Investigation on Corrosion and its effect on Mild steel and 304L Stainless steel in Food Processing Industries

Senait Tefera Gedefaw

A Thesis Submitted to the Department of Mechanical Engineering

School of Mechanical, Chemical, and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's

In Manufacturing Engineering

Office of Graduate Studies

Adama Science and Technology University

Augest, 2022

Adama, Ethiopia

Investigation on Corrosion and its effect on Mild steel and 304L Stainless Steel in Food Processing Industries

Senait Tefera Gedefaw

Advisor:

Moera Gutu Jiru (Ph.D.)

A Thesis Submitted to the Department of Mechanical Engineering

School of Mechanical, Chemical, and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's

In Manufacturing Engineering

Office of Graduate Studies

Adama Science and Technology University

Augest, 2022

Adama, Ethiopia

DECLARATION

I declare that this thesis entitled "**Investigation on Corrosion and its effect on Mild steel and 304L Stainless Steel in Food Processing Industries**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Senait Tefera Gedefaw	______________	______________
Name of Student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Investigation on Corrosion and its effect on Mild steel and 304L Stainless Steel in Food Processing Industries**" prepared under my guidance by Senait Tefera Gedefaw. Submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Manufacturing Engineering.

Therefore, I recommend the submission of a revised version of the thesis to the department following the applicable procedure.

Dr. Moera Gutu Jiru	______________	______________
Advisor	Signature	date

APPROVAL SHEET

I, the advisor of the thesis entitled "**Investigation on Corrosion and its effect on Mild steel and 304L Stainless Steel in Food Processing Industries**" developed by Senait Tefera Gedefaw. Hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr Moera Gutu Jiru	____________	____________
Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Senait Tefera Gedefaw have read and evaluated the thesis entitled "Investigation on Corrosion and its Damage analysis in Food Processing Machineries" and examined the candidate during the open Defence. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of Master of Science in Manufacturing Engineering.

____________	____________	____________
Chairperson	Signature	Date
____________	____________	____________
Internal Examiner	Signature	Date
____________	____________	____________
External Examiner	Signature	Date

Finally, approval and acceptance of the thesis is contingent upon the submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

____________	____________	____________
Department Head	Signature	Date
____________	____________	____________
School Dean	Signature	Date
____________	____________	____________
Office of Postgraduate Studies, Dean	Signature	Date

ACKNOWLEDGMENT

In the journey of completing this thesis, I have experienced a lot of ups and downs. I have encountered many kind people, faced many challenges and **GOD** made it possible. So above all I would like to thank almighty God for his support, encouragement, unending blessings and endless love throughout completing this work. Secondly, I do like to express my gratefulness to my thesis advisor **Dr Moera Gutu Jiru** Ass. Professor, for his priceless help in completing this thesis, his advice, for his encouragement, support and deserve special thanks for his understanding throughout the thesis.

Moreover my special thanks goes to Dr. G.M. Sayeed Ahmed for his support in facilitating this research work and for giving me marvellous suggestion, important recommendations and direction in completing this work.

I would also like to thank for all found in ASTU Chemical Engineering Lab, Mr Henock the Lab Assistant of Metal Lab at Material Science Engineering, Mr Leta Lab Assistant of Biology Department and Mr Abebe Manufacturing Shop chief for their support and help for finishing this thesis.

My special and deepest gratitude and love, to my husband Mr. Anteneh T. for his unconditional love, support and understanding. You have been my motivation throughout this work and I thank you so much and appreciate you for all your help.

Finally, I would like to thanks, all my families, and all of my friends for their support, appreciation and continued encouragement

TABLE OF CONTENT

Contents **page**

LIST OF TABLE

LIST OF FIGURE

ACRONYMS

ANOVA	Analysis of Variance
CR	corrosion rate
DOE	Design of Experiment
EDS	energy-dispersive spectrometry
EIS	electrochemical impedance spectroscopy
HV	Vickers Hardness
LPP	linear potentiodynamic polarization
MS	Mild steel
MSS	Mean Sum of Square
OA	Orthogonal Array
OCP	open circuit potential
OM	Optical microscope
S/N	Signal to Noise Ratio
SCC	Stress Corrosion Cracking
SEM	Scanning electron microscopy
SS	Stainless steel
SST	Total sum of squares
SSTR	Treatment sum of squares
XRD	x-ray diffraction

ABBREVIATIONS

Ecorr	corrosion potential
Icorr	corrosion current density
mmpy	millimetre per year
βa	anodic tafle slope
βc	cathodic tafle slope

ABSTRACT

Corrosion is a naturally occurring phenomenon defined as the degradation of material due to chemical interaction with the environment. The materials most commonly used for food processing machineries are different types of steels which are selected on the basis of corrosion resistant, non-toxic, mechanical property, and surface quality. The main aim of this research was to investigate the cause of corrosion and its damage analysis of metals used in construction of food processing machineries. The corrosion rate and morphology of the material after immersing in different food environment as corrosive media were mango juice, tomato juice and orange juice prepared for coupon test was investigated. Results were anylazied with weight loss method and corrosive pit measurement using surface profilometry based on which corrosion rate were calculated. In addition qualitative analyst by imaging using SEM and optical microscopy were used. The electrochemical measurements of the stainless steel and mild steel specimens was measured using a three-electrode electrochemical cell by E-Clab software for corrosion measurement conducted using potentiostat. The effect of corrosion on hardness was measured using Vickers hardness test. Mixed taguchi design, L_{18} *orthogonal array was employed for the experimental study with selected parameters such as test media, metal type and exposure time. The analysis of the results revealed corrosion rate of samples were decreased while weight loss was more when exposure time increased. From the results of corrosion rate study 304L stainless steel showed more corrosion resistance than mild steel. The lowest corrosion rate was recorded in stainless steel in tomato media as 0.0015mmpy. The micro hardness result revealed that the hardness of metallic materials decreased due to corrosion since pits developed on the surface of material aggravating corrosion process. This research revealed that 304L stainless steel and mild steel materials mostly attached by pitting and uniform corrosion.*

Keywords: *corrosion , mild steel, 304L stainless steel, food processing industry, test media, corrosion rate*

CHAPTER -1

INTRODUCTION

1.1. Background

Materials exposed to aggressive environments may undergo chemical and physical degradation due to electrochemical reaction between material and environment. This degradation is called “corrosion” when the material concerned is a metal. The term corrosion derives from Medieval Latin (corrosionis, from the verb corrodere), Middle English (corosioun) and Old French (corrosion). Corrosion is often defined as “destruction or degradation of a material caused by a reaction to its environment” and also “the spontaneous tendency of a metallic component to return to its original state as found in nature” (Pedeferri, P and Ormellese, M., 2018). For this reason, corrosion is also called metallurgy in reverse, because the corrosion process returns metals to their more thermodynamically stable natural state as oxides or sulphides or other compounds, from which metallurgy transforms to metal by supplying energy (Jellesen et al., 2006). Corrosion is conveniently classified according to the manner in which it manifests itself and is regularly encountered in the chemical, petrochemical, oil and food processing industries (Ogundare et al., 2012). There are numerous forms of corrosion. One of such categories includes chemical and electrochemical corrosion (Kim et al., 2006). Chemical corrosion is the direct result of exposure of a material to a chemical and is governed by the kinetics of chemical reactions similarly electro chemical corrosion is a quantitative relationship between chemical action and electric current. Corrosions are of many kinds, but they can be subdivided into two main types, internal and external. External corrosion is regarded as the corrosive effect of high temperature, high humidity, high salt, and highly acidic environments on the metallic part of the alloy (Tiu and Advincula , 2015).On the contrary, internal corrosion is associated with stored or transported gases or liquids (Nesic S, 2007).

Corrosion which is the deterioration of a material of construction or its properties due to reaction with the environment, is a problem in a lot of industries and is even a greater challenge in the food processing and pharmaceutical industries, where in addition to the loss of production time for maintenance and risk of equipment failure, there exists the additional risk of product contamination by corrosion products which may result in food poisoning. Serious attention is being paid to corrosion study in oil and gas industries because of its economic, safety, and conservation concerns. However, few research studies are available in the literature on corrosion in food processing industries (Hamzat et al., 2020). As a consequence food processing machinery, in spite of cost considerations have been as a standard constructed using stainless steels. Stainless steel owing to its exceptional corrosion resistance is widely used as an important and specific construction material in many fields such as electrical industry, construction industry, nuclear power industry, petrochemical industry, oil and gas industry, food processing industry, pharmaceutical industry and transportation industry. Whereas most industrial food processing equipment are fabricated/specified in stainless steel, other materials like tinned copper had been employed successfully and the suitability of other materials especially for specific environments should not be overlooked (Ofoegbu et al., 2011). Many food and agro-processing environments are corrosive as a result of their salt and chloride contents, which often lead to the corrosivity of foods manufactured. There are also instances when organic acids, as well as oxidizing chlorides are used as disinfectants. Moreover, the cycle of disinfections involves heat at high temperature. Often, due to gas evolving from food products, the industries are always under “wet” conditions and corrosion occurs in the presence of moisture. The pH value of the damp atmosphere, the velocity of flow of substances (example, edible oil in agricultural processing industries), wears and fretting, and heat transfer boiling are also initiators of corrosion in food industries (Jekayinfa et al., 2005).

Corrosion leads to huge economic waste especially in the processing and manufacturing industries (Oluwole et al., 2012). Studies carried out have shown that corrosion is recognized as one of the most serious problems facing the modern world resulting to losses worth of billions of US dollars each year; approximately ranging from one to five percent of Gross National Product (GNP) in countries like United Kingdom, Germany, United States of America and Japan (Oluwadare and Agbaje, 2007).

Therefore this research focused on the impact of corrosion damage in food processing machineries and its consequence for these industries as well as the effect of food environment on the corrosion behaviour of materials. Consequently, in this work, fruit juices are employed as model corrosive media to study the corrosion behaviour of metallic material in food media. This choice is based on their similarities in complex chemical composition and pH with foods, favourable texture, and state (liquid), which makes contiguous contact with metallic test samples easier. This paper, therefore, seeks to study in depth the corrosion of mild steel and stain less steel in selected fruit juice processing environments (orange juice, mango and tomato juice).

1.2. Problem Statement

Corrosion which is the deterioration of a material of construction or its properties due to reaction with the environment (Ofoegbu et al., 2011), has been a major problem in food processing industries, since chemical composition of the metal combined with food processing environment is crucial as it will to a large extent determine the possible corrosion reactions, the corrosion product formed, exposing more metallic surface and enhance metal loss.

The other factor for this phenomenon to occur and leads to cause corrosion is food stuff contain a lot of chemicals (mainly organic), and which when allowed to stand can become substrates for much microbial activity which results the production of chemical products that may be more danger to metallic material (Jekayinfa et al., 2005). As a result corrosion have an economic factor due to the loss of production time for maintenance as well as equipment failure and have additional risk of product contamination by corrosion products which may lead in food poisoning and raise serious health problem. Furthermore, it has significant impact on the degradation of constructional materials for food processing machineries like mild steel and 304L stainless steel leading shutting down of the machineries. Corrosion also main problem on the two materials in our locally occurred food processing industries since in Ethiopia most food processing machineries are constructed from mild steel and 304L stainless steel materials.

Therefore This work presented the cause and type of corrosion happened in food processing machineries as well as experimental investigation on the effect of food stuff on the corrosion behaviour of steels designed by Taguchi L_{18} orthogonal array with three parameters such as type of test media, metal type and exposure time with each having three, two and three levels respectively which are selected by their influence on the existent of corrosion.

1.3. Research Question

Regarding all the above-mentioned facts among corrosion in food processing industries and from the problem statement, the following research questions were raised.

i. What are the causes of corrosion and type of corrosion materials in food processing machineries?

ii. What is the effect of type of food environment on the corrosion behaviour of materials?

iii. What is the effect of corrosion on the hardness of materials?

iv. What does the morphology of materials looks like after corrosion?

v. At what condition the corrosion rate of materials will be low?

1.4. Objective

1.4.1. General objective

The main objective of this work is to investigate the corrosion causes and its damage analysis of machineries in food processing industries

1.4.2. Specific objective

Through the following highlighted objectives, the stated main objectives will be implemented. Therefore, the specific objectives of the study would be:

- Identification of corrosion causes and its types of steels utilized in food processing machineries.
- To determine corrosion loss of steels in different food environment using weight loss method.
- Investigation of electrochemical corrosion behaviour of the steels using a 3-electrode electrochemical cell (Potentiostat).
- Characterization of corrosion morphology, microstructure and topography using SEM, OM and 3D surface profiler.
- Determination of the hardness of steels after corrosion.

1.5. Significance of the Study

Even though Corrosion is main problem in a lot of industries, it is a greater challenge in the food processing industries. Apart from failure of equipment and production downtime, there exists additional risk of product contamination which may result in food poisoning and health concern like cancer. The corrosion process in food processing machineries largely depends on the nature of material and food environment. Therefore studying on the effect of corrosion damage in these machineries is very important to know the cause and type of corrosion happened in order to conduct the solution and controlling mechanisms for it at early stage or during initiation of corrosion. Beside that the investigation work helps to maintain the reduction in loss of production time and cost due to equipment failure. Furthermore the work comes with a benefit for food processing industries like fruit juice processing industries (mainly for local industries such as Upper Awash Agro Industry Enterprise (UAAIE), 3D mango juice factory, maza mango juice factory etc…).

1.6. Scope and limitation of the Study

The research concerned on study of cause, type and effect of corrosion on materials used for the construction in food processing machineries , its impact in food processing industries and also investigation on the corrosion behaviour of mild steel and 304L stainless steel with in three parameters, since most of food machineries are constructed by stainless steel material. The work was highly focused on Identifying and determination of the most significant corrosion parameter on the corrosion behaviour of steel during investigating it in different food environment such as orange juice, mango juice and tomato juice. The experiment have been designed by using mixed taguchi design with three parameters which were selected by considering their influence on the existent of corrosion, and S/N ratio and ANOVA were conducted to show which parameter will be significant. In addition characterization of corrosion morphology was conducted using SEM.

Limitation: The effect of temperature and thickness of the material on the corrosion behaviour of steels were not investigated due to difficulties to make experiment with different temperature without need of temperature controlling unit and because of expensiveness of stainless steel to purchase it in thickness wise respectively.

1.7. Structure of the thesis

Chapter one provides the introduction, background and problem statement for conducting this research and states the aim and objectives of the study. It also states the scope and expected significance.

Chapter two is the literature review of the study which covers the general corrosion concept of corrosion and provides corrosion behaviour of metallic materials. It examines the characteristics of fruits environments and corrosion mechanism of mild steel and stainless steel. In addition, it also explains types and causes of corrosion occurred in food processing machineries.

Chapter three explains the research materials and methodology used for experimentation which involves the logical sequence of operations outlined in the objectives of this study. It also describes sample preparation, procedures and techniques by which the experiments are conducted to obtain the results.

Chapter four reports the experimental results and discussion on the weight loss measurements, electrochemical studies and characterisation of the corroded mild steel and stainless steel samples.

Chapter five states the conclusions based on the analyses of the results with recommendations for further studies.

CHAPTER-2

LITERATURE REVIEW

2.1. Introduction

The literature review is an important aspect of any research because it is based on the thesis topic and investigates a wide range of relevant publications. Many literatures on corrosion are available in journals and books, implying material corrosion behaviour, corrosion causes, and corrosion's social and economic consequences. Corrosion has a wide range of implications, including effects on the safe, dependable, and efficient operation of equipment or structures, as well as the basic loss of metal mass. The following major points have been explored in this literature review:

- General concept of corrosion,
- Types of Corrosion,
- Corrosion Monitoring and Detection Techniques,
- Causes of corrosion in food processing industries,
- Economic impact of corrosion,
- Effect of corrosion on hardness of material,
- corrosion behaviour of stainless steel,
- corrosion behaviour of mild steel
- corrosion behaviour of steel in different food environment,
- The effect of temperature and pH Value on the Corrosion Behaviour of Material.

2.2. Concept of corrosion

Corrosion is a gradual physiochemical destructive attack on metals through interaction with the environment (Ogunleye et al., 2011). In broad aspect, corrosion is a process of destructive alteration of metal or an alloy by chemical reaction with any solid, liquid or gaseous substance. Historically, corrosion has been observed in all civilizations since the inception of technology and is widely dependent on the use of metals and alloys. Indeed all metals except for some noble metals such as gold are subject to corrosion (Shreir, 2010). It usually begins at the surface of a material and occurs because of the spontaneous tendency of the materials to return to their thermodynamic stable state or to one of the forms in which they were originally found. According to Tait, (2018) almost all metals are oxides in their natural state, and considerable energy is required to transform these oxides into metals. Unfortunately, metals and their alloys have a very strong tendency to corrode and thus return to their stable oxide form. Indeed, metal alloys often have an even stronger tendency to corrode than their constituent metal components. For example, in certain situations pure iron is significantly more resistant to corrosion than low-carbon steel. Shreir, (2010) reported metals are generally prone to corrosion because most of them occur naturally as ores, which is the most stable state of low energy and there is a net decrease in free energy from metallic to oxidized state . The Corrosion of a material cannot happen without any electrochemical reaction taking place; likewise corrosion cannot take place without the appropriate environment (Ayoola et al. 2018; Gaber et al. 2017). The electrochemical reactions that take place within metals consist of oxidation and reduction reactions and these reactions occur simultaneously (Aghuy et al., 2015; Atkins and Depaula, 2010). Oxidation reaction cannot take place without reduction reactions and vice versa. Corrosion takes place at the anodic side of the reaction. In other words, dissolution of the metal into its ionic form takes place at the anode while the cathode is where electrons from the solution enter into the metal. A representation of the typical reactions that happen at the anode and cathode of the corrosion of Iron is shown below through equation.

<u>Anodic Reaction</u>

$$\mathrm{Fe} \longrightarrow Fe_2{}^{+} + 2e^{-} \tag{2.1}$$

<u>Cathodic Reactions</u>

$$O_2 + H_2\mathrm{O} + 4e^{-} \longrightarrow 4OH^{-} \tag{2.2}$$

$$O_2 + 4H^{+} + 4e^{-} \longrightarrow 2H_2\mathrm{O} \tag{2.3}$$

$$2H^{+} + 2e^{-} \longrightarrow H_2 \tag{2.4}$$

$$Fe^{3+} + e^{-} \longrightarrow Fe^{2+} \tag{2.5}$$

Equation 2.1 represents the anodic reaction of Iron as electrons leave it and enter the solution to form Iron ions. The Cathodic reactions are represented by equations 2.2 to 2.5.

2.3. Types of Corrosion

By talking consideration of the different cause of corrosion and their mechanisms, as well as the appearance of the attack one can differentiate between several types of corrosion. There are many different types of corrosion that are visible to the naked eye: uniform corrosion, pitting, crevice corrosion, filiform corrosion, galvanic corrosion, environmental cracking, and fretting corrosion. Some types of corrosion are little more than a nuisance, such as uniform rusting, and some types of corrosion, such as pitting and stress-corrosion cracking, are more serious and can lead to catastrophic equipment failure or failure of the entire chemical process (tait et al., 2018).

A. Uniform Corrosion

Uniform corrosion is the most common variant of corrosion. This corrosion occurs naturally when metal deteriorates through a chemical or electrochemical reaction with the surrounding environment that deteriorates the entire surface, corroding it 'uniformly.' This type of corrosion is the most widespread, but is predictable and can be managed by using the appropriate preventative measures and determined by direct measurement and by calculation from the mas per unit area, when the density of material is known (Corrosionpedia, 2019).

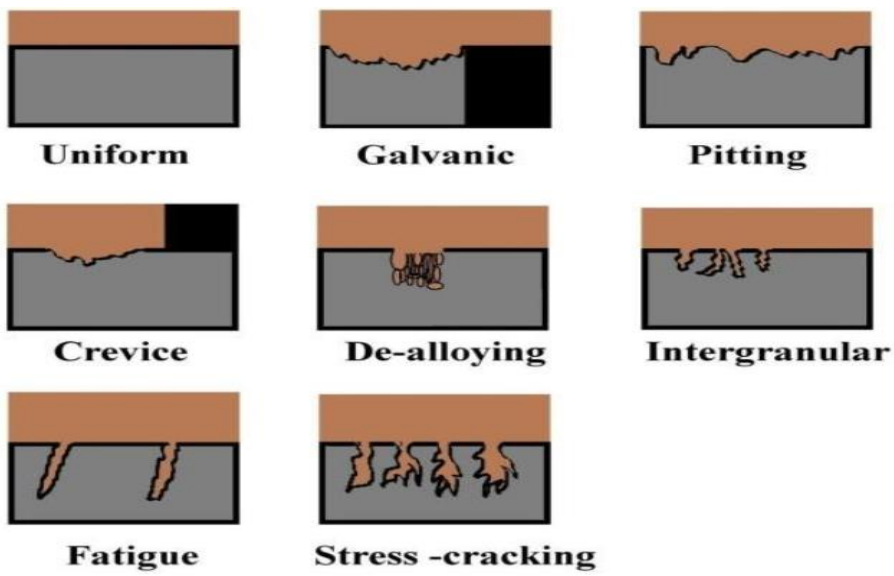


Figure 2.1 Different Types of Corrosion. (Kansara et al., 2018)

B. Localized Corrosion

Localized corrosion comes in many variations, such as pitting, crevice corrosion, and filiform corrosion (tait et al., 2018).

- ***Pitting corrosion***: This type of corrosion happens when a small break in the metal forms. The subsequent hole or cavity becomes anodic, while the surrounding metal becomes cathodic. This produces a localized galvanic reaction, leading to the structural failure of the metal. Pitting is difficult to locate and manage, as it is often masked by other materials produced during the formation of corrosion (tait et al., 2018).
- ***Crevice corrosion***: This localized corrosion can often be found under gaskets, clamps,

and other unmoving areas where low oxygen and acidic conditions can lead to corrosion within crevices (tait et al., 2018).

- ***Filiform corrosion:*** This corrosion occurs under surfaces that have been painted or coated. Defects in the paint or coating allow water to intrude, thereby causing corrosion below the protective layer, resulting in a weakened structure (tait et al., 2018).

C. Intergranular corrosion

It is the corrosion in or the adjacent to the grain boundaries of the metal. Intergranular corrosion occurs in most metals under unfavourable conditions. Most well-known is intergranular corrosion in stainless steel as consequence of chromium carbide formation when carbon concentration is too high and an unfavourable heat treatment has occurred (Wikipedia, 2021).

D. Fretting Corrosion

This type of corrosion occurs as repeated weight, vibration, or wearing causes pits and grooves on the surface of the metal. This occurs most often in machinery parts in motion, or surfaces that suffer vibration as they are transported from place to place (Corrosionpedia, 2021).

E. Galvanic Corrosion

Galvanic corrosion is the result of a very specific set of conditions. It is only found in environments where there are electrochemically dissimilar metals in electrical contact that are also exposed to an electrolyte. This corrosion happens when galvanic coupling occurs between the anodic and cathodic metals. The anode corrodes faster by being coupled, while the cathode deteriorates more slowly (TWI, 2020).

F. Erosion corrosion

It is the process which involves conjoint erosion and corrosion which is usually caused by a rapidly streaming liquid and the attack is thus dependant on the degree of turbulence. Erosion corrosion con occur with most metals, but copper bearing materials are particularly sensitive (Poulson, 2013).

G. Environmental Cracking

This corrosion process occurs when environmental conditions arise that negatively affect carbon steel. Chemicals, stress, and temperatures can create conditions that produce stress corrosion cracking (SCC), corrosion fatigue, liquid metal embrittlement, and hydrogen-induced cracking (Raman et al., 2003).

2.4. Corrosion Monitoring and Detection Techniques

Corrosion measurement employs a variety of techniques to determine how corrosive the environment is and at what rate metal loss is being experienced. Corrosion measurement is the quantitative method by which the effectiveness of corrosion control and prevention techniques can be evaluated and provides the feedback to enable corrosion control and prevention methods to be optimized. Common methods used for corrosion monitoring and detection are destructive and non–destructive (Kansara et al., 2018). In non-destructive method ultrasonic guided wave, radiographic and electromagnetic and in destructive methods corrosion coupons, electrical resistance and linear polarization resistance are included.

Non-Destructive Method

Non-Destructive Testing (NDT) is a wide group of analysis techniques used in science and technology industry to evaluate the properties of a material, component or system without causing damage (Kansara et al., 2018).

Destructive Method

Destructive Physical Analysis, (DPA) test is carried out to the specimen's failure, in order to understand specimen's performance or material behaviour under different loads. These tests are generally much easier to carry out, yield more information, and are easier to interpret than non-destructive testing (Kansara et al., 2018).

Types of Destructive Method

A. Corrosion Coupons

The weight loss technique is the best known and simplest of all corrosion monitoring techniques. The method involves exposing a specimen of material (the coupon) to a process environment for a given duration, then removing the specimen for analysis. The basic measurement which is determined from corrosion coupons is weight loss; the weight loss taking place over the period of exposure being expressed as corrosion rate (Emt, 2017).

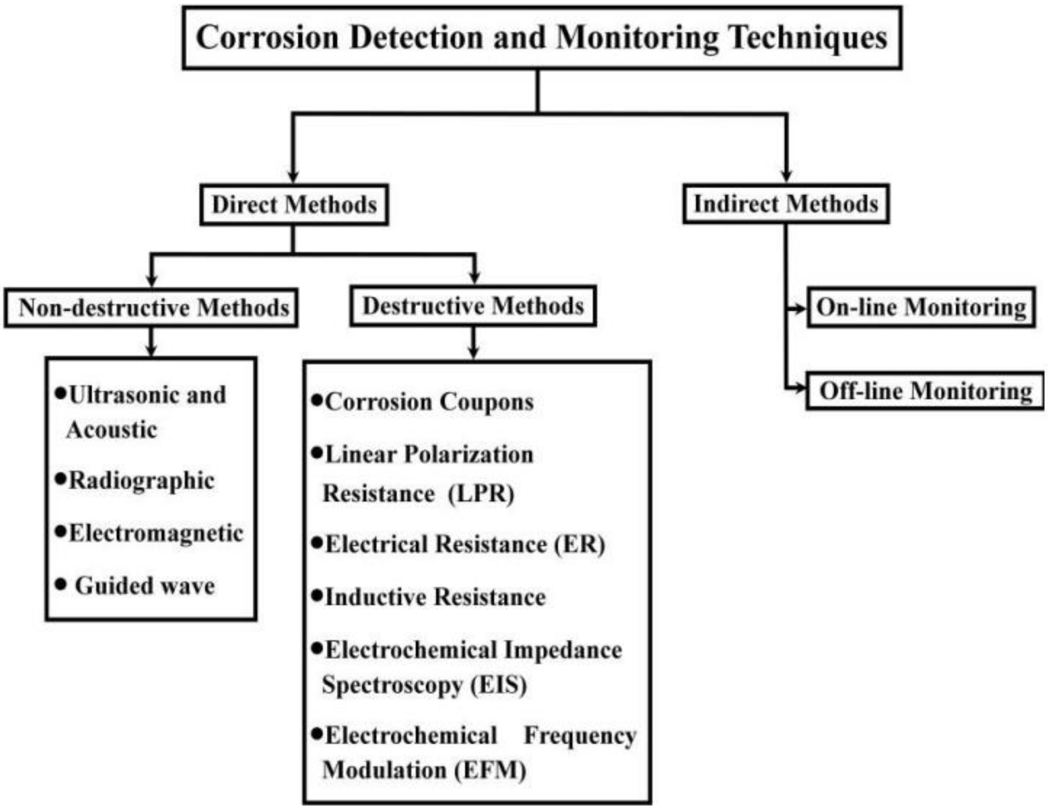


Figure 2.2 Corrosion monitoring and detection methods (Kansara et al., 2018)

B. Linear Polarization Resistance (LPR) method

It is an electrochemical method of corrosion. Electrochemical potential and current generated between electrically charged electrodes in process stream monitoring relationship between these two allows the calculation of corrosion rate. LPR is a continuous monitoring system. Here the solution resistance (Rs) is the resistance between the corroding interface and the reference electrode and polarization resistance (Rp) is related to corrosion rate. In a making direct current, or a low frequency, corrosion rate measurements (Kansara et al., 2018).

C. Electrical resistance method

There are several techniques for online corrosion monitoring the most commonly techniques used is electrical resistance technique. The ER technique measures the effects of both the electrochemical and the mechanical components of corrosion such as erosion or cavitation. It is the only on-line, instrumented technique applicable to virtually all types of corrosive environments. The electrical resistance of this probe is compared with that of an identical reference probe that is shielded from corroding (Metal samples, n.d.).

D. Electrochemical Impedance Spectroscopy (EIS)

The influence of surface in homogeneities on corrosion processes is demonstrated by EIS. EIS is another more recently developed technique that is continuous measurement of corrosion rate. In this method measurement of polarization resistance (Rp) is directly measure of corrosion rate. To make an EIS measurement, a small amplitude signal, usually a voltage between 5 to 50 mV is applied to a specimen over a range of frequencies of 0.001 Hz to 100,000 Hz. The EIS instrument records the real (resistance) and imaginary (capacitance) components of the impedance response of the system (BV, 2021).

2.5. Corrosion in the Food Industry

Food industry is a complex network conformed by primary producers and the industries linked to them. The plants involved in the processes of products and packaging must preserve the capital invested and minimize operation costs. The physicochemical characteristics of processed foods permit them to achieve different corrosively grades depending on the type of content (Jellesen et al., 2006). Three types of foods are recognized according to their corrosively:

- Non corrosive: milk, meat, fish, oil, fat, cereals
- Mild corrosivity, foods with pH 6 – 7 and less than 1% of salt: dairy products, fruit syrups, wine, carbonated sweet drinks, beer, soups, canned meat.
- High corrosivity, foods with pH 3 – 5, such as citric fruit juices, jams and acidic canned fruits or hot gravies, sauces and dressings, vegetables and fish pickled in

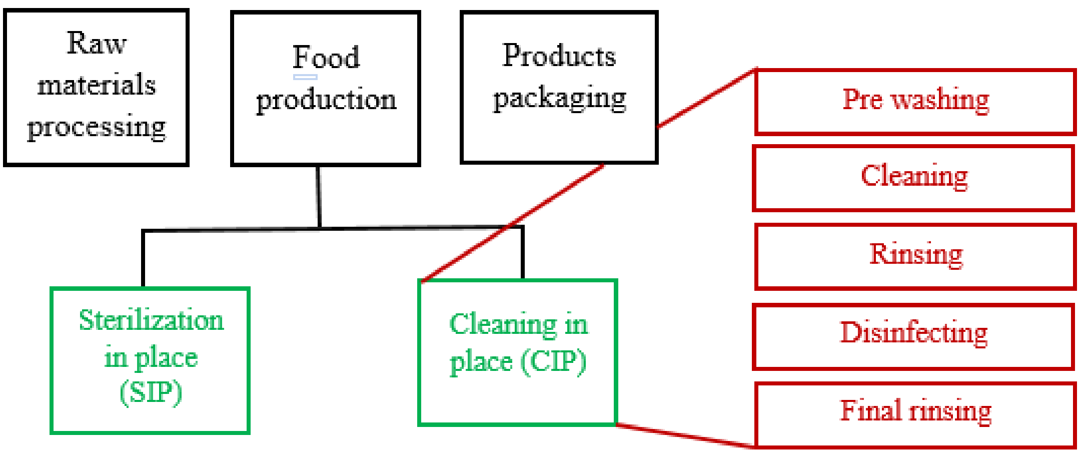


Figure 2.3 Manufacturing process in food industry (Zaffora et al., 2021).

In the foods manufacturing industry, different phases can be distinguished: raw material processing, food production, and product packaging. Food production foresees the contact of

equipment material with organic acids at low pH, moderately to highly concentrated chlorides solutions, and/or proteins-rich media, at high operating temperature in some cases.
Every single manufacturing phase can be highly corrosive for the equipment materials, leading to possible poisoning and contamination of produced food/drug. For this reason, the choice of equipment materials is crucial because they must be easily cleaned, corrosion resistant, cost-effective, and not dangerous for operators (Zaffora et al., 2021)

2.6. Causes of corrosion in food processing industry

Because of their salt and chloride concentration, many food and agro-processing environments are corrosive, which often leads to the corrosivity of foods made. Organic acids, as well as oxidizing chlorides, have been utilized as disinfectants in the past. Proteins, carbs, and fats make up the majority of what we eat. A variety of aqueous solutions, syrups, and additives are used in processed foods to improve the look, quality, and preservation of the food. They have a wide pH range, as well as salt, water, and vinegar content, all of which affect food corrosivity (Salas et al., 2012). The one with the higher chemical content such as dirt, fatty acids, impurities and Bacteria, had undergone higher rate of corrosion (Stephen et al., 2018)**.** Furthermore, the disinfection cycle requires high-temperature heat. The industries are frequently "wet" due to gas emissions from food products, and corrosion develops in the presence of moisture. In food processing sectors the processes which are; washing, transporting, blanching, heating, cooling, and cleaning are done with water. Heating and cooling operations, in particular, necessitate enormous amounts of water. The use of water in boilers, rotary cookers, and hydrostatic sterilizers causes under deposit corrosion. In the food industry, other factors such as the pH value of the damp atmosphere, the velocity of substance flow (for example, edible oil in agricultural processing industries), wears and fretting, and heat transfer boiling are also corrosion initiators. (Jekayinfa et al., 2016).

