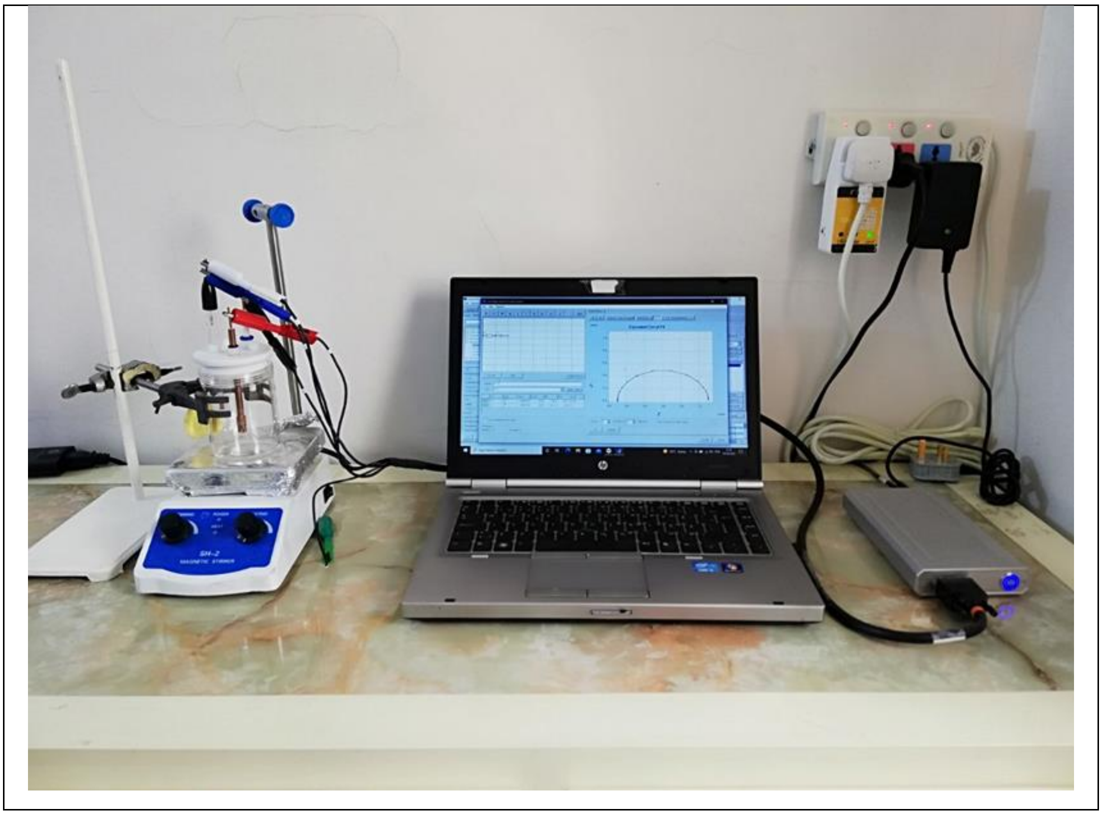


Figure 5. 7. The system of corrosion/EIS measurement.

5.6. DESCRIPTION OF CORROSION/EIS SYSTEM.

5.6.1. The Corrosion/EIS Cell

An electrochemical cell made of Pyrex with (100 ml) capacity Consists of two vessels, Internal and external. Figüre 5.9 shows the corrosion/EIS cell and the three electrodes. An electrochemical cell typically contains three electrodes and a thermocouple

Figure 5. 8. Set up the corrosion cell and three electrodes.

The three electrodes can be explained as follows; a reference electrode was used to determine the working electrode potential according to the potential of a reference electrode. The potential of reference electrodes is well-known and accurate. It combines two tubes; the inner tube contains Hg/Hg_2Cl_2 saturated with KCl solution, as illustrated in Fig (6.10), and the reference electrode is placed at 2 mm from the working electrode.

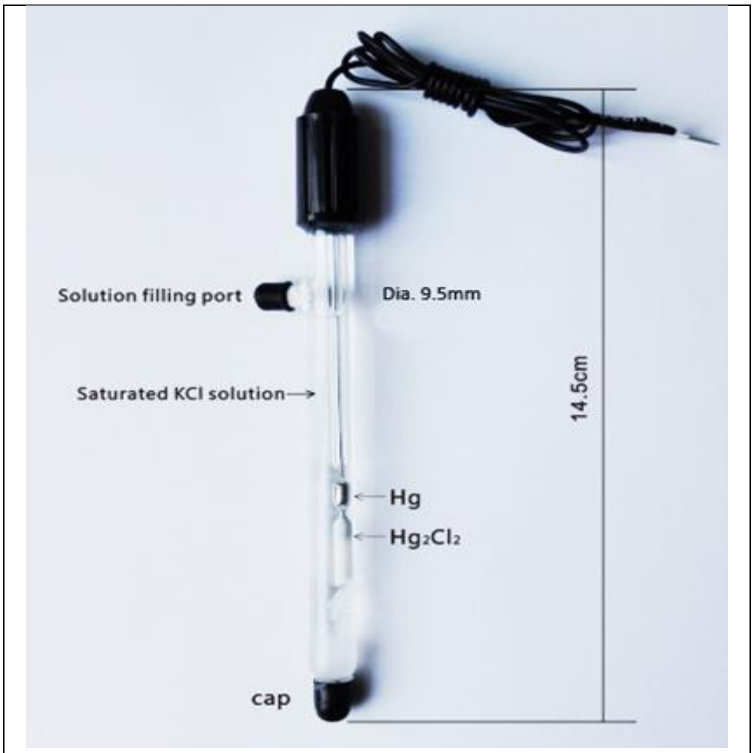


Figure 5. 9. Saturated calomel electrode.

The Auxiliary Electrode was made of high-purity platinum metal with an area (of 1 cm2) as explained in Figure 5.11.

Figure 5. 10. Platinium electrode.

The Working Electrode is the subject under study, where its potential should be measured. This electrode was formed from 20 cm length metallic wire and connected to the mounted specimen, see Figure 5.12.

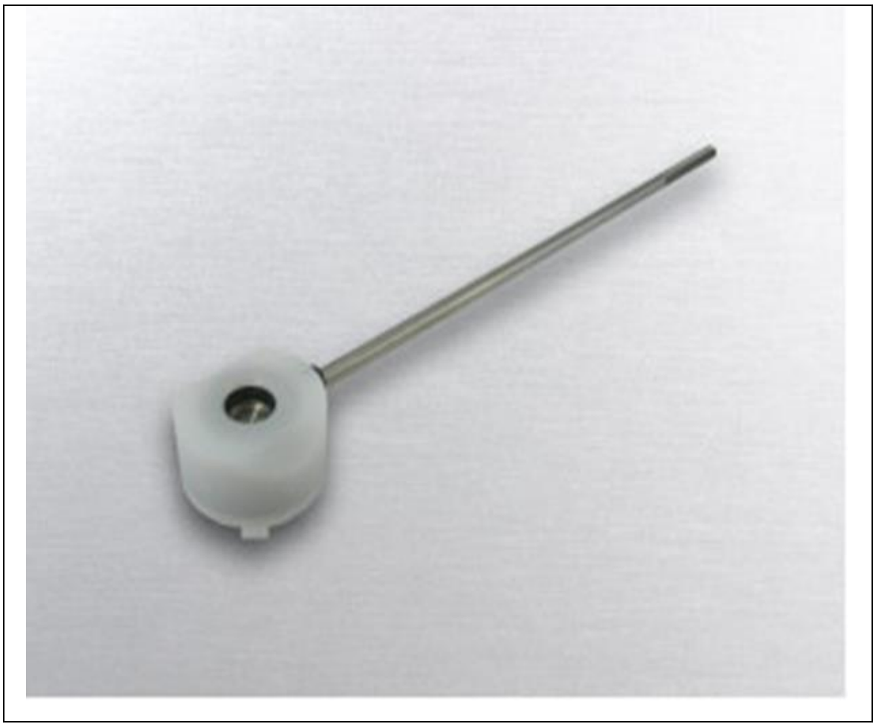


Figure 5. 11. Specimen holder.

The iron sample was cleaned thoroughly to remove any surface contaminants. The cell was prepared by installing the iron sample in the position of the working electrode in the three-electrode cell. The cell was also filled with the appropriate electrolyte solution. The instrument settings are prepared: set the voltage/galvanostat to the desired potential range and frequency range. We connect the impedance analyzer to the potentiostat/galvanostat and the cell.

Measuring an EIS spectrum takes time (often up to many hours). The restrained system must be steady throughout the time it is obligatory to measure the EIS spectrum. A typical root of problems in EIS measurements and investigation is drift in the measured classification. In practice, a steady state can be challenging to achieve. The cell can change through the adsorption of solution impurities, the advance of an oxide layer, a build-up of reaction products in explanation, coating degradation, or temperature changes, to list just a few influences. Electrochemical techniques include volt amperometric techniques, electrochemical impedance spectroscopy, pulsed techniques, a tool to build complex experiments, manual control, and an ohmic drop determination technique by EIS measurements. Electrochemical applications include battery testing, corrosion measurement, and custom and unique applications.

5.6.2. Field-emission Scanning Electron Microscope (FESEM)

Scanning electron microscopes are currently widely used in universities and research centers to obtain helpful information in line with the properties of materials in different sciences using software capabilities. Electron microscopy is based on scanning the sample's surface with an electron beam. Electronic scanning microscopes generally operate in a vacuum. After creating a vacuum by scanning the electron beam on the sample surface, an image of the sample surface is displayed on the screen. By changing the light recording instrument (rays), images containing different information about the sample surface can be images of surface height or phase distribution on the surface.

Sample preparation: The sample is prepared so that it is conductive and can withstand the discharge environment of the microscope. It usually involves coating the sample with a thin layer of conductive material, such as gold or platinum.

Sample loading: the prepared sample is carefully placed in the sample compartment of the microscope. This chamber is emptied to create a vacuum that allows the electron beam to travel freely without colliding with air molecules.

Scanning and photography; The electron beam is scanned in a telescopic pattern across the sample's surface. When a beam hits the sample, it interacts with atoms in the material, causing the emission of secondary electrons, bounced electrons, and X-rays. These signals are collected by detectors located around the sample. The secondary electron detector is used to photograph the surface terrain of the sample. The bounce electron detector is used to provide information about the composition of the sample. An X-ray detector is used to analyze the atomic structure of the sample.

5.6.3. Chemical Composition Analysis

The combination of SEM and EDS gives us morphological characterization and synthetic information together, making it easier to link conclusions and draw conclusions.

