

**GRAFTING CYSTEINE-CITRIC ACID TO CELLULOSE AEROGEL AS ANTI
CORROSION**

(Undergraduate Thesis)

By

Jeremia Christian



**FACULTY OF MATHEMATICS AND NATURE SCIENCE
UNIVERSITY OF LAMPUNG
BANDAR LAMPUNG
2023**

ABSTRACT

GRAFTING CYSTEINE-CITRIC ACID TO AEROGEL CELLULOSE AS ANTI CORROSION

By

Jeremia Christian

Pineapple waste was produced by industry of Indonesia. Pineapple waste contains cellulose. Cellulose can be modified by cysteine-citric acid become anti corrosion coating material as aerogel. Cellulose was modified in 10%-10% of cysteine-citric acid mixture solution. Modified cellulose aerogel was synthesized by using Tetraethyl Orthosilicate (TEOS) by ratio 1 gram:5 mL. The functional groups of the synthesise process were observed by Fourier Transform Infrared (FTIR). HCl 5%; 10%; and 15: solution was used as corrosive medium of the stainless steel 304. Coating process applied sol-gel dip coating for 30 seconds. Corrosive medium damage to stainless steel was observed by using Scanning Electron Microscope (SEM). Gravimetric was used to find out the weight change to calculate Inhibitor Efficiency (IE). The results of IE of variation HCl 5%: 10%; and 15 are 23.37%, 21.80%, and 12.81%, respectively.

Keywords: Cellulose; Sol-gel dip coating; FTIR; SEM; Inhibitor Efficiency

ABSTRAK

OKULASI SISTEIN-ASAM SITRAT TERHADAP SELULOSA AEROGEL SEBAGAI ANTI KOROSI

Oleh

Jeremia Christian

Limbah nanas diproduksi oleh industry di Indonesia. Limbah nanas mengandung selulosa. Selulosa dapat dimodifikasi dengan sistein-asam sitrat menjadi material anti korosi sebagai aerogel. Selulosa dimodifikasi dengan campuran sistein-asam sitrat sebesar 10%-10%. Selulosa aerogel termodifikas disintesis menggunakan Tetraetil Ortosilikat (TEOS) dengan perbandingan 1 gram:5 mL. Gugus fungsi dari proses sintesis diamati menggunakan *Fourier Transform Infrared* (FTIR). HCl 5%; 10%; dan 15% digunakan sebagai media korosif terhadap baja anti karat 304 Proses pelapisan menggunakan metode pencelupan sol-gel selama 30 detik. Media korosi. Mofrologi baja anti karat diamati menggunakan *Scanning Electron Microscope* (SEM). Metode gravimetri digunakan untuk mengetahui perubahan berat untuk mengetahui Efisiensi Inhibisi. Hasil dari Efisiensi Inhibisi pada varias HCl 5%; 10%; dan 15% adalah masing-masing 23.37%; 21,80%; dan 12,81%

Kata kunci: selulosa, pencelupan sol-gel, FTIR, SEM, Efisiensi Inhibisi

**GRAFTING CYSTEINE-CITRIC ACID TO CELLULOSE AEROGEL AS
ANTI CORROSION**

By

JEREMIA CHRISTIAN

Undergraduate Thesis

**As a partial fulfillment of the requirement for of
BACHELOR OF SCIENCE**

At

Chemistry Department

Faculty of Mathematics and Natural Science

University of Lampung



FACULTY OF MATHEMATICS AND NATURAL SCIENCE

UNIVERSITY OF LAMPUNG

BANDAR LAMPUNG

2023

Title : **Grafting Cysteine-Citric Acid to Cellulose
Aerogel as Anti-Corrosion**

Student Name : **Jeremia Christian**

Student ID : **1757011014**

Department : **Chemistry**

Faculty : **Mathematics and Nature Science**

APPROVAL

1. Supervisor Commission

First Supervisor



Dr. Eng. Suropto Dwi Yuwono, M.T.

NIP. 19740705 200003 1 001

Second Supervisor



Akhmad Ues, S.Si.

NIP. 202005027

2. Head of Chemistry Department



Mulyono, Ph.D.

NIP. 197406112000031002

APPROVED

1. Examiner Commission

Chief : Dr.Eng. Supto Dwi Yuwono, M.T.



Secretary : Akhmad Ues, S.Si.



**Examiner
Non Supervisor : Dr. Ilim, M.S.**



2. Dean of Mathematics and Natural Science



Dr. Eng Heri Satria, S.Si., M.Si.
ID 197110012005011002

Undergraduate Thesis Exam Pass Date: 14th July 2023

AUTHENTICITY OF UNDERGRADUATE THESIS DECLARATION

The undersigned below:

Name : Jeremia Christian
ID : 1757011014
Majority : Chemistry
Faculty : Mathematics and Natural Science
College : Lampung University

Hereby declares that the undergraduate thesis with titled "Grafting Cysteine-Citric Acid to Cellulose Aerogel as Anti Corrosion" does not contain works written or published by other people, except those referred to in writing in this manuscript as stated in bibliography. Furthermore, I also have no objection if some or all of the data in the thesis is used by the lecturer or study program for publication purposes, as long as my name is mentioned and there is an agreement prior to publication.

I make this statement consciously and truthfully to be used as it should be.

Bandar Lampung, 3th August 2023

Signed,



Jeremia Christian
ID 1757011014

BIOGRAPHY



The author was born in Bogor on December 1996, 17th, the third of Edward Siringoringo and Sinurpita Sitorus. Author graduated from Kedung Jaya 01 Elementary School in 2009, Bogor Twelve Junior High School in 2012, Bogor Chemical Analyst Vocational High School and carried out field work as student of Bogor Chemical Analyst Vocational High School in Tropical Biopharmaca Research Centre in 2017.

In 2017, the author was accepted as a student in the Department of Chemistry, Faculty of Mathematics and Natural Sciences. The author was assistant of Organic Chemistry I and II practicums, and active in Chemistry Student Association at Lampung University in 2018 and 2019.

MOTTO

“Ijazah itu tanda orang pernah sekolah. bukan tanda orang pernah berfikir.”
(Rocky Gerung)

“Janganlah kamu kalah terhadap kejahatan,
tetapi kalahkanlah kejahatan dengan kebaikan.”
(Roma 12:21)

PREFACE

Praise Almighty God for His grace, so the author can complete this undergraduate thesis with title “Grafting Cysteine-Citric Acid to Cellulose Aerogel as Anti Corrosion” as partial fulfillment of the requirements for the degree of Bachelor of Science at Chemistry Department in University of Lampung.