According to (Jekayinfa et al., 2016) in the food processing industry, product quality, health, and sanitation are key concerns. Because of their unique functions, industries cannot tolerate corrosion deposits in manufactured items. Due to their extremely complex composition, determining the specific ingredients of food is difficult. Citrus species are used to make a variety of juices in a variety of businesses. Rust is formed as a result of an interaction between steel (Fe), moisture (H_2O), and oxygen (O_2). Although this is a complicated process, it may be expressed by a chemical equation. (Afolabi et al., 2013).

$$4Fe + 2H_2O + 2O_2 \longrightarrow 2Fe_2O_3.H_2O \tag{2.6}$$

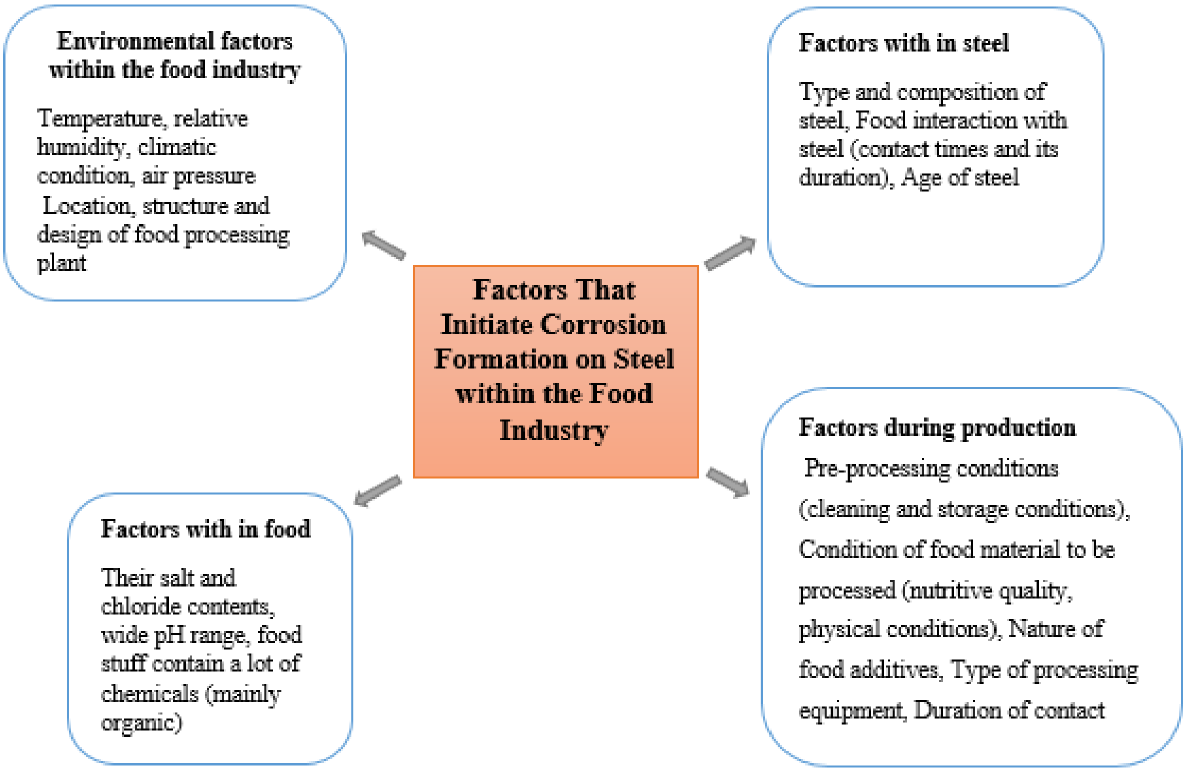


Figure 2.4 Factors That Influence The Initiation of Corrosion on Steel in The Food Industry During Processing and Production (Dula et al., 2021).

Corrosion and its effects must therefore be appropriately accounted for in food production lines when metallic components come into direct touch with items intended for human consumption. Foulant attaches to industrial surfaces, generating films that are difficult to remove during cleaning operations, due to the physicochemical properties of the processed products. Under deposit corrosion is a type of crevice corrosion that is common in cooling systems that have scales or foulants. Inadequate cleaning can lead to decreased efficiency, energy loss, product contamination, and machine corrosion. (Sierra et al., 2018). Many different types of corrosion can limit the service lifetime of processing equipment. Purity and sanitation standards need high corrosion resistance to pitting and crevice corrosion. The processing equipment's water side can range from steam heating to brine cooling. As a result, identifying the type of corrosion that is destroying the processing equipment is a key strategy for preventing and managing corrosion. (William S. Tait, 2018). Sulphating agents producing sulfur dioxide when used to treat foods include sodium sulphite, sodium bisulfite, potassium bisulfite, sodium metabisulfite, and potassium metabisulfite. All are generally corrosive to food-processing equipment.

2.7. Economic impact of corrosion

Corrosion is a major source of concern because of the high expense of replacing metal parts in a variety of applications (Loto, 2012). Corrosion is a universal enemy that must be accepted as an unavoidable process. As products and manufacturing processes have become more sophisticated, and the costs of corrosion failures have increased, more awareness has been developed (Fayomi et al., 2019). Due to the deterioration of metallic materials, the cost of corrosion has risen dramatically. Orisanmi et al., (2017) reported the engineering economy approach and statistical analysis method were used to estimate and analyse the cost of corrosion. Cleaning, followed by the use of oil, grease, and painting, contributed the most to the cost of corrosion prevention methods, while repair contributed the most to the cost of corrosion maintenance methods in the food processing industry.

According to this analysis, corrosion is predicted to account for 10% of global metal output. Some corrosion effects are cost-effective, resulting in the following:

- Replacing the corroded equipment
- Taking preventive measures, such as painting
- Equipment shut down due to corrosion failure
- Overdesigning to allow for corrosion
- Efficiency loss
- Damage of equipment adjacent to one in which corrosion failure occurs.

According to Bardal, (2003) Corrosion costs 3-4 percent of a country's GDP in industrialized countries. Deductively, third-world countries spend ten times more to combat corrosion than the preceding estimate. Furthermore, the loss of production caused by equipment failure has an impact on the company's profit.

Economic effect analysis also serves as a performance evaluation tool for identifying and evaluating cost-cutting options related to corrosion. (Shekari et al., 2017). Accordingly, corrosion costs and corrosion losses are defined as

- Corrosion cost is the cost of all efforts that prevent, control, or mitigate corrosion losses;
- Corrosion loss is financial loss caused by failures due to corrosion

Table 2.1: Elements of Corrosion Cost and Corrosion Loss (Shekari et al., 2017)

Types of economic impact	*Classification*	*Example*
Corrosion cost	Preventation cost	• Coating • Inhibitors • Catodic protection
	Monitoring cost	• Corrosion monitoring (corrosion coupons and probs. • Corrosion test • Inspection
	Maintenance cost	• Maintenance and repair • Replacement of equipment • Redundant equipment
	Management cost	• Training • Quality assurance • Corrosion control planning • Safety and integrity management system • Administration
Corrosion losses	Accidental losses	• Human health loss • Asset loss • Environmental clean-up cost
	Business loss	• Business interruption loss • Reputational loss

2.8. Effect of Corrosion on Hardness of material

The hardness of materials is defined as the resistance of a specific material to localized plastic deformation or indentation. The phrase can also refer to a material's scratch, abrasion, or cutting resistance. Hardness is most typically used to evaluate a metal's ability to withstand permanent deformation owing to concentrated applied loads when it comes to metals. Gutu Jiru et al. (2018) reported that the higher the metal's hardness, the better its capacity to maintain its shape in the face of external forces. The metal softens and loses its hardness as a result of corrosion. Hardness dropped virtually linearly from the top surface to the substrates, and corrosion had a significant impact. According to Duanjie, (2017) Corrosion has a negative impact on the surface mechanical property such as hardness on the alloy steel, reducing the surface hardness from ~6.7 to ~4.6 GPa during the first seven days immersion in the 3.5 wt. % NaCl solution. (Orozco et al., 2019) Reported that the behaviour of the hardness of A335 P92 steel decreased from 60.2 HRA up to 55 HRA, which is mainly due to corrosion after immersion of it in acetone.

2.9. The Effect of Temperature and pH Value

Temperature can affect the corrosion behaviour of materials in different ways. If the corrosion rate is only controlled by the metal oxidation process, the corrosion rate will increase exponentially with an increase in temperature following an Arrhenius relationship (Handbook, 1987). Furthermore, a change in temperature can also affect the resistance of a material to localized corrosion (pitting) (Jessima et al., 2020). Increase in the corrosion rate with increase in temperature both in the absence and presence of the inhibitor. This is due to the increase in the thermal agitation of the acid medium that obviously will enhance the metal dissolution. Also Gadpale et al. (2014) investigated Lower ageing temperature resulted lower corrosion rate also decrease the hardness of the material Because during Increasing the time of duration and temperature these fine precipitates are increase in size results increases the precipitate’s kinematics which degrade the properties of hardness and increases the corrosion rate.

Table 2.2: Ranges of pH values for different foodstuffs (Zaffora et al., 2021).

Food Stuff	pH range
Vegetable	3.0 to 6.0
Fruits	2.0 to 5.0
Bakery	5.0 to 6.5
Meat	6.0 to 7.0
Fish	5.5 to 6.
Dairy	5.0 to 6.5
Beverage	2.0 to 5.5

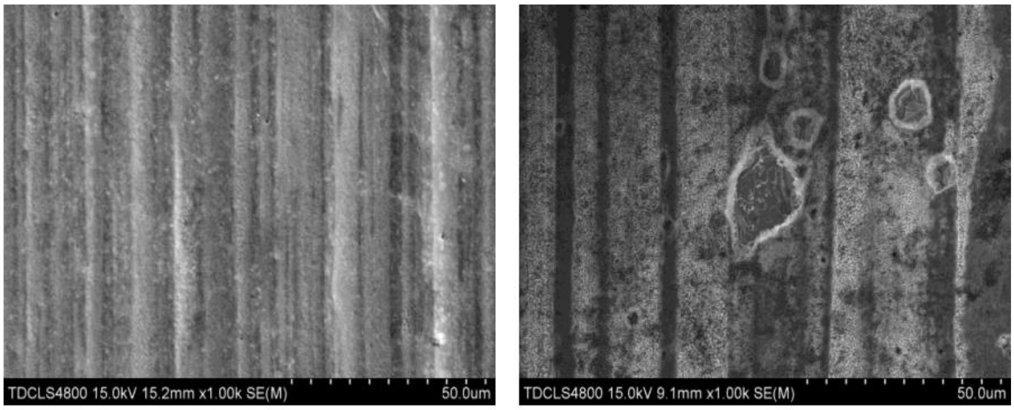
According to Trépanier and Pelton (2006) the pH of a solution also an important factor in the corrosion resistance of materials because hydrogen ions can interact and modify the surface and therefore alter the corrosion resistance of a material. As the pH is decreasing (acidity increase), the corrosion rate is increasing. This is because low pH solutions accelerate corrosion by providing hydrogen gas. Temperature also influences the corrosion rate. The pH values associated with foods ranges from 3 to 8 that corresponds to a mildly acidic water and has an acceptable corrosive behaviour for aluminium, stainless steel and tin (Zaffora et al., 2021). Here are studies have investigated the effect of temperature and pH on the Corrosion Behaviour of Material.

Benea and Simionescu, (2020) performed study on Effect of Solution and pH on Corrosion Resistance accuracy of corrosion resistance of commercially available 304L stainless steel in Saliva Fusayama Meyer artificial saliva was also selected because it is found in citrus juice, apples, tobacco leaf, wine, etc. Electrochemical methods was adapted for investigating corrosion behaviour of the material performed at room temperature (22 ± 2°C). From the result it was conclude that the corrosion rate of 304L stainless steel increase with decrease in pH value. The corrosion rate values of 304L stainless steel surface in SFM and Hank biological solution are lower as compared with those measured in citric acid solution.

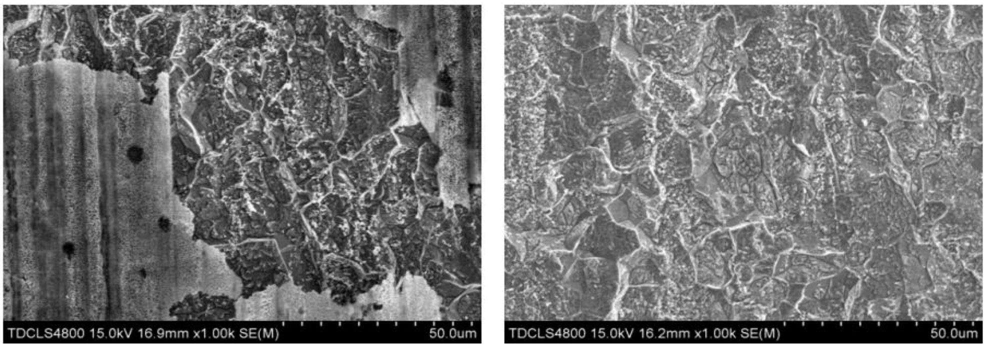
Wang et al., (2020) carried out investigation on the effect of high temperature on the corrosion behaviour and passive film composition of 316L stainless steel in high H_2S-containing environments by using electrochemical tests and chemical composition of the passive films was characterized by X-ray photoelectron spectroscopy. The test specimens were cut from a hot-rolled 316L stainless steel plate and test solutions containing 20 g/L NaCl were mixed with N_2 for 2 h in order to remove dissolved oxygen. They conclude that:

- ✓ The corrosion rate of 316L dramatically increase as the temperature increased which decrease the corrosion resistance of the material.
- ✓ The composition of the outer passive films formed on 316L disappeared as temperature increased.

Wang et al., (2019**)** worked on the effect of Storage Temperature on the Corrosion Behaviour of Tinplate in 0.1mol/L Citric Acid Solution. Immersion test, polarization curve and electrochemical impedance spectroscopy (EIS) was used for determining corrosion rate and scanning electron microscopy (SEM) for characterization of surface morphology of tinplate before and after corrosion. Tinplate samples with the dimension of 60 mm×60 mm were immersed in 0.1 mol/L citric acid solution at the temperatures of 5 °C, 20 °C and 37 °C were obtained by using biochemical incubator in order to simulate the different storage temperature for 30 days. The experimental results show that with the increasing of storage temperature the corrosion rate of tinplate in citric acid solution is increased dramatically.

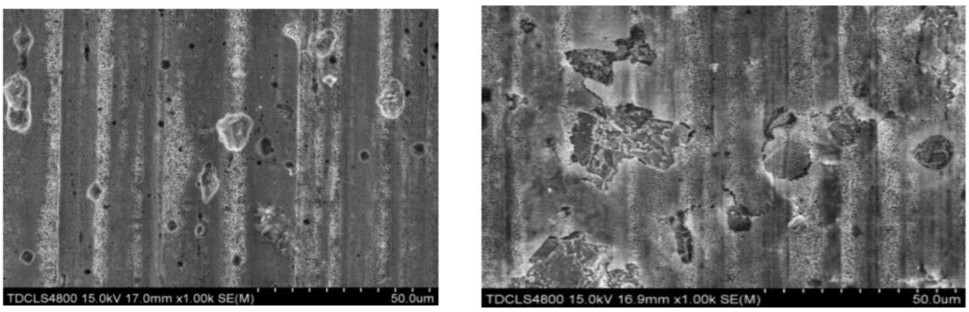


(a) Before immersion (b) After immersion time of 1 day



(c) Immersion time of 10 days (d) Immersion time of 30 days

Figure 2.5 Surface morphology of tinplate before and after immersion test in citric acid solution at 20°C (Wang et al., (2019**).**



(a) Immersion time of 10 days (b) Immersion time of 30 days

Figure 2.6 Surface morphology of tinplate after immersion in citric acid solution at 5°C (Wang et al., 2019**).**

Figure 2.6 shows: At the temperature of 5°C, there are corrosion pits observed on the tinplate, and the density and size of corrosion pits are increased with the prolonging of immersion time and At the temperature of 20°C, there are also corrosion pits occurred on the tinplate surface under the immersion time of 10 days also half of the tin coating has been peeled off. When the immersion time is increased to 30 days, corrosion pits are formed on the steel substrate.

Poku et al., (2015) performed experimental research on effect of temperature and salinity on corrosion rate of aluminium and mild steel. Machined mild steel and aluminium of different shapes were inserted into sodium chloride solution for seven days. Coupon technique was employed, and the corrosion rate was calculated accordingly. Corrosion rate of 0.1862 mmph–0.2065 mmph was obtained for aluminium at 35°C while 1.0567 mmph–1.994 mmph was obtained when the temperature rises to 65°C. The same trend is observed for mild steel.

Fekry et al., (2020) conducted study on Protection of Surface of material used in Food Processing using Silver Nanoparticle/Graphene Oxide/Chitosan Coatings since Graphene oxide (GO) is mixed with silver nanoparticles (AgNPs) in chitosan (CS) is a best solution to form a novel interesting nano-composite that is safe for food and also studied The effect of pH, temperature, and surface modification on the corrosion character of ceramic alloy. Corrosion behaviour and morphology of ceramics was considered by using electrochemical tests and Scanning Electron Microscopy (SEM) respectively. The work founds that PH and Temperature strongly affect the corrosion performance of the material. Increase in temperature will increase the corrosion rate of the material.

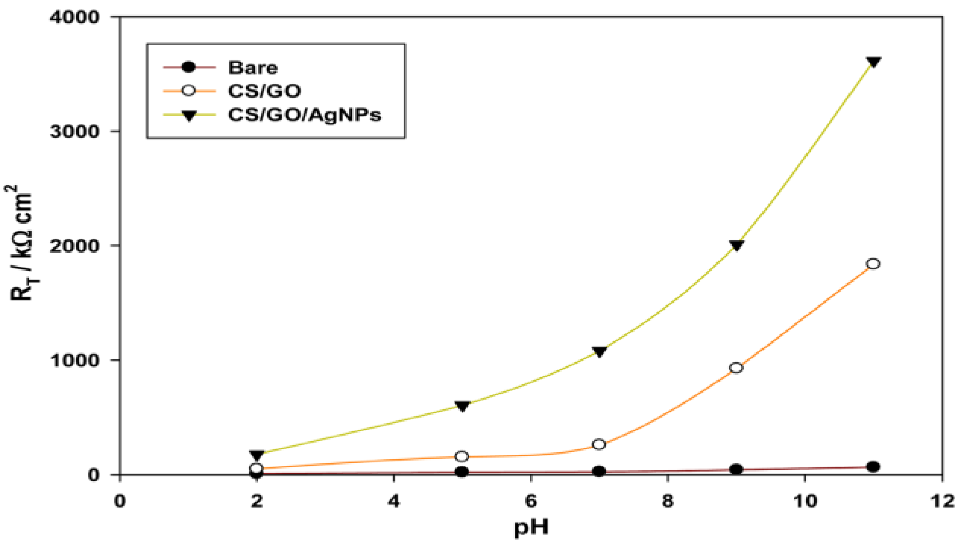


Figure 2.7 The relation between the corrosion resistance and the pH (Fekry et al., 2020).

The figure 2.7 shows the corrosion resistance of the material decrease with decrease in pH value of the environment.

Douadi et al., (2017) investigated the influence of temperature (25–55 °C) and hydrodynamic conditions (0–2000 rpm) on corrosion inhibition of mild steel in a 1 M HCl using Potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) techniques. As the same with other researchers the result reveals corrosion resistance and inhabitation efficiency of mild steel decrease with increase in inhibitor concentration and decrease with temperature.

Ibrahim et al., (2019) conducted study on influence of solution's pH on the corrosion of tinplate which is a low carbon mild steel plate that is coated by a small coat of pure tin (Sn) in saline solution (stagnant 2 wt. % NaCl solution) containing functional amino acids, using electrochemical techniques like potentiodynamic polarization and electrochemical impedance spectroscopy. The work was carried out at pH 2 and at pH 5 measured by pH-meter. During the investigation it is found that solution's pH variation has affected the corrosion rate of pure tin metal in saline solution, as well as, its mechanism and the inhibition efficiency of tested amino acids was considerably influenced by the solution's pH value, and the higher performance was obtained at pH 5 against pH 2.

Ismail et al., (2018) presented the corrosion performance of tinplate (Sn) and aluminium (Al) used beverage packaging in different acidity of soft drinks available in market to evaluate the acidity of different beverage to corrosion attack using Electrochemical analysis to identify breakdown potential and SEM and energy dispersive spectrometry adapted for analysing corrosion damage. The result reviled that Coating by manufacturer will prolong corrosion resistance on Al and will give a good protection over food and beverage and Corrosion resistance of aluminium (Al) is higher than tinplate (Sn) in acidic solutions.

Faille et al., (2018) highlighted the ways in which the choice of materials plays a major role in surface hygiene to mitigate the risk of bacterial food contamination with respect to environmental concerns. Hygienic design of food processing equipment is nowadays considered to be mandatory in the reduction of the risk of microbial food contamination. Material and equipment design combined with mild alternate cleaning conditions, minimizing water load and all environmental impacts of cleaning operations will become mandatory if food industries are able to meet future challenges while preserving our environment.

2.10. Corrosion Behaviour of Metals in Fruit Juice Environments

Fruit juice and beverages are widely consumed by the world population, but people seem to ignore the complex processing stages involved before the final product. This process involves crushing and squeezing of raw fruit for juice extraction, optional filtration, batch preparation, pasteurization, filling, and bottling (Amit et al., 2017). Fruit juices are usually included in daily diet structure because of their nutritional values. They are widely consumed in different ways such as nutritional supplement, condiment, digestive, and health drinks (Hamzat et al., 2020) Metal or alloys are always in contact with the extracted juice during these processes. This leads to the corrosion of food processing equipment because of the acidic content of the fruit. Fruit-juice production plant operating environments include contact with organic acids (citric acid, ascorbic acid) in the fruits which often lead to the corrosivity of the juice. Sometimes, other organic acids and oxidizing chlorides are used as disinfectants involving high temperatures. Often, fruit-juice manufacture occurs in wet conditions and corrosion occurs mostly in the presence of moisture (Enveremadu et al., 2008). It is reported that the pH value of the damp atmosphere, the velocity of flow of substances, wears and fretting, and heat transfer boiling are all initiators of corrosion in such industries. The following are some researches focused on Corrosion Behaviour of Metals in Fruit Juice Environments.

Hamzat et al., (2020) carried out investigation on Corrosion Rate of Mild Steel in Fruit Juice Environment Using Factorial Experimental Design. Corrosion rate of mild steel was determined using coupon method in orange, pineapple, and cashew fluid for a duration of 25 days with measurement taken at 5-day intervals. Design of experiment has been employed using significant parameters media, duration time, and thickness of material with each having three, five, two levels respectively. From the experimental results, it is concluded that all those there parameters have significant effect on corrosion rate of mild steel. Highest corrosion rate of 0.71 mmpy occurs in cashew fluid with a 1.5 mm mild steel thickness. Moderate corrosion rate of 0.54 mmpy is observed in pineapple fluid with 1.5 mm thickness, while the lowest corrosion rate of 0.08 mmpy is noticed in both orange and pineapple fluid.

Dey and Agrawal, (2017**)** Performed experimental research on the corrosion effect of a tin plate container for food packaging in fruit juice environment. Coupon techniques were adopted to calculate the rate of corrosion, and scanning electron microscopy was used to study the morphological structure of the corrosion product. Test coupon of a known weight was immersed in different fruit juices containing preservatives, natural fruit juice, and water with a total exposure time of 20 days. Specimen was reweighed for possible weight loss at six-day intervals. The result showed a significant deterioration of the tin plate sheet. Corrosion is more pronounced in packed fruit juice with preservative followed by natural fruit juice and water, respectively.

Ofoegbu et al., (2011) investigated Corrosion Behaviour of Steels, mainly mild steel (uncoated), galvanized steel and stainless steel (304L) in Nigerian Food Processing Environments. The average corrosion rate and average specific weight loss of the materials have been examined using the weight loss method over a period of 98 days with measurements made at 14 days' interval in different food environments like ground melon, cassava pulp, mashed palm fruit, tomato pulp, and black-eyed bean pulp. The result of the study revealed that:

- ✓ 304 stainless steel have best corrosion resistance and then mild steel possesses better than galvanized steel in the food processing environment, as a result the use of galvanized steel for the construction of food processing machinery is not recommended from the corrosion and economic point of view.
- ✓ Ground melon environment was the least corrosive of the food processing environments rather the cassava pulp tomato pulp were the most corrosive environments to all the three steels except stainless steel.

Durowoju et al., (2014) investigated Corrosion Effect of Sweet Cassava Fluid on the corrosion behaviour of Galvanized steel, painted mild steel, and normal steel under different working conditions. The samples were machined into rectangular sections of 20mm by 30mm by 1mm thickness using cutting machine then immersed in cassava fluid. The sample was exposed for 8 weeks and reweighed at using weight loss. From the result it was observed that galvanized steel has the highest corrosion rate compared to painted mild steel during the time of exposure, while normal steel with no surface protection has the least rate of corrosion during immersion duration

Afolabi et al., (2013) presented the Stress Corrosion Cracking and microstructural analyses of mild steel by immersing in orange juice medium using weight loss technique and SEM analysis. The mild steel coupons were heat treated to various austenitic temperatures, cooled in water and corrosion rate was the determined by measuring the weight losses of the mild steel samples within two days interval for 30 days . The results showed that SCC on mild steel is mainly a function of the acidity of the medium, and the corrosion rate increases with increase in exposure time throughout the exposure time. Also, the higher the austenitic temperature the more the resistance to corrosion attack due to higher hardness obtained from heat treatment at higher temperatures. The SEM analysis emphasised that the transgranular and intergranular attacks were visibly responsible for the corrosion of mild steel in this medium.

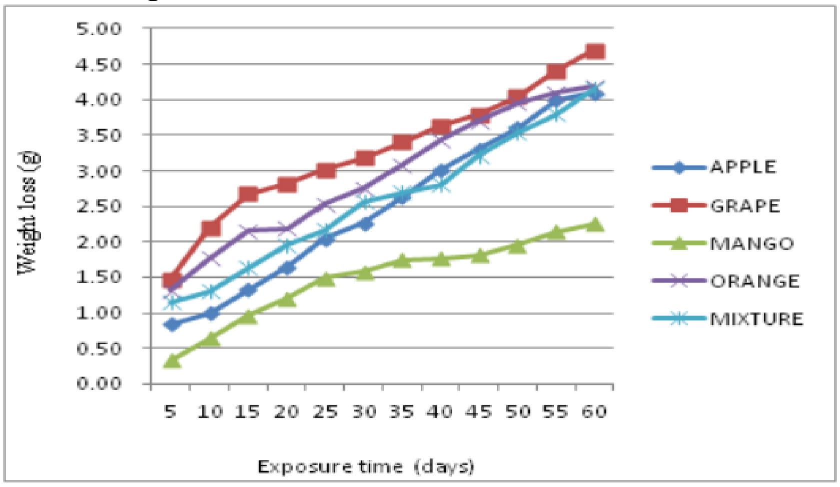


Figure 2.8 Weight loss analysis of mild steel in the agro media (Afolabi et al., 2013)

Figure 2.8 shows the variation of weight loss of mild steel with exposure in the various agro media. From the results, it is evident that generally weight loss increases as corrosion period is extended. This could be as result of concentration reduction of various carboxylic acids in the agro media.

Sharma et al., (2019) studied fruit juice and chloride ion effects on the corrosion behaviour of orthodontic arch wire. AISI 316L stainless steel of 0.018 inches (0.0472 cm) was used for the experiment. The fluid samples were prepared at a control amount. The samples were inserted for approximately 24 hours in artificial saliva (AS) having different fruit juices and another sample in a separate fluid juice with 1% NaCl in AS. The result shows an appreciable increase in corrosion rate in AS in the presence or absence of salt. Pitting corrosion was observed upon addition of 1% of NaCl to the AS. Surface analysis was done using scanning electron micrograph to show blister formation on the steel surface.

Adetunji et al., (2012) deals with the corrosion behaviour of Austenitic Stainless Steel are investigated in cassava fluid, maize pulp, and seawater during eighteen days of immersion. SEM was used to characterise the corrosion morphology of steel. The sourced samples were prepared 50× 50×0.6 mm in dimension cut into sizes, using a shearing machine .and weighed using a sensitive weighing balance. The result showed that the rate of corrosion of Austenitic stainless steel was highest in seawater (0.00179 mm/y) than in maize pulp (0.001217 mm/y) and cassava fluid (0.001149 mm/y) after eighteen days of immersion.

Mudashiru et al., (2018) performed the Corrosion behaviour of ASTM A513 Steel in Cashew and Pineapple Juice Using RSM. The weight loss method was conducted for evaluating the corrosion rate of ASTM A513 steel in both environments immersed period of twenty-five days, with the checking interval of five days. The pH of the environments was measured each monitoring day. The result revealed that ASTM A513 steel corrodes faster in pineapple fluid than cashew fluid, the two media having highest values of 0.71mm/yr and 0.54mm/yr at the end of five days respectively.

2.11. Corrosion Behaviour of Mild Steel

Oparaodu et al., (2014) worked on Percentage Weight Loss and Corrosion Rate mild steel (MS) from two Soil Environments in a water-logged soil (WL) and a sandy soil (SD) for the observational periods of 40, 100 and 190 days, APWLs in the MS coupons from the waterlogged site were 2.3%, 5.5% and 8.5%, respectively, representing an overall average of 5.4%.(Figure 2).In the sandy soil site, the APWLs were 1.6%, 2.0%, and 4.8%, respectively (overall average of 2.8%).At both sites, there was increase in weight loss with respect to days of exposure.

Zhang et al., (2020) investigated Effects of the Addition of Cu and Ni on the Corrosion Behaviour of mild Steels in Corrosive Industrial Environments. Electrochemical impedance spectroscopy and linear polarization resistance methods. Scanning electron microscopy with energy-dispersive spectrometry (EDS) and x-ray diffraction (XRD) were used to analyse the sample. As the corrosion process proceeds, the protection provided by the rust layer on the steel surface was increased and increase the content of Cu and Ni in mild steel to increase the resistance of steels used in corrosive industrial environments.

Omotoso et al., (2017) deals with investigation on corrosion performance of 1014 mild and 304 stainless steel in acidic media. 180 metal samples were immersed in sulphuric acid (H_2SO_4), hydrochloric acid (HCl), and nitric acid (HNO_3) at different concentrations. The sample was exposed for 15 days and reweighed at 3-day interval for corrosion rate calculations. Energy-dispersive X-ray (EDX) and scanning electron microscopy were used to determine the morphology of the sample. The morphological result revealed that pitting corrosion damage and crack development on sample surfaces. It was conclude that Corrosion rate increases with increasing molarities of the reagent, and that of mild steel is have high corrosion rate compared to stainless steel sample.

Luna et al., (2019) carried out corrosion behaviour of mild steel in 0.5 M $H_2\ SO_4$solution at different temperatures using gravimetrical, electrochemical, spectroscopic simulation method and scanning electron microscopy for characterization. It was observed that the inhibition efficiency increases with the increase of the inhibitor concentration and Temperature. SEM and AFM characterizations revealed less surface damage in the corroded samples confirming the effectiveness of the inhibition.

Liu et al., (2021) performed study of corrosion performance of mild steel with different tin coating thickness in H_2SO_4 by electrochemical measurements like potentiodynamic polarization and electrochemical al impedance spectroscopy (EIS) at 25 °C and scanning electron microscope observation. The result reviled that the corrosion resistance of tinplate increase with a higher tin coating mass because of that a lower tin coating mass may not uniformly cover the base steel surface with roughness or other defects. Therefore, samples with lower coating mass cannot provide enough protection ability to base steel in $H_2\ SO_4$ solution

Ojo et al., (2021) performed Adsorption and Inhibiting Mild Steel Corrosion in Natural Lemon and Lime Citrus Fruit Juices by Alanine using weight loss and potentiodynamic polarization measurements. The pH of each juice was done in the absence of inhibitor with a Horiba pH meter and scanning electron microscopy was used to study the morphological structure of the corrosion product. Test coupon of a known weight was immersed in a 100 ml beaker that contains natural lemon or lime citrus juices with and without inhibitor (Alanine) At 48 h (hrs) for 240 h which have been measured 48h interval. It was observed that Alanine is effective to retard corrosion of mild steel in citrus fruit juices and Alanine behaviour depends on the pH of solutions to which it is applied.

Stephen et al. (2019) Investigated the Corrosion Behaviour of Heat Treated and Nickel Plated Mild Steel in Citrus Fruit (Lime and Lemon). Annealing, normalizing, hardening and tempering heat treatment were adapted for the heat treatment on mild steel, and their effects on microstructure of the mild steel were studied by Optical Micrograph. It was observed that Heat treated mild steel samples had better corrosion resistance in citrus solution than untreated sample with a corrosion rate of 1.88 mmpy. Additionally, Nickel plated tempered mild steel substrate has a better corrosion resistance in lemon than samples when exposed to lime environment with corrosion rate of 0.11 mmpy.

2.12. Corrosion behaviour of stainless steel

Tengur and Surnam (2012) presented Corrosion Problems in Sugar Factories to identify the different modes of corrosion damage and the corrosivity of commonly used metals such as low carbon steel, 3Cr12 steel and 304L and 316L stainless steels with in corrosive fluids utilized in the juice extraction process. Metal samples were immersed in different types of juices produced in the factory (mainly Pre-extractor mill juice, Draft juice, Clarified juice, Syrup, Masscuite, Molasses and Caustic soda) and Electrochemical tests (Tafel tests) were adopted to determine the corrosion rate of them performed between - 1000 mV to 1500 mV at a scan rate of 150 mV/min . From the study it was found that;

- The rate of corrosion was dependent on pH, whereby the rate of corrosion had a tendency to increase with increasing acidity of the sugarcane juices.
- stainless steels provide better corrosion resistance than carbon steel
- The one with the higher chemical content such as dirt, fatty acids, impurities and Bacteria, had undergone higher rate of corrosion.

Shtefan et al., (2019) presented the corrosive behaviour of AISI 304 steel in solutions of sulphuric acid with additions of NaCl and $Na_2MoO_4*H_2O$ by using the method of a linear voltamperometry electrochemical measurements. Potentiostat system IPC-pro and the frequency analyser employed to measure the electrochemical impedance. It was established that the availability of NaCl and Na_2MoO_4 in sulphate solutions affects the steel behaviour in the conditions of anode polarization. The addition of NaCl results in metal dissolution occurrence at lower potential values and therefore the passivity comes earlier.

Mareci et al., (2017) performed Electrochemical Studies on the Stability and Corrosion Resistance of Two Austenitic Stainless Steels namely FeCrNi and FeCrNiMo, in three popular carbonated soft drinks for Soft Drinks Containers. Electrochemical testing techniques was performed like linear potentiodynamic polarization (LPP) and electrochemical impedance spectroscopy (EIS). Additionally, scanning electronic microscopy (SEM) was applied to monitor the surface condition of passive films retrieved after electrochemical tests. The result revealed that the high corrosion resistance of the austenitic stainless steel alloys in different soft drinks was because of the formation of a protective passive film, since low corrosion current densities, typical of passive materials, were obtained for both steel alloys.

Dhaiveegan et al., (2016) investigated the pitting corrosion behaviour and mechanical stability of 316L and 304 stainless steels (SS) exposed to Industrial-Marine Urban (IMU) environment for 3 years from April 2012- March 2015.for this study atomic force microscopy (AFM) and scanning electron microscopy equipped with energy dispersive X-ray analysis (SEM-EDAX),electrochemical impedance spectroscopy (EIS) , Vickers micro hardness test and FT-Raman spectroscopy was employed to investigate morphology. From the result it was observed that;

- 304 SS showed more weight loss and corrosion rates compared to 316L SS.
- The corrosion behaviour of SS was found to be maximum during the winter season due to the high moisture content
- It was concluding that 316L SS exhibited better corrosion resistance in the highly severe atmospheric environment.

Nistoran et al., (2020) performed the effect of Organic Acids on welding in various pipes and pieces of stainless steel in Food Processing Industry. Weight loss measurement technique was adapted for determination of the corrosion rate of stainless steel after immersing it in solution of lactic acid 80%, acetic acid 30% and citric acid 20% for 96 hours. The result revealed that there was reduced rates of corrosion in lactic acid as compared to others due to some microorganisms and polysaccharides or products from fermentation process can act as a strong corrosion inhibitor. Exposures of stainless-steel samples in citric acid promotes corrosion.

Jun Chen et al., (2014) deals with Investigation of corrosion and tribocorrosion behaviours of AISI 316 stainless steel sliding against AL_2O_3 in artificial seawater using a pin-on-disk test rig also emphatically evaluated the synergistic effect between corrosion and wear. Corrosion-wear test setup combined with in-situ electrochemical measurement were employed. From this it was concluded, the synergistic factor between corrosion and wear leads greater weight loss in seawater than that in pure water on AISI 316 stainless steel, In addition, Temperature have a great influence on the corrosion rate for metal in seawater.