Chemical composition analysis was performed using energy dispersive X-ray (EPX), an auxiliary tool available in SEM. This analysis was performed on all brackets from all groups. The area evaluated was the buccal surface of the left gingival blade of each slide at 500x magnification, according to the methodology of Menezes et al. According to this analysis, the chemical compositions of each slice can be measured and compared. The presence of O, C, Zn and other components was evaluated. SEM analyses were conducted on a type of device (INSPECTF 50) made in the Netherlands, as shown in Figure 5.12 and EDS was also analyzed on a device (THERMO SCIENTIFIC) made in the Netherlands. Each slide evaluated produced a file containing a table of the items, their composition, and their percentages.

Figure 5. 12. FE SEM analyzer type INSPECT F50.

PART 6

RESULTS AND DISCUSSIONS

This chapter includes the results of treating three types of water inside the pipes: river water, well water, and sulfur water, which were magnetized with a magnetizer. The pipes were made of galvanized iron. Six samples were taken from the tube to the laboratory, the tube samples before and after magnetization, meaning three samples from the tube before and three after magnetization. We wanted to know whether the magnetized water affected the corrosion in the pipe. If it decreased or increased, we counted. The tubes were analyzed for each (scem, epx, eis, corrosion)—elements in the tube, micrographs, curves, and other details.

6.1. EXPERIMENTAL SITE AND MATERIALS

Three field experiments were placed in basins of water under study, and some of the water components were analyzed before and after magnetization, including (sulfur, number of salts, pH measurement, and electrical conductivity. The samples were placed in normal and magnetized water and moistened for 192 hours in different drying stages. We also replaced magnetized water with new magnetized water every 24 hours because magnetized water loses its properties after a while. The experiment was conducted at a temperature between 25 and 50 degrees.

Table 6. 1. Analysis of The Water.

sample	Positive ions				negative ions			EC	TDS	NACL	PH
	meq.L^{-1}				meq.L^{-1}			Ds.m^{-1}	PPm	%	
	Ca	Mg	Na	K	Cl	HCO_3	SO_4				
Wells water	32.5	33.5	12.9	0.15	10	10	22.3	4.1	2070	8.1	7.6
Magnetize	37.5	4.5	13	0.15	10	9	26.4	4.15	2100	8.2	7.66
Sulfate water	36	26.5	21.5	0.7	18.5	15	27	6.11	3070	12.1	7.43
Magnetize	45	11.5	20.9	0.73	17.5	4.5	25.3	6.14	3080	12.1	7.52
River water	15	20	4.7	0.13	10	6.5	4.9	1.46	737	2.9	7.44
Magnetize	10	4.5	4.6	0.08	4.5	10	5.7	1.4	703	2.8	7.81

As shown in the Table 6.1 , there is a difference between average and magnetized for each type of water. As for water, the range of (Ca, Na, SO4, PPm, NACL, and PH) increases while the other reduces or remains the same.

The simultaneous occurrence of the ionic and particle mechanisms in the magnetization process is made possible by the presence of Ca2+ and other cations in water. The solution's ionic and particle compositions determine the dominating mechanism. Some researchers, e.g. Higashitani et al. [30], Barret and Parson [29], and Chibowskia et al. [31], found a memory effect in ionic mechanism in magnetized CO3 2− ionic solution.

In general, the pH rises somewhat as the intensity of the magnetization increases due to an increase in the amount of free carbonate in the water [32]. Temporary hardness salts are present in ordinary water. When water breaks down into (+H & -OH) and calcium hydroxide (Ca (OH)$_2$) and magnesium hydroxide (Mg (HCO3)2), which are both weak acids, the salts dissociate due to the magnetic field into Ca+2 and (-HCO3) and Ca(OH)2, respectively. The addition of calcium hydroxide increases the pH of the solution because it's a more substantial base than the weak acid present. The impact was discovered to depend on the durations and intensities of the magnetic field exposure, which alters the structure of the water molecule and the permeability pressure [41]. A magnetic field alters the hydrogen bonds that hold water molecules together, changing the pH. The other researchers [6] observed that water exposure to a magnetic field softens the water and increases its pH due to the rearrangement of the water molecules in one direction. It was supported by Hasson and Bramson [33] , who reported an increase of 12% in water pH post-magnetisation. pH affects the metabolism and other physiological processes[25].

The pH and corrosion rate correlation reflects carbonate equilibrium processes involving carbon dioxide and carbonate and hydrogen ion (H +) impacts. The corrosion of most metals is accelerated by the increased H + concentration at a low pH. The layers of oxide and hydroxide that can shield a metal surface tend to disintegrate at pH levels below 5. The cathode will experience both oxygen reduction and hydrogen evolution. The formation of protective oxide and hydroxide scales and the corrosion rate decreases as the pH rises (> 5). When scales form, the corrosion type might shift from uniform to confined beneath the surface layers.

reported by Tai and Chen (1998), who used a constant-composition approach to determine that the most common CaCO3 precipitation at a pH higher than 12.0 was calcite. A significant amount of aragonite formed when the solution was magnetized 24 hours before nucleation, which was more significant than 50%. If the magnetization period was increased to 48 hours, aragonite emerged as the main polymorphic form, and calcite vanished. The clusters in the supersaturated solution in this study did not have time to change their form during the nucleation process because the CaCO3 crystals were induced spontaneously by changing the pH; therefore, the clusters had distinct forms with and without magnetization, and as a result, different polymorphs of CaCO3 crystals were produced [34].

6.3. CORROSION MEASUREMENT

The potentiostat set up includes a Host computer, thermostat, magnetic stirrer, (EmStat 4s, Palm Sens, Holland) potentiostat, and galvanostat. The cell is (250 ml) capacity made of Pyrex and consists of internal and external bowls. The electrochemical corrosion cell has three electrodes. Carbon steel is used as a working electrode to determine the potential according to the reference electrode. An auxiliary electrode is a block of platinum with a length (10 cm), and the reference electrode is a saturated calomel (Hg/Hg2Cl2 sat.KCl). The working electrode was immersed in the test solution for 15 min to establish steady state open circuit potential (Eocp). Then, electrochemical measurements were performed in a potential range of (± 200) mV. All tests were carried out at 298K by using a cooling-heating circulating water bath. Each type of water was shown, and its effect on galvanized steel was shown.

6.3.1. Polarization Curves

The corrosion parameters were evaluated from the resulting data. The corrosion current density (icorr) and corrosion potential (Ecorr) were obtained by extrapolating the cathodic and anodic. The anodic (ba) and cathodic (bc) Tafel slopes were also calculated for the corrosion potential Ecorr (mV), corrosion current density score (A/cm2), cathodic and anodic Tafel slopes (mV/Dec), and protection efficiency PE% [21]:

$$\%\mathrm{IE} = \frac{(\mathrm{icorr})\mathrm{o} - (\mathrm{icorr})}{(\mathrm{icorr})\mathrm{o}} * 100$$

Where (icorr) is the corrosion current density in the absence of inhibitors, (icorr) is the corrosion current density in the presence of inhibitors [22], [23],[36].

6.3.1.1. Iron Sample in NormainRiver Water and Magnetized River Water

Table 6.2 shows corrosion parameters for blank and compound in HCl solutions and different compounds for River water + magnetized River water.

Table 6. 2. Corrosion Parameters for Blank and Compound in HCl Solutions.

Comp.	**E corr.**	**I corr.**	**I corr./ r**	**Resis.**	**Anodic β**	**Cathodic β**	**Corr. rate,**	**IE%**
River water	-0.928	217.8	4.357E-4	574.5	0.410	0.973	2.138	**-**
Magnetized River Water	-0.805	35.79	7.157E-5	1699	0.283	0.277	0.351	**84**

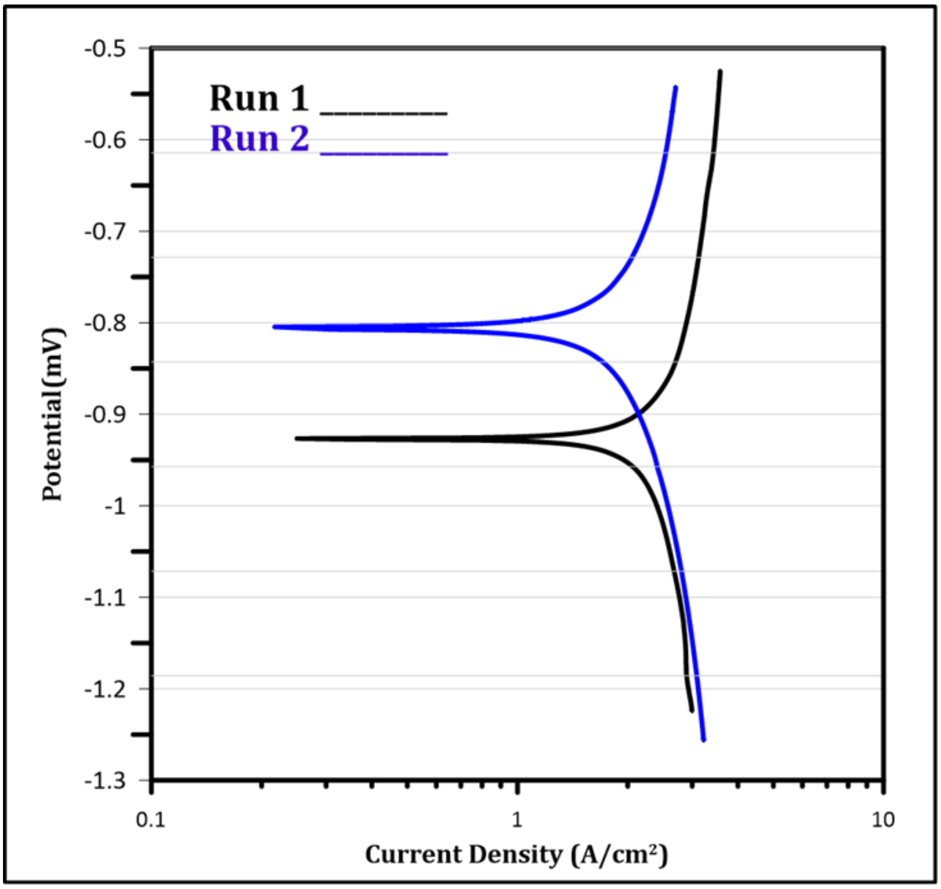


Figure 6. 1. Polarization curves for corrosion of run 1 (normal water) and run 2 (magnetized water).

The relative position of the curves is essential. In this case, the curve for magnetized river water (Run 2) is on the left compared to the curve for normal river water (Run 1). If water could be magnetized, such magnetized water might exhibit a lower current density than regular water at the same potential difference., in theory, could lead to a slower corrosion rate. The curves appear relatively flat, indicating that the corrosion process is likely controlled by activation. The rate-limiting step is the reaction between iron atoms and water to form ions.