During the process, the author got many hands, support, and advice from a lot of people to finish this undergraduate thesis. In this section, author respectfully thanks to:

1. My parents, Mr. Edward Siringoringo and Mrs. Sinurpita Sitorus, who support me in many situations.
2. Mr. Dr. Eng. Suropto Dwi Yunowo, M.T. as Supervisor for his direction about this research and knowledge to finish this project.
3. Mr. Akhmad Ues, S.Si. as Co-supervisor for his hands about problems fixing and suggestion in this research to finish this project.
4. Mrs. Dr. Ilim, M.S. as Examiner who helped and recommended for this undergraduate thesis.
5. Mr. Drs. Supriyanto M.S. and Mr. Diky Hidayat, S.Si., M.Sc. as academic counselors for the advices and motivations.
6. Mr. Dr. Eng. Heri Satria, S.Si., M.Si. as Dean of Mathematics and Natural Science Faculty.
7. Mr. Fathan Bahfie as researcher from Metallurgy
8. All lecturer in Chemistry Department who taught, motivated, and supported me during the lessons.
9. All staff in Chemistry Department, Mathematics and Natural Science Faculty, and University of Lampung who helped me in academic system and administration system until this undergraduate thesis could be made.

10. My brother, Josua Andrio Siringoringo and Jericho Yuda Siringoringo who donated me.
11. Group, Kadek Suprajaya and Ramy Zahra who supported, helped, and stressed out because of me.
12. Corrosion Research Group, Laila Hidayah, Al Huda Zavira, Nabila, Sahrul Junaedi, and Arya.
13. Organic Laboratory Member, Nur Vita Sari, Fitri Puspita, Ni Made Feni, Aulia Gadis, Dhita Amarhani, etc. who were ruined by me.
14. Davincent Andreas Lihardo Sinaga, Andreas Tua Parulian Sibuea, Muhammad Rizky Fadilah Simanulang.
15. Tiara Manedra from Sepuluh November Institute for looking for the method together.
16. Mia Saputri Krisentiana and Eroh Muhayaroh for giving me some conclusion for this research.
17. All of Member of Chemistry Men for supporting me.
18. All of participant who helped me in completing this undergraduate thesis.

This undergraduate thesis has still mistake. The author expects the critics and suggestions from the reader to improve for the next research. Hopefully this undergraduate thesis can be useful for the development of science in the future.

Bandar Lampung, 3th August 2023

Signed,

Jeremia Christian
ID 1757011014

LIST OF CONTENTS

	Page
LIST OF CONTENTS	i
LIST OF FIGURES	iii
LIST OF TABLES	v
I. INTRODUCTION	1
1. 1. Background	1
1. 2. Objective Research	2
II. LITERATURE REVIEW	3
2.1. Pineapple	3
2.1.1 History of Pineapple	3
2.1.2 Taxonomy of Pineapple	4
2.1.3 Content of Pineapple.....	4
2.2. Lignocellulose	5
2.3. Cellulose	7
2.4. Aerogel	8
2.5. Corrosion	9
2.6. Corrosion Inhibitor	14
2.7. Corrosion in Industry.....	15
2.8. Coatings	17
2.9. Scanning Electron Microscope (SEM).....	18
2.10. Fourier Transform Infrared (FT-IR).....	19
III. RESEARCH METHODS	20
3.1. Time and Place	20
3.2. Tools and Materials	20
3.2.1. Tools	20
3.2.2. Materials	20

3.3.	Procedure	21
3.3.1	Isolation Cellulose of Pineapple Waste	21
3.3.2	Modification Cellulose	22
3.3.3	Cellulose Aerogel Synthesis	22
3.3.4	Corrosive Medium Preparation.....	22
3.3.5	Clarke's Solution Preparation.....	23
3.3.6	Stainless steel Plate Preparation	23
3.3.7	Dip Coating.....	23
3.3.8	Fourier-Transform Infrared (FTIR)	23
3.3.9	Scanning Electron Microscope (SEM)	24
3.3.10	Inhibitor Efficiency.....	24
IV.	RESULT AND DISCUSIONS	26
4.1.	Preparation of Cellulose	26
4.2.	Modification Cellulose	29
4.3.	Cellulose Aerogel Synthesis.....	32
4.4.	Scanning Electron Microscope.....	35
4.5.	Inhibitor Efficiency	37
V.	CONCLUSIONS AND DISCUSSIONS.....	40
5.1.	Conclusion.....	40
5.2.	Discussion	40
	REFERENCES	41

LIST OF FIGURES

Figure	Page
1. Pineapple	3
2. Lignin Structure	6
3. Hemicellulose Structure	6
4. Cellulose Structure	7
5. Hydrogen Bond of Cellulose.....	8
6. Pitting Corrosion Mechanism	11
7. Optical Image of Creviced Alloy	11
8. SEM Image of Intergranular Stress Corrosion of Stainless Steel wire	12
9. Erosion Corrosion Appearance	12
10. Microbial Corrosion Mechanism	13
11. TPA is Formed after Multidehydration.....	15
12. Esterification of Cellulose and TPA	15
13. Scanning Electron Microscope Mechanism.....	18
14. FTIR Mechanism	19
15. Cleavage of β -aryl Bonds in Alkaline Conditions	26
16. Lignosulfonate Reaction	27
17. Isolation Process of Cellulose	27
18. Isolated Cellulose	28
19. FTIR Spectrum of Isolation of cellulose.....	28
20. Impregnated Solution of Cellulose/Cytric Acid-Cysteine	30
21. FTIR Spectrum of Cellulose Modification	30
22. Modified Cellulose Powder Result	31
23. Reaction of Cellulose and Cytric Acid-Cysteine	32
24. Viscous Modified Cellulose Aerogel	33
25. FTIR Spectrum of Modified Cellulose Aerogel.....	34

26. Morphology of Stainless steel	35
27. Stainless Steel Plat Condition	35
28. Trendline of Inhibitor Efficiency	38

LIST OF TABLES

Table	Page
1. Content of Pineapple	5
2. Fluid selection guidelines for preflush fluids.....	17
3. FTIR Peak Data of Pineapple Isolation.....	29
4. FTIR Peak Data of Cellulose Modification.	31
5. FTIR Peak Data of Modified Cellulose Aerogel.....	34
6. Inhibitor Efficiency on HCl Various.....	37

I. INTRODUCTION

1. 1. Background

Indonesia is a tropical country in Asian. It makes Indonesia to be the one country that supporting 38,000 species of plants of which 55% are endemic in its territory. One of a popular tropical fruit is pineapple. Pineapple is a fruit can grow in various seasons. It makes many people plant pineapple and consume it.

Pineapple is consumed about 20% of the whole pineapple and the other 80% is waste. Pineapple wastes consist pineapple flesh, peeled skin and pineapple crown. Pineapple wastes is generated by pineapple Industries as liquid and solid waste. It was estimated more than 1,651,672 tons pineapple wastes are generated by canning industries worldwide, which are 50% liquid waste and 50% solid waste (Mile, 2017).