Li et al., (2019) worked on Enhancing Pitting Corrosion Resistance of Severely Cold-Worked High Nitrogen Austenitic Stainless Steel by Nitric Acid Passivation and with increase of the passivation temperature. Passivation was performed in a 25 wt% nitric acid solution for 1 h at different temperatures in a range of 25∼75°C. They conclude that the pitting corrosion resistance of high Nitrogen Austenitic Stainless Steel was significantly improved by a nitric acid passivation and by increasing passivation. Cold-worked High Nitrogen Austenitic Stainless Steel showed a weaker passive film formation ability than solution-treated matrix.

Nishimoto et al., (2019) investigated the role of Mo alloying in the pitting corrosion resistance MnS inclusions in austenitic stainless steels using polarization measurements technique performed in 0.1 M sodium chloride, 0.1 M sodium sulphate, and 1 hydrochloric acid solutions. From the result they showed that both specimens are dissolved in the potential range of ca. 0.1 to 0.5 V. From this, during MnS inclusion in the Mo-free specimen Metastable and stable pits were generated.

Mazinanian et al., (2016) investigated Metal release and corrosion resistance of different stainless steel grades from austenitic (grades AISI 201, 204, 304 and 316L), ferritic (grades AISI 430 and EN1.4003), and lean duplex stainless steel (grade EN 1.4162) in simulated food contact using 5 g/L citric acid (pH 2.4) and artificial tap water (pH 7.5) Exposures of all stainless steel grades in citric acid and artificial tap water was up to 10 days (at 70/40 °C). The result stated Exposures in citric acid initially increase the release of metals from stainless steel, but result in increased surface passivation and reduced metal release with time due to the enrichment of chromium in the passive surface oxide and The total amount of metal release (dominated by Fe, >80%) in citric acid (pH 2.4) decreased with increasing bulk alloy content of chromium.

Gupta et al., (2017) carried out the induction of pitting corrosion or micro-bialy induced corrosion on stainless steel (grades 304 and 316) used in dairy industry by biofilms since the formation of a biofilm on a metal surface changed local conditions and associated changes in gradients of pH, dissolved oxygen, chloride and sulphate, which then created conditions associated with localised corrosion. It was concluded that pitting corrosion on the 304 stainless steel and 316 coupons could be induced by the prolonged contact with biofilms.

2.13. Research gap

There have been many studies conducted on corrosion. Even though researchers are working on the corrosion behaviour of metallic materials, few research studies are available on the corrosion behaviour of these metallic materials used in food processing machineries. There is a research gap on corrosion damage of materials in different food environments, since the organic acids present in foods are the most important corrosion agents. The effects of these chemicals can be influenced by the environmental conditions of processing, such as temperature, flow rate, and viscosity of the food medium while in contact with machinery parts, and the presence of stresses in the system. There are a number of fruit juice and paste processing industries in Ethiopia, and steel is a common material utilized in these industries. Some research work is carried out on the corrosion behaviour of mild steel in different fruit juice environments, but limited research works were experimentally conducted to know the corrosion behaviour of stainless steel. Therefore, this work focused on the corrosion behaviour of steel (mainly 304L stainless steel and mild steel), used in fruit juice processing machineries.

CHAPTER -3

MATERIALS AND METHODOLOGY

3.1. Introduction

In this thesis work; the effect of corrosion on machineries in food processing industries that uses mild steel and stainless steel in different fruit juice environment was investigated. The aim of this chapter was demonstrating the experimental procedures and material used for the study. All machines and instruments used for corrosion testing like electrochemical measurement, morphology, 3D surface image, hardness and others were discussed with supporting photographs and diagrams.

3.2. Experimental Procedure

The work has started from collecting data from locally occurred food processing industries like fruit juice industries in order to conduct the cause of corrosion damage on the machineries as well as to get data regarding to the economic loss, they face due to corrosion. After this the experimental investigation was implemented.

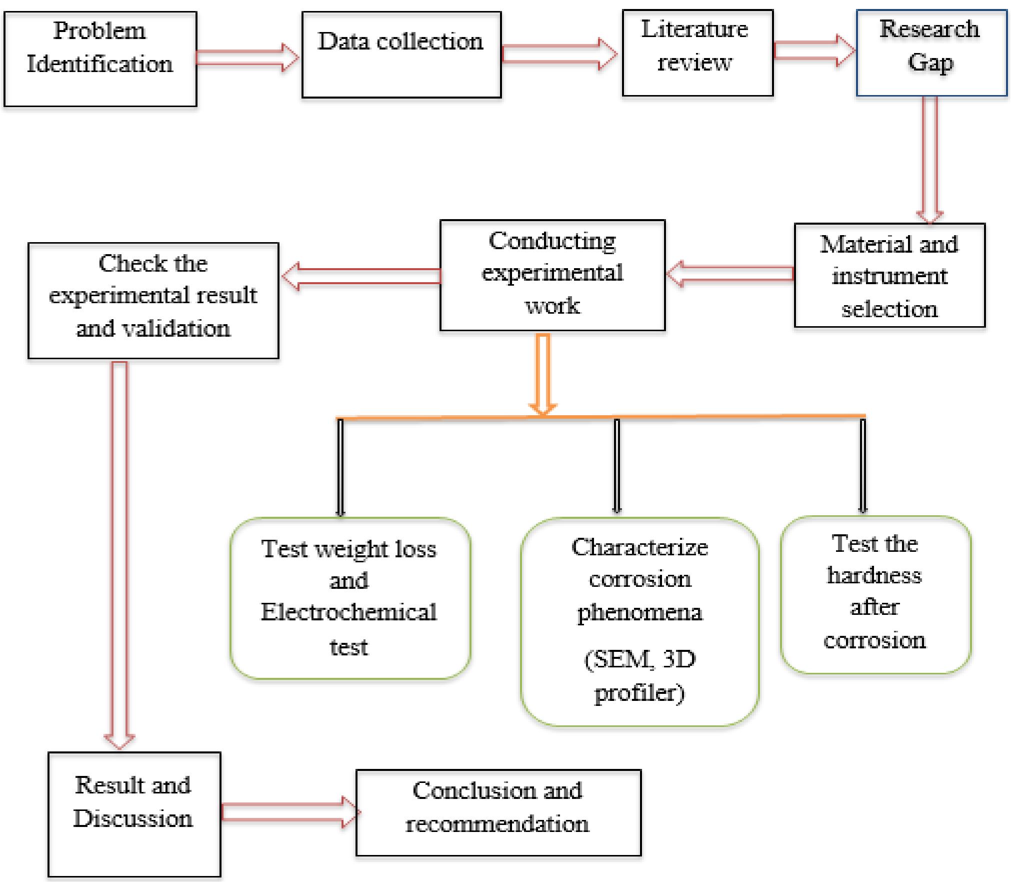


Figure 3.1 Diagrammatic experimental procedure

The data used under this research work was collected through literatures that are the work of various researchers which are done on the same area and also some secondary data and necessary information's was surveyed from upper awash agro-industry enterprise which is locally occurred fruit and vegetable processing industries in Ethiopia.

3.3. Description of the Study Area

3.3.1. Site Description

Upper Awash Agro Industry Enterprise (UAAIE) found on the citrus-belt of the world. It was built with economic and technical co-operation between the governments of federal republic of German and socialist Ethiopia in December-3-1983Gc (1976Ec). It is the biggest producer of fresh vegetables, tropical and sub-tropical fruits and processed fruits and vegetables in the country. It also produces a variety of cereals, fiber crops (cotton), cut flowers, seeds and others for local and foreign markets and consumers at the beginning of the processing of the plant. It uses raw materials obtained from Nura Era and Merit Jeju for the extraction tomato products. Moreover, the Enterprise is the only source of parent planting materials for citrus and is a pioneer in modern commercial horticulture farming in the country.

The cropping pattern has gone through several changes, and it was during the late 70's and early 80's that effort have been made to work on expansion of tropical and non-tropical fruits, the diversification of vegetables in all farmers parallel to the installation of the processing plant as a result of which the area coverage of the Enterprise increased significantly. The effort has enhanced the production of fresh agricultural and processed fruit and vegetable products both to the local and foreign markets. The Enterprise is situated along the upper bank of the Awash River 174Km, East of Addis Ababa. And it is economic units are in Oromia Regional State. The Enterprise has a logistic office located at Addis Ababa, and this office organizes monitors and deals with matters concerning logistics and export work. The flow of the process performed in the factory to produce tomato paste and orange juice depicted in the Figure 3.2. Currently the total area of the land under the ownership of the Enterprise has reached 6,110.68 hectars out of 5,583.68 hectars is cultivable while some 527 hectars is held by bushes and such infrastructures as roads, residential houses, canals, etc. Although, 318.68hectar of the arable land needs further investment, 5,096hectars of cultivable area is irrigable.

According to the organizational structure the total professional and non-professional man power of the enterprise is composed of 1744 permanent labours of different educational levels. Currently the existing numbers of permanent employees is 1474 at the end of December 2008.

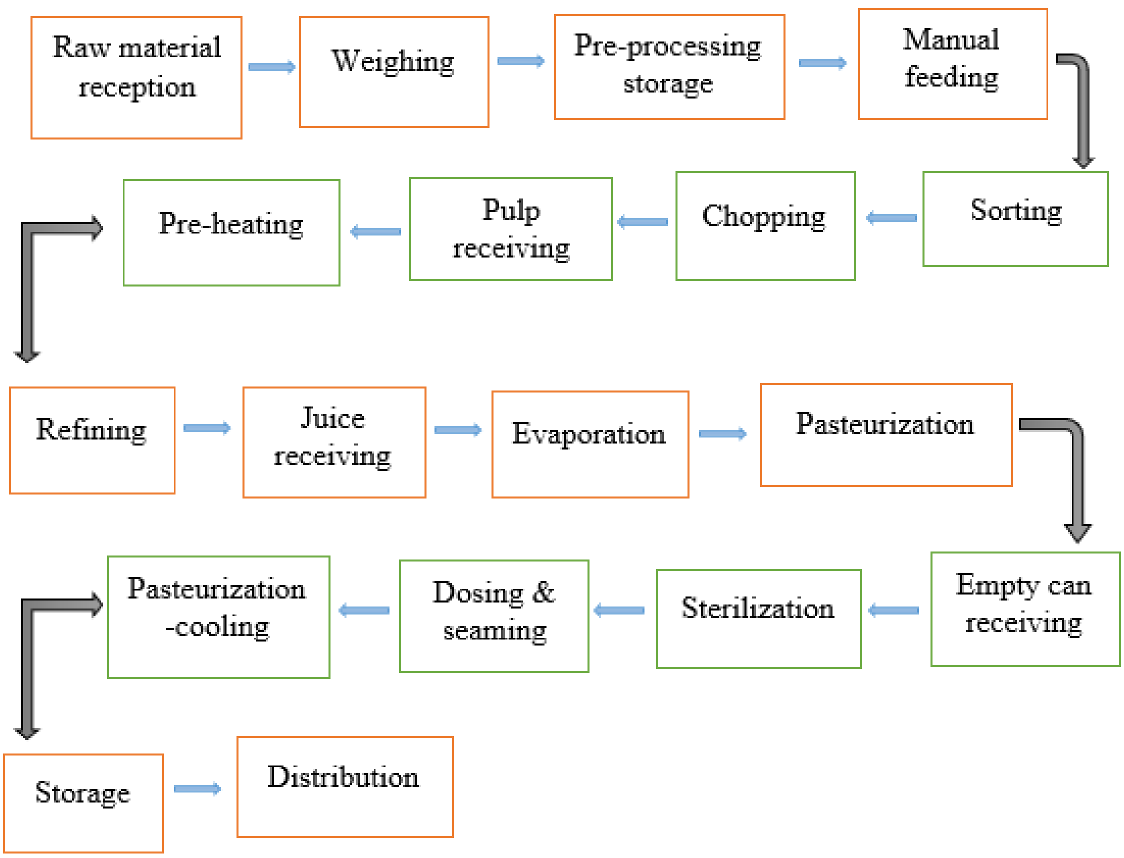


Figure 3.2 Flow diagrams of processing steps in MFVPP

3.3.2. The problems identified in the factory in case of corrosion damage

The corrosion in food processing factory is serious problem; because of the produced part is a food that was consumed by children and adults. The production was needing several processes that starts from cleaning of the raw materials to some heat treatments processes that were needed some protection to overcome corrosion. So, in this factory some corroded machinery parts observed due to the environment they operate in, and process performed by them. Some machineries such as pumps, tube hose parts, filling machinery parts, sorting Hooper affected by corrosion in this factory. Figure 3.3 below shows corroded parts of machineries.

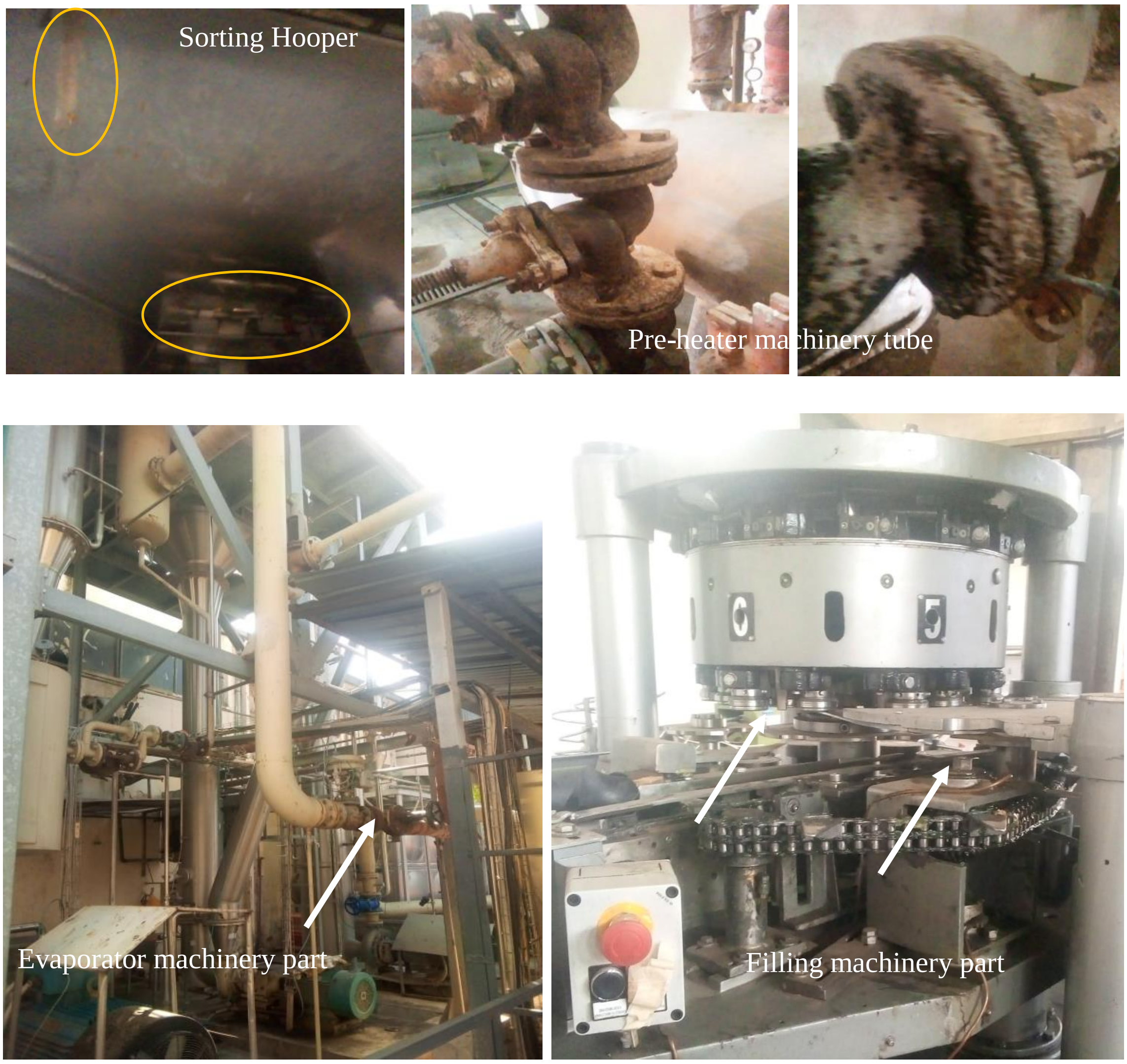


Figure 3.3 Corroded machinery parts in MFVPP

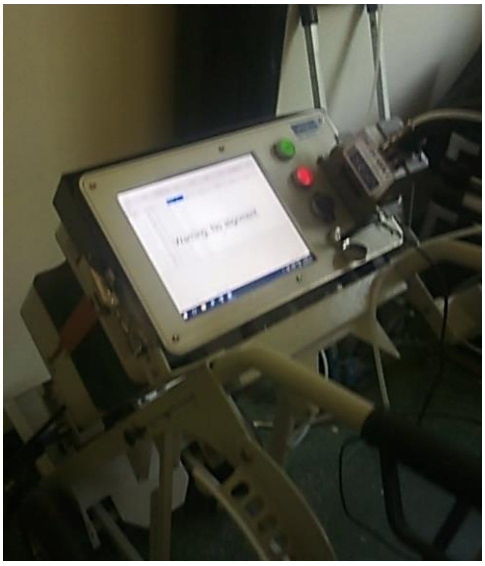
3.4. Materials, tools, and Equipment's

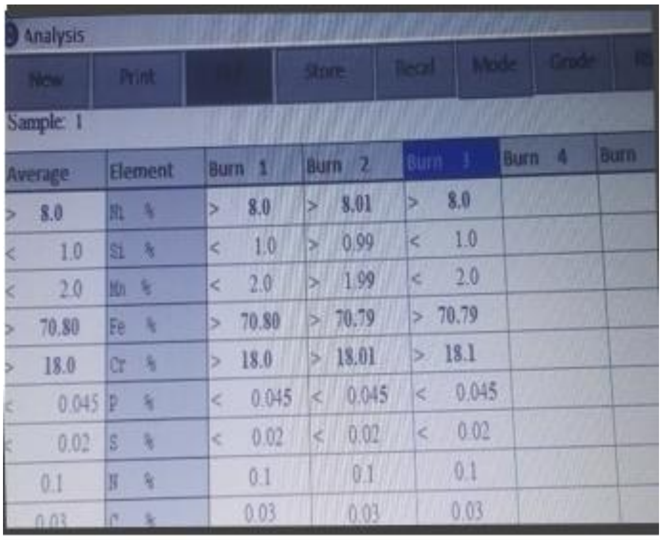
This sub-topic describes the materials, Equipment and machine tools used for the experimental investigation on corrosion behaviour of steel in different fruit juice environment.

3.4.1. Materials

3.3.1.1. 304L Stainless steel

AISI 304L is a high-quality stainless steel with a wide range of applications. It's employed in the chemical industry, food processing, and a variety of harsh settings, such as chemical operations and desalination (Loto et al., 2014). Because of their chemical makeup, which includes approximately 18% chromium and 8% nickel by weight, stainless steel grades 304 and 304L are also known as 18/8 stainless. They are commonly utilized in the food and beverage processing sectors because they are simple to fabricate and weld and have excellent corrosion resistance. They're also magnetic, with good ductility, tensile-property stability, and corrosion, thermal fatigue, and stress-corrosion cracking resistance. As observed from spectrometer testing in weight percentage as shown in figure 3.4. The specific chemical composition of 304L stainless steel used for experimental study is shows in Table 3.1.





a) b)

Figure 3.4 a) ARC-MET8000 spectrometer model machine found in Ethiopian technical institute, b) chemical composition display from the machine

Table 3.1 Chemical Composition of 314L stainless steel

C	Si	Mn	P	S	N	Cr	Ni	Fe
0.03 %	1.0 %	2.0 %	0.045 %	0.02%	0.1 %	18.0%	8.0%	70.80

3.3.1.2. Mild steel

Mild steel is the most often used and least expensive type of steel, and it gets its name from its low carbon content. Mild steel is noted for its malleability, weldability, and ability to change mechanical properties by heat treatment. It is used in the food processing industry as well as in ordinary objects. Mild steel is sometimes used to make kitchen utensils including pans, pots, and spoons. (Hamzat et al., 2020). Because of its ability to offer a hygienic environment for food, better packaging, product transportation, and food additive, mild steel coated with tin is widely used in the food processing sectors. Because the impermeable can contains no oxygen, the loss will be kept to a bare minimum. (Ojo et al., 2021). As observed from spectrometer testing in weight percentage. The specific chemical composition of mild steel used for experimental study is shows in Table 3.2.

Table 3.2 The chemical composition of mild steel

C	Fe	Mn	P	S
0.17 %	99.235 %	0.52 %	0.040 %	0.035 %

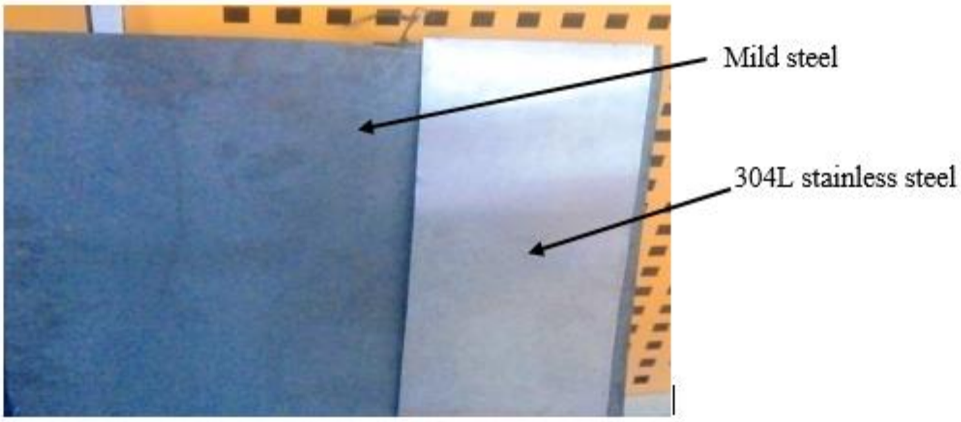


Figure 3.5 Metals used for experimental study

3.4.2. Rinsing fluid

Immersion corrosion testing is performed to measure a material's resistance to corrosion in a harsh aquatic environment. Cleaning is the most important aspect of immersion testing, both before and after the test. The samples are rinsed for a minute in a special rinsing fluid to eliminate dust particles from the substance and prevent further oxidation. Ethanol alcohol, distilled water, and acetone were employed for this purpose. In this experimental investigation, we used ethanol alcohol and distilled water. In this experiment, ethanol alcohol and distilled water were utilized. Ethanol is a common industrial chemical that is used as a solvent, in the production of other organic compounds, and as a fuel additive (forming a mixture known as a gasohol). Many alcoholic beverages, such as beer, wine, and distilled spirits, contain ethanol as an intoxicating element. Water that has been cooked into vapour and then condensed back into liquid in a separate container is known as distilled water. The distilled water used in this experiment came from ASTU's chemistry lab.

Figure 3.6 Rinsing fluids used during experiment a) Ethanol, b) distilled water taken from chemistry lab c) distilled water in chemistry lab

3.4.3. Analytical weight balance

When a balance can detect slight weight variations, it is said to be sensitive. When the balancing beam's centre of gravity is just below its rotating axis, it is most responsive. One of the most significant criteria of a balance is its sensitivity. Make sure the balance has been left on power for a suitable amount of time before using it (mentioned in the balance operating instructions) Make sure the balance is levelled. For this work the samples were weighted before and after corrosion using sensitive weight balance in ASTU chemical laboratory.

Figure 3.7 Analytical weight balance (ASTU chemical laboratory)

3.4.4. pH meter

A pH meter is a device that measures the acidity or alkalinity of a solution, which is also known as pH. The degree of acidity or alkalinity is measured in pH, which is a unit of measurement. On a scale of 0 to 14, it is rated. The pH value provides quantifiable information about the degree of activity of an acid or basic in terms of hydrogen ion activity. The ratio of hydrogen ions [H+] to hydroxyl ions [OH-] concentrations determine the pH value of a substance. The material is acidic if the H+ concentration is more than the OH- concentration, i.e., the pH value is less than 7. If the OH- concentration is more than the H+ concentration, the material is basic and has a pH value of less than 7.

Figure 3.8 pH-016 pH meter (ASTU chemical laboratory)

3.4.5. Hardness testing machine

Hardness is a measure of a material's resistance to localized plastic deformation. A small indenter is forced into the surface of a material to be tested, under controlled conditions of load and rate of application.

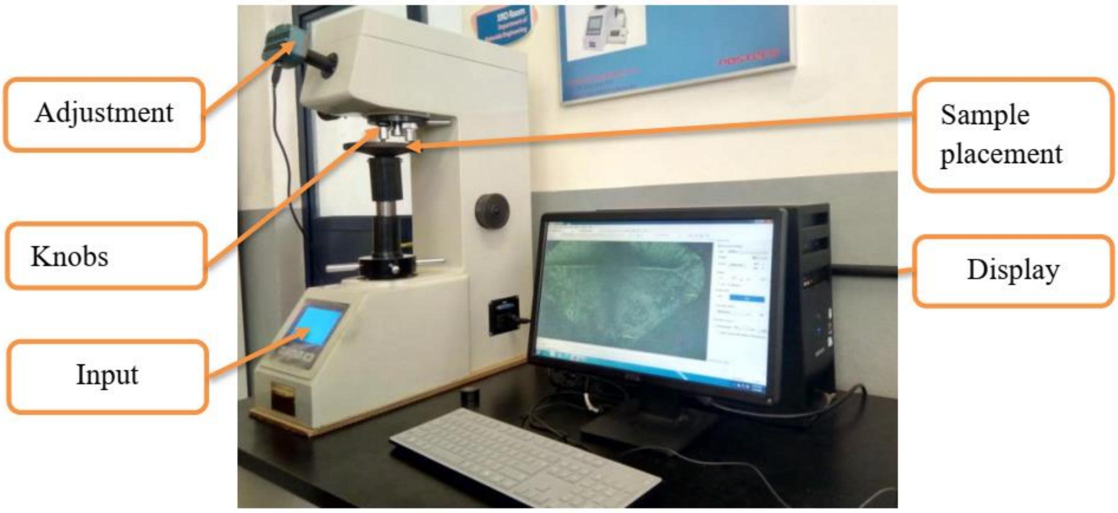


Figure 3.9 HVS50 hardness testing machine (ASTU material laboratory)

For this work micro hardness test was conducted using Vickers hardness test, Vickers (sometimes also called diamond pyramid). For each test a very small diamond indenter having pyramidal geometry is forced into the surface of the specimen. The test was conducted in a materials engineering laboratory using an HVS50 hardness testing machine.

3.4.6. Potentiostat

A potentiostat is an analytical instrument designed to control the working electrode's potential in a multiple electrode electrochemical cell. The circuits generate and measure potentials and currents. External wires in a cell cable connect the potentiostat circuit to the electrodes in the electrochemical cell. In a conventional three-electrode cell, the cell cable connects to the working, counter (auxiliary), and reference electrodes on one end and the potentiostat cell cable connector on the other end. In this study potentiostat was used for determination of corrosion rate of materials in testing environment. The test was conducted in a materials engineering laboratory using a potentiostat machine.

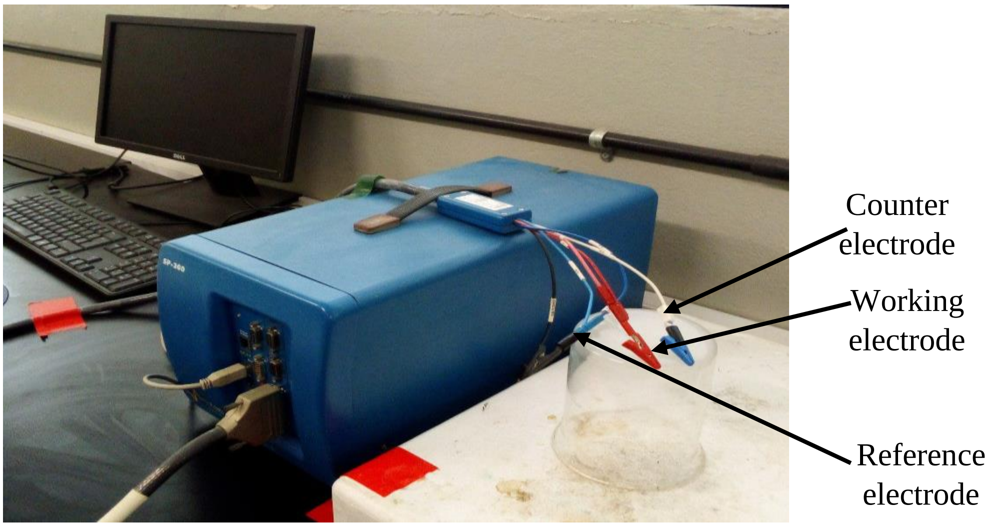


Figure 3.10 Potentiostat (ASTU Material laboratory)

3.4.7. Scanning electron microscope

The morphological observation was conducted using scanning electron microscopy in ASTU Biology laboratory, using JCM-6000Plus scanning electron microscopy. The specimen preparation considers the sample's size, shape, state, and conductive properties before sample preparation. The samples were prepared with mm diameter and 1 mm thickness. The samples were cleaned and dried (to avoid water vapour) without changing the texture of the sample.

Figure 3.11 JCM-6000Plus scanning electron microscope (ASTU biology laboratory)

3.4.8. 3D optical Profilometry

Optical profilometry is a rapid, non-destructive, and noncontact surface metrology technique. An optical profiler is a type of microscope in which light from a lamp is split into two paths by a beam splitter. One path directs the light onto the surface under test, the other path directs the light to a reference mirror. Reflections from the two surface are recombined and projected onto an array detector. When the path difference between the recombined beams is on the order of a few wavelengths of light or less interference can occur. This interference contains information about the surface contours of the test surface. It have many applications like surface topography, coating thickness, step height, corrosion pit depth, and 3D imaging. For this work 3D image observation was conducted using scanning electron microscopy in AASTU using Zeta 20, 3D optical profiler.

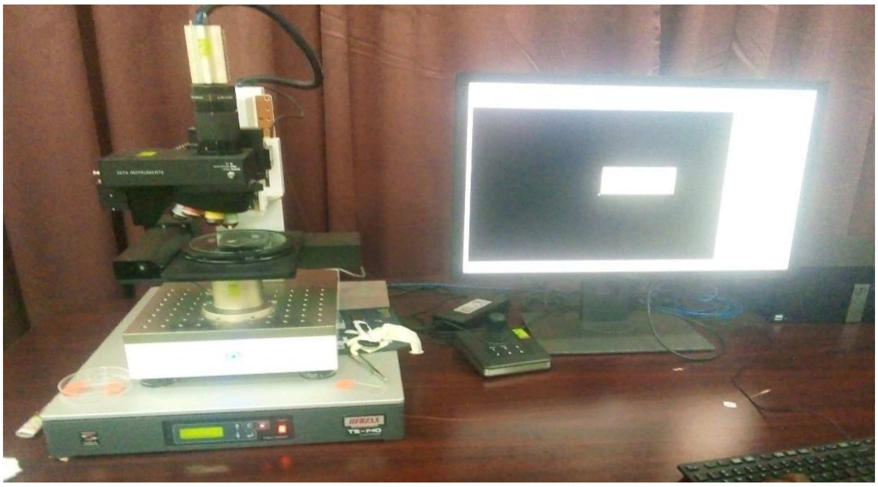


Figure 3.12 Zeta 20, 3D optical profiler (AASTU central laboratory)

3.5. Test media

Because of the salt, organic acid contained in the food media, and chloride content, the food processing environment is critical because it will influence to a considerable extent the possible corrosion reactions. As a result, fruit juices were used as test media in this study to investigate the corrosion behaviour of mild steel and 304L stainless steel in food media. This choice is based on their similarity in complicated chemical makeup and pH to foods (low pH value of 2.0 to 5.0), which influence food acidity, palatable texture, and state (liquid), which facilitates contiguous contact with metallic test samples.

3.5.1. Chemical composition of test mediums

I. Tomato

Tomatoes are a fleshy berry that is widely grown as a perishable fruit and vegetable in tropical and temperate climates around the world. Tomatoes are perishable vegetable fruits because they contain enzymes that cause the fruit's flavor, colour, and texture to alter in an unfavourable way. (Babalola et al., 2021). Fresh red ripe tomato is composed of 94.20% water. Per 100 g of the dry matter, it is reported to contain 5.66 g citric acid, 0.88 g malic acid, 0.10 glactic acid, 0.14 g acetic acid, 0.17 g chlorogenic acid, 0.14 g quinic acid, 12.07 mg ferulic acid, 0.03 g fumaric acid, 3.28 mg pyruvic acid, 0.41 g oxaloacetic acid, 2.24 mg salicylic acid, 34.48 mg histamine, 10,206.90 mcg beta-carotene, 3.97 g polyuronic acid, 6.21 g cellulose, and 189.66 mg myoinositol (Souci et al., 1994).

II. Orange

Corrosion in orange medium, for example, is significant due to varied levels of citrus acid contained in the fluid, which are estimated to be around 70%. These acids include folic acid, pectin, flavonoids, malic, tartanic, benzoic, succinic, oxalic, and formic acids, among others. (Afolabi et al., 2013). According to Souci et al., (1994) Orange contains 88.3 g water, 0.11 g total nitrogen, 0.72 g protein, 0.17 g fat, 8.80 g available carbohydrate, 0.45 g dietary fiber, 1.23 g available organic acids, and 0.40 g minerals per 100 g of the edible component. 1112 mg citric acid, 123 mg malic acid, and 13 mg volatile acid make up the organic acid composition.

III. Mango

Mango fruit is a good source of carbohydrates, lipids and fatty acids, protein and amino acids, and organic acids, among other macronutrients. In addition, mango contains micronutrients like vitamins and minerals, as well as non-nutrients such phenolic compounds, flavonoids and other polyphenols, chlorophyll, carotenoids, and volatile compounds (Malandenado et al., 2019). Mango is high in a variety of citrus acids. Ascorbic acid is 27.2/mg, pantothenic acid is 0.16 mg, saturated fatty acids are 0.066/g, monosaturated fatty acids are 0.101/g, and polyunsaturated fatty acids are 0.101/g [17]. Tryptophan 0.008/g, threonine 0.019/g, valine 0.026/g, alanine 0.051/g, aspartic acid 0.06/g, glycine 0.021/g, serine 0.022/g, and others are among the amino acids. Carboxylic acid, despite being a weak acid, has a corrosive action in solution. Even at room temperature, this causes transcrystalline stress cracking in metallic alloys. (Afolabi et al., 2013).

Figure 3.13 Fruits used as test media for the work

3.6. Experimental set-up

3.6.1. Specimen preparation

304L stainless steel and mild steel specimen of 1mm thickness was used in the experimental set up. The samples were machined into rectangular sections to form a coupon.

Figure 3.14 a) Shearing machine (ASTU sheet metal shop), b) prepared specimens using shearing machine.