There seems to be a plateau at the end of each curve. This plateau suggests that the mass transport of ions to and from the metal surface becomes the limiting factor at higher potentials.

Overall, the image suggests that magnetized water may protect against iron corrosion. However, it’s essential to consider some limitations.

The polarization curves suggest that magnetized river water might offer some protection against iron corrosion compared to normal river water.

By comparing the values across the table for River water and Magnetized River water, you can analyze how magnetization affects the corrosion of iron. For instance, a lower corrosion current density (I corr.) in magnetized river water would indicate a slower corrosion rate for iron in that condition.

6.3.1.2. Iron Sample in NormainWell Water and Magnetized Well Water

Table 6.3 shows corrosion parameters for blank and compound in HCl solutions and different compounds for Well water + magnetized well water

Table 6. 3. Corrosion Parameters for Blank and Compound In HCL Solutions And Different Compounds for Well Water + Magnetized Well Water.

Comp.	E corr.	I corr.	I corr./ r	Resis.	Anodic β	Cathodic β	Corr. rate,	IE%
Wells water	-0.789	191.6	3.831E-4	593.3	0.549	0.501	1.880	-
Magnetize Wells water	-0.792	50.2	1.422E-4	891.4	0.330	0.262	0.698	74

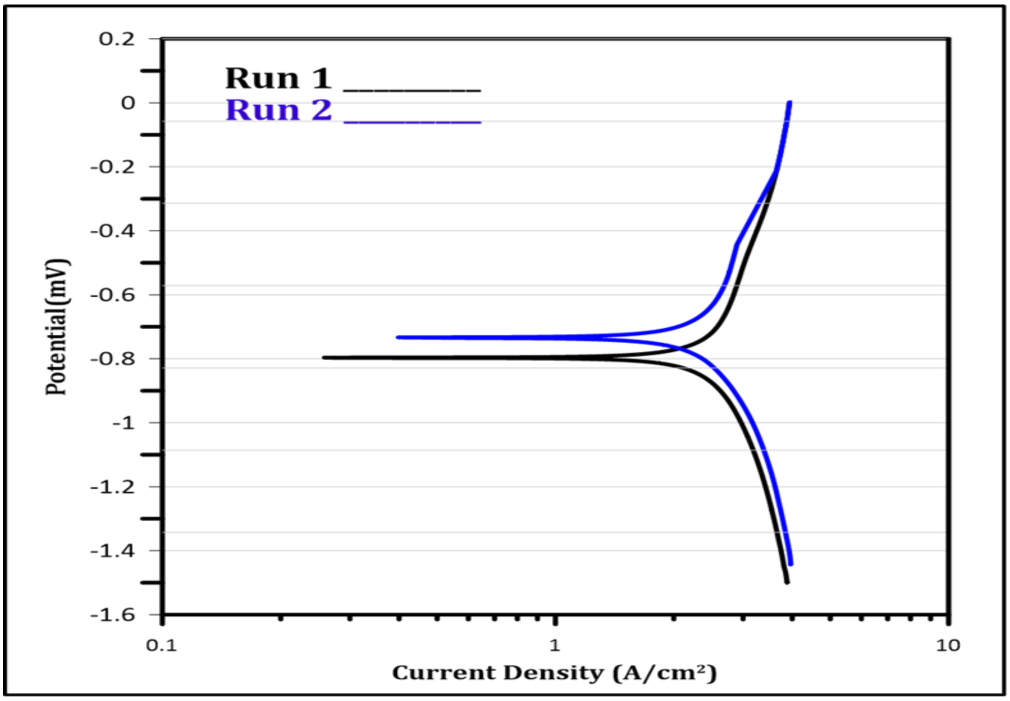


Figure 6. 2. Polarization curves for corrosion of run 1 (well water) and run 2 (magnetized well water) .

Polarization Curves: The image shows two polarization curves, one for Run 1 (well water) and another for Run 2 (magnetized well water). These curves represent the relationship between the potential (voltage) applied to the iron sample and the resulting electrical current density. Current Density (X-axis): Measured in Amperes per square centimeter (A/cm²), it signifies the corrosion rate. Higher values indicate faster corrosion. Potential (Y-axis): Measured in millivolts (mV), it represents the electrical driving force for corrosion. Relative position of curves: In most of the potential range, the curve for Run 2 (magnetized well water) is positioned to the left compared to the curve for Run 1 (well water). The experiment's results indicate that, at a given potential, the current density is lower for the magnetized well water. Interpretation: Lower current density at the same potential implies a reduced corrosion rate for iron in magnetized well water compared to regular well water. The exact mechanism is still under research, but here are some potential explanations: Altered Ion Movement: The magnetic field might influence the movement of ions in the water, affecting the rate at which they reach or leave the iron surface, thus impacting the corrosion rate. Magnetite Layer Formation: The magnetic field could promote the formation of a protective magnetite (Fe_3O_4) layer on the iron surface, hindering further corrosion. The analysis based on the polarization curves suggests that magnetized well water (with a magnetic field strength of 1500 gauss) may offer some protection against iron corrosion compared to well water.

6.3.1.3. **Iron Sample in NormainSulfur Water and Magnetized Sulfur Water**

Table 6.4 shows corrosion parameters for blank and compound in HCl solutions and different compounds for Sulfur water + magnetized Sulfur water

Table 6. 4. Corrosion Parameters for Blank and Compound in HCL Solutions and Different Compounds for Sulfur Water + Magnetized Sulfur Water.

Comp.	E corr.	I corr.	I corr./ r	Resis.	Anodic β	Cathodic β	Corr. rate,	IE%
Sulfur water	-0.797	223.2	4.464E-4	571.7	0.650	0.537	2.191	-
magnetized sulfur water	-0.778	76.40	1.648E-4	861.0	0.352	0.305	0.809	66

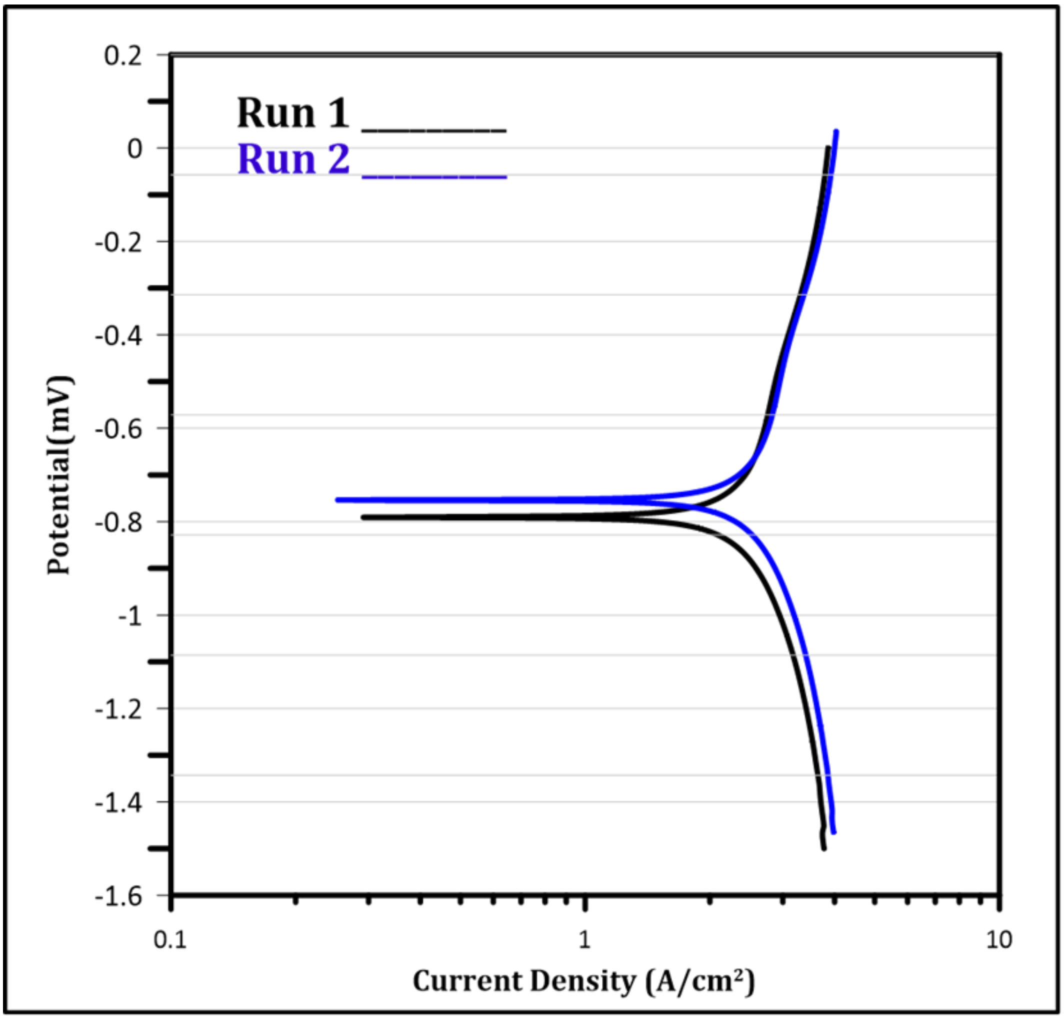


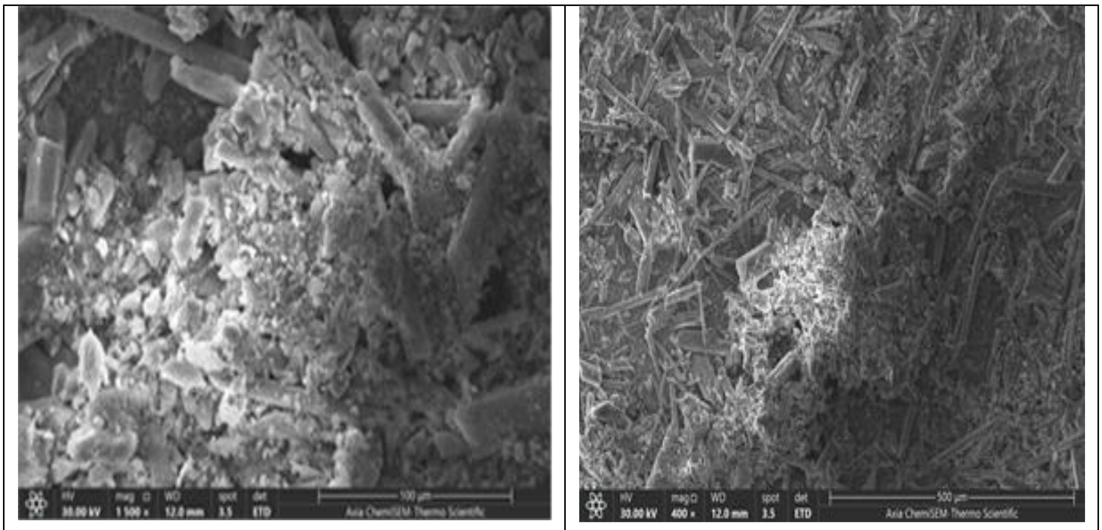
Figure 6. 3. Polarization curves for corrosion of run 1 (sulfur water) and run 2 (magnetized sulfur water).