In 2020, Indonesia produced 2,447,243.00 tons of Pineapple. Lampung is the province that produced largest amount of Pineapple in Indonesia, it is about 662,588.00 tons. It means about 1,957,794.4 tons of pineapple waste was produced in Indonesia, and 530,070.4 tons of pineapple waste was in Lampung. 265,035.2 tons of 530,070.4 pineapple were solid waste.

Pineapple waste is one of significant domestic waste. Pineapple waste contains a lot of water and organic compounds. There are mainly carbohydrates and little protein. The pineapple waste is usually used as animal feed for economic value or ensilaged. Peel of pineapple is the major biowaste of pineapple processing (Lobo and Paull, 2017). The simple thing solution of the waste is returning it to the fields and us it as soil amendment. But, the waste is easily ferment because of the high

moisture contents. It will make another problems, especially unpleasant odor (Bartholomew, Paull and Rohrbach, 2003).

Corrosion is crucial cause in industry. Corrosion problems include economics, health, environment damage, and working safety. Industry takes above-average steel, it means it is made of mild steel. About 1.5 billion rupiah is used every year in Indonesia to maintenance expense, replacement the material, working hours, the lost benefits due to the stop of production, costumer dissatisfaction, administration fee, physical lost, and health treatment (Aliofkhazraei, 2018). Indonesia is in equator lane, and extent two continental land masses and wide differences in elevation. The climate of the lowlands is marked by heaved rainfall, low winds, high temperature, and very high humidity. The humidity averages in Indonesia is over 80 percent the year around (Henderson, 1970).

1. 2. Objective Research

The objectives of this research are as follows:

1. Synthesis a new anti-corrosion material based on grafting of cellulose of aerogel cellulose
2. Analysis percentage of inhibition of the new anti-corrosion material

II. LITERATURE REVIEW

2.1. Pineapple

2.1.1 History of Pineapple

Pineapple or *Ananas Comosus* L. is a plant came from South America that found by European in 1493 in Caribbean. Spanish and Portuguese borrowed the plant to Asia, Africa, and South Pacific, from 16th Century until 18th Century (Lawal, 2013). In 15th Century, Spanish came to Indonesia brought Pineapple to Indonesia and they planted it. It had been planted in a huge scale. Pineapple is a simple fruit as dessert in many events(Agoes, 2010).



Figure 1. Pineapple

2.1.2 Taxonomy of Pineapple

Kingdom : *Plantae*
Division : *Spermatophyta*
Sub Division : *Angiospermae*
Ordo : *Farinosae*
Class : *Liliopsida*
Family : *Bromeliacea*
Genus : *Ananas*
Species : *Ananas sp.*

(Lubis, 2020)

2.1.3 Content of Pineapple

Pineapple is the famous fruit in the world. This tropical fruit is usually used as meat softener because of the bromelain enzyme. The enzyme can do break down the protein structure (New et al., 2004). However, the pineapple contains another compound. The compounds contain carbohydrates as lignocellulose and fiber, fat, some vitamin, etc.

Crucial thing of pineapple is about flesh of that fruit. Pineapple contains a lot of chemical compounds that are good for the body. Here is the content of pineapple per 100 grams:

Table 1. Content of Pineapple

Content	Unit	Result
Water Content	g	87
Carbohydrates	g	12.3
Protein	g	0.6
Fat	g	0.1
Potassium	mg	250
Magnesium	mg	17.0
Calcium	mg	12.0
Phosphorus	mg	10.0
Sodium	mg	1.5
Iron	mg	0.4
Copper	mg	0.4
Carotene	IU	50
Folic Acid	mg	4.0
Vitamin B2	mg	0.12
Vitamin B1	mg	0.02
Vitamin C	mg	50.0
Energy	Calorie	50

(Peter, 2007)

2.2. Lignocellulose

Lignocellulosic biomass is the most abundant raw materials on Earth. Lignocellulose is essential part of the cell wall of plants. Lignocellulosic resources are classified as forest resource or agricultural resource. Lignocellulose is formed by plant photosynthesis, contains cellulose, hemicellulose, and lignin (Chen, 2015). Lignin is the high concentration of the plants, whereas lower lignin is present in annual plants. Cell walls have three dimensional structure that made by cellulose, hemicellulose, and lignin (Karimi, 2015).

Lignocellulose present in biomass is a heteropolymer compound which is essentially composed of cellulose (hexose), hemicellulose (pentose, hexose), and lignin (aromatic polymers). Cellulose and hemicellulose are major polysaccharide in plants. There are approximately about 10,000 molecules of glucopyranose linked with each other by β -1,4 linkage to make a simple linear of cellulose and 50-200

units chain length 50-200 units that make hemicellulose that have β -1,4- linked xylopyranosyl linked to arabinofuranosyl (Kuhad and Singh, 2007).