17 samples of each type of steel were cut from metal sheets to dimensions of 40 x 35 x 1 mm for both Stainless steel and mild steel for weight loss examination using shearing machine at manufacturing engineering sheet metal shop to ensure uniform structure of the metal. Additional six rectangular base mild steel and 304L stainless steel test specimens (4mm x 1.5 x 1mm thickness) were used for electrochemical studies.

The prepared samples were treated by abrading them through successive grades of abrasive paper. The sample was rinsed in distilled water and then in ethanol for 5 minutes before drying. This procedure has been followed by (Hamzat et al., 2020). The prepared specimens were stored in desiccators to avoid atmospheric corrosion.

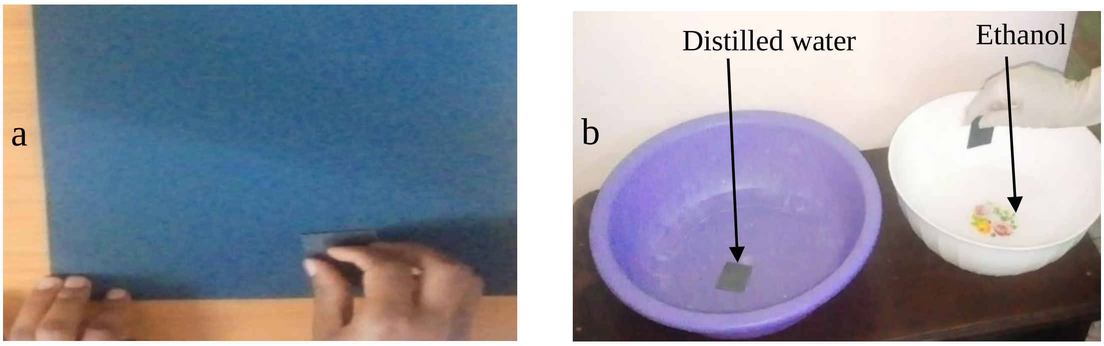


Figure 3.15 a) Polishing the samples with abrasive grade paper b) rinsing the samples in ethanol and distilled water

3.6.2. Test Solution Preparation

The fruits were obtained from the local market, and the experiment was conducted on a 10-day basis this procedure has been followed by (Babalola et al., 2021). The fruit juices were prepared from fresh tomatoes, oranges, and mango by mechanical juicer machine release the juices after the fruits washed in cold tap water followed by distilled water, dried with clean piece of cloth, and then pilling them. Finally, 120ml of freshly prepared juice was filled into each beaker which are important for immersing metallic samples during weight loss measurement. Graduated cylinder utilized for measuring the volume of the juice. The pH of the freshly prepared fruit juices was determined using pH-016 pH meter.

Figure 3.16 Experimental set-up: a) test solution preparation, b) test solution measurement, c) test solution in flask (beaker), d) pH measurement

3.7. Methods

3.7.1. Microstructure measurement

The microstructure of a material can influences its physical properties including corrosion resistance, strength, toughness, ductility, and hardness. These properties help determine how the material will perform in each application. The microstructure of steel influences the inhibitor efficiency and the properties of the corrosion layers, such as morphology and proportion of the various chemical compounds present (Lopez et al., 2003). For this work the microstructure of the base metal performed using optical microscopy before corrosion test. Microscopic analysis of the corroded mild steel samples and stainless steel was carried out to study their surface morphologies, topography and to determine the extent of corrosion on the corroded specimens in the test media. The techniques used to evaluate corrosion products after electrochemical studies were scanning electron microscopy (SEM) and 3D surface profiler

3.7.1.1. Experimental procedure for microstructure measurement

The preparation started by cutting a small representative piece of the metal from the studied base metal. Small piece of stainless steel and mild steel samples mounted using phenolic resin in hot mounting press RB 206 Met-press –A machine.

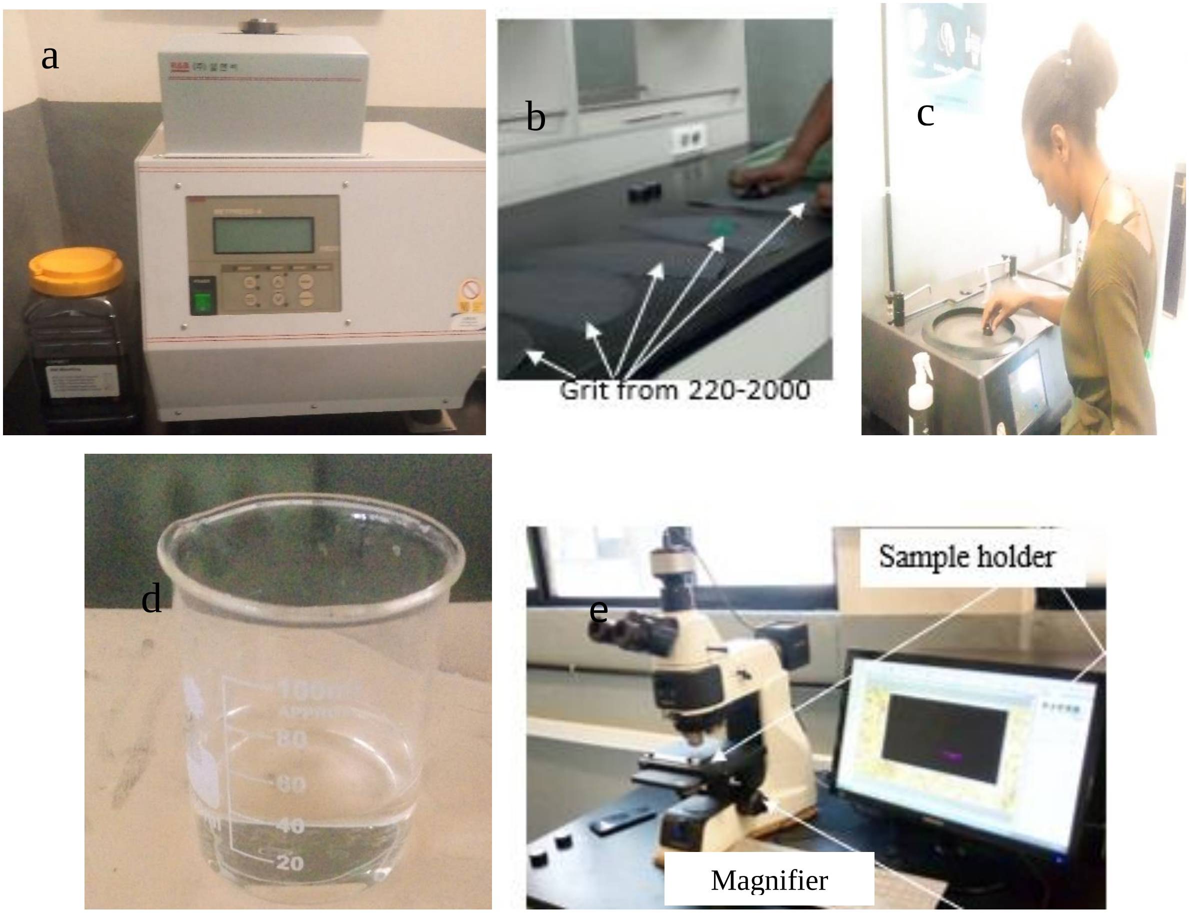


Figure 3.17 Microstructure specimen preparation: a) mounting, b) grinding, c) polishing, d) etchant, e) OM microscopy

After mounting hand grinding done with 800-, 1200-, and 2000 silicon carbide grit papers to flattening the surface to be examined and removing any damage caused by sectioning. Then polishing used to enhance the appearance of an item, prevent contamination of instruments, remove oxidation, and create a reflective surface. Distilled water, hydrochloric acid, and nitric acid in 1:1:0.1 ratio (Stainless & Etchants, 2017) respectively was used for etching purpose which is the last step of sample preparation. This solution was selected depending on the material type since it is recommendable for stainless steel material.

3.7.2. Weight Loss Measurement

The cut stainless steel and mild steel metallic samples weighed using an analytical weighing balance and recorded. The already washed containers with water and ethanol were filled with tomato, mango and orange juice as shown in Figure 3.16 (test medium) and the weighed sample coupon were immersed for a period of thirty days, and reweighted at regular interval of five days. Each corrosion samples removed from the corrosion environment (tomato, mango and orange fluid) rinsed in ethanol and distilled water and then dried with air.

The study conducted at room temperature for the entire immersion period while the pH values of the competing agro media obtained for every immersion period to indicate any change in their concentration using a standard portable pH meter. The pH values of the ago media recorded before and after the exposure time to establish difference in their acidic level. The dried metallic samples coupons re-weighed with analytical weighing balance and recorded, as well as the pH values of the test medium was recorded using a pH meter within regular interval of five days. The weight loss and pH measurement were conducted at the Chemical Engineering laboratory. The weight losses were determined using the expression in equation 3.1.

$$W = W_o - W_f \tag{3.1}$$

Where W, W_o and W_f are weight loss, initial weight loss and final weight loss in gram, respectively.

The corrosion rate calculated using the formula in equation. The pH meter calibrated with distilled water used to study the acidity of the corrosion medium. The pH meter was immersed in the distilled water and shaken to reach the neutral pH of 7 before subsequently immersed in the juice. The readings taken at the stable points of the pH and these values were recorded at the interval of five days.

The weight loss and pH measurement were conducted at the Chemical Engineering laboratory.

$$\mathrm{CR} = \frac{\mathrm{k\,w}}{\rho \mathrm{AT}} \tag{3.2}$$

Where CR is the corrosion rate of the specimen in millimetre per year (mm/y), W is the weight loss in g, ρ is the density of metal in g/ cm^3, A is the area of specimen in cm^2, T is the exposure time in hours and k is constant with value 87600.

3.7.3. Potentiodynamic Polarization measurement

The basic electro-chemical cell involves a working electrode, reference electrode, counter electrode and the freshly grinded Tomato, mango, and orange juice. The electrochemical measurements of the stainless steel and mild steel specimens in three food environments were conducted using a three-electrode electrochemical cell ASTU Material laboratory Biologic Potentiostat linked to my personal computer fully installed with E-Clab software was engaged for the electrochemical corrosion measurement. About 50ml of each of the test medium was poured into a glass beaker and measured for every experiment. The working electrode was the mild steel and 304L stainless steel, whereas saturated silver/silver chloride (Ag/AgCl) in 3 mol of potassium chloride (KCl) was the reference electrode, while the counter electrode was platinum rod. All the three electrodes were connected together to allow free flow of electrons before the commencement of electrochemical measurement. Six samples were immersed in the three corrosion media (two for each agro medium) while the potential and current distribution were monitored and measured by the E-C lab corrosion software from the potentiostat which controlled the scan rates. Experimental measurements were taken after 30 second immersion period to control some environmental disturbance. During potential distribution measurement, the cell enabled of the potentiostat was switched off, while all the electrodes were temporarily disconnected from the corrosion media to avoid altering the open circuit potential (OCP) results. This was in accordance with the procedure used by Wang et al., (2012). A Graphical plot of Potential Versus logarithm of current drawn using software application (Excel). The E_{oc} potential also plotted on the graph. Using Tafel analysis, an extrapolation of the linear portion of the cathodic curve to the corrosion potential to indicate the corrosion current ($I_{corr)}$ at which corrosion is occurring.

3.7.4. Design of experiment

Design of Experiments (DOE) is a statistical technique for quickly optimizing performance of systems with known input variables. It starts with a screening experimental design test plan involving all of the known factors that are suspected to affect the system's performance (or output). Design of Experiment is an effective tool for maximizing the amount of information gained from a study while minimizing the amount of data to be collected, which, in this case, is minimizing the number of experimental runs (Uy and Telford, (2009).

Taguchi's which is one of the Design of Experiment (DOE) applications are used to analyse the effect of parameters and their comportment by performing a minimum number of experimentations and observing their effect on a specific behaviour (Krishnaiah & Shahabudeen, 2012) ; (Onuoha et al.,(2016). In this work the experiment was conducted by varying the corrosion parameters such as duration time, type of material and type of food environment have been split into different level values. In order to determine the most influential cause of corrosion of steel in food processing industry the listed parameters with three level have been considered for this study. From these there parameters the levels of duration time were taken by selecting three durations from these six during weight loss measurement method within ten days interval. Also, these corrosion parameters were selected depending on reviewed literatures the factors which accelerate the corrosion rate of materials.

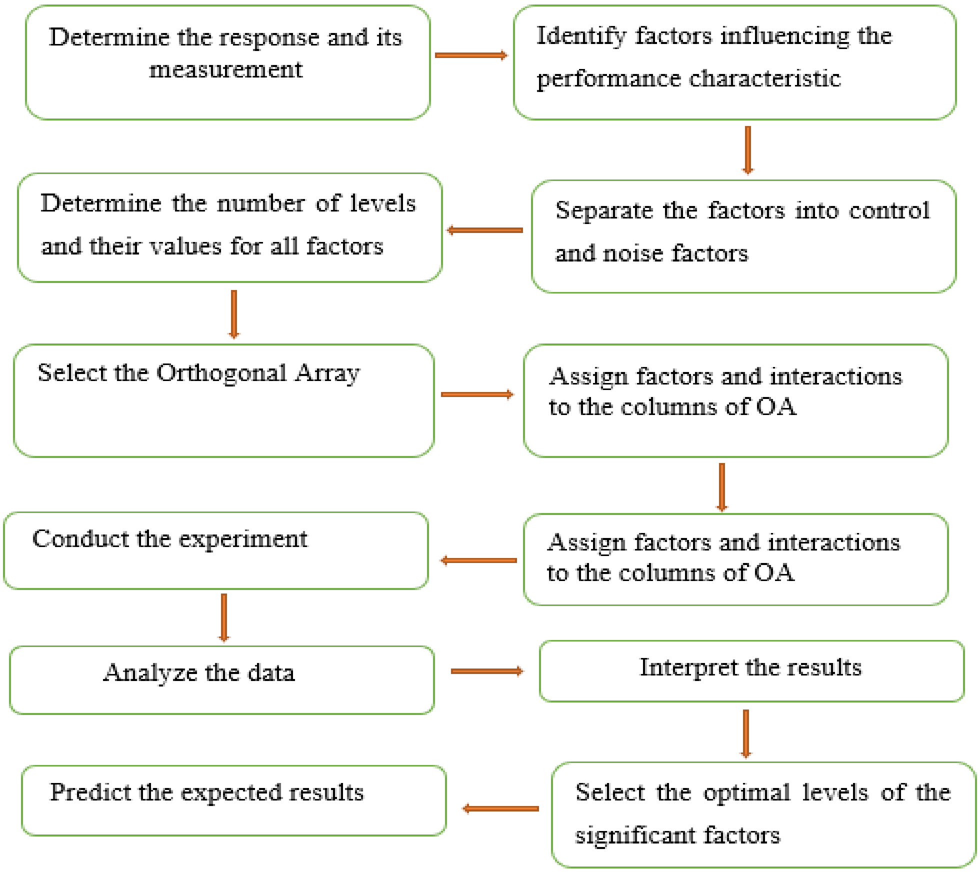


Figure 3.18 Design producer of Taguchi methods

The experimental design of process parameters and numerical analysis is done by the Minitab statistical software with three factors and three levels of the experiment.

Table 3.3: List of corrosion parameters and their level

Corrosion parameters	Level 1	Level 2	Level 3
Metal type	Stainless steel	Mild steel	
Test media	Mango	Orange	Tomato
Exposure time(days)	10	20	30

3.7.4.1. Selection of the Orthogonal Array

The minimum number of experiments that must be run to study the factors shall be more than the total degrees of freedom available (Krishnaiah & Shahabudeen, 2012)

Table 3.4: experimental runs using L_{18} orthogonal array

Corrosion parameters			
NO	Metal type	Test media	Exposure time(days)
1	Stainless steel	Mango	10
2	Stainless steel	Mango	20
3	Stainless steel	Mango	30
4	Stainless steel	Orange	10
5	Stainless steel	Orange	20
6	Stainless steel	Orange	30
7	Stainless steel	Tomato	10
8	Stainless steel	Tomato	20
9	Stainless steel	Tomato	30
10	Mild steel	Mango	10
11	Mild steel	Mango	20
12	Mild steel	Mango	30
13	Mild steel	Orange	10
14	Mild steel	Orange	20
15	Mild steel	Orange	30
16	Mild steel	Tomato	10
17	Mild steel	Tomato	20
18	Mild steel	Tomato	30

In this study, the selection of a particular orthogonal array was based on the number of levels of several factors. the levels were then oriented according to the Taguchi L_{18} orthogonal array (OA) which is shown in Table 3.4 Taguchi based Orthogonal array has the property of reducing the number of experiments without affecting the outcome significantly (Johari (2008); Onuoha et al. (2016))

3.7.4.2. Signal to Noise (S/N) Ratio

Taguchi method stresses the necessity of studying the response variation using the signal-to-noise ratio, resulting to decrease the effect of quality characteristic variation due to uncontrollable parameter. Signal to noise ratio is interpreted as the ratio of the mean value of the signal to the standard deviation of noise value. The experimental Investigation data of weight loss and corrosion rate were transformed in to Signal-to-Noise (S/N) ratio.
The S/N ratio can be used in three types:

A. Larger the better

$$\mathrm{S/N\ ratio} = -10\log\left[\frac{1}{\mathrm{n}}\sum_{\mathrm{i}=1}^{\mathrm{n}}\frac{1}{\mathrm{Yi}^2}\right] \tag{3.5}$$

B. Smaller the better

$$\mathrm{S/N\ ratio} = -10\log\left[\frac{1}{\mathrm{n}}\sum_{\mathrm{i}=1}^{\mathrm{n}}\mathrm{Yi}^2\right] \tag{3.6}$$

C. Nominal the best

$$\mathrm{S/N\ ratio} = 10\log\left[\frac{1}{\mathrm{n}}\sum_{\mathrm{i}=1}^{\mathrm{n}}\frac{\mathrm{Y}^2}{\mathrm{S}^2}\right] \tag{3.7}$$

Where, Y = observation, n = total number of observations, $\bar{Y}$ = the average of observed data, S^2 = the variation of Y and $i = i^{th}$ response. From the above three the work used larger is the better during determination of the hardness of material after corrosion and smaller is the better for the response of corrosion rate and weight loss.

3.7.4.3. ANOVA (Analysis of Variance)

The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error (Krishnaiah & Shahabudeen, 2012). In the analysis of variance, the percentage contributions of each control factor were used to measure the corresponding effects on the performance characteristics. The significance level of 5%, i.e., for a 95 % level of confidence was considered.

$$P\ (\%) = \frac{SSTR}{SST} * 100 \tag{3.8}$$

Where P = is the percentage contribution of individual factors, SSTR = is the sum of squares or treatment sum of squares, and SST = total sum of squares.

CHAPTER- 4

RESULTS AND DISCUSSIONS

4.1. Introduction

This research was carried out to know more about the corrosion characteristics of steel in a fruit juice environment, as well as to investigate how these different fruit juice types affect metal corrosion, as some of the organic acids and other chemical compounds found in fruit can inhibit the corrosion of certain metals. The influence of three distinct test media on corrosion behaviour of mild steel and stainless steel was evaluated by utilizing the weight loss method and electrochemical measurement, as detailed in chapter three. Following these two tests, morphological analysis was carried out. This chapter goes through discussion on the outcome results for each experiment. The temperature and thickness of the material were kept constant during all 36 experiments. The response based on an orthogonal array experiment was analysed using a mixed Taguchi design (L_{18}). Qualitative analyses such as morphology and microstructure, as well as quantitative analyses such as 3D image segmentation, weight loss, micro hardness, and electrochemical tests, were carried out, and the results are detailed in this chapter.

4.2. Microstructural analysis

The microstructure analysis of materials looks at how the material was created and helps predict how it will perform in service. Physical qualities such as strength, toughness, ductility, hardness, corrosion resistance, high/low temperature behaviour, and wear resistance can all be influenced by the microstructure of a material (such as metals, polymers, ceramics, or composites). Optical microscopes were used to examine the microstructure of stainless steel and mild steel base metals. The microstructure of steel is mostly martensite, with allotriomorphic ferrite, Widmanstätten ferrite, bainite, and pearlite thrown in for good measure. The martensite (bright region denoted by arrows) is spread throughout the ferrite (dark area) matrix in the steel microstructures. The manufacturing method, as well as the composition of allying materials, can produce defect that lead to corrosion formation, especially when the structure contains voids and micropores.

The microstructure of 304L stainless steel basic metal, is shown in Figure 4.1(a) before corrosion testing. Under optical metallurgical microscopy, the microstructures were examined at magnifications of 100 x, 50 x, and 20 x, but here microstructures at magnification 20x were presented with base materials. Fully austenitic structure with little ferrite structure was observed in stainless steel base microstructure in Figure 4.1(a). The structures were identified as austenite with a white colour and ferrite with a dark colour. Surface machining during manufacture causes microstructural changes in 304L stainless steel, making it more susceptible to chloride stress corrosion cracking this is have negative impact on corrosion resistance of 304L stainless steel since it is the most widely utilized of all stainless steels, and it is most commonly seen in industrial applications and culinary equipment (Dessalegn et al.,2021).

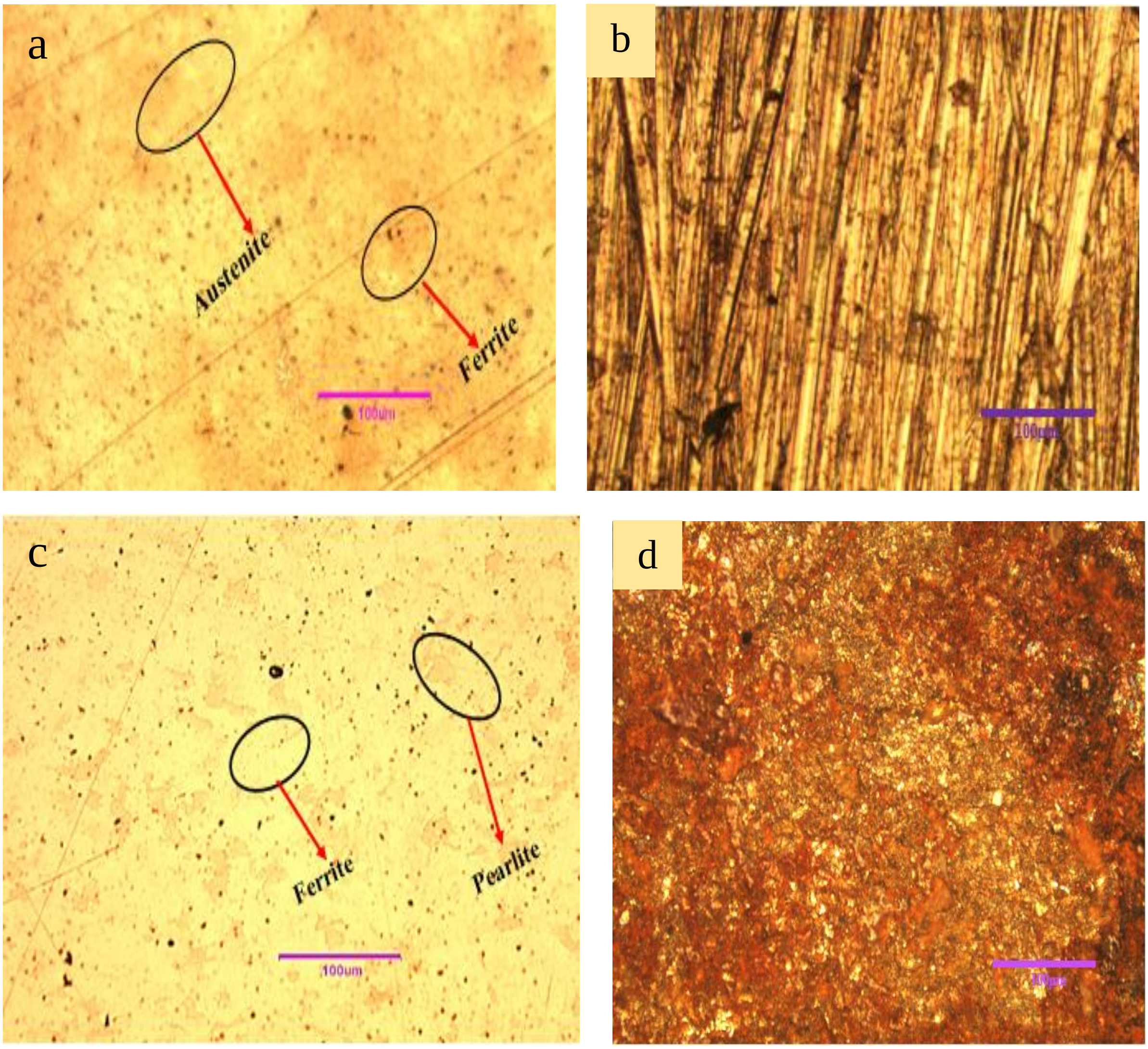


Figure 4.1 Microstructure of metals; a) 304L stainless steel before corrosion, b) 304L stainless steel after corrosion, c) mild steel before corrosion and d) mild steel after corrosion

Figure 4.1(b) shows the microstructural image of 304L stainless steel after corrosion which is stainless steel in mango juice environment after 30 days exposure time. The whiter regions revealed the austenitic structure changed in to darker colour, there was slight initiation of corrosion product and some pitting corrosion attacks were observed. Figure 4.1(c) shows the microstructure of mild steel base metal, the structure reveals a mixture of pearlite and a dominant ferrite phase. A blend of pearlite and a dominating ferrite phase can be seen in the mild steel structure. The sample's microstructure revealed ferrite in the grain borders of the acicular pearlite grains. Corrosion can start at the interfaces of pearlite or ferrite due to their different structures. Micro cracks emerge at the borders as a result of the uneven distribution of alloying elements (Dessalegn et al., 2021), and the products have low corrosion resistance, resulting in Intergranular corrosion along the contact lines. Intergranular corrosion, which results in the production of micro cracks in the structure, can be caused by directional grains. Figure 4.1(d) reveals the microstructural image of mild steel after corrosion which is mild steel in orange media after 30 days exposure time. The structure showed formation of uniform brown corrosion products and pitting corrosion attack with fine Intergranular corrosion initiating at the surface of mild steel. This result agreed with Parapurath et al., (2022). There were no any defined gain structure observed on the image, since the Intergranular corrosion attack developed on the grain border of the structure.

4.3. Weight loss result analysis

Metallic corrosion is a type of material loss that can be identified using a variety of methods. Visual examination of the metal before and after exposure to the corrosive environment is the simplest method, and the number of pits or fraction of corroded areas determined through visual procedures. A simple, direct and time-consuming, approach to examine metallic corrosion is gravimetric loss or weight loss, which is evaluated by a weight difference referenced to the surface exposed to corrosion. It is still a reliable source of information (Andrade and Alonso, 1995**)**. The study of the variation in the masses of steel samples immersed in the mango, orange, and tomato of these media over time is used to determine weight loss. In different media, different metals corrode in different ways. The original weight of the metal coupons decreases by varying amounts when immersed in test media at room temperature. Demonstrating this, the coupons were cleaned and tested after each trial period of 5, 10, 20, 25, and 30 days, in order to establish the metal loss and, as a result, the corrosion rate. The weights of duplicate sets of all mild steel and stainless steel coupons measured before and after immersion and then weight loss analyses in orange, mango, and tomato test medium, respectively. The weight loss was calculated based on the formula which is stated in chapter three.

W = Wo – Wf   Where W, Wo and Wf are weight loss, initial weight loss and final weight loss in gram respectively. For instance the original weight of mild steel in mango juice is 16.2364, after immersion for five days the weight become 16.1042. Therefor:

$$W= 16.2364 - 16.1042 = 0.1322 \quad (4.1)$$

The same with this the weight loss experimental result of mild steel and stainless steel are presented in Figure 4.2 and 4.4.

According to the weight loss results in Figure 4.2, 0.55 g of mild steel was lost in mango juice after 30 days, 0.61 g in orange juice, and 0.51 g in tomato juice. Overall, due to the mild steel's chemical properties, chemical makeup, and physical surroundings, it lost a substantial amount of weight while exposed to the fruit juice media.

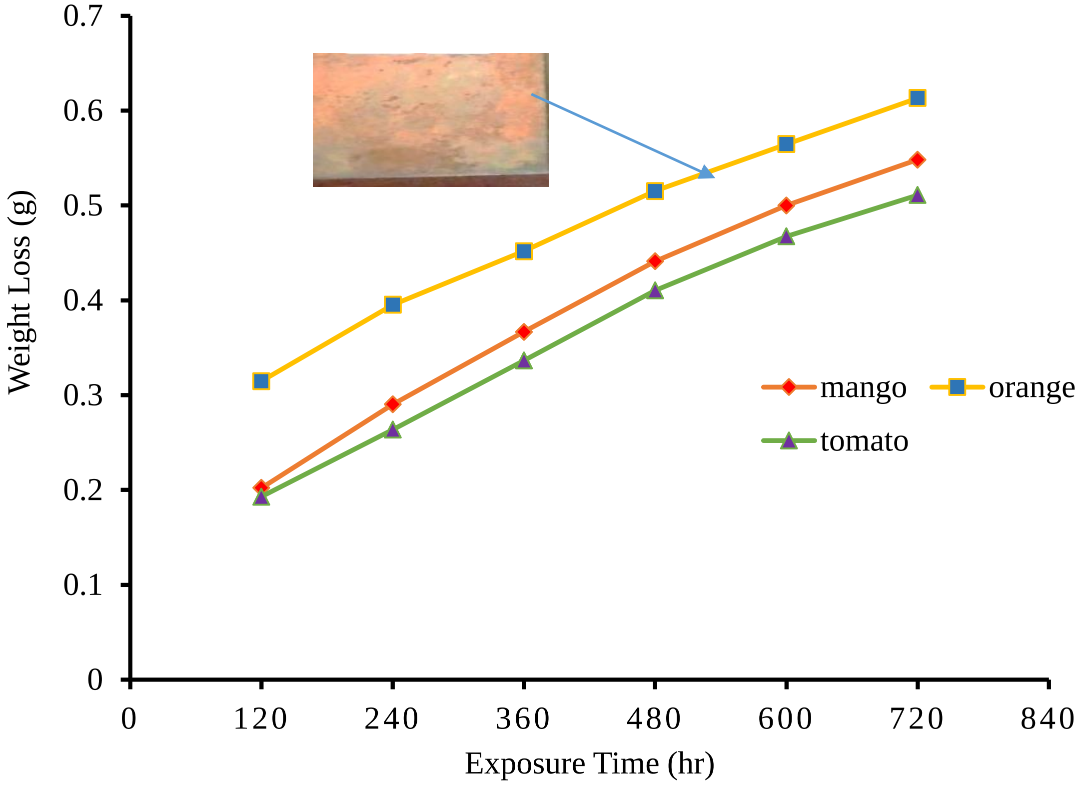


Figure 4.2 Weight loss graph of mild steel after 30 days of exposure time

From the 30 days of immersion, Figure 4.2 reveals that the mild steel sample in the orange medium lost more weight than the other two test media, closely followed by specimens in the mango medium and those in the tomato. This behaviour shows that the orange medium has a more corrosive effect on the steel sample than the other two competing media. Tomato medium has a mild corrosion effect on mild steel samples, resulting in minimal weight loss. During the first 5 to 10 days of immersion, the weight loss rates of the mild steel samples in mango and tomato were practically identical. This behaviour could point to a corrosive similarity between these two competing test environments. Weight loss of mild steel in all mango, orange, and tomato juice during immersion of 30 days increases with an increase in duration time. This is due to the increase in acidity of test media since weight losses followed the same trend as the pH of the respective fruit juices, increasing with the increasing acidity of the fruit juices. The percentage weight loss of a mild steel sample after 30 days of immersion is 3.3% in mango juice, 3.76% in orange juice, and 3.11% in tomato juice. After the observational periods of 5, 10, 15, 20, 25, and 30 days, the percentage weight loss in the mild steel coupons in mango was increased from 1.2% to 3.33%, in orange juice from 1.91% to 3.75%, and in tomato juice from 1.19% to 3.11%. A greater percentage weight loss was observed in the orange juice medium, followed by the mango and tomato mediums, respectively.

The summary of percentage contribution of the test medium to weight loss of the mild steel samples is illustrated in Figure 4.3. The mild steel samples in mango indicate approximately percentage weight loss of 32%, while sample in orange medium lost 40%. The percentage weight loss in tomato medium are 28% which is the minimum.

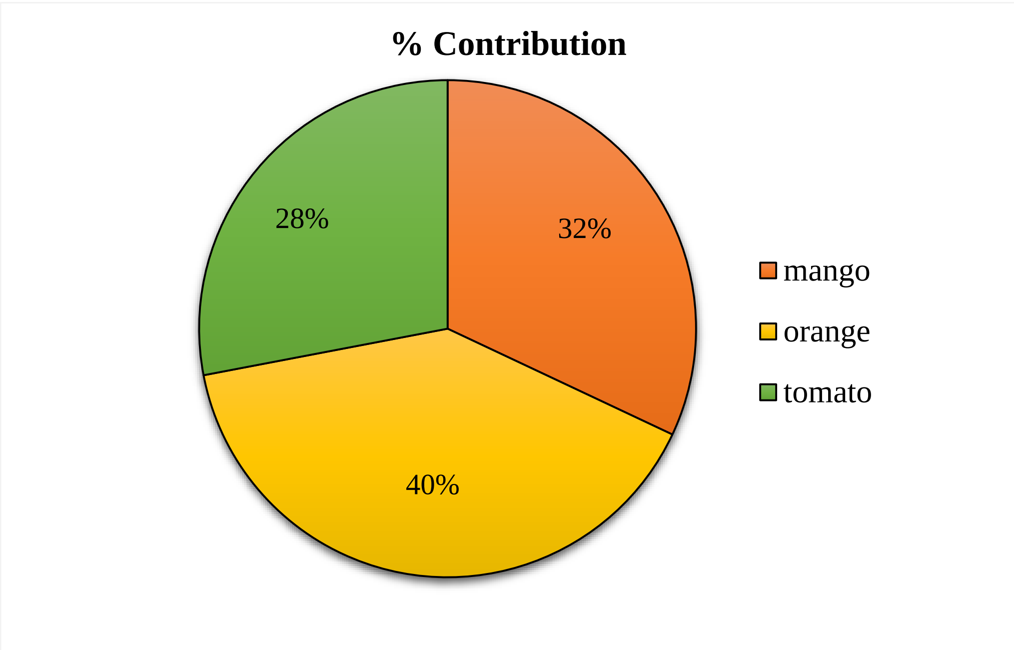


Figure 4.3 Percentage contribution chart of test media to weight loss of mild steel

Within 30 days of immersion, 0.0026 g of the stainless steel sample was lost in mango juice, 0.0022 g in orange juice, and 0.0015 g in tomato juice liquids, according to the weight loss results in Figure 4.4. In the fruit juice media, the overall results showed that stainless steel had a far lower weight loss than mild steel since it has 19 percent chromium and is a result of a very thin (about 5 nanometres) oxide layer on the steel's surface. Figure 4.4 shows that weight loss of stainless steel samples in the mango and orange medium lost more weight than in other tomato media. Tomato medium showed less effect of corrosion on stainless steel samples and subsequently had less weight loss. The same goes for mild steel. The weight loss of stainless steel in three mediums increases with an increase in exposure time and acidity of the juice. Generally, the results showed that stainless steel had the highest resistance to corrosion at the end of the experimental test, followed by mild steel in the weight loss experiment.