Relative position of curves: The curve for Run 2 (magnetized sulfur water) is positioned to the left of the curve for Run 1 (sulfur water) across most of the potential range. The lower current density observed in magnetized sulfur water at a given potential indicates a reduced corrosion rate for iron compared to regular sulfur water altered Ion Movement The magnetic field might influence the movement of ions in the water, affecting the rate at which they reach or leave the iron surface, thus impacting the corrosion rate. Magnetite Layer Formation: The magnetic field could promote the formation of a protective magnetite (Fe_3O_4) layer on the iron surface, hindering further corrosion. The information provided about the sulfur water properties (pH, EC, TDS) offers some context regarding the overall corrosivity of the environment. pH (7.43 and 7.52): Both values are slightly neutral to slightly alkaline. Generally, a lower pH (more acidic) indicates a higher corrosion risk for iron. In this case, pH might not be a significant factor.

Electrical Conductivity (EC) (6.11 and 6.41): The moderate EC values suggest a moderate level of dissolved salts, which can influence corrosion rate depending on the specific ion types. Total Dissolved Solids (TDS) (3070 and 3080): The high TDS values indicate a significant amount of dissolved material, potentially contributing to higher corrosion rates. The analysis based on the polarization curves suggests that magnetized sulfur water (with a magnetic field strength of 1500 gauss) may offer some protection against iron corrosion compared to regular sulfur water. The sulfur water properties (pH, EC, TDS) suggest a moderately corrosive environment due to dissolved salts.

6.3.2. MICROSTRUCTURAL CHARACTERIZATION

6.3.2.1. River Water



(a) (b)

Figure 6. 4. Optical micrographs of the Fe alloy at river water low (a) and high (b) magnifications.

Table 6. 5. Analysis of Steel Material After Exposed to Normal River Water.

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	25.0	2.7	11.5	1.2
O	47.0	2.8	28.7	1.7
Ca	10.3	0.4	15.8	0.5
Zn	17.7	0.7	44.0	1.8

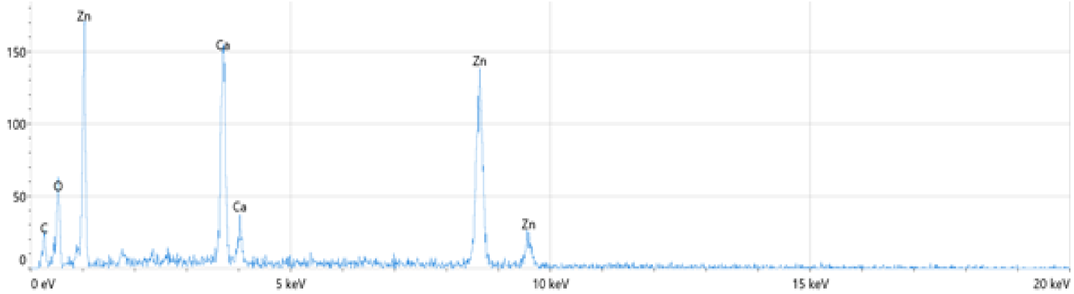
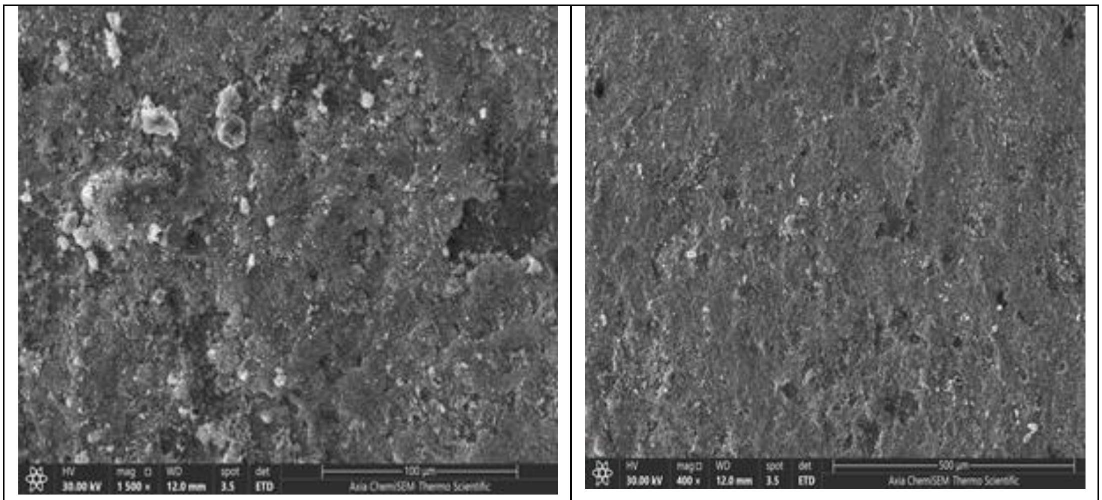


Figure 6. 5. Eds spectrum for fe in river-water.

6.3.2.2. Magnetized River Water



(a) (b)

Figure 6. 6. Optical micrographs of the Fe alloy at magnetized river water low (a) and high (b) magnifications.

Table 6. 6. Analysis of the Steel Material After Exposing It to Magnetized River Water.

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	23.8	2.5	9.0	0.9
O	39.4	2.0	19.8	1.0
Si	2.7	0.2	2.4	0.2
Ca	0.8	0.2	1.0	0.2
Fe	0.6	0.1	1.0	0.2
Zn	32.6	0.7	66.8	1.5

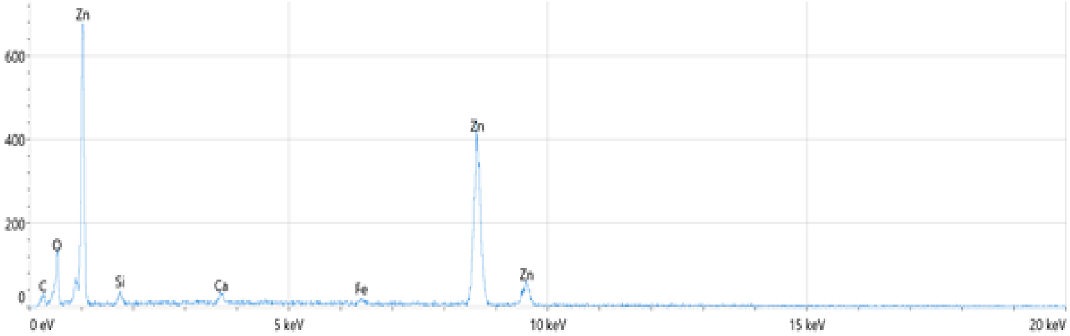


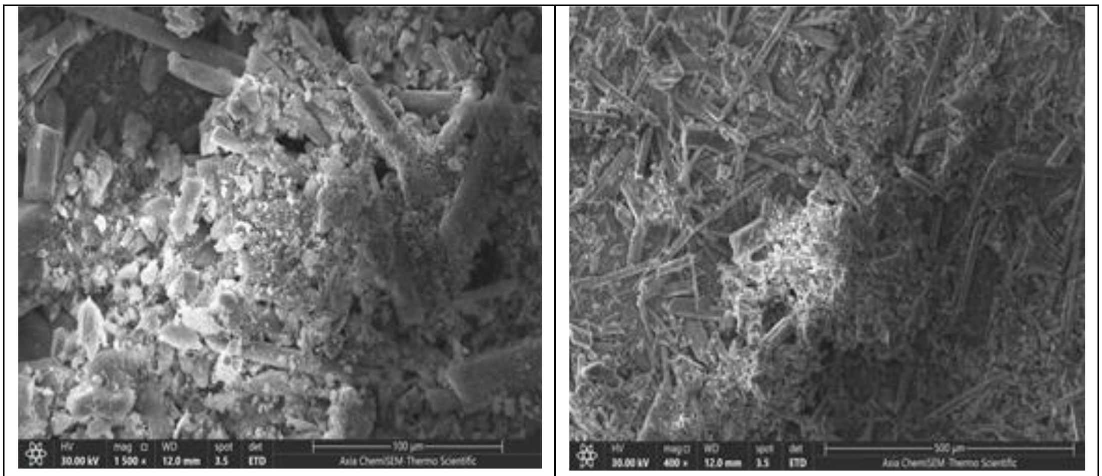
Figure 6. 7. EDS spectrum for Fe in river water.

According to analyses of the iron sample in the river and magnetized river water, the corrosion rate in normal water is higher than in magnetized river water. The percentage of chlorides in river water was higher than the percentage of chlorides in magnetized water. As in (6.1), where normal river water has a higher chloride level (10 mEq/L) than magnetized water (4.5 mEq/L). High chloride levels can accelerate the corrosion process.

Also, the level of acidity factor and a lower pH (more acidic) can increase corrosion rates. The pH in the river water was 7.44, and the pH in the magnetized river water was 7.81.

Increased TDS leads to increased corrosion of iron. Reason Increased conductivity TDS increases water's conductivity, facilitating the passage of electric current, thus increasing iron corrosion. The TDS in river water was 737 ppm, and in magnetized water was 703 ppm.

6.3.2.3. Sample Iron in Normal Well Water



(a) (b)

Figure 6. 8. Optical micrographs of the Fe alloy well Water low (a) and high (b) magnifications.

Table 6. 7. Analysis of Steel Material After Being Exposed to Normal Wells Water.