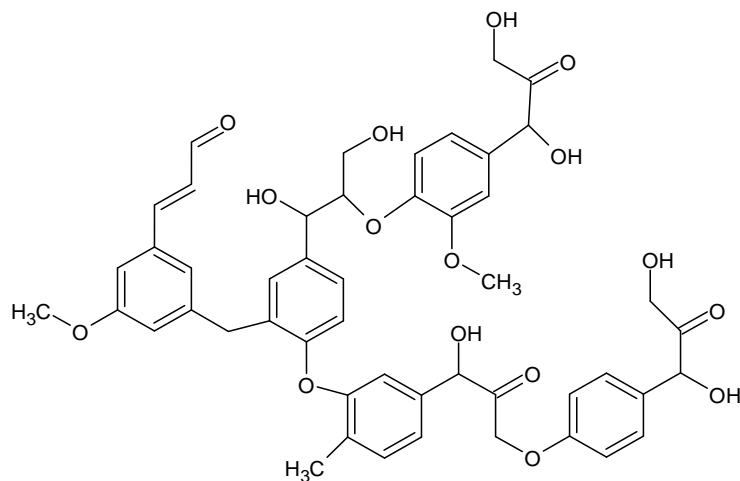


Figure 2. Lignin Structure

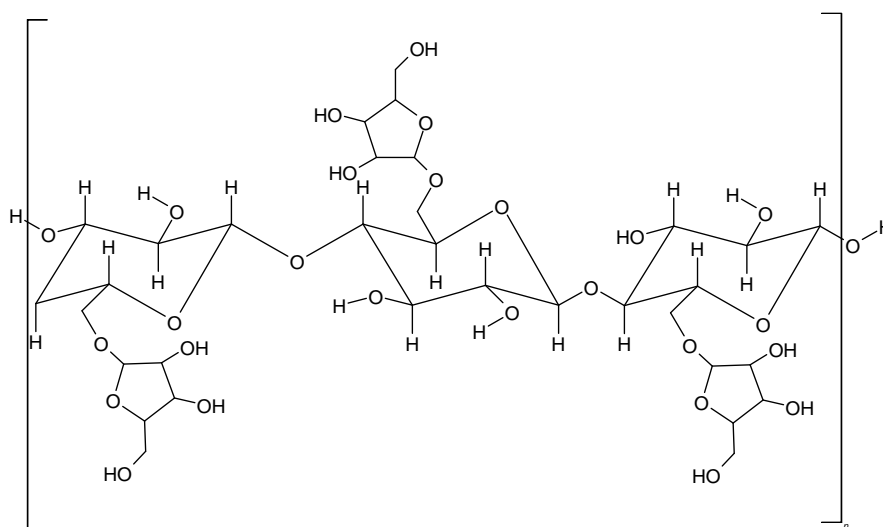


Figure 3. Hemicellulose Structure

2.3. Cellulose

Cellulose is the most abundant, renewable polymer in this world. Cellulose is synthesized about 10^{11} - 10^{12} tons by photosynthesis (Wüstenberg, 2012). Cellulose fibers can be obtained from plant cells. Cellulose is obtained from cotton, bast, flax, hemp, sisal, and jute or wood (Aegerter, Leventis and Koebel, 2011). Cellulose has stimulated basic and applied research throughout the years. Cellulose has high potential for future applications, especially in manufacture, Biotechnology. Etc. (Timell and Wimmer, 2018). Cellulose has high Degrees of Polymerization (DP), it is about 1,000-30,000, which corresponds to chain length of 500-15,000 nm (Rojas, 2016).

Cellulose is a raw material polymer used for many purposes. Cellulose can also be used in construction material. On the other side, cellulose derivatives are used in many industry and domestic life (Wüstenberg, 2012). Cellulose is a polymer that made by many glucoses with chain 1-4 linked β -D-glucopyranose and indicates great chemical variability and potential in applications (Timell and Wimmer, 2018).

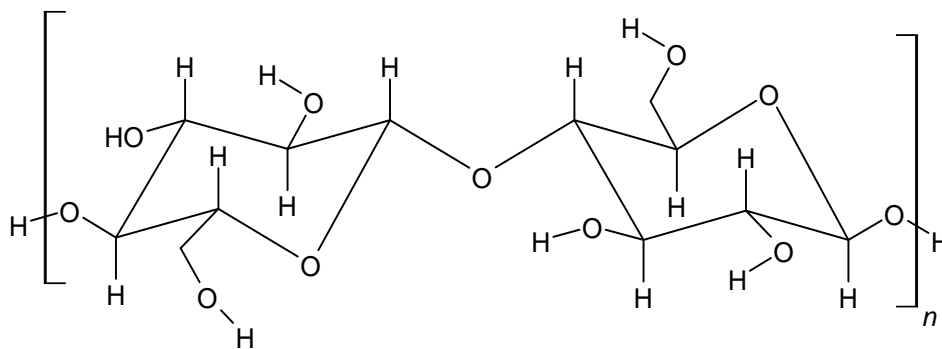


Figure 4. Cellulose Structure

It is good reinforcing agent in composites. Cellulose is a linear homopolymer, it contains three hydroxyl groups at C-2, C-3, and C-6 atoms (Thakur and Singha, 2013). The unbranched chain of glucose makes fibrillar structure and the number of free hydroxyl groups generate extensive intra-molecular and inter-molecular hydrogen bonding between adjacent chains (Thakur, 2015).

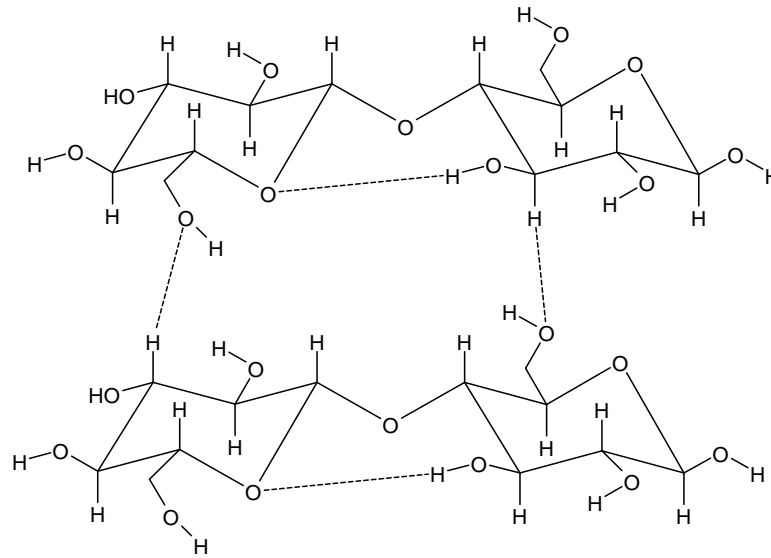


Figure 5. Hydrogen Bond of Cellulose

2.4. Aerogel

Aerogels are the best materials as superinsulation with low thermal conductivity, it's about half of the value of standing air. The heat losses because of the skeletal conduction (phonons), gas conduction (collisions between gas molecules), and radiation contributions (Levy and Zayat, 2015). Aerogels are one group of very solid material, highly porous and known to posse significantly higher thermal insulation properties (Sachithanadam and Joshi, 2016). Aerogel is usually made by extracting liquid from a gel by supercritical drying. In this case, volatile liquid will be evaporated. (Impey and Henry, 2013).

The process of making an aerogel involves the removal of liquid phase on placeholder. The sol-gel process for making aerogel consists of:

1. Gel preparation
2. Aging of the gel
3. Drying of the gel

(Gladysz and Chawla, 2014)

In a sol, colloidal particles are in 1-1000 nm diameters are dispersed in a liquid. A gel consists of sponge like, three-dimensional solid network and the pores is filled by liquid (Hall, 2010). In the sol-gel process, ceramic polymer precursors are formed in solution at ambient temperature; haped by casting, film formation, or fiber drawing; and then consolidated to furnish dense glasses or polycrystalline ceramics (Charles E. Carraher, 2013).

Aerogel silica is a relatively advanced version of silica particles. It is like a solid some and consist of 95% of air. The remaining of silica aerogel is made by silicon dioxide (Chauhan, 2018). Cellulose is polymer that has many hydroxyl groups, its can be bound with other high hydrogenium bonding, it is called graft. Graft of cellulose will make block grafting (Ferry *et al.*, 1965).

Aerogels have low thermal conductivity. Thermal conductivity of aerogel is about $0.015 \text{ W m}^{-1} \text{ K}^{-1}$ at ambient temperature, pressure, and relative humidity (Aegerter, Leventis and Koebel, 2011).

Cellulose is the abundant source, it can be found on plants, bacteria, animals, and fungi. Because of that, aerogel based in cellulose is used commonly. Cellulose aerogel is the most useful biopolymer that can discovered in the living world., (Hashmi and Choudhury, 2020). Silica-cellulose composite aerogels were fabricated by immersing the cellulose matrixes inside the solution containing a silica precursor. The thermal stability and mechanical strength of silica-cellulose aerogel is improved (Thomas, Pothan and Mavelil-Sam, 2018).