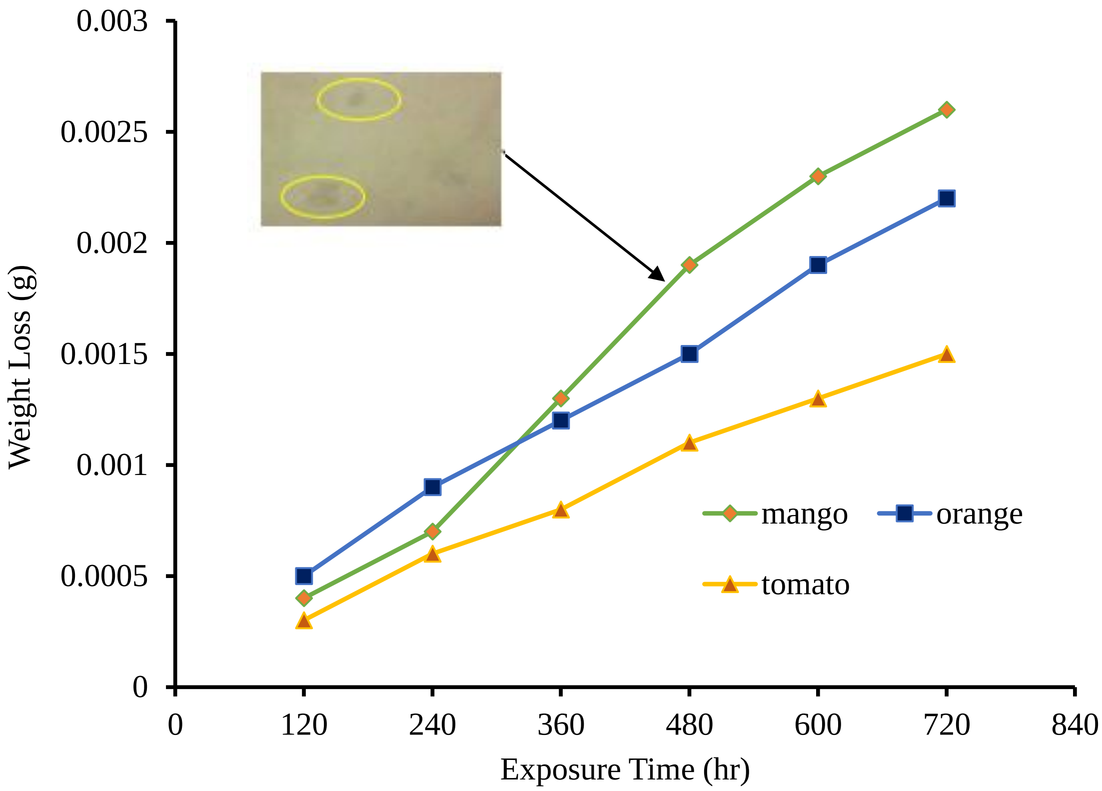


Figure 4.4 Weight loss graph of stainless steel after 30 days of exposure time

Within 30 days of immersion, 0.017% of the stainless steel sample was lost in mango juice, 0.014% in orange juice, and 0.011% in tomato juice. In all three food environments, the percentage weight loss of stainless steel increases with exposure time. The highest percentage weight loss rate was recorded in mango juice due to higher interaction between stainless steel and mango medium, and the lowest was in tomato juice. The summary of the percentage contribution of the test medium to the weight loss of the stainless steel samples is illustrated in Figure 4.5. The stainless steel samples in mango indicate an approximate percentage weight loss of 35%, while the samples in the orange medium lost 33%. The percentage weight loss in tomato medium is 32%, which is the minimum. In stainless steel, almost the same result was recorded. Nevertheless, mango juice had the maximum contribution when compared to the other two media.

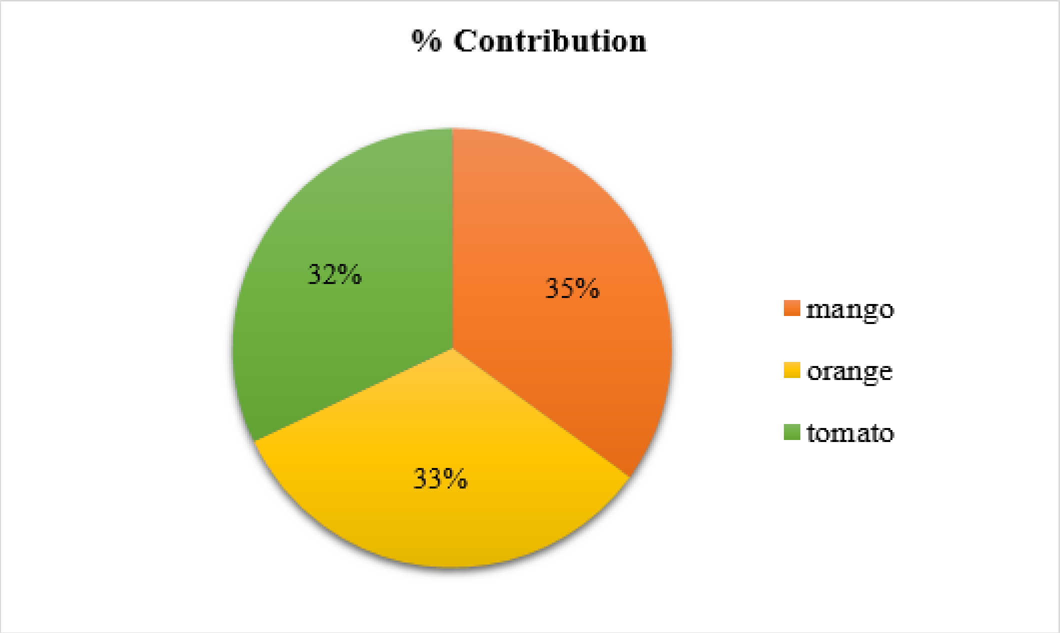


Figure 4.5 Percentage contribution of fruit juice environment to weight loss of stainless steel

4.4. Corrosion rate analysis

The corrosion rate is defined as the quantity of corrosion produced by a unit of surface area over a given duration of time. As previously stated, this characteristic can be determined by comparing the weight of the metal before and after exposure to the corrosive environment. It is an integral along the testing time (Andrade and Alonso, 1995**)**.

. The corrosion rate was calculated based on the formula which is stated in chapter three.

$$\mathrm{CR} = \frac{\mathrm{k\,w}}{\rho \mathrm{AT}}$$

Where CR is the corrosion rate of the specimen in millimetre per year (mmpy),

W is the weight loss in g,

ρ is the density of metal in g/ cm^3,

A is the area of specimen in cm^2, and

T is the exposure time in hours

The area of the specimen was calculated from the data of the dimension of the sample was 40cm x 35cm x 1cm. and the density of mild steel is 7.87g/cm^3

A = L x w where A for area, L for length, w for width

A = 3.5cm x4cm = 14cm^2 = 0.0014m^2

Figure 4.6 show the corrosion rate of mild steel coupons after immersion time and the corrosion rate analyses in orange, mango, and tomato test medium. The corrosion rate of mild steel is 0.6mmpy in mango juice, 0.67mmpy in orange juice and 0.57mmpy in tomato juice after 30 days of immersion.

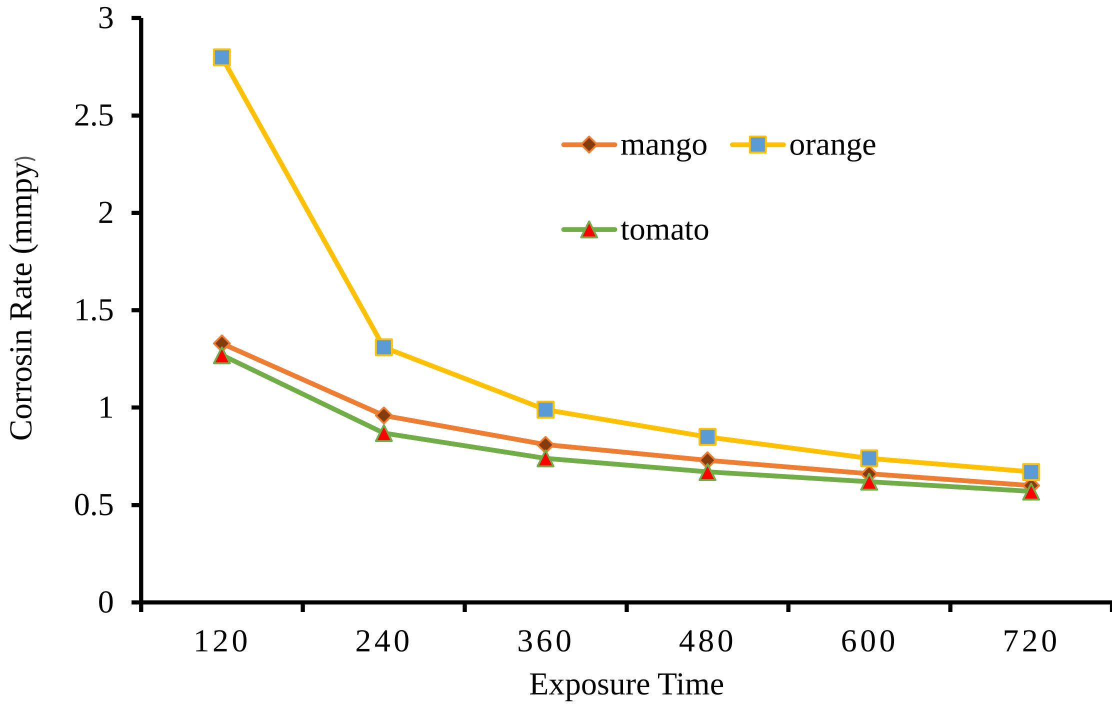


Figure 4.6 Corrosion rate graph of mild steel after 30 days of exposure time

The corrosion rates of mild steel samples in the orange media show more aggressive attack than in other media, as can be deduced from the curves (Figure 4.6) throughout the duration of immersion followed by the samples in mango and tomato media, respectively. The least aggressive medium was tomato juice, which showed a gentle attack on the mild steel sample. In comparison, the curve of corrosion rate from the mango medium is positioned between the two more and less corrosive media, possibly suggesting the competitive nature of chemical reaction among the participating ions in the combined solution. However, from the 5th day of immersion and onward, all the slopes declined gently and appeared to have converged towards the end of the exposure period. The corrosion rate will gradually decrease as the exposure time increases, and it will eventually decrease. Because of the fermentation process, suspended particles from the agro juices may have had an impact on the mild steel samples' reduced corrosion rates. The steel specimen surface regions were covered in precipitates, which may have also contributed to the slow volume decline of test media with increased immersion times, preventing further exposure to these media. The corrosion rate of stainless steel sample after immersion period of 30 days was 0.0028mmpy in mango juice, 0.0021 in orange juice and 0.0016mmpy in tomato juice as shown in figure 4.7. The same with weight loss analysis in the fruit juice media, the stainless steel had lower corrosion rate and percentage weight loss than mild steel.

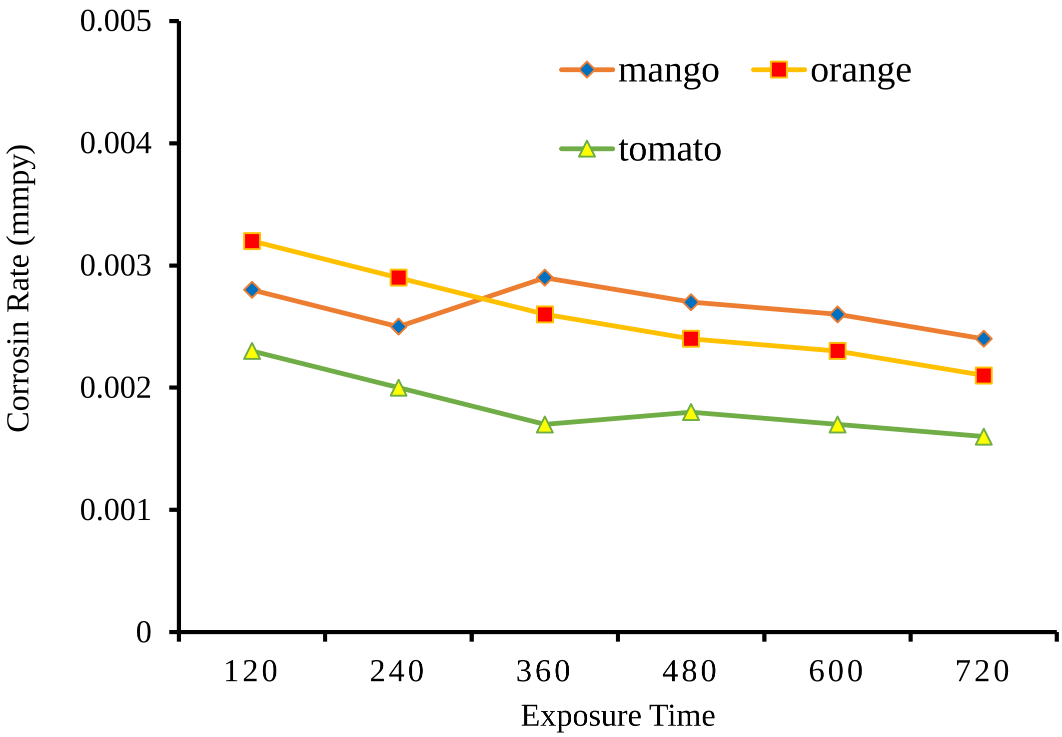


Figure 4.7 Corrosion rate of 304L stainless steel after 30 days of exposure time

Figure 4.7 shows the corrosion rate graph of stainless steel in three fruit juice mediums. The acidity of orange juice was higher than mango and tomato juice, but the maximum corrosion rate of stainless steel was observed in mango juice, followed by orange juice and tomato juice. This indicates that the interaction between stainless steel and mango juice was higher than the other two mediums. Even though stainless steel immersed in the test environment did not show any noticeable corrosion rate throughout the experimental period, this shows it has a higher corrosion resistance to the media, which is similar to the result obtained by Babalola et al. (2021). Generally, it was also found that the rate of corrosion was dependent on pH, whereby the rate of corrosion had a tendency to increase with the increasing acidity of the juices. Generally, the results showed that stainless steel had the highest resistance to corrosion at the end of the experimental test, followed by mild steel in the weight loss experiment since it had a low percentage weight loss and a very low corrosion rate. The increasing corrosion resistance of 304L stainless steels may be explained by their high level of chromium. Chromium provides better resistance to oxidizing environments such as diluted organic acids (Tengur and Surnam, 2012).

Figure 4.8 shows photographic images of the corroded mild steel and stainless steel samples in the test medium after 30 days of immersion from the weight loss analysis. Visual examination of the coupons after exposure in a mild steel specimen indicated uniform corrosion in mango juice and localized corrosion like pitting corrosion in orange and tomato juice food processing environments studied and more attack locked mild steel in the orange juice environment than others due to its higher acidity. No visible corrosion product was observed in stainless steel. They appeared brighter.

Only in figure 4.8 (c) was a very small pit and a slight loss in luster was evident for 304stainless steel sample. In mild steel, brownish corrosion products were observed. The images depict different surface appearances. Brownish images could reveal greater effects of corrosion on the samples which also correspond to the results of the corrosion rates. Physical observation showed that images in Figure 4.8 (a) and (b) appeared brighter than images in Figure 4.5 (c) on mild steel sample These characteristics might have been attributed by the intensity of corrosion effects on these mild steel samples.

Figure 4.8 Image of corroded samples of stainless steel and mild steel; a) after 5 days exposure time, b) after 15 days exposure time and c) after 30 days of exposure time

Generally the various metals were found to corrode differently in different media. This is evident by the decrease in the original weight of the metal coupons by different amounts when immersed in test media at room temperature. This indicates selection of material with respect to type of food environment in food processing industry is mandatory.

4.5. pH value analysis of test media

The pH values of the agro media indicated differences in acid concentrations of the test media during the exposure period. Measured pH of freshly prepared fruit juices and within exposure of 5, 10,15,20,25 and 30, are presented in Table 4.1 and table 4.2 respectively.

Table 4.1: pH value result of freshly prepared fruit juices

Fruit juice	mango	Orange	Tomato
pH value	4.2	3.58	4.24

Table 4.2: pH value result of three fruit juices within 30 days exposure time

		Exposure time					
Test media	Type of material	5 days	10 days	15 days	20 days	25 days	30 days
Mango	Mild steel	3.59	3.72	3.93	4.1	4.22	4.68
	Stainless steel	3.34	3.1	3.54	3.85	4.15	4.33
Orange	Mild steel	3.26	3.21	3.49	3.79	3.83	4.25
	Stainless steel	2.94	3.13	3.02	3.81	3.11	3.99
Tomato	Mild steel	4	6.23	4.09	6.31	4.62	6.66
	Stainless steel	3.91	6.12	3.93	6.29	4.54	6.53

As the pH is decreasing (acidity increases), the corrosion rate is increasing. This is because low pH solutions accelerate corrosion by providing hydrogen gas. Hydrogen attacks and damages the surface of steel, which increases the weight loss. The pH values of the test media indicated differences in acid concentrations of the test media during the exposure period. From table 4.2, it was shown that the acidity of test media increases highly in the first 10 days because the interaction between the metal and the environment is higher in the first few days. Then the material will adapt to the environment and acidity will decrease. This indicates corrosion rate decreases with an increase in exposure time. As shown in Figure 4.9, the pH value of mango juice slowly increases as exposure time increases. If the pH value is less than about 4, protective oxide films tend to dissolve and corrosion rates increase. From the graph, it was observed that the pH value of mango juice for both metals is blown at 4 to 25 days of exposure time.

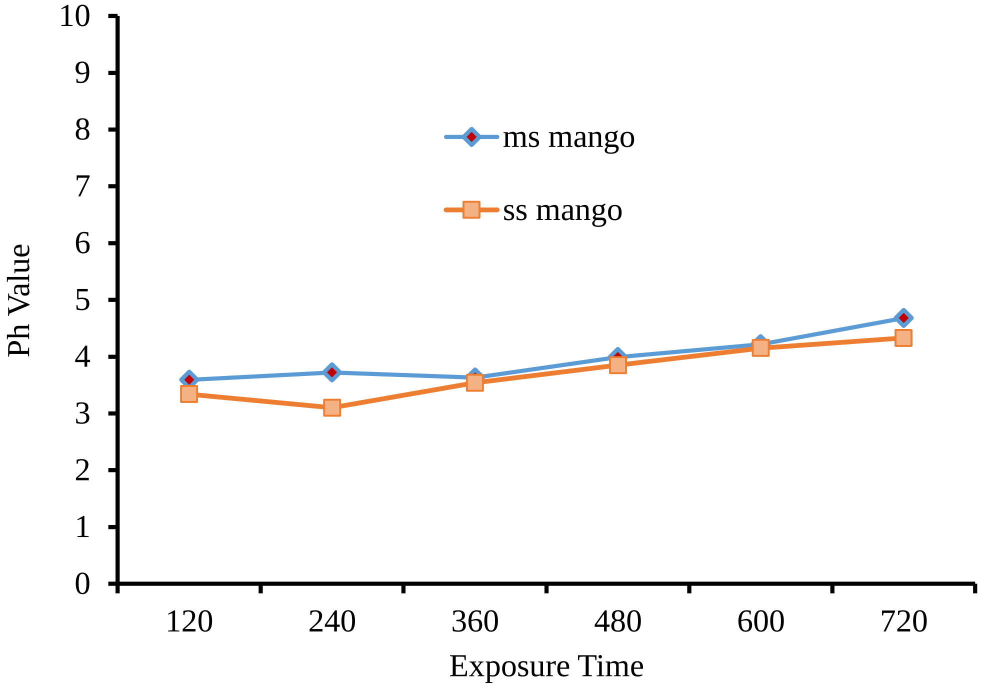


Figure 4.9 pH value of mango juice environment in mild steel and stainless steel

The pH value of mango juice in stainless steel was lower than in mild steel due to higher interaction between them and higher food environments interacting with nickel and chromium, increasing their acidity since stainless steel has chromium content, but the corrosion rate of mild steel in all juice was higher than stainless steel due to its low corrosion resistance and increase in acidity of the fluid, since acidity of food stuff is determined by measuring their pH value. Figures 4.10, show the pH value of orange juice during a 30 day exposure time. The same with the pH value of mango juice. The pH values of orange juice and tomato juice in stainless steel were lower than in mild steel. From figure 4.10, it was observed that the value of orange juice for both mild steel and stainless steel was below four till 25 exposure time. The acidity of orange juice was higher than the two fruit juice environments, which resulted in a higher corrosion rate of mild steel in this medium than others.

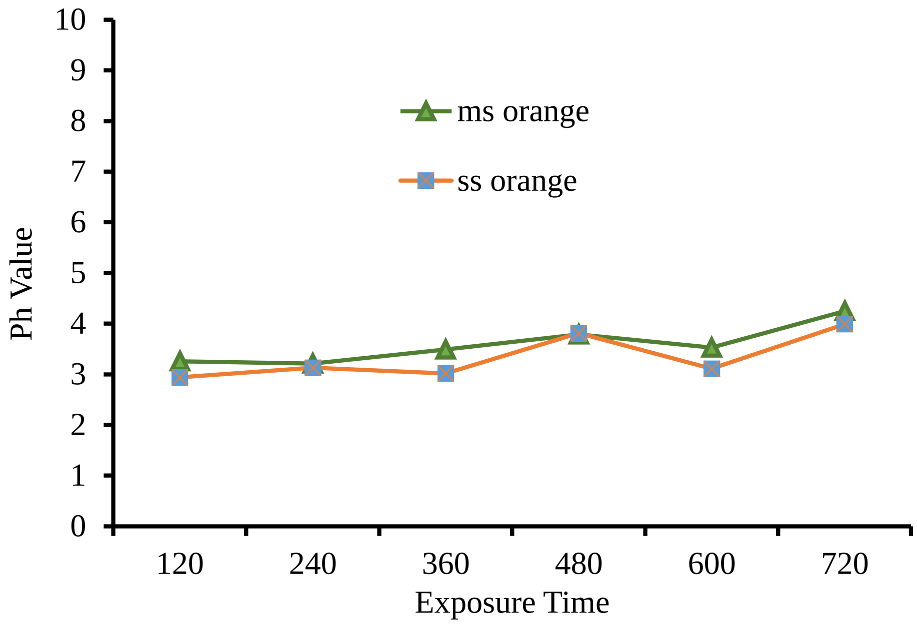


Figure 4.10 pH value of orange juice environment in mild steel and stainless steel

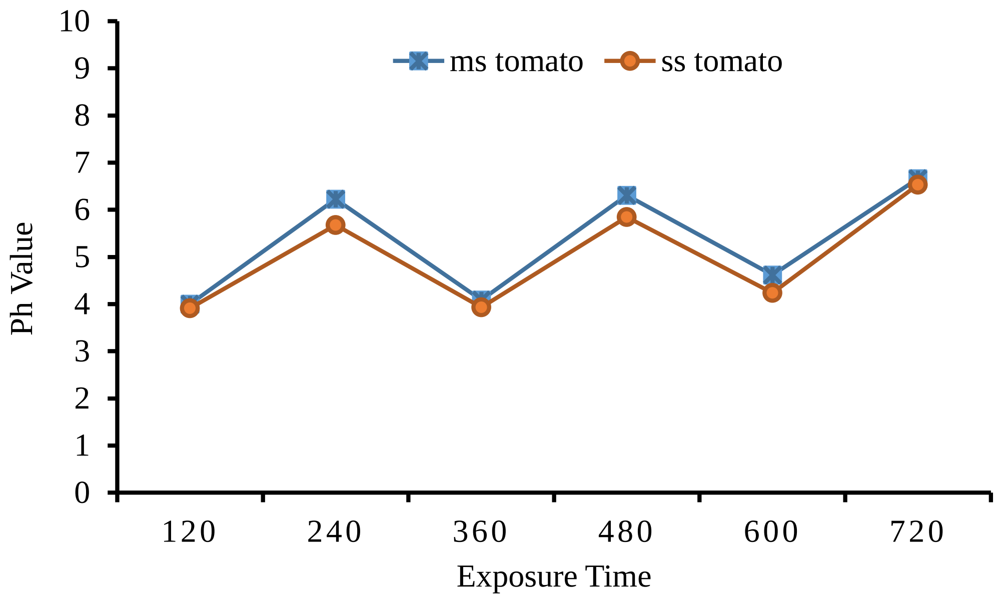


Figure 4.11 pH value of mango juice environment in mild steel and stainless steel

Figure 4.11 shows the pH value of tomato juice for both stainless steel and mild steel fluctuates within five days. In chapter three it was explained that for this work the fruit juice was changed every ten days, which is the main cause of the fluctuation of the graph. When the juice was changed, the value decreased up to five days of exposure and after that increased radically. As a result, the acidity of tomato juice was lower than mango and orange juice, which caused a decrease in the corrosion rate of materials.

4.6. Electrochemical behaviour analysis

The electrochemical behaviour of the metal involves dissolution of the metal in the various agro-media by the action of electrochemical cells (De-Giorgi, 1992). The electrochemical scans were acquired by observing the behavior of the mild steel and stainless steel in the test medium in both the cathodic and anodic regions of the electrochemical cell. Because of this, the tafel areas of the polarization curves were extrapolated at the intersection of the Ecorr and Icorr of each scan to display additional corrosion information required for the analyses of the study in accordance with standard procedures (Amin et al., 2010). The corrosion potential (Ecorr), corrosion current density (Icorr), and values of electrolyte parameters such as anodic Tafel (ba) and cathodic Tafel (bc) slopes were determined. Figures 4.12 to 4.14 show cathodic and anodic polarization curves for mild steel and 304L stainless steel specimens in three test media. The shapes of these curves look very similar, suggesting that the main reactions at the metal-solution interface may be identical. But there exists huge differences when closely observed because the test samples were corroding at different rates in these media.

Table 4.3: Electrochemical corrosion parameters of mild steel and stainless steel

Electrolyte	Metal type	Parameters			
		Ba	βc	Icorr (A/cm^2)	Ecorr (mVolt)
Mango	Stainless steel	0.155	0.116	-0.39	-167
	Mild steel	0.052	0.222	-0.139	-573
Orange	Stainless steel	0.153	0.126	-0.250	-361
	Mild steel	0.081	0.263	-0.111	-596
Tomato	Stain less steel	0.181	0.0978	-0.378	-144
	Mild steel	0.0925	0.167	-0.135	-601

Figure 4.12 shows the tafle plot of mild steel and stainless steel in mango juice. From the graph, it was observed that stainless steel has more corrosion resistance than mild steel in mango juice since the potential of stainless steel is higher and the corrosion current density is lower than mild steel. If the metal has a high potential, it will have a low corrosion rate and high corrosion resistance. If the material has a high corrosion current density, it will have a high corrosion rate.

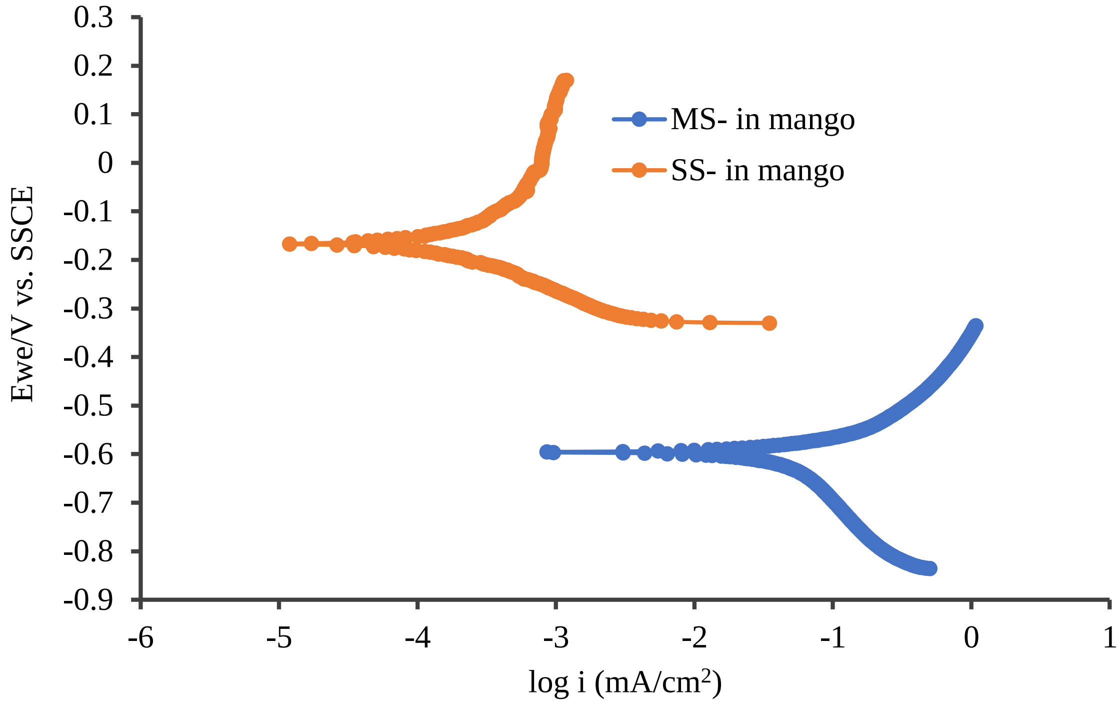


Figure 4.12 Polarization curves of mild steel and stainless steel in mango juice immersion

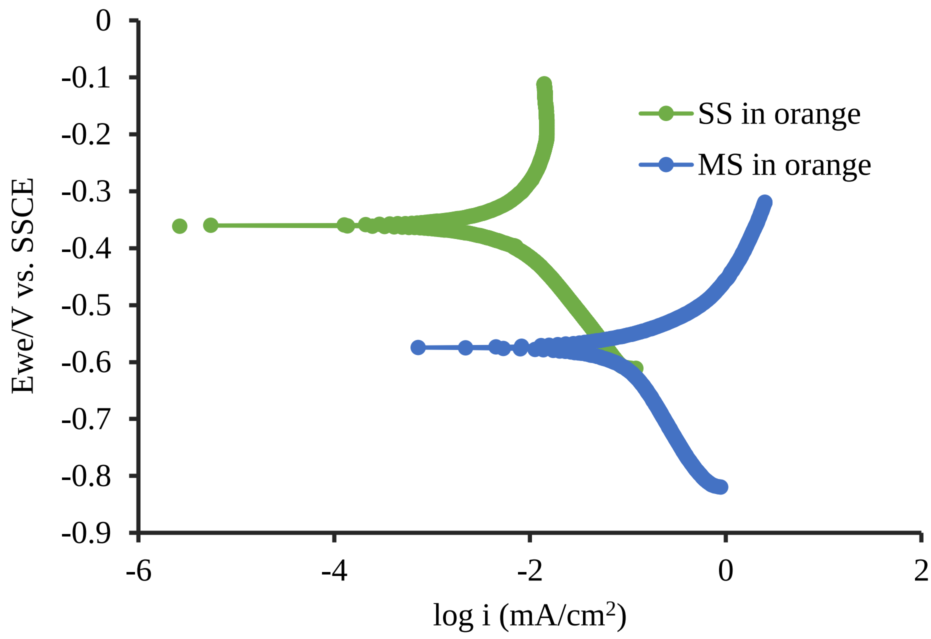


Figure 4.13 Polarization curves of mild steel and stainless steel in orange juice immersion

As shown in graph 4.12, the chatodic curve of mild steel increased to the positive side as a result of the corrosion rate increasing. Figure 4.13 shows a tafle plot graph of mild steel and stainless steel in orange juice. The graph reveals the potential of stainless steel at 361 mVolt was higher than mild steel at 573.5 mVolt and the anodic curve of mild steel increased gradually to the positive side, so the corrosion rate of mild steel was much higher than stainless steel.

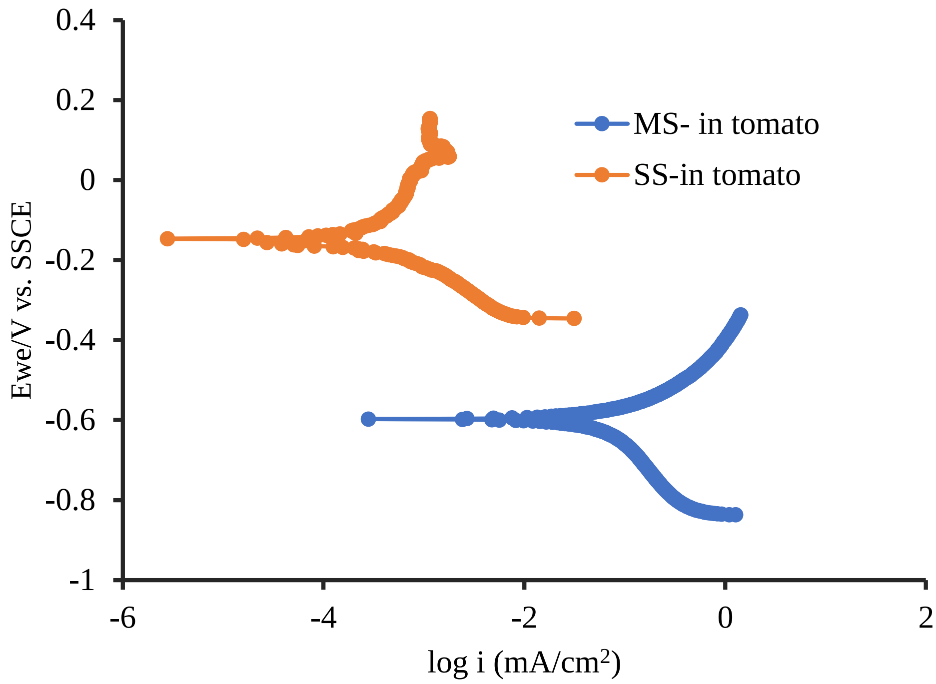


Figure 4.14 Polarization curves of mild steel and stainless steel in tomato juice immersion

The summary of linear Tafel extrapolation data obtained from Figure 4.12 to Figure 4.14 is tabulated in table 4.3. It can be deduced that mild steel samples in orange medium exhibited a unique and distinct characteristic of passivation from other corrosion media. The corrosion potential of the mild steel sample is lowest in the orange medium (-596mV), while the specimen in mango exhibited the highest Ecorr (-573 mV). Stainless steel in all three test mediums shows little or no sign of passivation to their polarisation curves. The summary of linear tafel extrapolation data shows that stainless steel in orange medium had the highest corrosion current density (Icorr) with a value of - 0.250 A/cm2 at 0.153 anodic tafel slope (a) and 0.126 cathodic tafel slope (c).This is followed by stainless steel specimens immersed in orange and tomato medium. The corrosion potential of stainless steel juice was higher in tomato juice with value -144mVolt, while the sample in orange media exhibited the lowest corrosion potential with value -361mVolt. From this, we can conclude that the electro-chemical corrosion analysis of 304L stainless steel indicates the corrosion resistance of stainless steel in mango and orange media was lower than tomato test mediums due to higher interaction between them.