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	19.1	2.0	9.8	1.1
O	53.3	2.3	36.6	1.6
Si	0.5	0.1	0.6	0.2
S	8.8	0.3	12.1	0.4
Cl	0.6	0.1	0.9	0.2
Ca	7.9	0.3	13.5	0.5
Fe	2.7	0.3	6.4	0.7
Zn	7.1	0.5	20.0	1.5

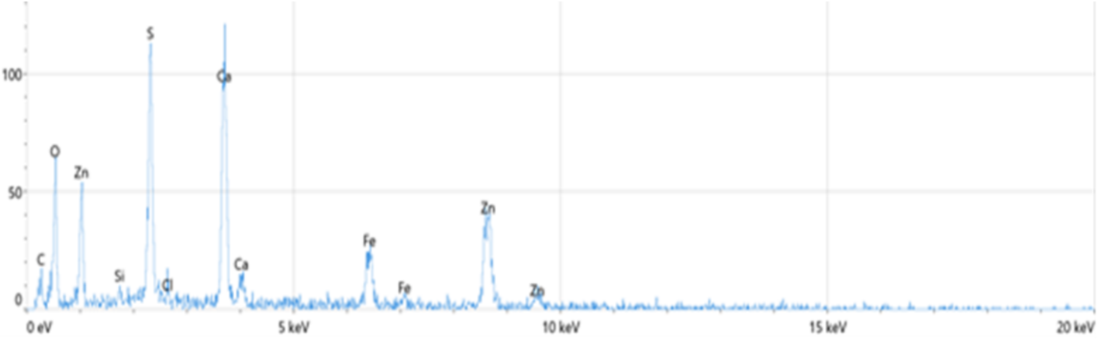
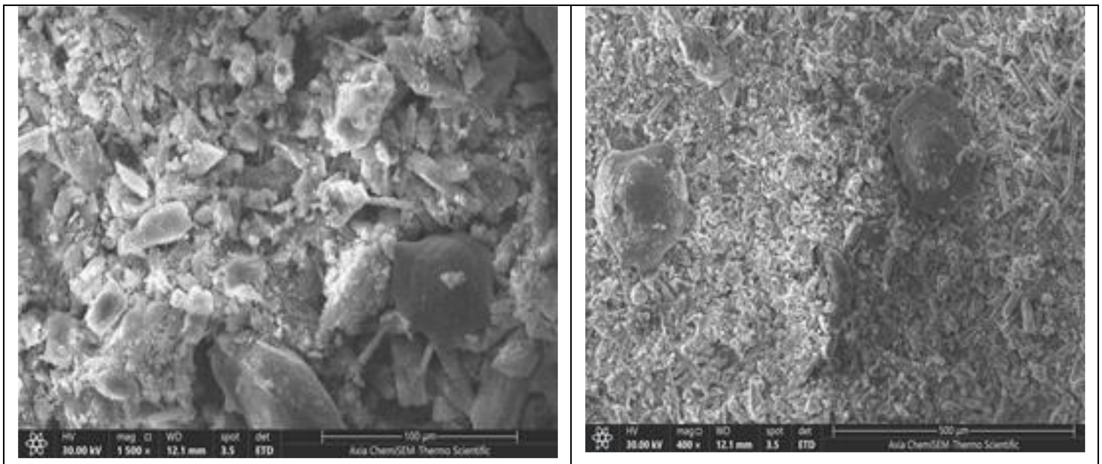


Figure 6. 9. EDS spectrum for Fe in well water.

The solubility of oxygen in the solution and the partial pressure of oxygen on the solution's surface adhere to Henry's law. That is, the dissolved oxygen content in a corrosive solution is proportional to the partial pressure of oxygen on the solution's surface. Owing to the cathodic reduction reaction of O2 in an acidic solution, electrons in the cathodic region are continuously consumed, which leads to the dissolution of electrons in the anodic region and the loss of electrons. Therefore, even a small amount of dissolved oxygen will cause severe corrosion to the tubing. It is found that the corrosion rate increases rapidly with the increase of dissolved oxygen content in different corrosion environments, and there is a positive correlation between the corrosion rate and dissolved oxygen content.

Some processes occur when oxygen atoms strike a spacecraft's surface at orbital velocities. These include chemical reactions with surface atoms or adsorbed molecules, elastic scattering, partial or complete thermal accommodation scattering, recombination, or excitation of ram species. The chemical reaction of ATOX with a surface may cause the formation of volatile oxides from polymers, carbon, and osmium, or oxides, which do not adhere very well to the surface and tend to spill, as in the case of silver. Volatile and spalling oxides contribute to the erosion of the surface. In many instances, the oxide remains adhered to the surface and is not porous. The surface oxide is protective in these cases, and the underlying material will not erode. Losing electrons and achieving a positive charge (oxidation) is a common characteristic of most metals. The oxidation product for most polymers is a gas and erosion results. The factors that may influence the erosion yield of materials in space are impact angle, material temperature, oxide spelling, ATOX flux, and ATOX fluence.

6.3.2.4. Iron Sample in Magneinc Well Water



(a) (b)

Figure 6. 10. Optical micrographs of the Fe alloy magnetized well water low (a) and high (b) magnifications.

Table 6. 8. Analysis of Steel Material After Exposed to Magnetized Wells Water.

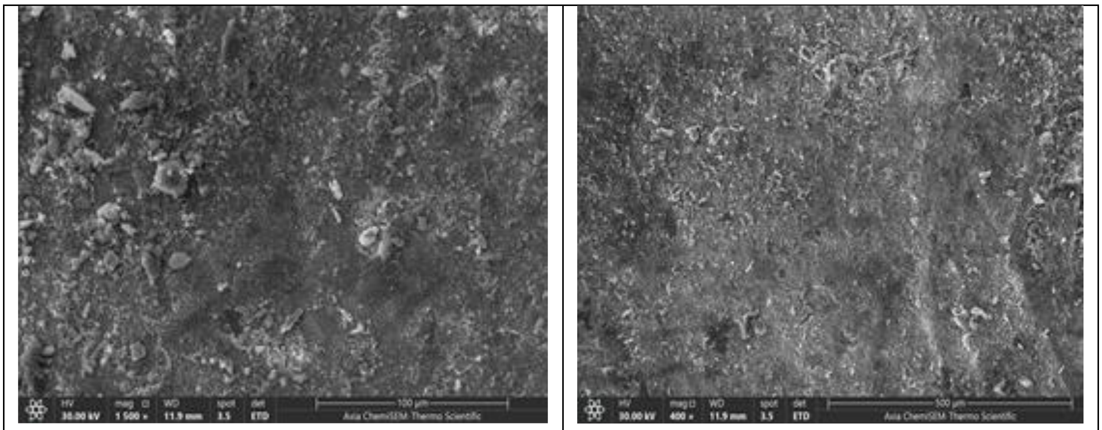
Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	17.6	2.7	9.5	1.5
O	56.0	2.6	40.1	1.8
S	9.8	0.3	14.0	0.4
Ca	9.4	0.4	16.9	0.6
Fe	3.7	0.3	9.3	0.8
Zn	3.5	0.3	10.2	0.9

Figure 6. 11. EDS spectrum for Fe in magnetized well water.

The effect of magnetization leads to an increase in steel corrosion caused by several factors. The first one is the increase of element O, which, in turn, increases oxygen content. Due to the film's instability, the corrosion medium penetrates the product film, so the dissolved oxygen content will accelerate the metal corrosion.

The second reason is the reduced amount of zinc. Zinc lies below steel in the galvanic series and, therefore, will corrode preferentially to steel, offering "galvanic protection". When galvanic protection is in operation, gaps in the zinc layer do not result in loss of steel but instead accelerate the corrosion rate of zinc.

6.3.2.4. Iron Sample in Sulfate Water



(a) (b)

Figure 6. 12. Optical micrographs of the Fe alloy sulfate water low (a) and high (b) magnifications.

Table 6. 9. Analysis of Steel Material After Exposed to Normal Sulfate Water.

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	27.6	4.6	11.2	1.9
O	40.6	3.2	22.0	1.7
Si	2.9	0.4	2.8	0.4
Zn	28.9	1.3	64.0	2.9

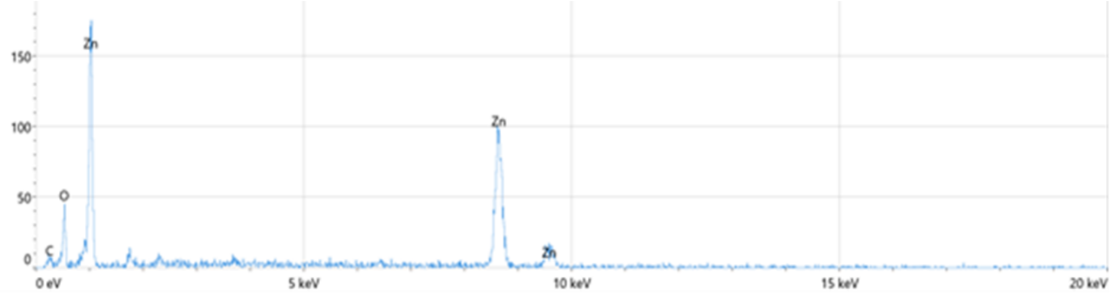


Figure 6. 13. EDS Spectrum for Fe in sulfate water.

Sulfurous water plays an important role in iron corrosion because it contains sulfur compounds, such as hydrogen sulfide, which react with the surface of iron and cause corrosion. Hydrogen sulfide also reacts with iron to form iron sulfide (FeS), an insoluble black substance.

Fe + H2S → FeS + H2 (6.1)

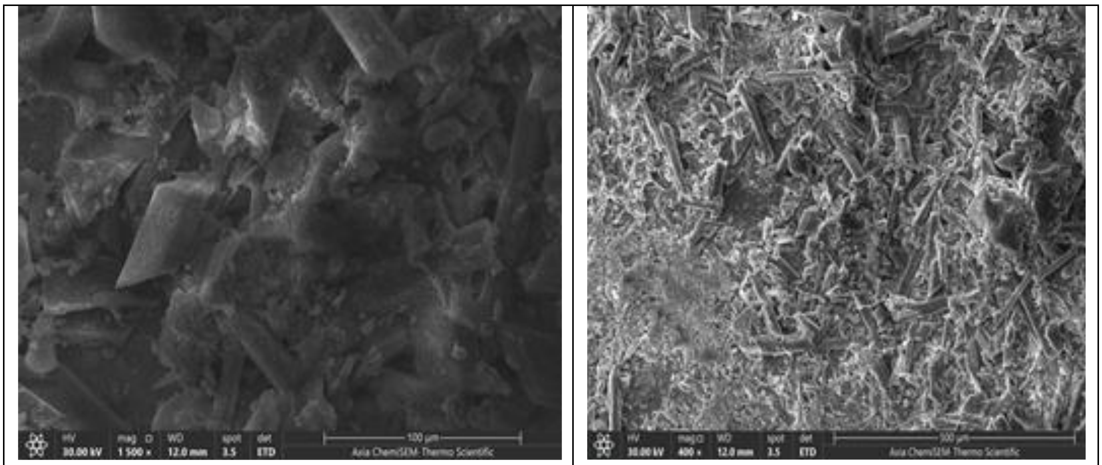
Iron sulfide also reacts with water and air to form sulfuric acid (H2SO4), a strong acid that causes iron corrosion.

2FeS + 2H2O + 3O2 → Fe2(SO4)3 + 2H2O (6.2)

Sulfuric acid also reacts with iron to form a layer of iron sulfate ($FeSO4$) soluble in water.

$$Fe + H2SO4 \rightarrow FeSO4 + H2 \qquad (6.3)$$

6.3.2.5. Iron Sample in Magnetized Sulfate Water



(a) (b)

Figure 6. 14. Optical micrographs of the Fe alloy magnetized sulfate water low (a) and high (b) magnifications.