2.5. Corrosion

Corrosion is spontaneous destruction of metals and alloys by chemical, biochemical, and electrochemical interaction between metals and alloys and the environment. Corrosive environments can be caused by moisture, oxygen, inorganic and organic acids, high pressure, temperature, and chlorides. In the reaction, the metals will become thermodynamically compounds such as oxides,

hydroxides, salt, or carbonates (Popov, 2015). Fontana describes that corrosion is the extractive metallurgy in reverse, which is expected since metals thermodynamically are less stable in their elemental forms than in their compound forms as ores. According to American Society for Testing and Materials (ASTM), Corrosion is defined as electrochemical reaction between material, usually metal, and its environment that produce deterioration of the material and properties. (Cicek and Al-Numan, 2011). The rust of corrosion is just on surface layer. It makes the layers are heterogeneous, porous, and flaky in nature (Dhawan *et al.*, 2020).

Metal corrosion makes rust of the surface of the metal or alloy. The kind of rust has different way of forming. Every type of corrosion is made by specific condition of it. The types of corrosion are follows:

1. Uniform Corrosion

It is a large fraction of metal surface area and results in uniform thickness reduction. The corroding metal must be compositionally and metallurgically uniform. A not fixed location of cathode and anode make no preferential corrosion sites. The uniform corrosion is made by spontaneous in atmospheric corrosion that controlled by temperature, humidity, wetness time, electrolyte pH, presence of contaminants such as chloride, ammonia, sulfur dioxide, nitrogen dioxide, and acidic fogs (Cicek and Al-Numan, 2011; Popov, 2015; Dhawan *et al.*, 2020).

2. Pitting corrosion

Pitting corrosion is the most localized corrosion. Pitting corrosion is hardly detected corrosion. One single pit can cause material fatigue, stress corrosion cracking, and may even catastrophic failure of subsea pipelines (Reddy and Arockiasamy, 1991). It forms small pits or cavities in the substrates as shown in **Figure 6**. The small size of the pit makes it hard to be predicted and sometimes the pits may be covered by corrosion product.

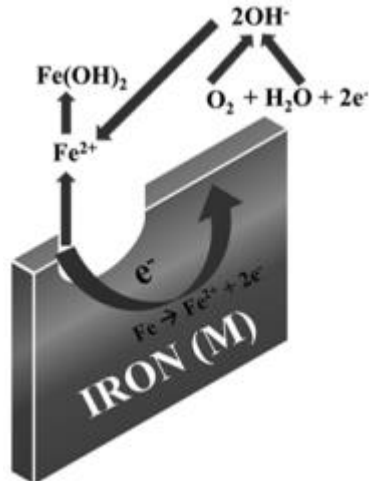


Figure 6. Pitting Corrosion Mechanism

3. Crevice Corrosion

Crevice corrosions are formed at welds, in condensers and between metal surfaces and valves. This corrosion type can be made because of small solution trapped in crevice of joint of the steels (Popov, 2015). Sometimes, the solution can penetrate into the crevice but too narrow for flowing out of it. After the solution come into the narrow and deep crevice, oxygen is more slowly transported into the crevice than it is consumed inside it. Conversely, dissolution of metal inside the crevice continues, driven by the oxygen reduction outside the crevice (Cicek and Al-Numan, 2011).

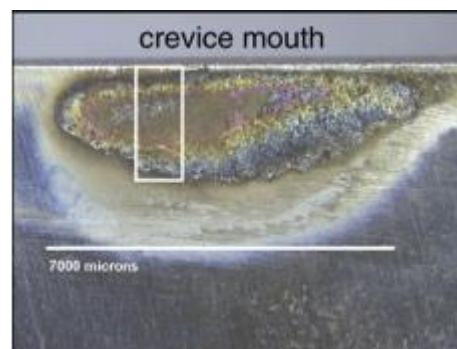


Figure 7. Optical Image of Creviced Alloy

4. Intergranular Corrosion

Intergranular corrosion is a special form of corrosion which generally occurs at grain boundaries or region next to its boundaries. This kind of corrosion is made by unprotected end grains that will initiate the grain boundaries and can cause separation of the metal grain structure (Sastri, 2015).

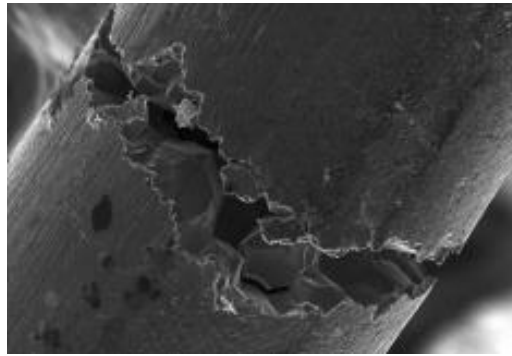


Figure 8. SEM Image of Intergranular Stress Corrosion of Stainless Steel wire

5. Erosion Corrosion

Erosion corrosion is a kind of corrosion that effect of corrosion or erosion which occurred due to relative movement between fluid and metal substrate surface. It depends of velocity and physical of the fluid (Sastri, 2015). The fluid movement carries corroded metal of the surface substrate. In this case, the material surface is exposed to mechanical wear, and scraping the surface substrate which results in a lower active metal layer (Cicek and Al-Numan, 2011).

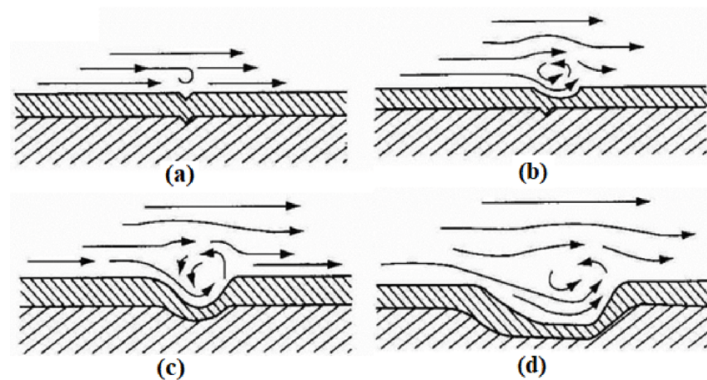


Figure 9. Erosion Corrosion Appearance

6. Microbial Corrosion

Electron flows are produced by some organism, it modifies local the local environment to a corrosive one.

Microbial deposits accumulate on the metal surface. They are regarded as inert deposits on the surface, covering area below corrosive electrolyte. The area directly under the colony will become the anode, and the metallic surface just outside the contact will become the cathode (Cicek and Al-Numan, 2011).