4.7. Micro hardness analysis

Hardness is the ability of a material to resist deformation, which is determined by a standard test where the surface resistance to indentation is measured. The most commonly used hardness tests are defined by the shape or type of indent, the size, and the amount of load applied (Tabor. D., 2000). the micro hardness of both mild steel and stainless steel base metal and after 30 days exposure time measured by using Vickers hardness test machine model (HVS50). The hardness measured on the diagonal side of the samples with seven trials starts and ends 0.5 cm from the edge, and the gap between each trial was 0.72 cm. The main reason for doing micro hardness is that corrosion has a negative impact on the surface mechanical properties such as hardness on the alloy steel (li, 2017). According to researchers, there is a correlation between corrosion and the depreciation of metals' mechanical properties. The study discovered that corrosion affects metal's tensile strength, fracture toughness, and hardness, and that corrosion occurs more frequently in environments that are more acidic (Hou et al., 2016). The micro hardness value of mild steel sample before and after corrosion test are shown in Figure 4.15. From the result it was observed that the micro hardness value before corrosion for mild steel base metal sample was found to be of 116.8Hv_{10} , however, the hardness was reduced to 93.7 Hv_{10} in mango juice, 88.2 Hv_{10} in orange juice and 94.8 Hv_{10} in tomato juice after the corrosion. This reduction was due to the dissolved metal ions of mild steel material in the corrosive medium. The hardness value of mild steel after 30 day exposure time in mango, orange and tomato media decreased compared to base metal due to small holes or pits are formed as a result of corrosion which reduces the resistance of resisting applied load in the other name the hardness of material and it have correlation with life time of the material. As shown in the graph minimum microhardness value was recorded on mild steel sample in orange juice at point of 1.22cm distance from the edge a result of development high corrosion attack and presence of small pits in that area. Generally figure 4.15 reveals hardness value varies with the level of corrosion attack on the surface and the exposure time increase corrosion resistance of material decrease and also hardness decrease. This is in agreement with researcher (Orozco et al., 2019). The reduction in hardness shows that the corrosion had removed some depth of the strong alloy region.

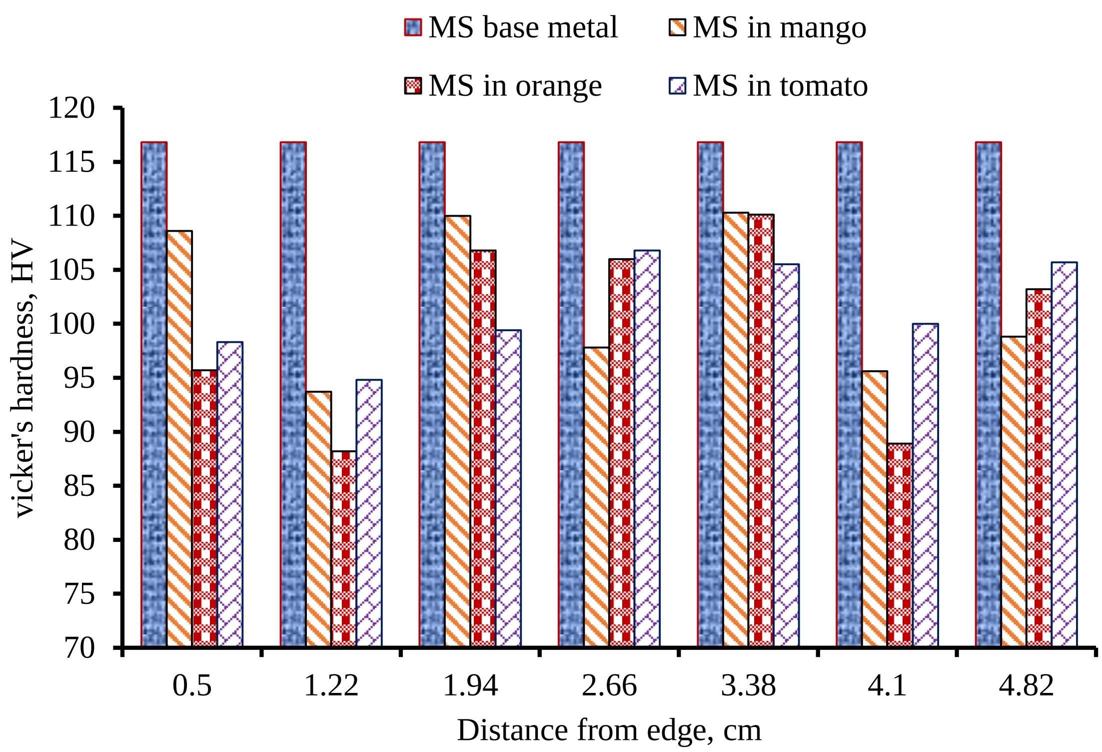


Figure 4.15 Michrohardness of mild steel before and after corrosion

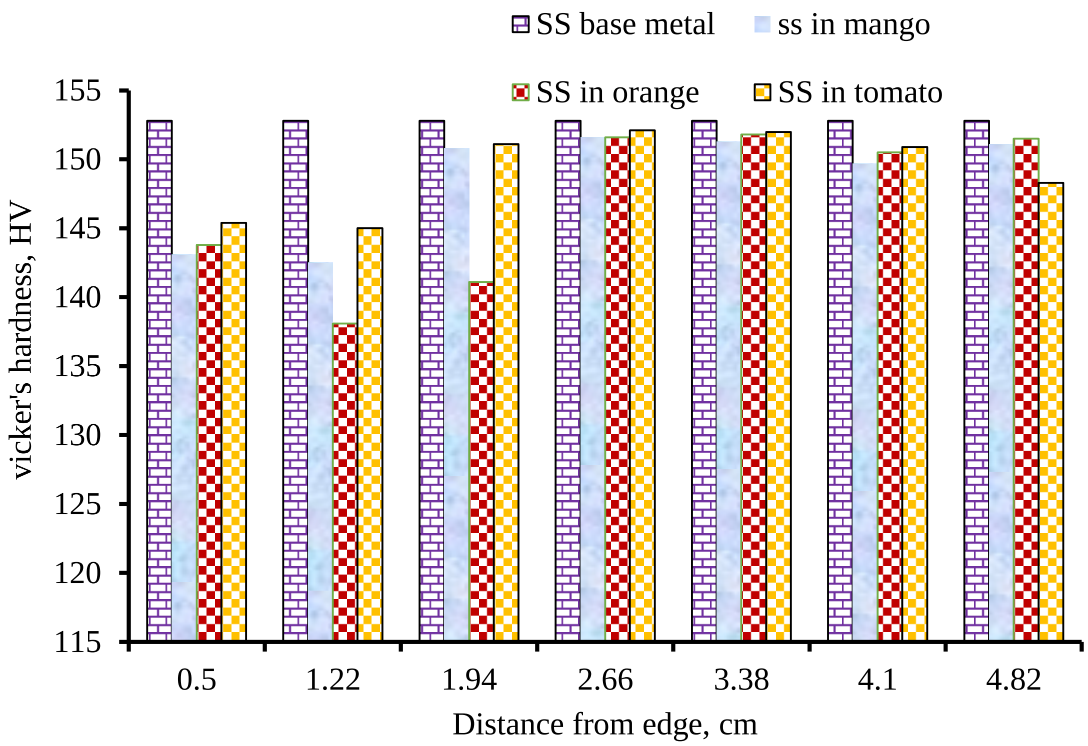


Figure 4.16 Michrohardness of Mild Steel before and after Corrosion

Figure 4.16 displays the variations in Vickers micro hardness values of 304L stainless steel after 30 days of exposure to mango, orange, and tomato juice media as a function of the distance from the sample's edge and the base metal. It is clear that all trials' base metal hardness values were higher than their corroded sample hardness values. According to the graph, micro hardness value before corrosion for 304L stainless steel base metal sample was found to be of 154.4 HV10, however, the hardness was reduced to 142.5 HV10 in mango juice, 138.1 HV10 in orange juice and 145 HV10 in tomato juice after the corrosion. Similar to Figure 4.15, stainless steel loses hardness over time in all three media when compared to base metal due to the high level of corrosion attack that mild steel had developed, the degradation of stainless steel was lower than that of mild steel since it mild steel have lower resistance of corrosion.

4.8. Corrosion rate analysis using Taguchi method

In this work the experiment was conducted by varying the corrosion parameters such as exposure time, metal and test media have been split into mixed level values. In order to determine the most influential cause of corrosion of steel in food processing industry the listed parameters for test media and exposure time with three and for metal type two levels have been considered for this study as shown in table 4.4. From these there parameters the levels of Exposure time were taken by selecting three durations from during corrosion rate data within ten days interval.

Table 4.4: Selected Corrosion Parameters and Their Levels

S. No	***Process parameter***	***Units***	***Levels***		
			1	**2**	**3**
1	Metal type	Type	Stainless steel	Mild steel	_
2	Test media	Type	Mango	Orange	Tomato
3	Exposure time	Days	10	20	30

Table 4.5 shows the experimental plan and experimental trial that shown 18 (L_{18}) trials of experiments using taguchi method. The data also show that the maximum and minimum values of corrosion rate during the experimental investigations of corrosion behaviour of mild steel and stainless steel three food environment.

Table 4.5: Experimental trial of corrosion rate as response parameter

NO	*Metal type*	*Test media*	*Exposure time*	*Corrosion rate*	*Signal/ noise ratio*
1	Stainless steel	Mango	10	0.0023	52.7654
2	Stainless steel	Mango	20	0.0031	50.1728
3	Stainless steel	Mango	30	0.0028	51.0568
4	Stainless steel	Orange	10	0.0029	50.7520
5	Stainless steel	Orange	20	0.0024	52.3958
6	Stainless steel	Orange	30	0.0021	53.5556
7	Stainless steel	Tomato	10	0.0019	54.4249
8	Stainless steel	Tomato	20	0.0018	54.8945
9	Stainless steel	Tomato	30	0.0016	55.9176
10	Mild steel	Mango	10	0.96	0.3546
11	Mild steel	Mango	20	0.73	2.7335
12	Mild steel	Mango	30	0.6	4.4370
13	Mild steel	Orange	10	1.31	-2.3454
14	Mild steel	Orange	20	0.85	1.4116
15	Mild steel	Orange	30	0.67	3.4785
16	Mild steel	Tomato	10	0.87	1.2096
17	Mild steel	Tomato	20	0.67	3.4785
18	Mild steel	Tomato	30	0.55	5.1927

4.8.1. Mean response analysis

A response table is calculated for each response characteristic, such as mean and signal-to-noise ratio. The response table can show which factors have the most impact on the response and which degree of the factor is associated with greater or lower response characteristic values. The steps for creating a response table are as follows:

1. Calculates the chosen response characteristic for each level's exposure time, test media, metal type.
2. After that, the delta values, which are the differences between the greatest average response characteristic value and the lowest average response characteristic value for levels of that factor, are determined.

3. The delta values are used to assign ranks from high to low. The factor with the highest delta value receives the top ranking.

Table 4.6: Response Table for Means

Level	Metal type	Test media	Exposure time
1	0.801111	0.383033	0.524517
2	0.002322	0.472900	0.376217
3	-	0.349217	0.304417
Delta	0.798789	0.123683	0.220100
Rank	1	3	2

From Table 4.6 metal type has the highest value so it is ranked first, Exposure time has the second highest value and ranked second, test media has the least value compared to other factors so it is ranked third. That means will be taken as a possible parameter combination for smaller is better values. Main effect plots for means helps adjust the mean on better value. The control factors main effect plot for means of corrosion rate value variations is as shown in Figure 4.17.

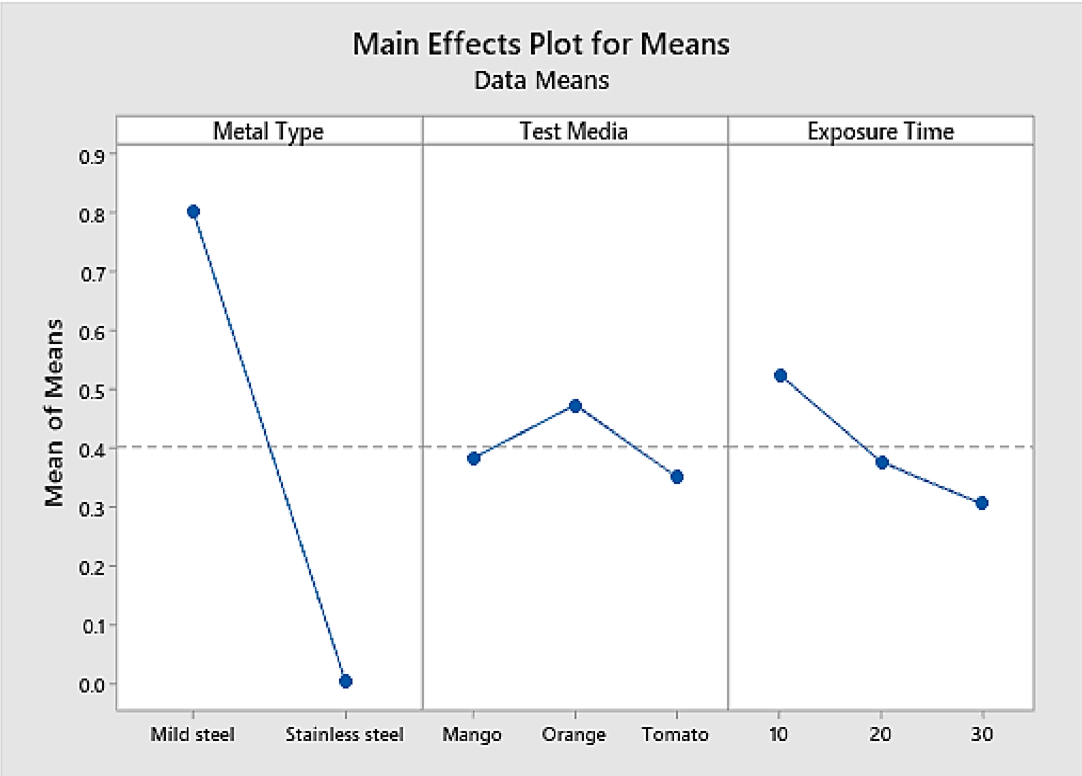


Figure 4.17 Mean effect plot for means

4.8.2. Signal to noise ratio analysis

As a result, the average to SD ratio matches the S / N ratio. Taguchi evaluated the quality attribute that differed from the desired value using the S/N ratio. As a result, the smaller the corrosion rate, good resistance of material and better quality. Based on the achieved corrosion rate result, the effect of the above parameters on corrosion rate was examined. Table 4.7 shows that the metal type percentage has the biggest effect (Delta = 50.665, Rank =1^{st}) followed by exposure time and test media (Delta =2.645, rank =,2^{nd} Delta =2.746, and3^{rd}).

Table 4.7: Response Table for Signal to Noise Ratios Smaller is better

Level	Metal type	Test media	Exposure time
1	2.227	26.920	26.194
2	52.882	26.541	27.514
3	-	29.186	28.940
Delta	50.665	2.645	2.746
Rank	1	3	2

The effect of corrosion parameters on corrosion rate, based on their rank, are shown in Figure 4.18. The numerical value of the maximum point in each graph shows the best value of that particular parameter at that level. The most effective parameter to increase the corrosion rate is the metal type when compared with other corrosion factors and the second exposure time and test media has the least effect on the value of corrosion rate analysis.

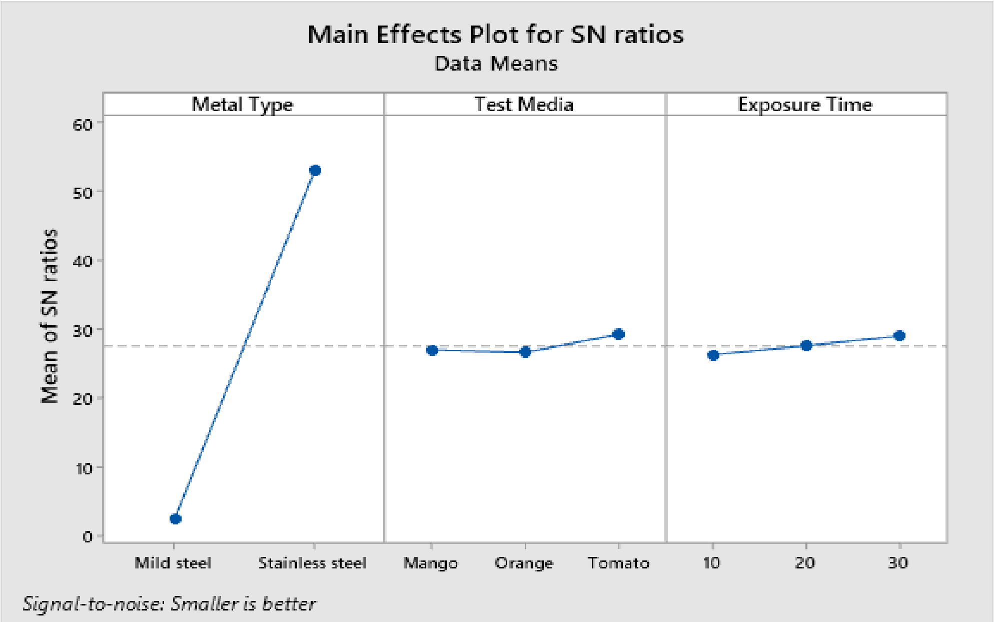


Figure 4.18 Main effects plot for S/N ratios

4.8.3. Analysis of Variance (ANOVA)

The adequacy of the developed models is tested using the ANOVA. As per this technique, if the calculated value of the Fratio of the developed model is less than the standard Fratio (F-table value 2.38) value at the desired level of confidence of 95%, then the model is said to be adequate within the confidence limit. The coefficient of determination 'R^2' for the above-developed models is found to be above 99%. The most significant parameters that affect the corrosion rate of steel are identified using analysis of variance (ANOVA). The study was performed based on their S / N ratios to obtain the percentage contribution of each of the factors.

Where, DF: Degree of freedom, SS: Sum of squares, %Contr.: percentage contribution, Adj. SS: adjusted sum of squares, Adj. MS: adjusted mean of squares, F-value: variance, P-value: calculated probability with a confidence interval of 95 percent is displayed in table 4.8.

Table 4.8: Analysis of Variance for SN ratios

Source	DF	Seq SS	% Contr.	Adj SS	Adj MS	F	P	Effect
Metal type	1	11551.2	99	11551.2	11551.2	5031.01	0	HS
Test media	2	24.6	0.21	24.6	12.3	5.35	0.022	HS
exposure time	2	22.6	0.19	22.6	11.3	4.93	0.027	HS
Residual Error	12	27.6	0.24	27.6	2.3			
Total	**17**	**11626**	**100**					

S=1.5153, $\mathbf{R^2}$= 99.76%, $\mathbf{R^2}$ **adj**. = 99.66%

The metal type (99%) has a highly significant impact on corrosion rate of steel and the test media (0.21%) and Exposure time (0.19%) have a significant impact on the corrosion rate of steel as shown in the Table 4.8. As a result, the metal type has a big influence on the responses corrosion of steel. There for, selection of material for food processing machineries is the most crucial issue in food processing industries.

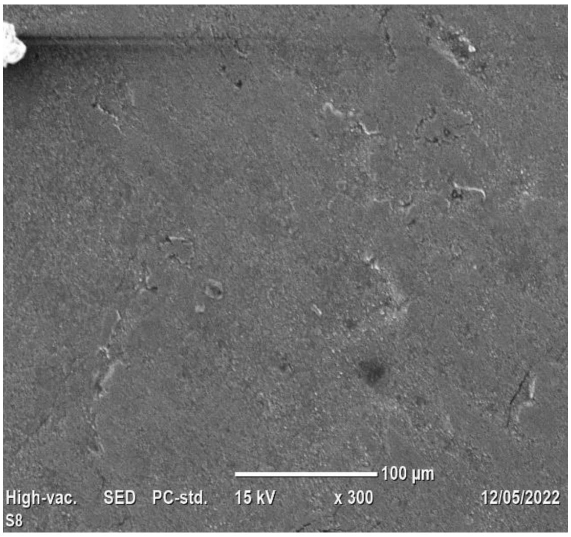
4.9. Morphological analysis

Figure 4.18 reveals scanning electron images of mild steel and stainless steel (304L) surfaces after 30 days of immersion in the studied fruit juices and even on the surface of base metal before corrosion. Significant corrosion products were observed on mild steel surfaces exposed to mango juice (pH 4.22), orange juice (pH 3.58) and tomato juice (pH 4.26).

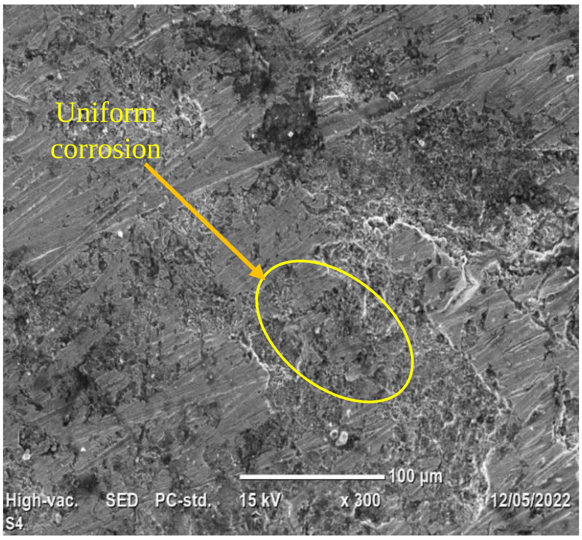
Figure 4.19 (a) shows the surface micrograph of mild steel base metal. There is no visible attack on the image due to the morphological analysis being done before the immersion and corrosion tests. The structure before immersion exhibits some parts with spot white patches, specifically at the top side of the image in the natural state. The surface micrograph in Figure 4.19(b) depicts the image of the corroded sample in mango medium. The structure shows no sign of cracks across the surface oxide layer of the mild steel sample but shows a uniform corrosion attack with a complete closed structure. The cross-sectional SEM image of mild steel surfaces after 30 days of immersion in orange juice presented in Figure 4.19 (c) shows localized corrosion like a pit with some iron oxide(s) around the pit and some micro cracks. It can be suggested that the wider the oxide cracks, the greater the corrosive effect of the test medium. The presence of comparatively more corrosion products on mild steel immersed in orange juice suggests that pH is a significant factor in mild steel. The SEM image in Figure 4.19(d) demonstrates a partial breakdown of the oxide layer and some corrosion attack, which may indicate localized corrosion on the mild steel sample's surface. Corrosion in fruit juices increases in parallel with the lowering of solution pH. Interestingly, the corrosion products formed in the fruit juices (particularly tomato and orange juices) are present as (apparently hollow) microspheres. This indicates that the complex chemical composition of the fruit juices exerts an influence on both the kinetics of oxide dissolution and the morphology of the oxides formed in them. The samples show different degrees of oxide scale incurred in the various test media after the immersion period.

Figure 4.20 (a) shows a surface micrograph of the stainless steel base metal before the corrosion test. One large crack was observed on the base metal image. This was due to a fabrication error. Figure 4.20 (b) shows the morphological SEM image of stainless steel in mango juice. In this structural surface, there was little pitting attack on the top side of the image, and the corrosive effect was increased at the sample's crack surface. The image shown in Figure 4.20 (c) depicts the same effect with stainless steel in mango juice. Nevertheless, the corrosion effect of stainless steel in mango juice was a little bit higher in mango juice than in orange juice.

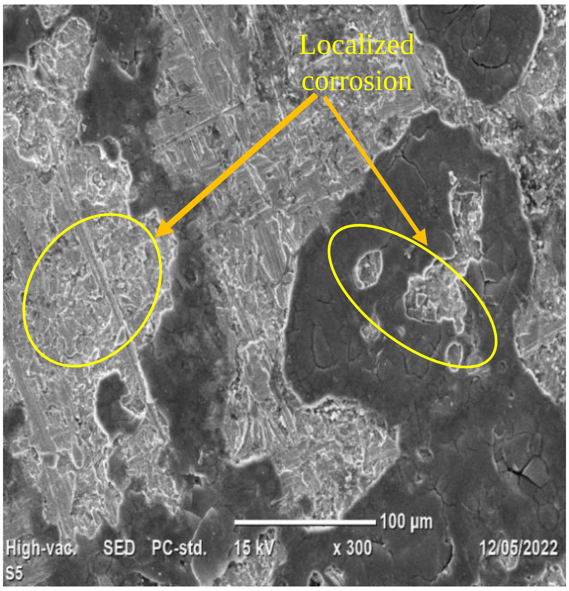
Generally, according to SEM image analysis, mild steel in an orange juice solution corroded at the fastest rate, whereas stainless steel in a tomato juice solution corroded at the lowest rate. Compared to samples of stainless steel, mild steel samples showed much greater rates of corrosion. This is in agreement with researchers (Omotoso et al., 2017; Loto, 2012). Depending on all corrosion analysis of mild steel and stainless steel mild steel is not recommended for food processing machinery because it is easily attacked by corrosion, leading to product contamination, failure of machineries, health problems for product users, and other problems. In the food processing industry, product quality, health, and sanitation are key concerns. Because of their unique functions, the industry cannot tolerate corrosion deposits on manufactured items. Due to their extremely complex composition, determining the specific ingredients of food is difficult.



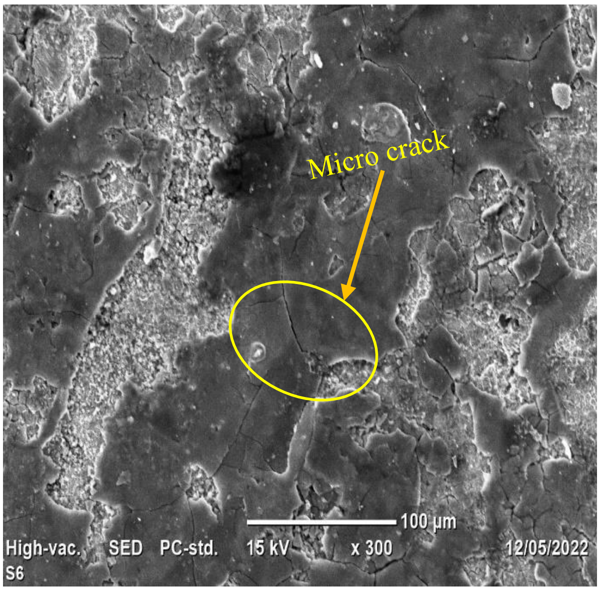
(a)



(b)

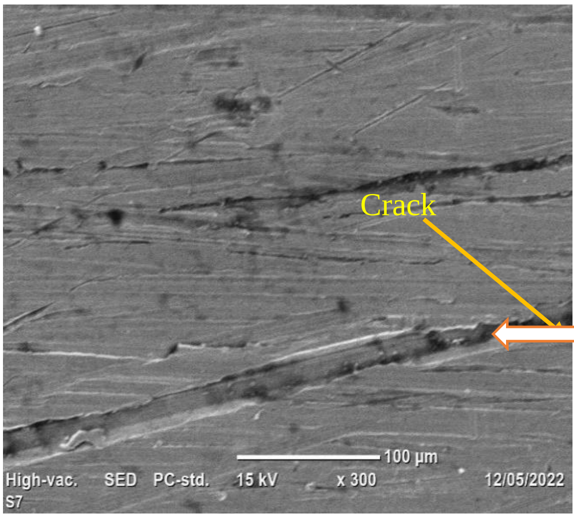


(c)

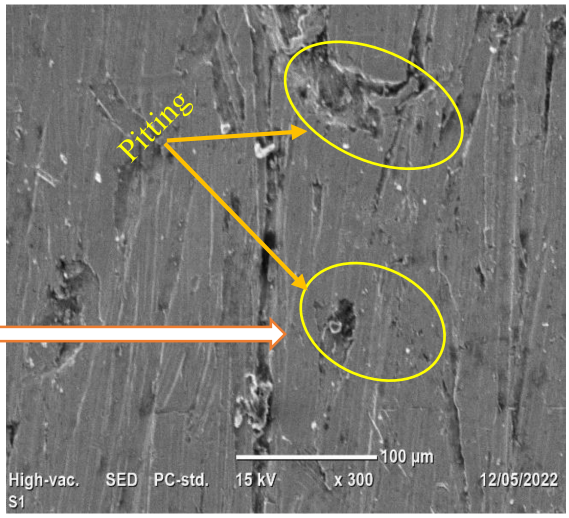


(d)

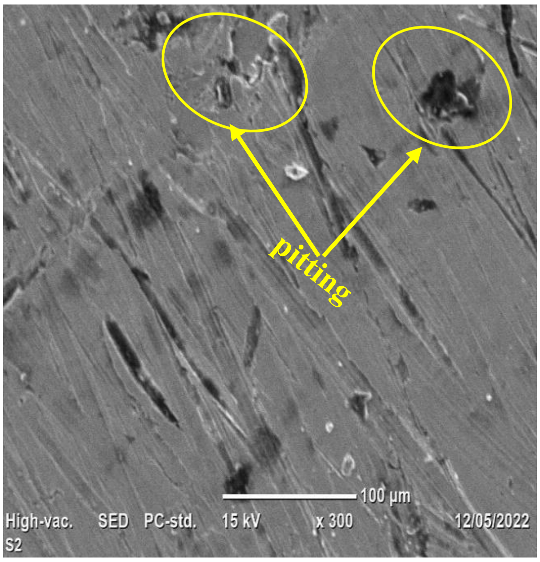
Figure 4.19 Morphology of mild steel sample after corrosion (a), mild steel base metal b) mild steel in mango juice, (c) mild steel in orange juice and (d), and mild steel in tomato juice



(a)



(b)



(c)

(d)

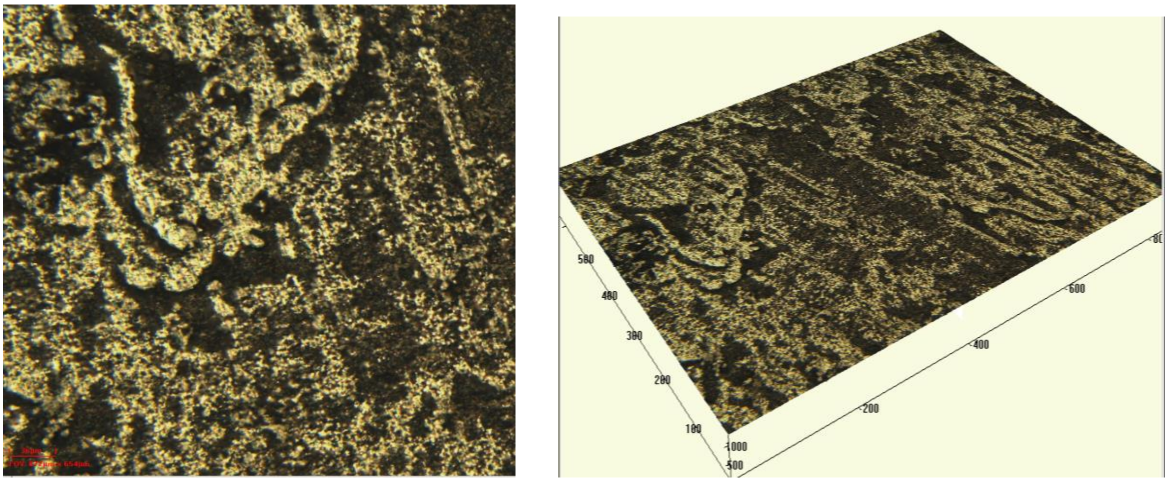
Figure 4.20 Morphology of stainless steel sample after corrosion (a), stainless steel base metal, (b) stainless steel in mango juice, (c) stainless steel in orange juice and (d) stainless steel in tomato juice.

4.10. 3D surface profiler analysis

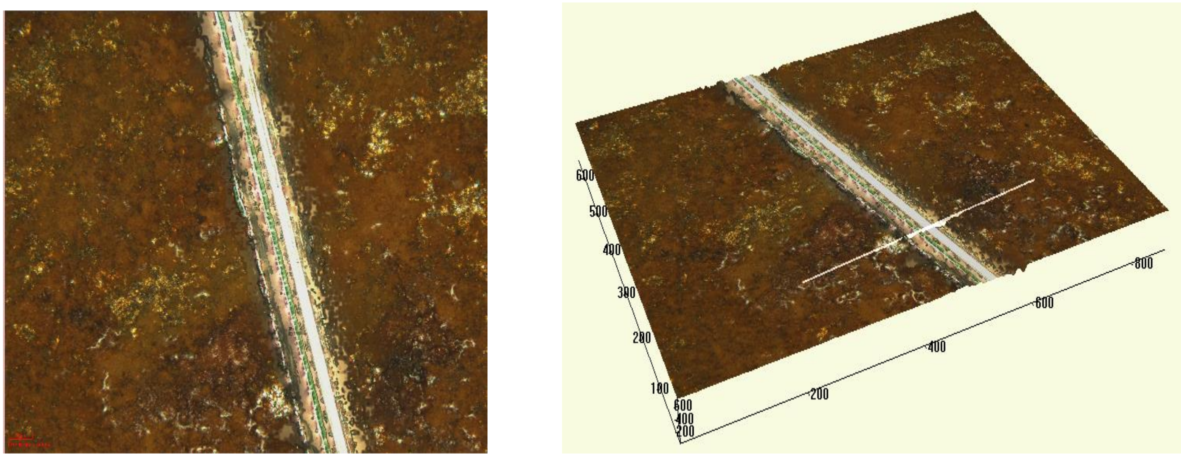
Besides tactile roughness measurements, an optical 3D roughness measurement is non-contact and non-reactive, preventing any non-destructive harm or influence from the measurement process on sensitive surfaces. Due to surface damage, it is challenging to evaluate the pitting corrosion. This kind of corrosion happens when salty and acidic surroundings erode the passivating oxide that has been produced on the metal surface. Pitting or tiny holes can readily start and then grow gradually in all directions. For all materials, corrosion pits spread more laterally than they do vertically (Woldetinsay et al., 2018). Nevertheless, an optical surface profilometry was employed to measure corrosion pit depth and width, topography and surface roughness for both mild steel and stainless steel samples. The analysis was done on three samples for mild steel, i.e., mild steel in orange and tomato juice with mild steel base metal, and two samples for stainless steel, i.e., stainless steel in mango juice and stainless steel base metal. The selection is based on the samples which have the highest and the lowest corrosion rate for mild steel, and for stainless steel, the samples which have only slightly higher corrosion rates due to the fact that there was no big difference between stainless steel samples in three environments after 30 days of exposure time. The specimen to be measured is placed on the table of the light sectioning microscope under the projected light. Real surface roughness measurement data provides an easy and thorough view of an entire surface and visualizes the 3D surface topography. The line which is indicated in white shows the reference path line important for measuring the corrosion depth. The capture software's focus is adjusted such that the roughness profile may be seen clearly on the screen (ELF-VGA). The capturing program is used to take a picture of the seen profile after choosing an appropriate section. For every 3D surface roughness measurement, this step was repeated. Figure 21 (a) shows the topographical 2D and 3D profile image of mild steel base metal. From the structural surface not indicate any corrosion attack rather the microstructure which reveals a mixture of pearlite and a dominant ferrite phase while the darker part indicates the pearlite phase and the other ferritic phase.