Table 6. 10. Analysis of Steel Material After Exposed to Magnetized Sulfate Water.

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
O	66.4	4.0	43.5	2.6
S	13.6	0.5	17.9	0.6
Cl	1.3	0.2	1.9	0.3
Ca	12.9	0.4	21.2	0.7
Zn	5.8	0.8	15.5	2.2

Figure 6. 15. EDS spectrum for Fe in magnetized sulfate water.

As shown from the figure and table, the number of corrosions increases due to the rise of the O element and reduction in Zn and Magnetic fields can either accelerate or reduce the rate of corrosion, depending on the geometry of the material and the magnetized will led to reduce the turbidity of water and hence increase the corrosions. It is believed that the magnetic field accelerates the reaction of hydrogen sulfide with the iron surface, leading to an increased rate of iron corrosion. It is thought that the magnetic field changes the properties of water, such as electrical conductivity, where the ES in sulfur water was 6.11 and increased in magnetized sulfur water to 6.14, which may affect the interaction of water with the iron surface. The magnetic field hinders the formation of an iron sulfate layer on the iron surface, leaving the iron surface vulnerable to corrosion. The results showed that magnetized water increased iron corrosion.

As one can conclude, significantly magnetized river water has the most favorable effect on steel due to reduced chemicals that lead to reactions and, hence, corrosion. In contrast, magnetized sulfate water has the worst effect as corrosion increases.

PART 7

CONCLUSION AND RECOMMENDATIONS

This study investigated the effect of corrosion on the used iron metal in different aqueous corrosive media. The current study involved taking iron samples to study corrosion in these media (normal and magnetized water) using two methods: Immersion of the iron samples in normal water and Immersion of the iron samples in magnetized water. The samples were immersed in different periods. After magnetic treatment, it was found that the magnetic field increases the rate of movement of metal ions to the metal surface. Additionally, the magnetic field increases the rate of movement of water ions away from the metal surface. It also reduces the thickness of the protective oxide layer that covers the metal surface. Based on the study of the effect of different types of water and their magnetization on the corrosion resistance of iron, the following conclusions can be drawn:

- This research indicated that using galvanized pipes was not suitable for natural irrigation in salty, sulfurous, normal, and magnetized water.

- However, the results showed that the corrosion rate in normal water was higher than in magnetized water. This is because the water molecules in magnetized water are restricted in their movement due to the polarization caused by the magnetic field. Additionally, the concentration of calcium and magnesium ions is lower in magnetized water than in regular water, which hinders the ions that cause corrosion.

- Galvanized pipes are only suitable when the pH of natural water is around seven or moderate Basic (between 8 and 12). Therefore, such tubes should not be used for this application,

- The protective zinc coating is not corrosion-resistant at acidic pH; hence, its service life under these Terms is limited.

- In addition to its acidic pH, the natural water used in this irrigation system contains large amounts of suspended solids, which contribute to the worsening deterioration of galvanized pipes due to corrosion and impact attacks.

- SEM/EDS analysis also indicated that the zinc coating showed some manufacturing defects, which increased its vulnerability to Corrosion performance.

- The recommended solution to solve the problem is to install a water treatment plant and adjust the pH level to an appropriate level via chemical treatment before water distribution

- In addition, a filtration system is required to reduce water-suspended solids content—water treatment to remove sulfates and sulfur bacteria before use.

- It is important to periodically monitor the metals' condition in magnetic environments and perform the necessary maintenance to prevent severe corrosion.

- Water magnetization can only be used to reduce corrosion in river water. According to the results, it reduced the corrosion occurring in galvanized iron.

- Use pipes explicitly designed for saltwater environments, such as certain types of stainless steel or plastic. Cathodic protection systems can also be used in some cases to provide electrical anti-corrosion action.

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APPENDIX A.

SAMPLE RESULTS

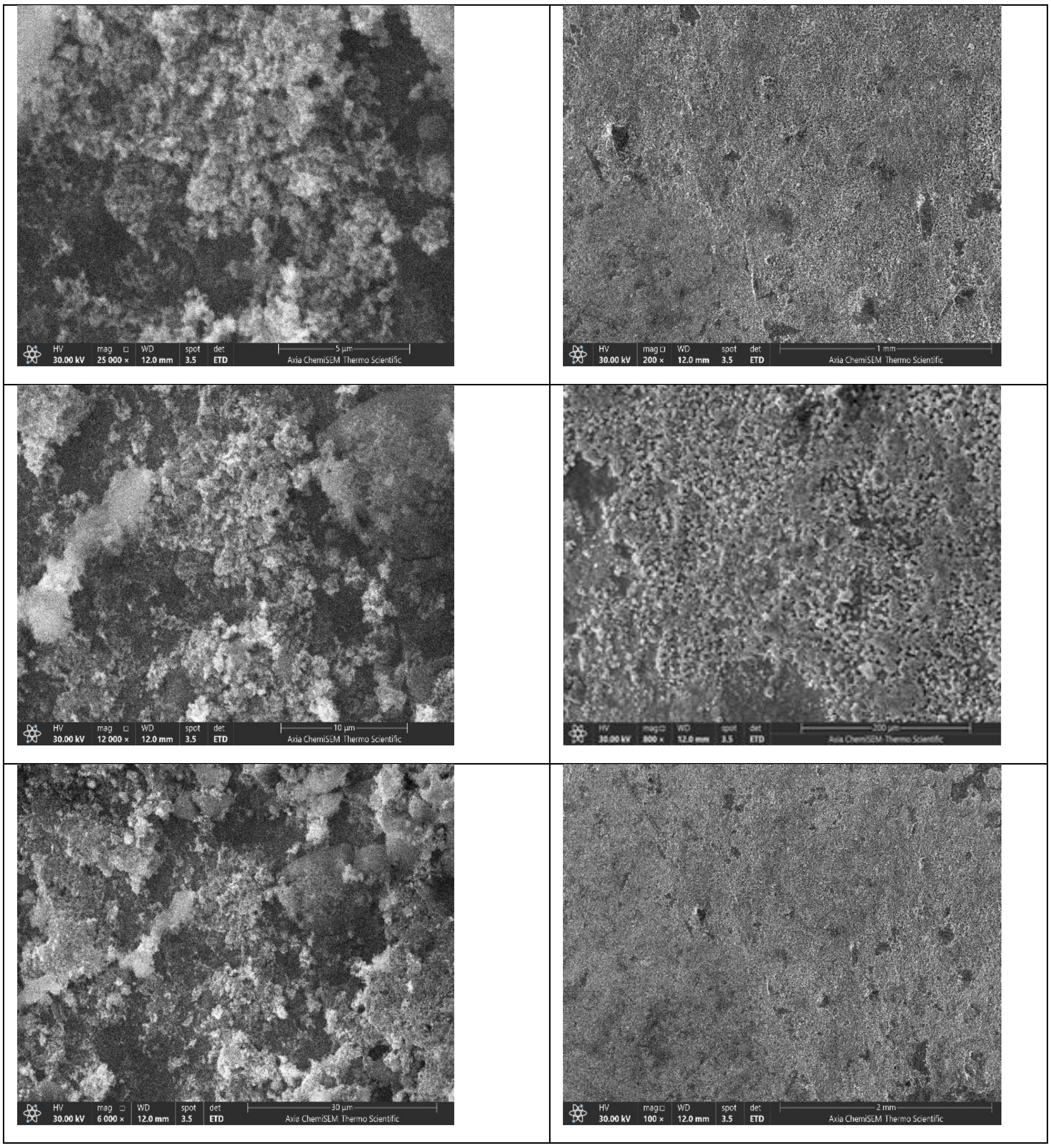

Figure Add A.1. Microscopic images of an iron sample.

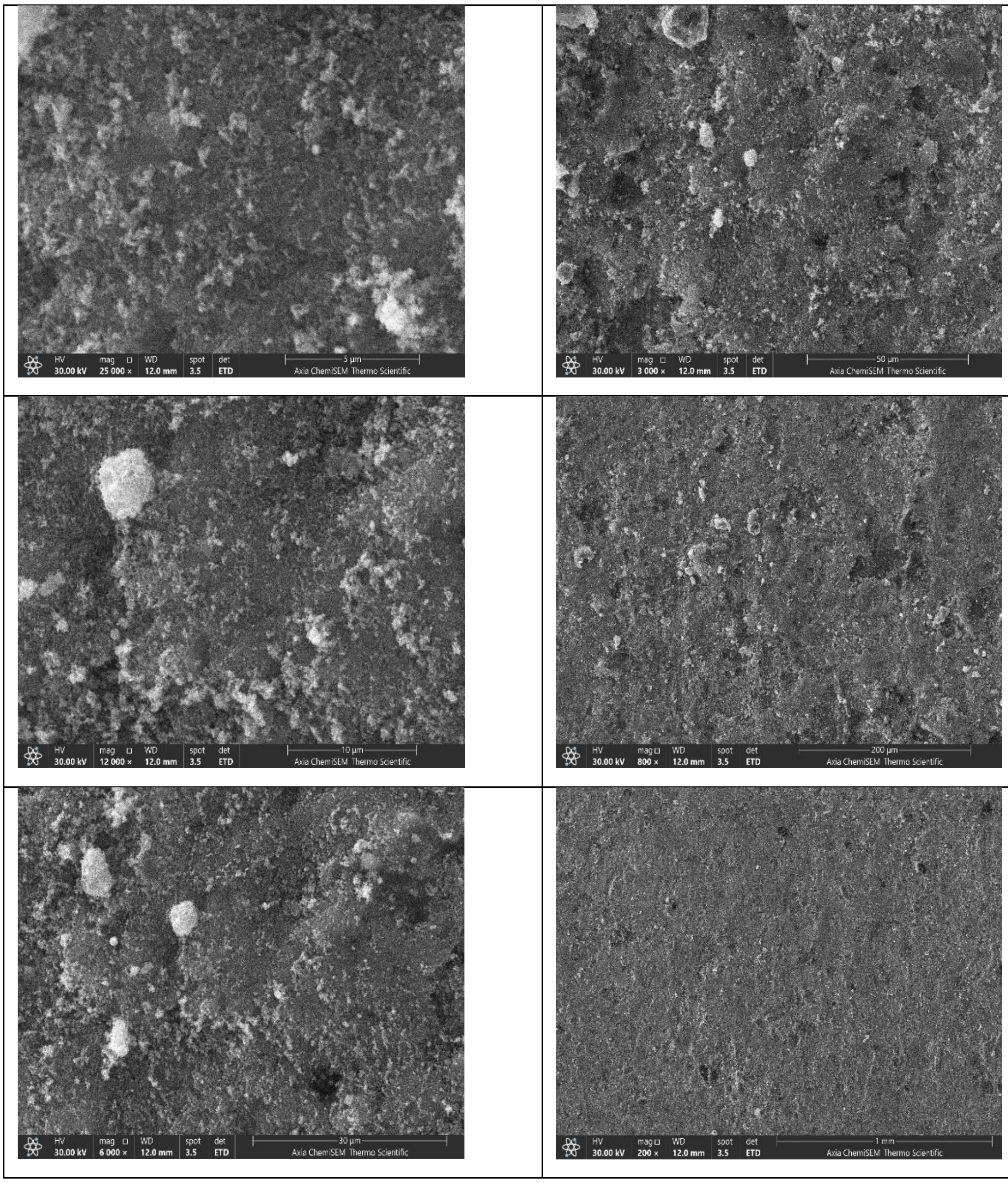

Figure Add A.2. Microscopic images of an iron sample in magnetized river water.