In anaerobic conditions, some bacteria can decompose sulphate ion as oxygen and sulfide ion. The sulfide ion will be reacted with ferrous ion to form iron sulfide. Some other bacterian can directly reduce metal atoms to ions (Cicek and Al-Numan, 2011)

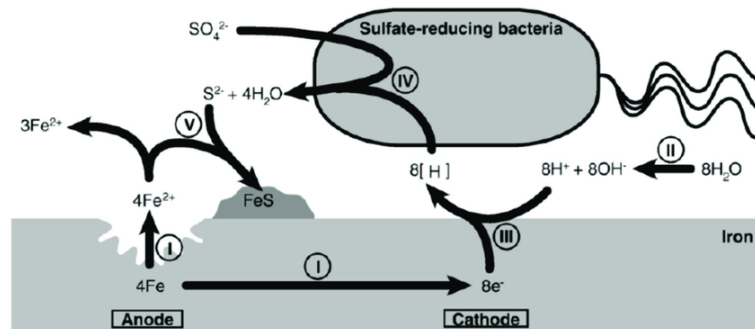
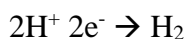


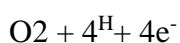
Figure 10. Microbial Corrosion Mechanism

Corrosion reaction can be defined by deterioration of metals because of the contact of the environment. The environments usually act as cathodic reaction and the metals act as anodic reaction. There is four reaction of cathodic reaction:

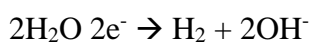
1. Hydrogen evolution in acid solutions:



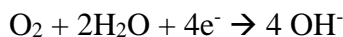
2. Oxygen reduction in acid solutions:



3. Hydrogen evolution in neutral or basic solutions:



4. Oxygen reduction in neutral or basic solutions:



5. The reaction of cathodic will affect the metals as anodic:



(Cicek and Al-Numan, 2011)

2.6. Corrosion Inhibitor

Corrosion inhibitors are chemical compound that added to environment to reduce metal rust rate that is exposed to that environment. Corrosion inhibitors would react with metal surfaces and adhere to the inner surface of the pipeline and protect the pipe from corrosion. The active compounds in the inhibitor help form a film layer of inhibitor on the surface and prevent the water from touching the pipe wall (Reddy and Arockiasamy, 1991). Corrosion inhibitors must provide protection to a coating, but they must possess additional properties that make them suitable for use. It requires high efficiency at low concentration, low water solubility, good thermal stability, effectiveness over a broad pH range, low toxicity, ease of addition, and little or no interaction with other components.

Organic inhibitors can be the one of many methods as anti-corrosion in Industry. Organic inhibitors work as adsorbent because of the large number of lone pairs of electrons, p-orbital character, and the molecular electronic structure (Quraishi, Chauhan and Saji, 2020).

Thiazole or derivates of it and pyridine are heterocyclic organic compound that present inhibition efficiency of 1 M HCl on stainless steel. Thiazolo pyridine carboxylic acid (TPA) is made by citric acid and L-cysteine reaction. TPA has two carbonyl groups that can be linked to cellulose by esterification reaction by multidehydration reaction (Chen *et al.*, 2017). The reactions are follow:

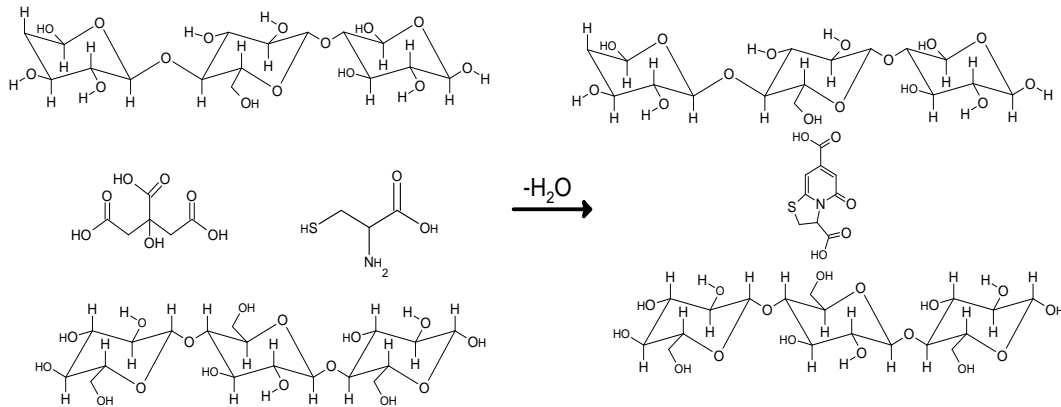


Figure 11. TPA is Formed after Multidehydration

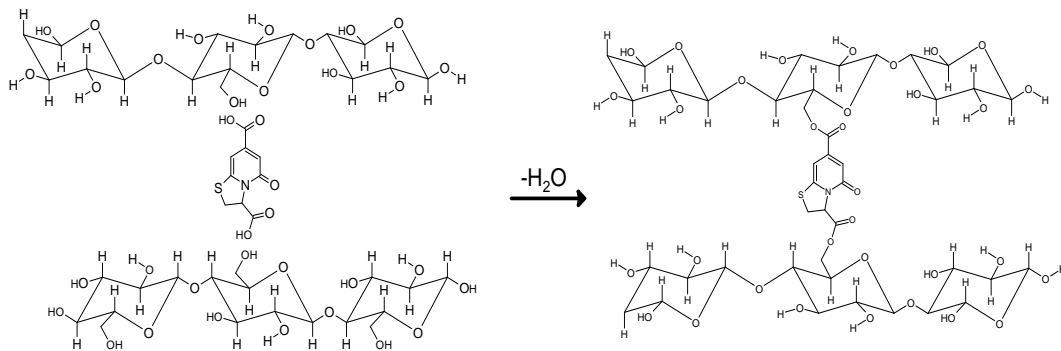


Figure 12. Esterification of Cellulose and TPA

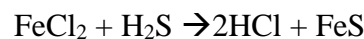
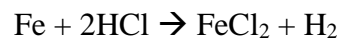
2.7. Corrosion in Industry

In industry, metals or alloys are used as pipeline or chamber of reactor. The metals and alloys depend on the purpose of its. Alloys have some overplus of the single metal, because alloys are made of mixing of some metals. These make alloys upgrade physic and chemistry properties, like hardness and anti-corrosive materials. Common alloys are using stainless steel and mild steel.

Stainless steels are alloys that made up by iron, chromium, nickel, and other alloying elements (Cicek, 2017). Stainless steels have different percentage of the composition of the alloy. The stainless steel major can be classified as martensitic

stainless steels, ferritic stainless steels and super ferritic stainless steels, austenitic stainless steels, duplex stainless steel (Motarjemi, 2013).