Figure 4.21 (b) shows the sample that has the highest corrosion attack, which is mild steel in an orange juice environment. In this structure, the colour of mild steel base metal changed to a brownish colour, which indicates a high corrosive effect on the metal due to the acidity of the environment. Figure 21 (c) depicts the 2D and 3D surface topography of mild steel in tomato juice. The structural image reveals surface damage indicated by a brownish colour and the initiation of corrosion observed on other surfaces. The lower corrosion surface looked more like mild steel in tomato juice than in orange juice.

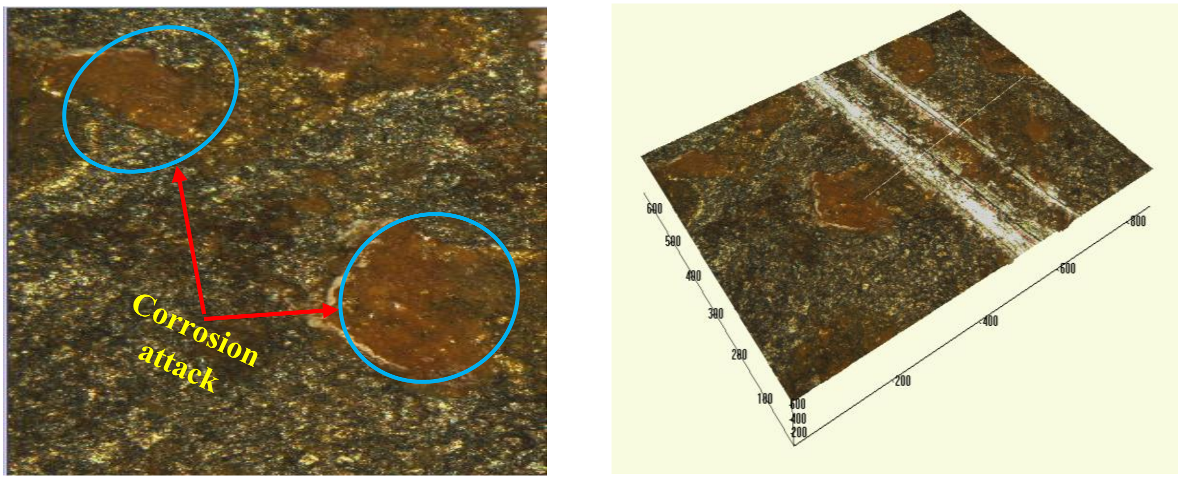
Figure 4.22 (a) shows the surface tophography of stainless steel base metal. The surface reveals the microstructure of the metal .The structures were identified as austenite with a white colour and ferrite with a dark colour. The structural image in figure 4.22 (b) reveals the surface topography of stainless steel in mango medium. The corrosion attack indicated darker colour.



(a)

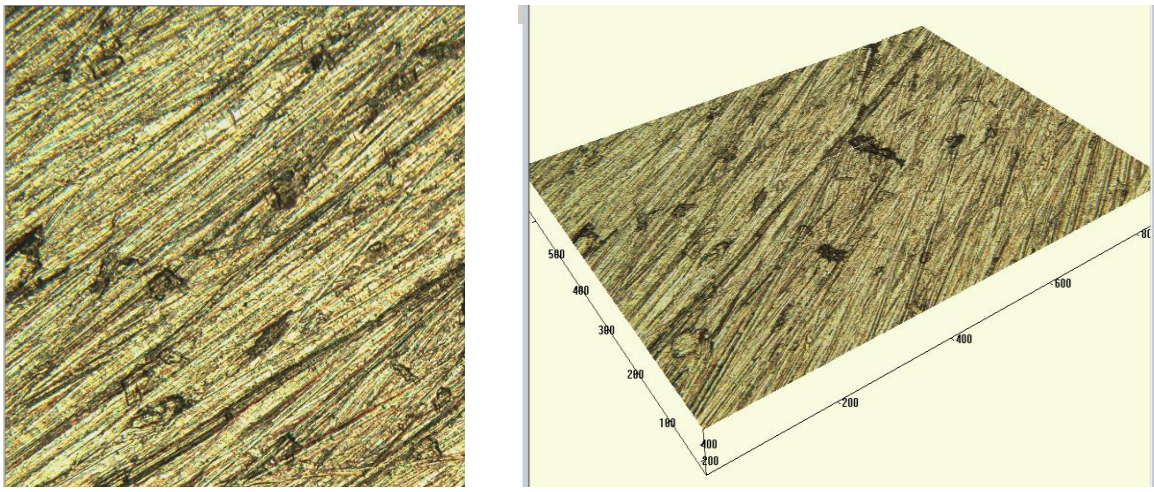


(b)

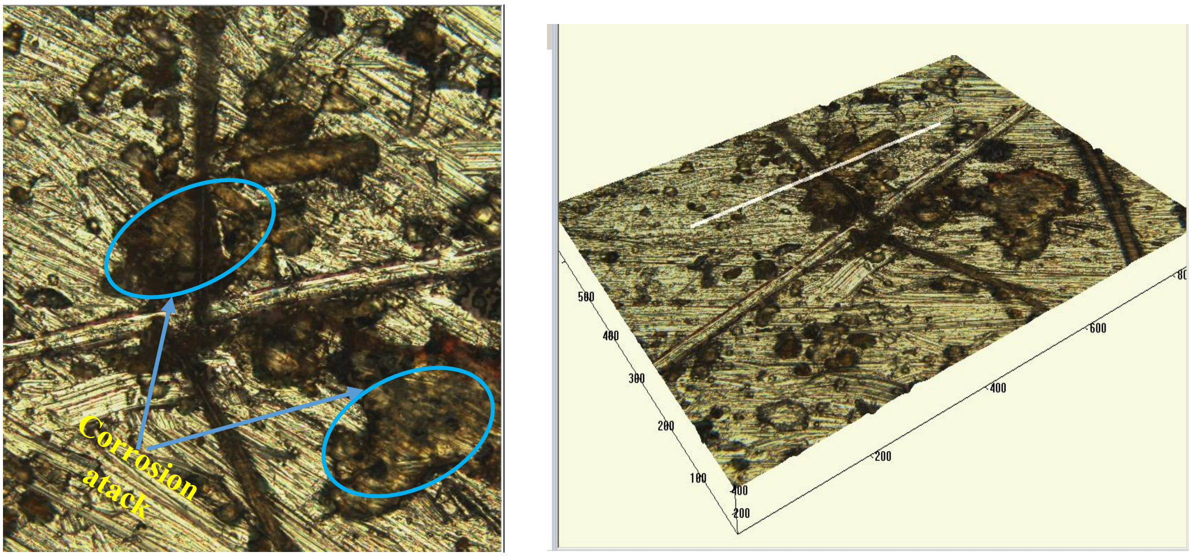


(c)

Figure 4.21 3D image of mild steel after corrosion (a) 3D image of mild steel base metal, (b) 3D image of mild steel in orange juice and (c) 3d image of mild steel in tomato juice.



(a)



(b)

Figure 4.22 Topographic image of stainless steel before and after corrosion (a) 3D image of stainless steel base metal and (b) 3D image of stainless steel in mango juice.

The corrosion damage was the maximum for mild steel in orange juice than other stainless steel and mild steel samples. The maximum corrosion pit depth and width were found to be 2.069µm and 11.35µm, respectively. The maximum corrosion pit depth and width for mild steel in tomato juice were 2.338µm and 5µm, respectively and finally for stainless steel in mango juice maximum corrosion pit depth and width were found to be 1.893µm and 4.5µm. The surface roughness of the metals also measured using 3D surface profiler. From the result, it was found that the surface roughness of both mild steel and stainless steel increases after corrosion. In the food processing industry, a reduction in surface smoothness has a negative impact; for example, it makes cleaning difficult because it is basic in the food processing industry, and if there is a poor surface on the surface of the machinery, dust will easily be sucked on the surface, resulting in contamination of food products. After corrosion, there was a significant reduction in the surface smoothness of mild steel. The average value of surface roughness for mild steel base metal was found to be 0.6842µm. It increased to 2.16µm for mild steel in orange juice and 1.538µm for mild steel in tomato juice. In the same manner, the surface roughness of stainless steel base metal was found to be 0.128µm. The value increased after corrosion. The average surface roughness of stainless steel in mango juice after an exposure period was found to be 2.165µm.

CHAPTER - 5

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This research investigated accelerated electrochemical corrosion behaviour of mild steel and stainless steel utilized for food processing machineries in, mango, orange and tomato food environments using weight loss measurement and open circuit potential electrochemical techniques. Morphological and 3D image analysis was performed in order to know surface damage and pit depth as well as pit width of the steel due to corrosion. Finally the experimental results were analysed using mixed taguchi design L_{18} orthogonal array, the signal-to-noise ratio method and ANOVA was used to determine the influential effect of each parameter to corrosion rate of steel. As a result of the experimental findings, the following conclusions were drawn:

- The analyses of the results obtained from the study showed weight loss of both mild steel and 304L stainless steel was increased with increase in exposure time and acidity of test medium. The weight loss of mild steel was highest in orange media losing 0.68g, followed by the sample mango media with 0.55g and in tomato media losing 0.51g. This behaviour shows that the orange medium has a more corrosive effect on mild steel sample than the other two competing media. The weight loss of 304L stainless steel sample in the mango and orange medium were higher with value 0.0026g and 0.0022g weight respectively than in tomato media losing 0.0015g. Tomato medium shows less effect of corrosion on stainless steel sample and subsequently had less weight loss. stainless steel had a far lower weight loss than mild steel since it have 19 percent chromium and is a result of a very thin (about 5 nanometres) oxide layer on the steel's surface results to have high degree of corrosion resistance.
- Corrosion rate decrease gradually for both mild steel and 304L stainless steel Exposure time increase and at some point it be slowly decrease. The same with weight loss the corrosion rate of mild steel was higher in orange media with value 0.67mmpy and lower in tomato media with value 0.57mmpy. The corrosion rate of 304L stainless steel was higher in mango media with value 0.0028mmpy and lower in tomato media with value 0.0016mmpy. Corrosion was dependent on pH, whereby the rate of corrosion had a tendency to increase with increasing acidity of the juices. Generally,

the results showed that stainless steel have the highest resistance to corrosion than mild steel

- ❖ From micro hardness result it was shown that the micro hardness of both mild steel and 304L stainless steel decrease after corrosion due to formation of small holes or pits as a result of corrosion. Hardness value varies with the level of corrosion attack on the surface and the exposure time increase corrosion resistance of material decrease and also hardness decrease.
- ❖ The electrochemical study showed that stainless steel have more corrosion resistance than mild steel in all three medium due to the potential of stainless steel have high potential and lower corrosion current density than mild steel. Corrosion potential of the mild steel sample is lowest in the orange medium (-596mV), while specimen in mango exhibited the highest Ecorr (-573 mV). The corrosion potential of stainless steel juice was higher in tomato juice with value -144mVolt, while the sample in orange media exhibited the lowest corrosion potential with value -361mVolt.
- ❖ The morphological and 3D image analysis of corroded mild steel and 304L stainless steel revealed that surface images of uniform and localised corrosion products across the oxide deposits with different sizes of surface and a partial breakdown of the oxide layer and dense surface fractures, especially in mild steel sample. The samples show different degrees of oxide scales incurred in three test media. The morphological SEM image of stainless steel show little pitting attack at the top side of the images in mango and orange juice and initiation of corrosion in tomato media. According to 3D image analysis the maximum corrosion pit depth and width of mild steel were 2.069μm and 11.35μm, respectively in orange juice and for stainless steel juice maximum corrosion pit depth and width were found to be 1.893μm and 4.5μm in mango media.

In order to determine the most influential cause of corrosion of steel in food processing industry experimental study was conducted by varying the corrosion parameters like test media ,exposure and metal type using mixed taguchi design L18 orthogonal array. According to ANOVA result the metal type (99%) has a highly significant impact on corrosion rate of steel and the test media (0.21%) and Exposure time (0.19%) have a significant impact on the corrosion rate of steel As a result, the metal type has a big influence on the responses corrosion of steel.

5.2. Recommendation

The following recommendations are made based on the study's findings and conclusions.

- ➢ The corrosion behaviour of 304L stainless steel and mild steel in three food environments focused on fruit juice industries was employed in this study, it is suggested further to study the corrosion behaviour of these metals in different varieties of food processing environments like in milk, biscuits and soft drink factories so as to compare their chemical composition of food environments and behaviours on the metallic specimen.
- ➢ For fruit juice processing industries it is recommended that to give critical concern for scheduled mentainance, scheduled cleaning for their machineries because in food processing industry product quality, health, life time of machineries and sanitation are key concerns. In addition it is suggested to give great attention in selection of materials depending on their corrosion behaviour during installation of machineries.

5.3. Scope for future work

The following will be investigated further as part of future research:

- ✓ The relationship between metal thickness and corrosion rates in the test media is important and should be investigated to determine the extent of corrosion effects on different sizes of the metal sample at the same physical condition, so further research could investigate the corrosion behaviour of metals in different thickness.
- ✓ change in temperature can also affect the resistance of a material to localized corrosion and food processing machineries are highly influenced by heat due to large amount of heat utilized in food processing industries especially in evaporator section, sterilization section and pre heating, there for the study should extend to include the effect of temperature on the corrosion behaviour of materials.
- ✓ The economic impact of corrosion in the food processing industry is a very critical issue and has not been well investigated. Therefore, further research could investigate economic loss due to corrosion in food processing Machineries, especially in Ethiopian food processing industries.

Research fund Acknowledgment

This research project is founded by Adama Science and Technology University under the grant number ASTU/SM-R/585/22, Adama, Ethiopia.

REFFERENCE

Abdel-Gaber, A. M., Hijazi, K. M., Younes, G. O., & Nsouli, B. (2017). Comparative study of the inhibitive action between the bitter orange leaf extract and its chemical constituent linalool on the mild steel corrosion in HCl solution. Química Nova, 40(4), 395-401.

Adetunji, O. R., Aiyedun, P. O., Arowolo, T. A., & Alamu, O. J. (2012). Corrosion Resistance of Austenitic Stainless Steel in Cassava Fluid, Maize Pulp, and Seawater. Pacific Journal of Science and Technology, 13(2), 8-12.

Afolabi, A. S., Ngwenya, T. G., Sanusi, O. K., & Abdulkareem, A. S. (2013). Stress corrosion cracking of mild steel in orange juice. In Proceeding of the World Congress on Engineering (Vol. 1, pp. 13-20).

Aghuy, A. A., Zakeri, M., Moayed, M. H., & Mazinani, M. (2015). Effect of grain size on pitting corrosion of 304L austenitic stainless steel. Corrosion Science, 94, 368-376

Amin, M. A., Khaled, K. F., & Fadl-Allah, S. A. (2010). Testing validity of the Tafel extrapolation method for monitoring corrosion of cold rolled steel in HCl solutions–experimental and theoretical studies. Corrosion Science, 52(1), 140-151.

Amit, S. K., Uddin, M., Rahman, R., Islam, S. M., & Khan, M. S. (2017). A review on mech-anisms and commercial aspects of food preservation and processing. Agriculture & Food Security, 6(1),

Atkins, P., & Depaula, J. (2010). Physical Chemistry, 8th edition. Oxfort: Oxfort Press

Avila-Sierra, A., Zhang, Z. J., & Fryer, P. J. (2019). Effect of surface characteristics on cleaning performance for CIP system in food processing. Energy Procedia, 161, 115-122.

Ayoola, A. A., Fayomi, O. S. I., & Ogunkanmbi, S. O. (2018). Data on inhibitive performance of chloraphenicol drug on A315 mild steel in acidic medium. Data in Brief, 19, 804-809.

Bardal, E. (2003). Corrosion and Protection: Engineering Materials and Processes.Spinger: Verlag London Limited

Benea, L., & Simionescu, N. Effect of biological solution and pH on corrosion resistance of 304L SS for dental brackets. Rev Chim, 71, 180-187.

BV, V. L. C. I. (2021). *Corrosion Testing via Electrochemical Impedance Spectroscopy (EIS) - Van Loon Chemical Innovations*. https://vlci.biz/corrosion-testing-via-electrochemical-impedance-eis/

Corrosionpedia. (2019). *What is Uniform Corrosion? - Definition from Corrosionpedia*. https://www.corrosionpedia.com/definition/6542/uniform-corrosion

Corrosionpedia. (2021). *Fretting Corrosion - Definition from Corrosionpedia*. https://www.corrosionpedia.com/definition/4444/weldability

De-Giorgi, V. G. (1992) Corrosion basics and computer modelling. Naval Research Laboratory Report, Department of the Navy, Washington DC, 203755000 USA

Dey, S., & Agrawal, M. K. (2017). Investigation of corrosion behavior of TinplateIn fruit juice. International Journal of Engineering and Technology, 9, 234-242.

Dhaiveegan, P., Elangovan, N., Nishimura, T., & Rajendran, N. (2016). Corrosion behavior of 316L and 304 stainless steels exposed to industrial-marine-urban environment: field study. Rsc Advances, 6(53

Douadi, T., Hamani, H., Daoud, D., Al-Noaimi, M., & Chafaa, S. (2017). Effect of temperature and hydrodynamic conditions on corrosion inhibition of an azomethine compounds for mild steel in 1 M HCl solution. Journal of the Taiwan Institute of Chemical Engineers, 71, 388-404.

Duanjie Li (2017). Corrosion Hardness Effect of Steel Screws By Nanoindentation. 6 Morgan, Ste156, Irvine CA 92618 · P: 949.461.9292 · F: 949.461.9232 · nanovea.com

Dula, S., Ajayeoba, T. A., & Ijabadeniyi, O. A. (2021). Bacterial biofilm formation on stainless steel in the food processing environment and its health implications. Folia Microbiologica, 66(3), 293-302.

Durowoju, M. O., Babatunde, I. A., Adedoyin, O. J., & Oladosu, K. (2014). Corrosion effect of sweet cassava fluid on steels under different working conditions. IOSR Journal of Mechanical and Civil Engineering, 11(4), 50-55.

El Ibrahimi, B., El Mouaden, K., Jmiai, A., Baddouh, A., El Issami, S., Bazzi, L., & Hilali, M. (2019). Understanding the influence of solution's pH on the corrosion of tin in saline solution containing functional amino acids using electrochemical techniques and molecular modeling. Surfaces and Interfaces, 17, 100343.

Emt. (2017). *Corrosion Coupon For Testing - Emt Pipe Cleaning Pig*. https://emt-pipe.com/product/corrosion-coupon-2/

Enveremadu, C. C., Adekunle, A. A., Tech, B., & Adeala, A. Evaluation of Corrosion Cost in Some Selected Fruit Juice-Processing Industries in South-West Nigeria.

Faille, C., Cunault, C., Dubois, T., & Benezech, T. (2018). Hygienic design of food processing lines to mitigate the risk of bacterial food contamination with respect to environmental concerns. Innovative Food Science & Emerging Technologies, 46, 65-73.

Fayomi, O. S. I., Akande, I. G., & Odigie, S. (2019, December). Economic impact of corro-sion in oil sectors and prevention: an overview. In Journal of Physics: Conference Se-ries (Vol. 1378, No

Fekry, A. M., Ahmed, R. A., & Bioumy, S. A. (2020). Silver nanoparticle/graphene oxide/chitosan coatings for protection of surfaces in food processing. Journal of Bio-and Tribo-Corrosion, 6(4), 1-16.

Gadpale, V., Banjare, P. N., & Manoj, M. K. (2018, March). Effect of ageing time and temperature on corrosion behaviour of aluminum alloy 2014. In IOP Conference Series: Materials Science and Engineering (Vol. 338, No. 1, p. 012008). IOP Publishing.

Gupta, S., & Anand, S. (2018). Induction of pitting corrosion on stainless steel (grades 304 and 316) used in dairy industry by biofilms of common sporeformers. International Journal of Dairy Technology, 71(2), 519-531.

Hamzat, A. K., Adediran, I. A., Alhems, L. M., & Riaz, M. (2020). Investigation of corrosion rate of mild steel in fruit juice environment using factorial experimental design. Inter-national Journal of Corrosion, 2020.

Handbook, A. (1987). vol 13: Corrosion. ISBN: 0-08170-019-0. ASM International, USA

Ismail, A., Kar, S. L., & Ibrahim, H. (2018). Corrosion performance of aluminum and stannum as beverage packaging. In Key Engineering Materials (Vol. 791, pp. 88-94). Trans Tech Publications Ltd.

Jekayinfa, S. O., Okekunle, P. O., Amole, I. G., & Oyelade, J. A. (2005). Evaluation of corrosion cost in some selected food and agro-processing industries in Nigeria. Anti-Corrosion Methods and Materials.

Jellesen, M. S., Rasmussen, A. A., & Hilbert, L. R. (2006). A review of metal release in the food industry. Materials and corrosion, 57(5), 387-393.

Jessima, S. J., Subhashini, S., & Arulraj, J. (2020). Sunova spirulina powder as an effective environmentally friendly corrosion inhibitor for mild steel in acid medium. Journal of Bio- and Tribo-Corrosion, 6(3), 1-13.

Jiru, W. G., Sankar, M. R., & Dixit, U. S. (2019). Laser surface alloying of aluminum for improving acid corrosion resistance. Journal of the Institution of Engineers (India): Series C, 100(3), 481-492.

Jun, C. H. E. N., Zhang, Q., Li, Q. A., Fu, S. L., & Wang, J. Z. (2014). Corrosion and tribocorrosion behaviors of AISI 316 stainless steel and Ti6Al4V alloys in artificial seawater. Transactions of Nonferrous Metals Society of China, 24(4), 1022-1031.

Kansara, D. P., Sorathiya, A. P., & Patel, H. R. (2018). Corrosion monitoring and detection techniques in petrochemical refineries. IOSR Journal of Electrical and Electronics Engineering (IOSRJEEE), 13(2), 85-93.

Kim, D. Muralidharan, S. Ha, T. Bae, J. Ha, Y. Lee, H. and Scantlebury, J. D. (2006) Electrochemical studies on the alternating current corrosion of mild steel under cathodic protection condition in marine environments. Journal of Electrochimica Actica. Vol. 51, pp. 5259-5267.

Li, J., Wang, Q., Yang, Y., Wu, Z., Tan, L., Ren, Y., & Yang, K. (2019). Enhancing pitting corrosion resistance of severely cold-worked high nitrogen austenitic stainless steel by nitric acid passivation. Journal of The Electrochemical Society, 166(13), C365.

Liu, B. Y., Wang, Y. W., & Guan, Y. (2021). A study of corrosion performance of tinplate with different tin coating thickness in H2SO4 solution. Materialwissenschaft und Werkstofftechnik, 52(4), 433-440.

Lopez, D. A., Schreiner, W. D., De Sánchez, S. R., & Simison, S. N. (2003). The influence of carbon steel microstructure on corrosion layers: an XPS and SEM characterization. Applied surface science, 207(1-4), 69-85.

Loto, R. T., Loto, C. A., Popoola, A. P. I., & Fedotova, T. (2014). Inhibition effect of 2-amino, 5-ethyl-1, 3, 4 thiadiazole on the corrosion of austenitic stainless steel type 304 in dilute sulphuric acid. Portugaliae Electrochimica Acta, 32(5), 337-354.

Luna, M. C., Le Manh, T., Sierra, R. C., Flores, J. M., Rojas, L. L., & Estrada, E. A. (2019). Study of corrosion behavior of API 5L X52 steel in sulfuric acid in the presence of ionic liquid 1-ethyl 3-methylimidazolium thiocyanate as corrosion inhibitor. Journal of Molecular Liquids, 289, 111106.

Maldonado-Celis, M. E., Yahia, E. M., Bedoya, R., Landázuri, P., Loango, N., Aguillón, J., & Guerrero Ospina, J. C. (2019). Chemical composition of mango (Mangifera indica L.) fruit: Nutritional and phytochemical compounds. Frontiers in plant science, 1073.

Mareci, D., Trinca, L. C., Cotea, V. V., & Souto, R. M. (2017). Electrochemical studies on the stability and corrosion resistance of two austenitic stainless steels for soft drinks containers. Int. J. Electrochem. Sci, 12, 5438-5449.

Mazinanian, N., Herting, G., Wallinder, I. O., & Hedberg, Y. (2016). Metal release and corrosion resistance of different stainless steel grades in simulated food contact. Corrosion, 72(6), 775-790.

Metal samples. (n.d.). *Introduction to Electrical Resistance (ER) Monitoring*. https://www.alspi.com/erintro.htm

Mudashiru, L. O., Olafimihan, E. O., Adetola, S. O., & Azeez, T. M. (2018). Corrosion Effects of ASTM A513 Steel in Cashew and Pineapple Juice Using RSM.

Nesic S (2007) Key issues related to modelling of internal corrosion of oil and gas pipelines. Corros Sci 49(12): 4308-4338

Nishimoto, M., Muto, I., Sugawara, Y., & Hara, N. (2019). Morphological characteristics of trenching around MnS inclusions in type 316 stainless steel: the role of molybdenum in pitting corrosion resistance. Journal of the Electrochemical Society, 166(11), C3081.

Nistoran, M. B., Mnerie, G. V., & Mnerie, D. (2020). Considerations about the Organic Acids Effect on Weldings in Food Processing Industry. In Advanced Materials Research (Vol. 1157, pp. 108-112). Trans Tech Publications Ltd.), 47314-47324.

Ofoegbu, S. U., Ofoegbu, P. U., Neife, S. I., & Okorie, B. A. (2011). Corrosion behaviour of steels in Nigerian food processing environments. Journal of Applied Sciences and En-vironmental Management, 15(1).

Ogundare, O. Momoh, I. M. Akinribide, O. J. Adetunji, A. R. Borode, J. O. Olusunle, S. O. and Adewoye, O. O. (2012) Comparative study of corrosion sensitivity of selected ferrous metals in crude oil. Journal of Minerals and Characterisation and Engineering. Vol. 11, No.6, pp. 559-568

Ojo, A. J., Daniyan, A. A., Atanda, P. O., Olorunniwo, O. E., Oyatogun, O. A., & Oluwasegun, K. M. (2021). Adsorption and Inhibiting Mild Steel Corrosion in Natural Lemon and Lime Citrus Fruit Juices by Alanine. Journal of Bio-and Tribo-Corrosion, 7(3), 1-12.

Okpokwasili, G. C., & Oparaodu, K. O. (2014). Comparison of percentage weight loss and corrosion rate trends in different metal coupons from two soil environments. International journal of environmental bioremediation & biodegradation, 2(5), 243-249.

Oluwadare, G. O. and Agbaje, O. (2007) Corrosion of steels in steel reinforced concrete in cassava juice. Journal of Applied Sciences Asian Network for Scientific Information. Vol. 7, No.17, pp. 2474-2479.

Oluwole, O. O. Garus-Alaka, W. and Ajide, O. O. (2012) Comparative study of corrosion behaviour of nickel and gold plated carbon steels used as ornamentals in saline environment. International Journal of Materials Engineering. Vol. 2, No.1, pp. 1-6.

Omotoso, A., Aiyedun, P. O., Adetunji, O. R., Arowolo, T. A., & Owoeye, F. T. (2017). Corrosion performance of 1014 mild and 304 stainless steels in acidic media. Journal of Natural Sciences Engineering and Technology, 16(1), 83-92.

Orisanmi, B. O., Afolalu, S. A., Adetunji, O. R., Salawu, E. Y., Okokpujie, I. P., Abioye, A. A., ... & Abioye, O. P. (2017). Cost of corrosion of metallic products in Federal University of Agriculture, Abeokuta. International Journal of Applied Engineering, 12(24), 14141-14147.

Parapurath, S., Jacob, L., Gunister, E., Vahdati, N. (2022). Effect of Microstructure on Electrochemical Properties of the EN S275 Mild Steel under Chlorine-Rich and Chlorine-Free Media at Different pHs. Metals 2022, 12, 1386. https:// doi.org/10.3390/met12081386

Pedeferri, P., & Ormellese, M. (2018). Corrosion science and engineering (p. 720). Ita-ly: Springer.

Poku, R., Lucky, B. O., & Ogbonnaya, E. A. (2015). Effects, evaluation and corrosion of heat exchangers performance in seawater. American Journal of Engineering Research, 4(9),

Poulson, B. S. (2013). Erosion Corrosion. In *Corrosion: Third Edition* (Vol. 1, pp. 1:293-1:303). https://doi.org/10.1016/B978-0-08-052351-4.50019-4

Raman, A., Farris, R. J., & Lesser, A. J. (2003). Effect of stress state and polymer morphology on environmental stress cracking in polycarbonate. *Journal of Applied Polymer Science, 88*(2), 550–564.

Salas, B. V., Wiener, M. S., Stoytcheva, M., Zlatev, R., & Beltran, M. C. (2012). Corrosion in the food industry and its control. Food Industrial Processes-Methods and Equipment, 29168.

Sharma, M. R., Mahato, N., Cho, M. H., Chaturvedi, T. P., & Singh, M. M. (2019). Effect of fruit juices and chloride ions on the corrosion behavior of orthodontic archwire. Materials Technology, 34(1), 18-24.

Shekari, E., Khan, F., & Ahmed, S. (2017). Economic risk analysis of pitting corrosion in process facilities. International Journal of Pressure Vessels and Piping, 157, 51-62.

Shtefan, V., Kanunnikova, N., Pilipenko, A., & Pancheva, H. (2019). Corrosion behavior of AISI 304 steel in acid solutions. Materials Today: Proceedings, 6, 150-157.

Stainless, M., & Etchants, S. (2017). *Metallographic Etchants for Stainless Steels* (pp. 26–27). https://www.metallographic.com/Metallographic-Etchants/Metallography-Stainless-steel-etchants.htm

Stephen, J. T., & Adebayo, A. (2018). Inhibition of corrosion of mild steel in hydrochloric acid solution using akee apple seed extract. Journal of Failure Analysis and Prevention, 18(2), 350-355.

Stephen, J., Olakolegan, O., Adeyemi, G., & Adebayo, A. (2019). Corrosion Behaviour of Heat Treated and Nickel Plated Mild Steel in Citrus Fruit: Lime and Lemon.

Tabor, D. (2000). The hardness of metals. Oxford university press.

Tait, W. S. (2018). Controlling corrosion of chemical processing equipment. In Handbook of Environmental Degradation of Materials (pp. 583-600). William Andrew Publishing.

Tait, W. S. (2018). Controlling corrosion of chemical processing equipment. In Handbook of Environmental Degradation of Materials (pp. 583-600). William Andrew Publishing.

Tengur, L., & Surnam, B. Y. R. (2012). Corrosion Problems in Sugar Factories in Mauritius. In Applied Mechanics and Materials (Vol. 110, pp. 1983-1989). Trans Tech Publications Ltd.

Tiu BDB, Advincula RC (2015) Polymeric corrosion inhibitors for the oil and gas industry: Design principles and mechanism. React Funct Polym 95: 25-45.

Trépanier, C., & Pelton, A. R. (2006). Effect of temperature and pH on the corrosion re-sistance of passivated nitinol and stainless steel. In SMST-2004: Proceedings of the In-ternational Conference on Shape Memory and Superelastic Technologies (p. 361). ASM International.

TWI. (2020). *What is Galvanic Corrosion and How Can it be Prevented? - TWI*. https://www.twi-global.com/technical-knowledge/faqs/faq-what-is-galvanic-corrosion-and-how-can-it-be-avoided

Uy, M., & Telford, J. K. (2009, March). Optimization by design of experiment techniques. In 2009 IEEE Aerospace conference (pp. 1-10). IE`EE.

Wang, J., Zhang, L., Gao, Y., Liu, X., & Hu, W. (2019). Influence of Storage Temperature on the Corrosion Behavior of Tinplate in Citric Acid Solution. Int. J. Electrochem. Sci, 14, 59-74.87-95.

Wang, W., Jenkins, P. E., & Ren, Z. (2012). Electrochemical corrosion of carbon steel exposed to biodiesel/simulated seawater mixture. Corrosion Science, 57, 215-219.

Wang, Z., Feng, Z., & Zhang, L. (2020). Effect of high temperature on the corrosion behavior and passive film composition of 316 L stainless steel in high H2S-containing environments. Corrosion Science, 174, 108844.

Wikipedia. (2021). *Intergranular corrosion - Wikipedia* (pp. 2–5). https://en.wikipedia.org/wiki/Intergranular_corrosion

Yeshanew, D. A., Jiru, M. G., Ahmed, G. M. S., Badruddin, I. A., Soudagar, M. E. M., Kamangar, S., & Tolcha, M. A. (2021). Corrosion Characterization at Surface and Subsurface of Iron-Based Buried Water Pipelines. Materials, 14(19), 5877.

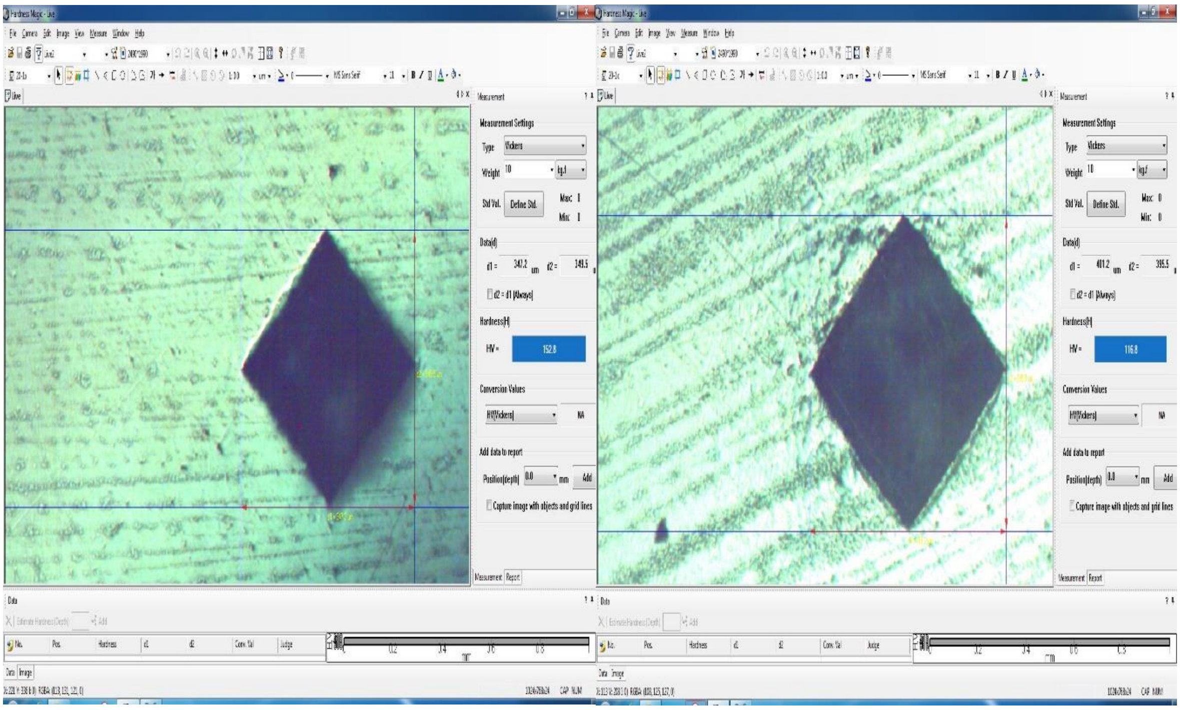
Yeshanew, D. A., Jiru, M. G., Ahmed, G. M. S., Badruddin, I. A., Soudagar, M. E. M., Kamangar, S., & Tolcha, M. A. (2021). Corrosion Characterization at Surface and Subsurface of Iron-Based Buried Water Pipelines. Materials, 14(19), 5877.