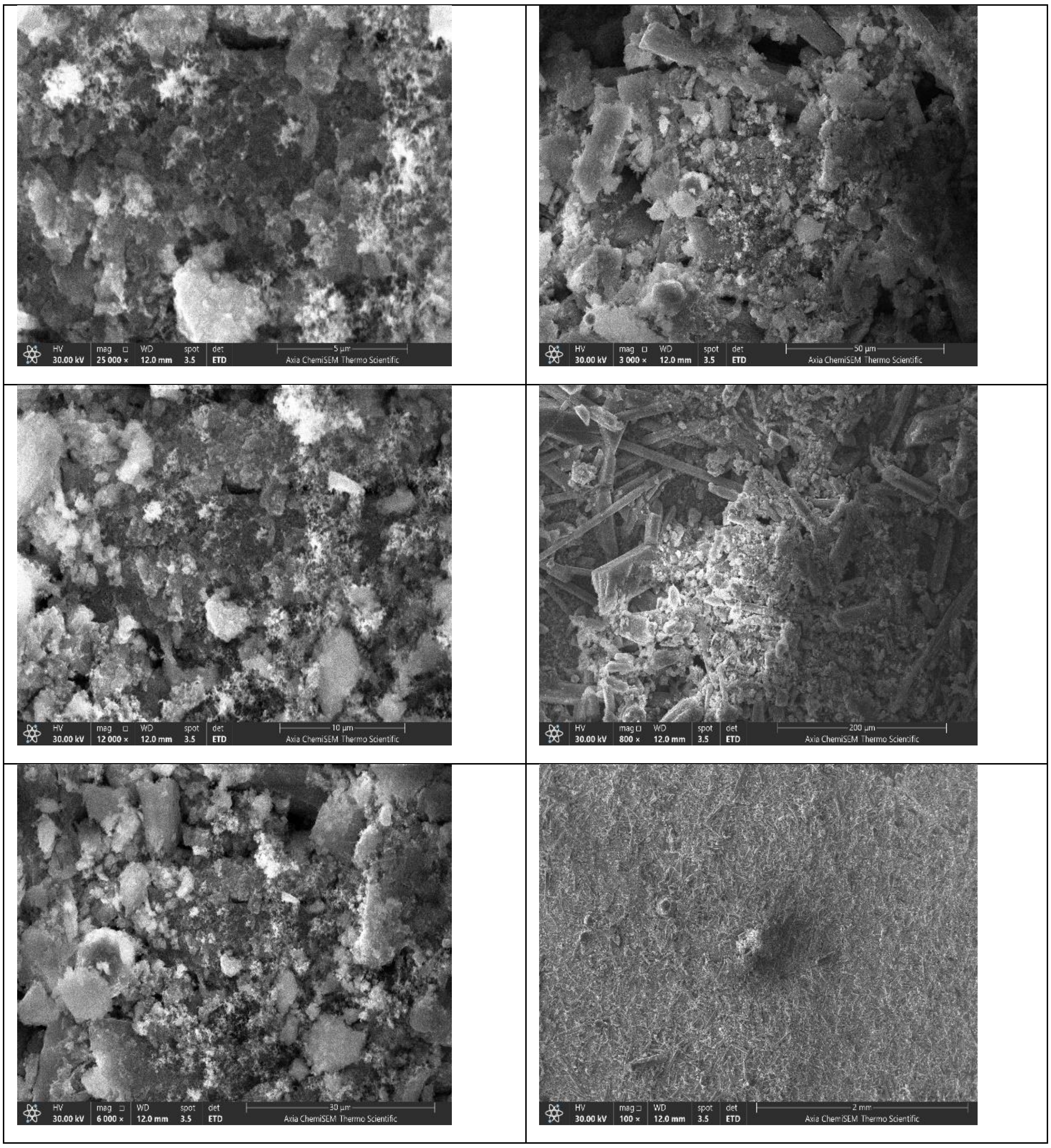

Figure Add A.3. Microscopic images of a well-water iron sample.

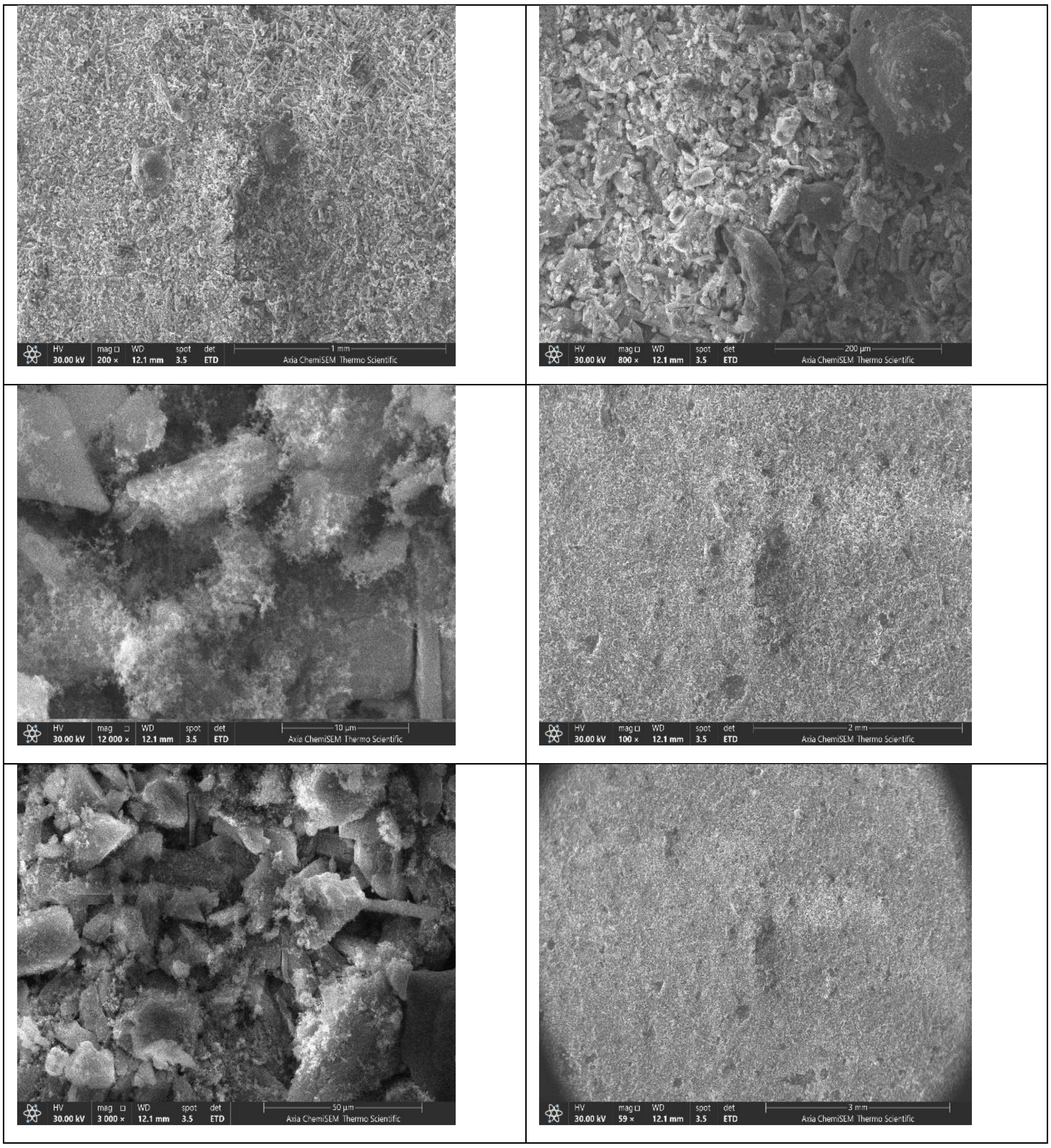

Figure Add A.4. Microscopic images of an iron sample in magnetized well water.