The crude petroleum always contains saltwater. Chloride can be obtained from the ovens in petroleum-refining unit and decomposition of organic chloride that are initially added to hydrogenize the petroleum. The excess of chloride of the crude oil processing must be neutralized to not cause corrosion in the following stages. All chlorides are determined as sodium chloride (NaCl). In this case, not all of chloride is formed as NaCl, when the solution is heated up to 149 °C until 204 °C (300 °F – 400 °F), they form hydrochloric acid (HCl), which is very corrosive in aqueous solution. HCl goes through the following corrosion reactions with iron in presence of Hydrogen Sulfide (H₂S):



Chloride content is set down to 2.85 g/m³ until 28.5 g/m³. At that condition, HCl corrosion still remains an issue. Corrosion can be considered negligible in pH range 5 until 8 (Cicek, 2017).

In acidizing of sandstone, fluids selection depends on mineralogy, temperature, and nature damage. HCl and organic acid are effective to remove carbonate, iron, hydroxide scales while chelating agents such as EDTA will be required to dissolve most sulfates. The damage can be characterized as relating to silts and clays, a blend of HCL and hydrofluoric acid (HF) are required. This acid blend is commonly referred to as mud acid and can be run at varying ratios using different concentration where the HF 3% to 5% and the HCl 3% to 13.5%

Table 2. Fluid selection guidelines for preflush fluids

Mineralogy			Permeability	
Silt	Clay	>100md	20 to 100 md	<20 md
<10%	<10%	15% HCl	10% HCl	7.5% HCl
>10%	>10%	10% HCl	7.5% HCl	5% HCl
>10%	<10%	10% HCl	7.5% HCl	5% HCl
<10%	>10%	10% HCl	7.5% HCl	5% HCl

(Lyons and Plisga, 2005)

In wastewater treatment, HCl is used as solvent of metal. The waste water must be adjusted in pH range 2.0 to 7.5. The lower pH of solution cause high corrosion of the metal (Viraraghavan, 1991)

2.8. Coatings

Coating is defined as the process of covering the surface of an object, commonly referred to as substrate. Coating aims are about enhance the properties of substrates, adhesion to substrate, wettability, and corrosion resistance (Li and Yang, 2018). Organic inhibitors build up protective hydrophobic film adsorbed molecules on the metal surface, which provides a barrier to the dissolution of the metal in electrolyte. The efficiency of an organic inhibitor depends of the:

1. Chemical structure, like the size of the organic molecule
2. aromaticity and conjugated bonding, as the carbon chain length
3. type the number of bonding atoms or groups in the molecule
4. nature and the charge of the metal surface of adsorption mode like bonding strength to metal substrate
5. ability for a layer to become compact or cross-linked
6. capability to form a complex with the atom as a solid within the metal lattice

7. type of the electrolyte solution like adequate solubility in the environment (Aliofkhazraei, 2014).

2.9. Scanning Electron Microscope (SEM)

Microscope word is derived from Greek, micros (small) and skopeo (look at). Microscope has meant the thing that can be used to see small things. SEM is an instrument to enlarge small objects otherwise the invisible human sight by scanning an electron beam of high energy on the sample surfaces. (Ul-Hamid, 2018). The magnification of scanning microscope is the ratio between the dimensions of the final image of the display and the field scanned on the specimen. Magnification changes are brought by altering the extent of scan on the specimen whilst keeping the size of the display constant. Magnification control on the microscope is varies the angle through which beam is deflected and the linear extent of the scan depends on the working distance of the specimen from the final lens (Watt, 1997).

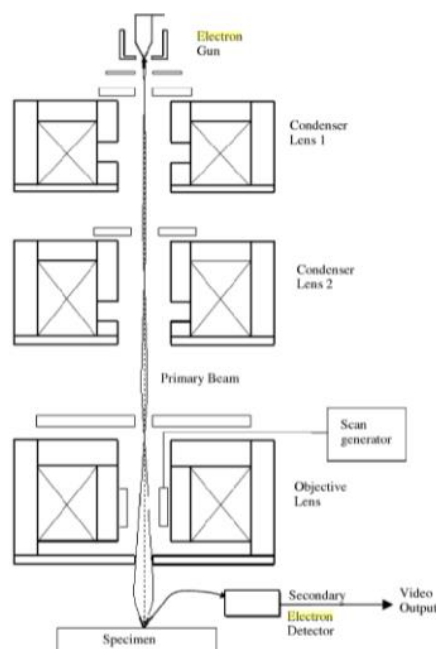


Figure 13. Scanning Electron Microscope Mechanism

2.10. Fourier Transform Infrared (FT-IR)

Infrared (IR) spectroscopy is a method to analyze functional group and concentration of the samples by using covalent chemical bonding of molecules and lattice vibration of ionic crystal. Infrared is an electromagnetic wavelength found in 700 nm -1,000 nm or 10 cm^{-1} - $15,000\text{ cm}^{-1}$ (Nishikida, Nishio and Hannah, 1995). IR Absorption spectrum represents the changes of radiation or a value proportional to it, as the function of wavelength at the same value. Energy is absorbed depends on the intra and intermolecular bonds. The absorption is low intensity, then the FT spectroscopy amplifies the IR signals by using beam splitter, movable mirrors, multiwavelength, and a Michelson interferometer (Martin, 2005).

FT-IR is working by transmitted light that through the thin layer sample, or reflected off. FTIR provides specific information about chemical bonding and molecular structure, primarily of organic molecules. The energy of IR radiation will be absorbed by specific bonds. The specific absorption of the energy causes the vibration of atoms (Portnoy, 2008).

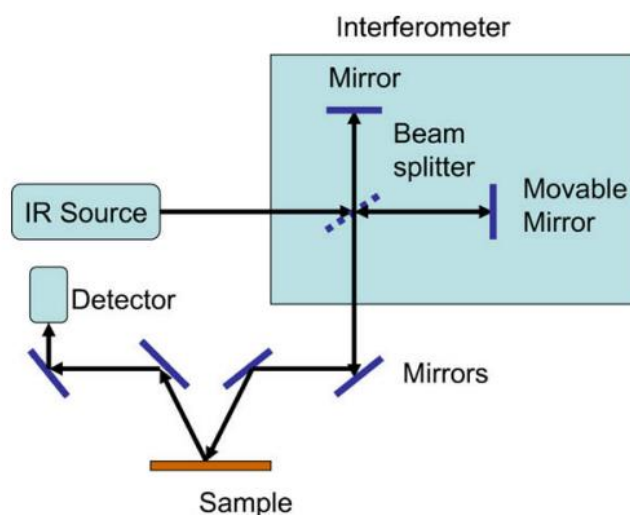


Figure 14. FTIR Mechanism

III. RESEARCH METHODS

3.1. Time and Place

The research has been held in December 2021 until April 2022 in Organic Laboratory, Nature Chemistry Majority, Mathematics and Science Faculty, Lampung University. Fourier Transform Infrared (FTIR) was analyzed at Teknologi Sepuluh November Institute. Scanning Electron Microscope (SEM) was analyzed in Research Unit of Mineral Technology Research Institute.