Zaffora, A., Di Franco, F., & Santamaria, M. (2021). Corrosion of stainless steel in food and pharmaceutical industry. Current Opinion in Electrochemistry, 100760.489

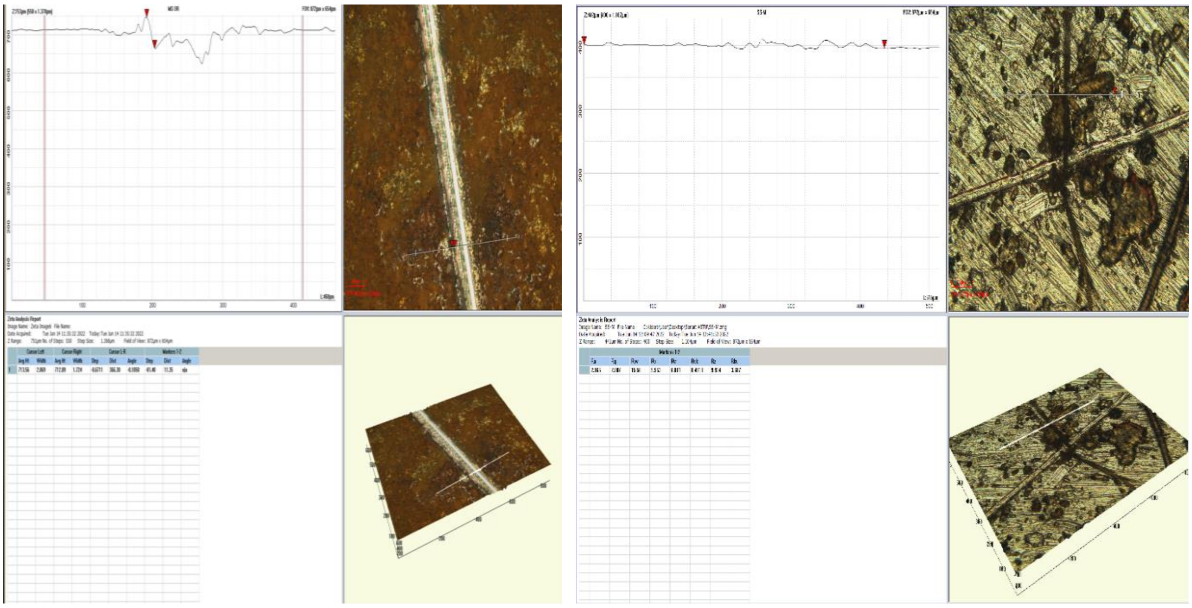
Zhang, T., Liu, W., Yin, Z., Dong, B., Zhao, Y., Fan, Y., & Li, X. (2020). Effects of the addition of Cu and Ni on the corrosion behavior of weathering steels in corrosive industrial environments. Journal of Materials Engineering and Performance, 29(4), 2531-2541.

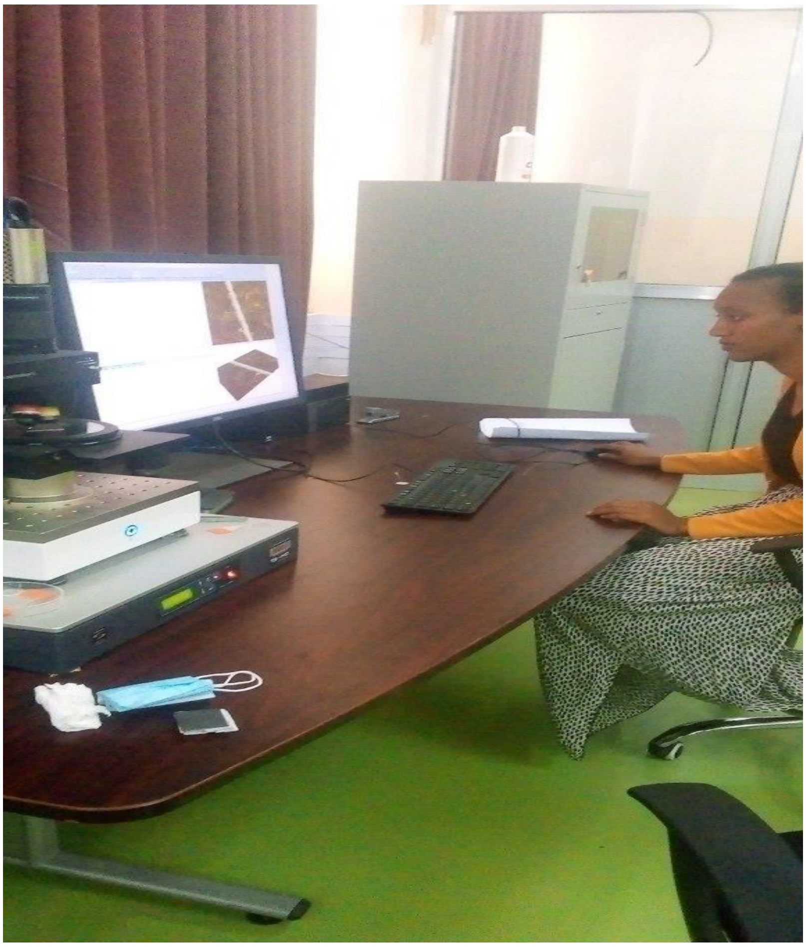
APPENDICES

Appendix 1: Hardness test results and equipment

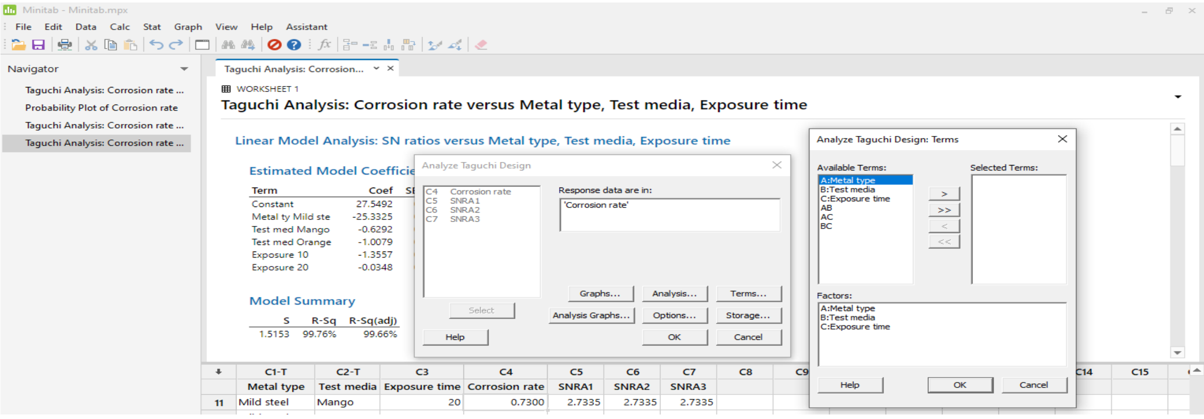


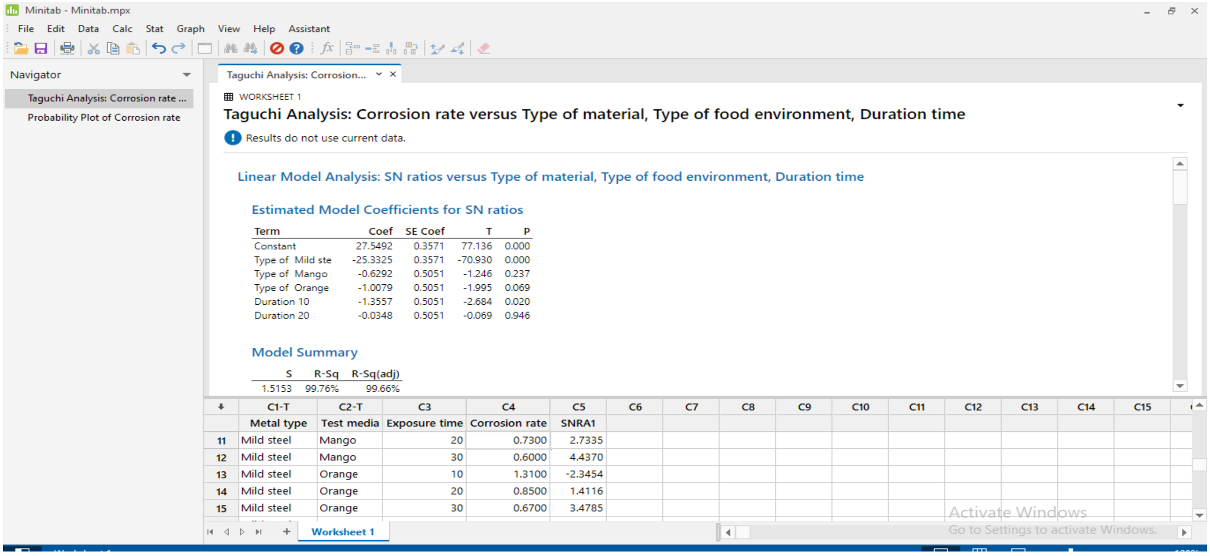
Appendix 2: 3D image test results





Appendix 3: DOE Minitab software and mixed Taguchi L18 orthogonal array design

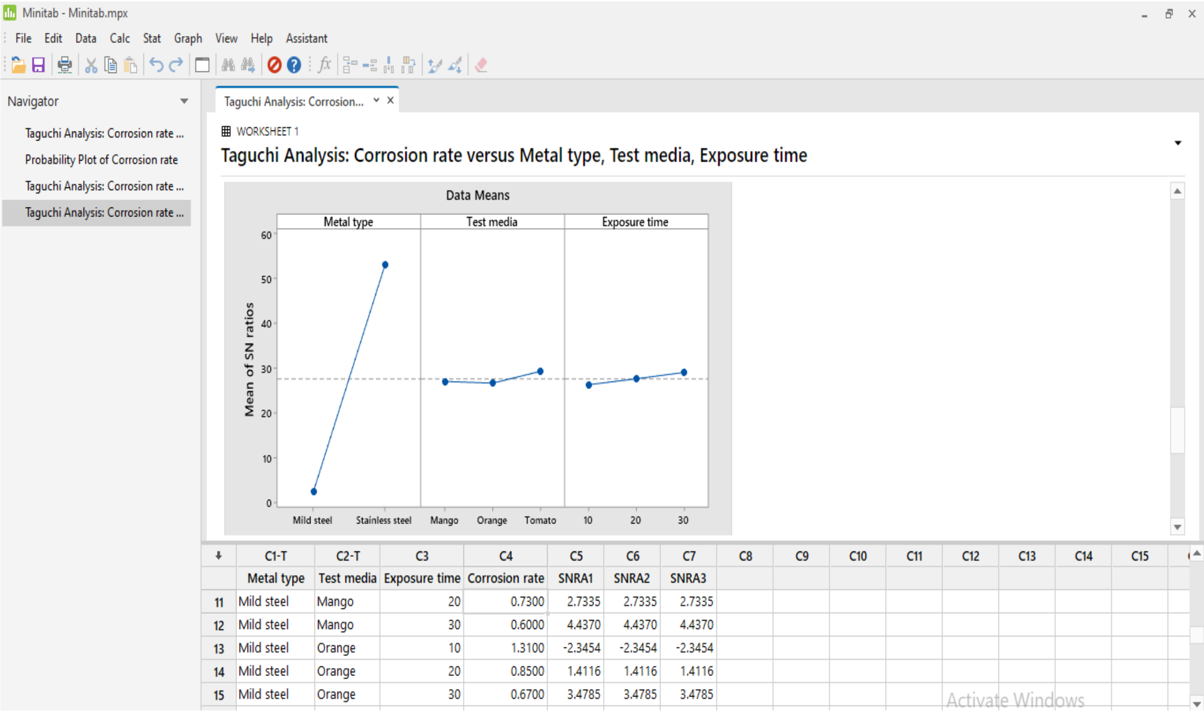




Term	Coef	SE Coef	T	P
Constant	27.5492	0.3571	77.136	0.000
Type of Mild ste	-25.3325	0.3571	-70.930	0.000
Type of Mango	-0.6292	0.5051	-1.246	0.237
Type of Orange	-1.0079	0.5051	-1.995	0.069
Duration 10	-1.3557	0.5051	-2.684	0.020
Duration 20	-0.0348	0.5051	-0.069	0.946

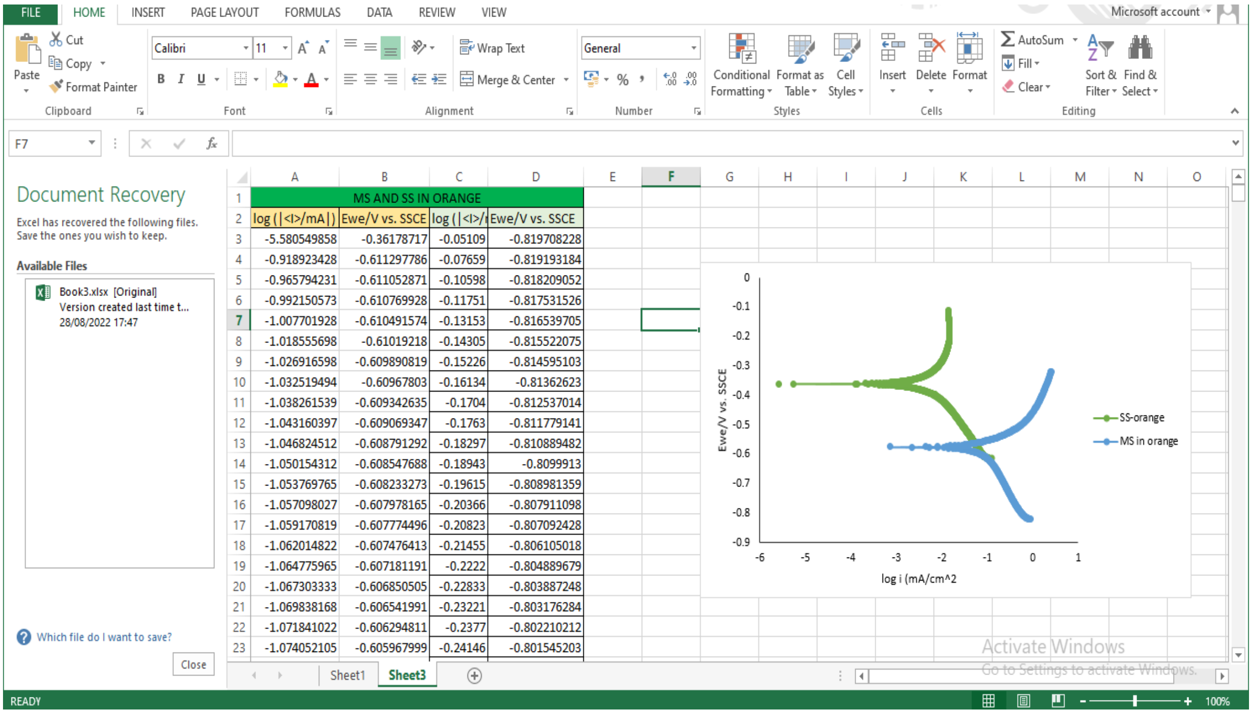
S	R-Sq	R-Sq(adj)
1.5153	99.76%	99.66%

	Metal type	Test media	Exposure time	Corrosion rate	SNRA1
11	Mild steel	Mango	20	0.7300	2.7335
12	Mild steel	Mango	30	0.6000	4.4370
13	Mild steel	Orange	10	1.3100	-2.3454
14	Mild steel	Orange	20	0.8500	1.4116
15	Mild steel	Orange	30	0.6700	3.4785

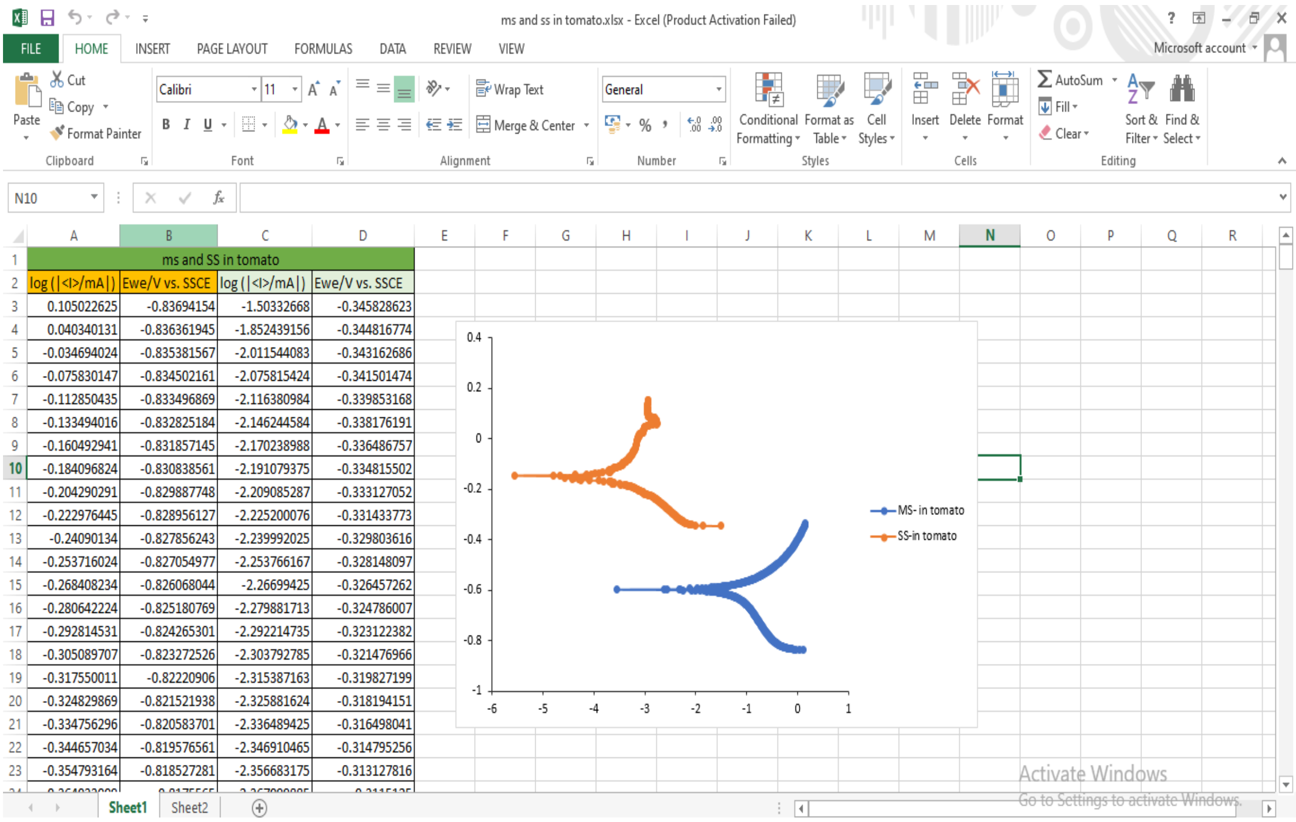


	Metal type	Test media	Exposure time	Corrosion rate	SNRA1	SNRA2	SNRA3
11	Mild steel	Mango	20	0.7300	2.7335	2.7335	2.7335
12	Mild steel	Mango	30	0.6000	4.4370	4.4370	4.4370
13	Mild steel	Orange	10	1.3100	-2.3454	-2.3454	-2.3454
14	Mild steel	Orange	20	0.8500	1.4116	1.4116	1.4116
15	Mild steel	Orange	30	0.6700	3.4785	3.4785	3.4785

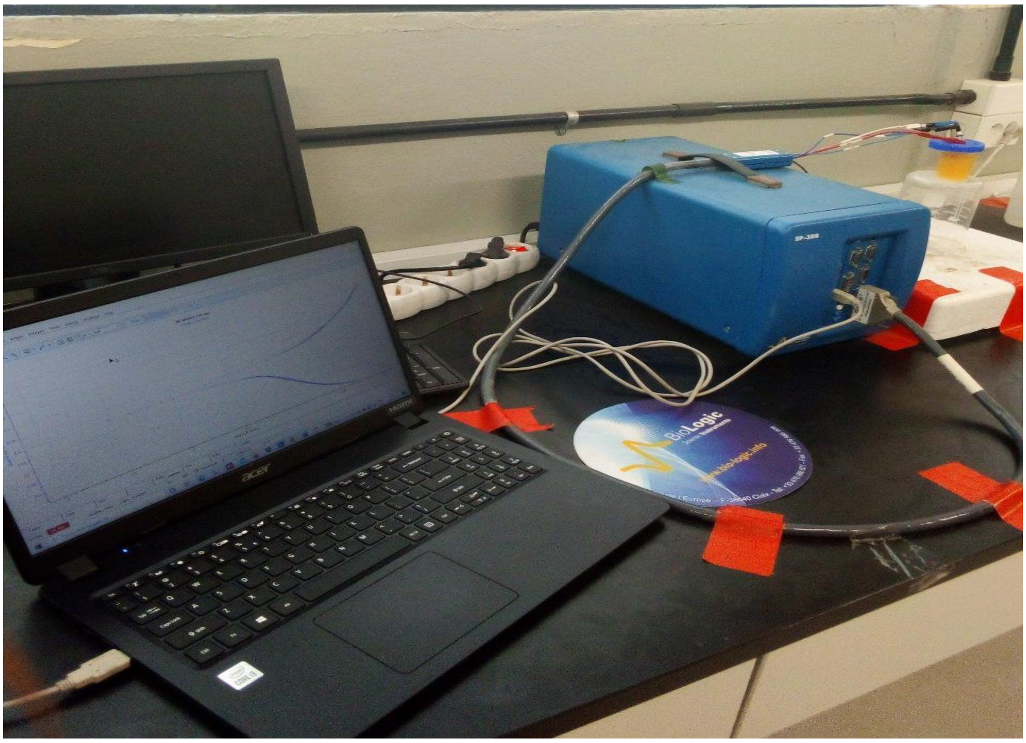
Appendix 4: Electrochemical analysis result and extrapolation analysis result

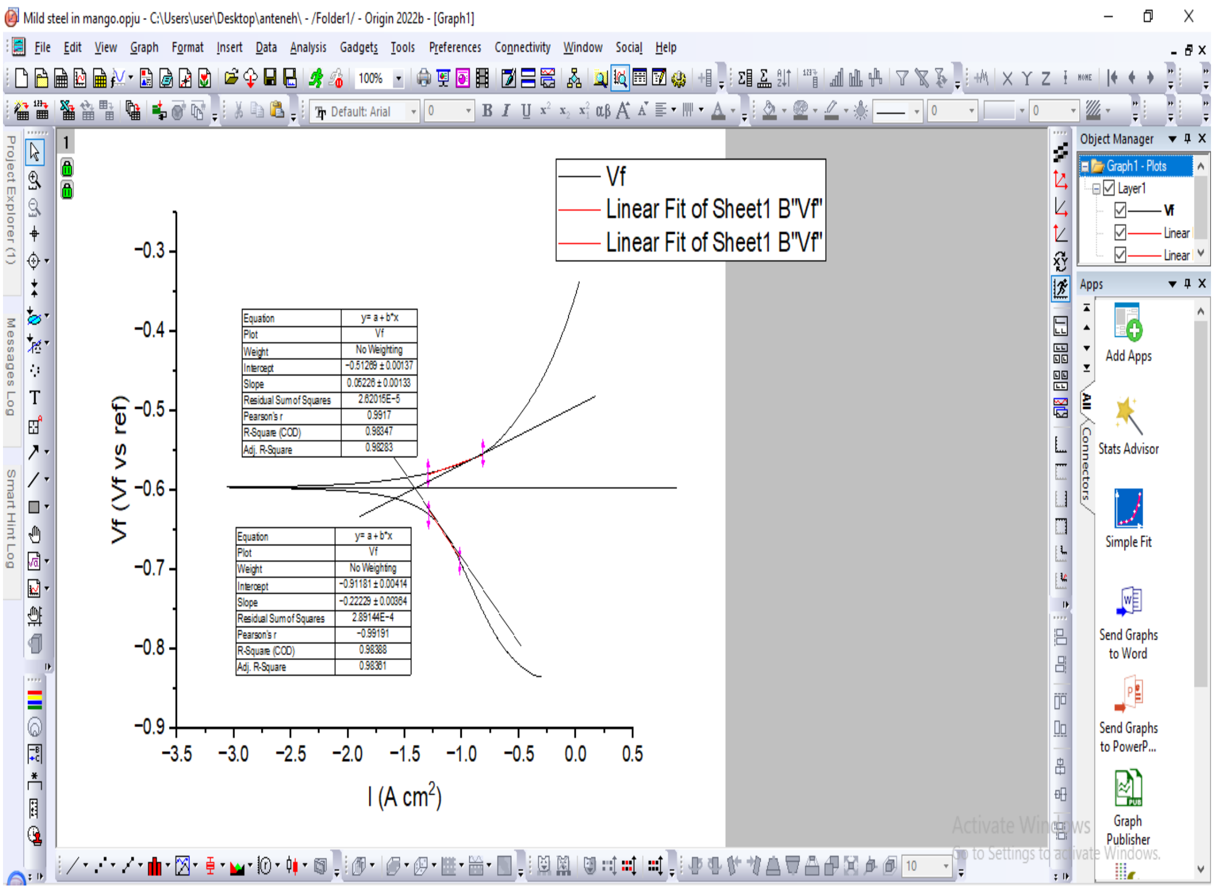


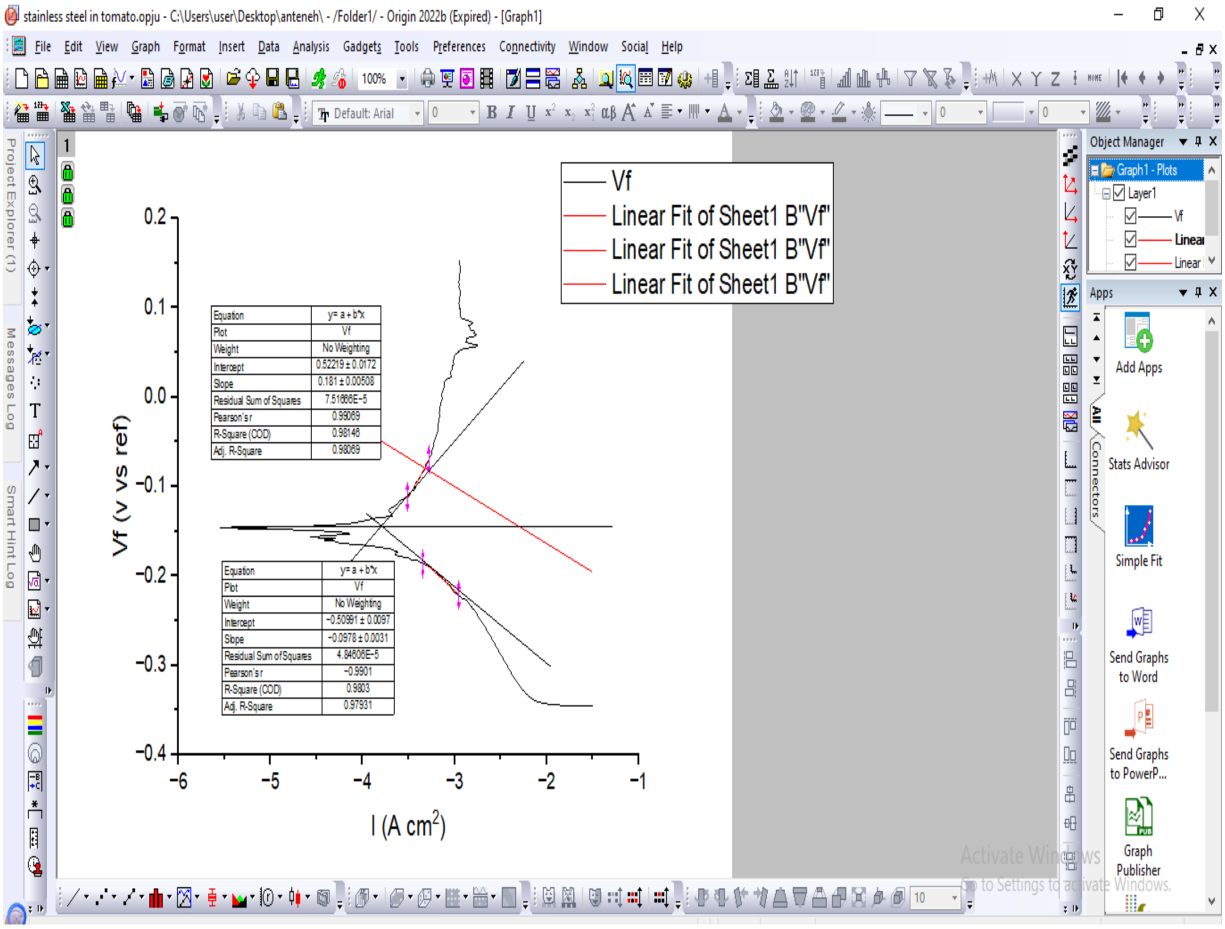
MS AND SS IN ORANGE			
log (|<I>/mA|)	Ewe/V vs. SSCE	log (|<I>/	Ewe/V vs. SSCE
-5.580549858	-0.36178717	-0.05109	-0.819708228
-0.918923428	-0.611297786	-0.07659	-0.819193184
-0.965794231	-0.611052871	-0.10598	-0.818209052
-0.992150573	-0.610769928	-0.11751	-0.817531526
-1.007701928	-0.610491574	-0.13153	-0.816539705
-1.018555698	-0.61019218	-0.14305	-0.815522075
-1.026916598	-0.609890819	-0.15226	-0.814595103
-1.032519494	-0.60967803	-0.16134	-0.81362623
-1.038261539	-0.609342635	-0.1704	-0.812537014
-1.043160397	-0.609069347	-0.1763	-0.811779141
-1.046824512	-0.608791292	-0.18297	-0.810889482
-1.050154312	-0.608547688	-0.18943	-0.8099913
-1.053769765	-0.608233273	-0.19615	-0.808981359
-1.057098027	-0.607978165	-0.20366	-0.807911098
-1.059170819	-0.607774496	-0.20823	-0.807092428
-1.062014822	-0.607476413	-0.21455	-0.806105018
-1.064775965	-0.607181191	-0.2222	-0.804889679
-1.067303333	-0.606850505	-0.22833	-0.803887248
-1.069838168	-0.606541991	-0.23221	-0.803176284
-1.071841022	-0.606294811	-0.2377	-0.802210212
-1.074052105	-0.605967999	-0.24146	-0.801545203



ms and SS in tomato			
log (|<I>/mA|)	Ewe/V vs. SSCE	log (|<I>/mA|)	Ewe/V vs. SSCE
0.105022625	-0.83694154	-1.50332668	-0.345828623
0.040340131	-0.836361945	-1.852439156	-0.344816774
-0.034694024	-0.835381567	-2.011544083	-0.343162686
-0.075830147	-0.834502161	-2.075815424	-0.341501474
-0.112850435	-0.833496869	-2.116380984	-0.339853168
-0.133494016	-0.832825184	-2.146244584	-0.338176191
-0.160492941	-0.831857145	-2.170238988	-0.336486757
-0.184096824	-0.830838561	-2.191079375	-0.334815502
-0.204290291	-0.829887748	-2.209085287	-0.333127052
-0.222976445	-0.828956127	-2.225200076	-0.331433773
-0.24090134	-0.827856243	-2.239992025	-0.329803616
-0.253716024	-0.827054977	-2.253766167	-0.328148097
-0.268408234	-0.826068044	-2.26699425	-0.326457262
-0.280642224	-0.825180769	-2.279881713	-0.324786007
-0.292814531	-0.824265301	-2.292214735	-0.323122382
-0.305089707	-0.823272526	-2.303792785	-0.321476966
-0.317550011	-0.82220906	-2.315387163	-0.319827199
-0.324829869	-0.821521938	-2.325881624	-0.318194151
-0.334756296	-0.820583701	-2.336489425	-0.316498041
-0.344657034	-0.819576561	-2.346910465	-0.314795256
-0.354793164	-0.818527281	-2.356683175	-0.313127816




Mild steel in mango.opju - C:\Users\user\Desktop\anteneh\ - /Folder1/ - Origin 2022b - [Graph1]
File Edit View Graph Format Insert Data Analysis Gadgets Tools Preferences Connectivity Window Social Help
Vf
Linear Fit of Sheet1 B"Vf"
Linear Fit of Sheet1 B"Vf"
Equation y= a + b*x
Plot Vf
Weight No Weighting
Intercept −0.51289 ± 0.00137
Slope 0.06226 ± 0.00133
Residual Sum of Squares 2.82015E−5
Pearson's r 0.9917
R-Square (COD) 0.98347
Adj. R-Square 0.98283
Equation y= a + b*x
Plot Vf
Weight No Weighting
Intercept −0.91181 ± 0.00414
Slope −0.22229 ± 0.00384
Residual Sum of Squares 2.89144E−4
Pearson's r −0.99191
R-Square (COD) 0.98388
Adj. R-Square 0.98361
Vf (Vf vs ref)
I (A cm2)
Object Manager
Graph1 - Plots
Layer1
Apps
Add Apps
Stats Advisor
Simple Fit
Send Graphs to Word
Send Graphs to PowerP...
Graph Publisher



stainless steel in tomato.opju - C:\Users\user\Desktop\anteneh\ - /Folder1/ - Origin 2022b (Expired) - [Graph1]
Vf
Linear Fit of Sheet1 B"Vf"
Linear Fit of Sheet1 B"Vf"
Linear Fit of Sheet1 B"Vf"
Equation y = a + b*x
Plot Vf
Weight No Weighting
Intercept 0.52219 ± 0.0172
Slope 0.181 ± 0.00508
Residual Sum of Squares 7.51666E-5
Pearson's r 0.99069
R-Square (COD) 0.98146
Adj. R-Square 0.98069
Equation y = a + b*x
Plot Vf
Weight No Weighting
Intercept −0.50981 ± 0.0097
Slope −0.0978 ± 0.0031
Residual Sum of Squares 4.84606E-5
Pearson's r −0.9901
R-Square (COD) 0.9803
Adj. R-Square 0.97931
Vf (v vs ref)
I (A cm2)
Object Manager
Apps
Add Apps
Stats Advisor
Simple Fit
Send Graphs to Word
Send Graphs to PowerP...
Graph Publisher