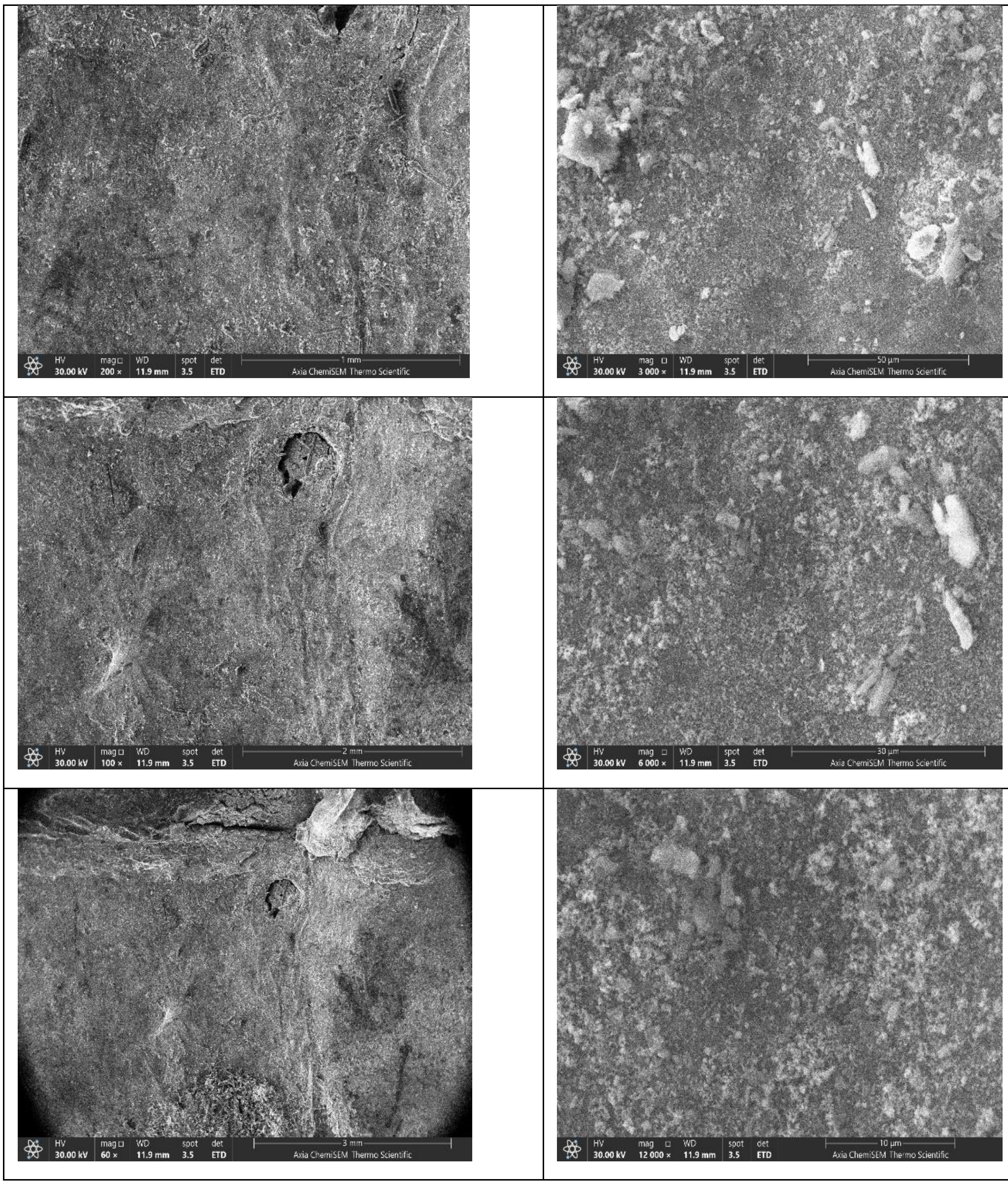

Figure Add A.5. Microscopic images of an iron sample in Sulphate water.

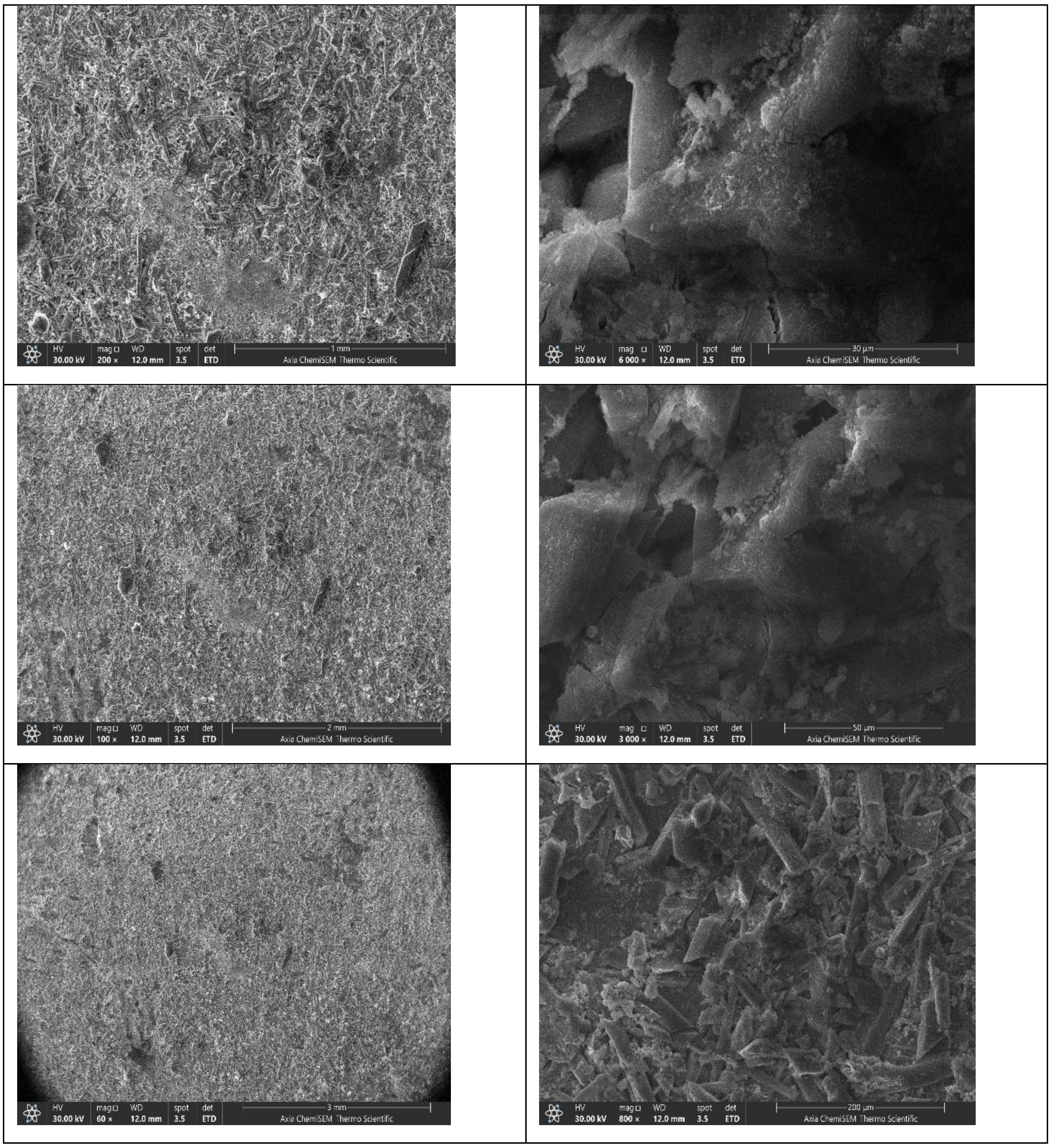

Figure Add A.6. Microscopic images of an iron sample in magnetized Sulphate water.

Table Add A. 1. Electrical parameters from EIS 1 corrosion analysis for river water.

	Par	Fixed	Value	Error%	Min	Max	Unit
Par[1]	R1		1.860E+00	1.00	1.0E-4	1.0E+13	Ohm
Par[2]	R2		3.224E+00	3.87	1.0E-4	1.0E+13	Ohm
Par[3]	R3		5.980E-01	20.40	1.0E-4	1.0E+13	Ohm
Par[4]	C1		2.099E-03	9.41	1.0E-13	1.0E+1	F
Par[5]	C2		1.576E-03	12.25	1.0E-13	1.0E+1	F

Table Add A. 2. Electrical Parameters from EIS Corrosion Analysis for Magnetized River Water.

	Par	Fixed	Value	Error%	Min	Max	Unit
Par[1]	R1		1.858E+00	0.99	1.0E-4	1.0E+13	Ohm
Par[2]	R2		3.004E+00	4.12	1.0E-4	1.0E+13	Ohm
Par[3]	R3		5.867E-01	20.75	1.0E-4	1.0E+13	Ohm
Par[4]	C1		2.008E-03	9.92	1.0E-13	1.0E+1	F
Par[5]	C2		1.473E-03	12.27	1.0E-13	1.0E+1	F

Table Add A. 3. Electrical parameters from EIS corrosion analysis for well water.

	Par	Fixed	Value	Error%	Min	Max	Unit
Par[1]	R1		1.861E+00	0.95	1.0E-4	1.0E+13	Ohm
Par[2]	R2		2.766E+00	4.30	1.0E-4	1.0E+13	Ohm
Par[3]	R3		5.959E-01	19.83	1.0E-4	1.0E+13	Ohm
Par[4]	C1		1.985E-03	10.11	1.0E-13	1.0E+1	F
Par[5]	C2		1.422E-03	11.09	1.0E-13	1.0E+1	F

Table Add A. 4. Electrical parameters from EIS corrosion analysis for magnetized well water.

	Par	Fixed	Value	Error%	Min	Max	Unit
Par[1]	R1		1.871E+00	0.88	1.0E-4	1.0E+13	Ohm
Par[2]	R2		2.593E+00	3.93	1.0E-4	1.0E+13	Ohm
Par[3]	R3		5.927E-01	17.08	1.0E-4	1.0E+13	Ohm
Par[4]	C1		1.980E-03	9.02	1.0E-13	1.0E+1	F
Par[5]	C2		1.419E-03	9.41	1.0E-13	1.0E+1	F

Table Add. A. 5. Electrical Parameters from EIS Corrosion Analysis for Sulfur water.

	Par	Fixed	Value	Error%	Min	Max	Unit
Par[1]	R1		1.880E+00	0.83	1.0E-4	1.0E+13	Ohm
Par[2]	R2		2.385E+00	4.35	1.0E-4	1.0E+13	Ohm
Par[3]	R3		6.450E-01	16.08	1.0E-4	1.0E+13	Ohm
Par[4]	C1		2.043E-03	9.74	1.0E-13	1.0E+1	F
Par[5]	C2		1.315E-03	8.31	1.0E-13	1.0E+1	F

Table Add A. 6. Electrical Parameters from EIS Corrosion Analysis for magnetized Sulfur water.

	Par	Fixed	Value	Error%	Min	Max	Unit
Par[1]	R1		1.882E+00	0.93	1.0E-4	1.0E+13	Ohm
Par[2]	R2		2.311E+00	4.74	1.0E-4	1.0E+13	Ohm
Par[3]	R3		6.032E-01	18.14	1.0E-4	1.0E+13	Ohm
Par[4]	C1		1.942E-03	10.47	1.0E-13	1.0E+1	F
Par[5]	C2		1.346E-03	9.33	1.0E-13	1.0E+1	F

RESUME

Bilal Ali Abbas AL-HALBOOSI obtained a bachelor's degree from Anbar University, Department of Soil Sciences, and received his master's degree from Istanbul Gedik University, Institute of Social Sciences. Engineering Management, MSc. He published Organizational Compliance, Int. Journal of Computer Science and Mobile Computing. Volume 9 Issue 7 July 2020, p. 1-11. ISSN 2320-088X. He holds a PMP Project Management Professional certification, a certificate in the foundations of business strategy from the University of Virginia, United States of America, a leading teams certificate from the University of Michigan, USA, and a certificate in the basics of financial awareness from the Kingdom of Saudi Arabia. He completed the courses: Graduated from English for Academic Purposes course, Middle East Technical University, ODTU (Ankara), Graduated from General English Language Education Course (TOMER – Ankara, Graduated from a Turkish language course (TOMER-Kırşehir). He holds a membership in the Syndicate of Agricultural Engineers and a membership in the Federation of Iraqi Chambers of Commerce.