3.2. Tools and Materials

3.2.1. Tools

Used tools in this research were Fourier-Transform Infrared (FT-IR) using Thermo Fisher Scientific from Sepuluh November Institute, Scanning Electron Microscope (SEM) using JEOL JSM-6510 LA from Research Unit of Mineral Technology Research Institute., analytical balance using Mettler Toledo AB-54-S, beaker glass, magnetic stirrer, thermometer, and spatula.

3.2.2. Materials

Used materials in this research were cellulose from pineapple waste, Sodium hydroxide, Tetraethyl Orthosilicate (TEOS), Aqua distillate, Citric acid, Cysteine, and methanol.

3.3. Procedure

3.3.1 Isolation Cellulose of Pineapple Waste

3.3.1.1. Pretreatment

500 gram of pineapple waste was measured in Beaker Glass, then added 2% NaOH. The mixture was saved for 24 hours at room temperature. The mixture was washed by aqua distillate until reach neutral pH and filtered to take the residue.

3.3.1.2. Delignification

Residue of the pineapple waste was added into 20% of Na₂SO₃ with ratio 1:15(w/v). After washing, the mixture was heated until 100°C for 2 hours. After the heating process, the residue was washed by aqua distillate and filtered to take the residue.

The residue of delignification was purified 2 times by adding 20% NaOH into the sample and the temperature was set on 80°C for 2 hours. The mixture was stirred during the heating process.

3.3.1.3. Bleaching

The final residue of delignification was added into 2% H₂O₂ at 60°C and stirred by using magnetic stirrer for 1 hour. After 1 hour of stirring and heating, the residue was filtered and dried in oven at 60°C. The residue was measured on analytical balance.

3.3.2 Modification Cellulose

10 grams of cellulose was measured. The cellulose was immersed by ratio 1:10 (w:v) by using mixture citric acid and cysteine (20% and 20%) at 25 °C for 25 hours. The solution was placed in a freezer for 24 hours for gelation. The sample was neutralized by using water distillate to remove unreacted chemicals and dry it.

3.3.3 Cellulose Aerogel Synthesis

Modified cellulose was measured .8 grams using analytical balance. The cellulose was impregnated with 76 mL aqua distillate at 5 °C for one hour. 84 mL cooled NaOH 15.2% and with 1.6 grams ZnO as monolith were mixed into the impregnated cellulose for two hours at 5 °C. Tetraethyl orthosilicate was entered as much as 40 mL to the mixture. The mixture was sealed. Let the mixtures solidified at ambient temperature. The solidified material was neutralized by using citric acid 0.2 M. The solution was frozen. After the solution was frozen, it would be thawed in room temperature, and immersed by ethanol 99% for coagulation for 3 hours. The sample was washed using methanol, then exchange with methanol, then wait until become viscous

3.3.4 Corrosive Medium Preparation

HCl was used as corrosive medium. The variant of HCl concentrations were 5%; 10%; and 15%. Concentrate HCl (37%) was measured as much as 405 mL and diluted in distilled water up to tera mark at a 1000 mL volumetric flask to obtain HCl 15%. Concentrate HCl (37%) was measured as much as 270 mL and diluted in distilled water up to tera mark at a 1000 mL volumetric flask to obtain HCl 10%. Concentrate HCl (37%) was measured as much as 135 mL and diluted in distilled water up to tera mark at a 1000 mL volumetric flask to obtain HCl 5%.

3.3.5 Clarke's Solution Preparation

Clarke's solution was made by mixing 12.5 gram of SnCl_2 , 5 grams of Sb_2O_3 and concentrate HCl in 250 mL volumetric flask. The mixture was diluted, then HCl was added until tera mark, and homogenized.

3.3.6 Stainless steel Plate Preparation

Stainless steels were cut with a size of $2\text{cm} \times 2\text{cm}$ and mashed using sandpaper 800 and 1200. After meshing the stainless steels, the stainless steels were cleaned using ethanol. The dimension and mass of the plates were measured.

3.3.7 Dip Coating

The viscous solution is sonicated for 5 minutes. The known mass stainless steel plat 304 was dipped to the viscous solution for 30 seconds. The plat was taken from the solution vertically and carefully. The plat was dried in room temperature.

3.3.8 Fourier-Transform Infrared (FTIR)

FTIR is a spectrum Instrument that can identify functional group of anti-corrosion before contact of hydrochloric acid and anti-corrosion after hydrochloric acid. The steps for this test were follows:

1. Sample powders was mixed with NaBr pure analysis
2. The mixture was entered to the pellet mold
3. The pellet mold were pressed using hydraulic press
4. The pellet sample was come out of the mold and analyzed using FTIR.

3.3.9 Scanning Electron Microscope (SEM)

SEM analysis is purposed to know the morphology of the sample, include mild steel before coating morphology, inhibitor corrosion on mild steel surface morphology before contact with hydrochloric acid, and inhibitor corrosion on mild steel surface morphology after contact with hydrochloric acid. The steps for this test were follows:

1. Sample was prepared and placed on specimen holder
2. The sample was cleaned by hand blower
3. The sample was entered to specimen chamber
4. Observation and taking picture could be seen on SEM display
5. Set up the spot to take the picture
6. Took a picture of SEM sample.

3.3.10 Inhibitor Efficiency

Inhibitor efficiency calculating was purposed to know effectively of the substance can decrease the corrosion rate of the metal. The steps for this test were follows:

1. The stainless steels inhibitor and substrate were dried in oven
2. The stainless steels were cooled down in exicator until reach room temperature
3. Stainless steels weight was measured with analytical measurement at specific weight
4. The stainless steels wre coated by inhibitor corrosion by spraying method and regarded as stainless steel inhibitor and the other as stainless steel substrate
5. The stainless steels inhibitor were dried in oven at 50 °C
6. The stainless steels inhibitor and substrate were dipped in 100 mL hydrochloric acid 1M for 24 hours at different chamber
7. Stainless steels inhibitor and substrate were cleaned by using Clarke Solution
8. Stainless steels inhibitor and substrate were washed by using methanol and dried in oven at 50 °C

9. Stainless steels inhibitor and substrate were cooled down in exicator until reach room temperature
10. stainless steels inhibitor and substrate were measured with analytical measurement to see the weight loses of those.
11. Calculate the Inhibitor Efficiency with this formula:

$$\%IE = \frac{CR_0 - CR_i}{CR_0} \times 100\%$$

%IE = %Inhibitor Efficiency

CR₀ = Corrosion rate without sample

CR_i = Corrosion rate with sample

V. CONCLUSIONS AND DISCUSSIONS

5.1. Conclusion

The conclusions obtained in this study are as follows:

1. Yield of cellulose isolation was 3.87%
2. Modification of cellulose using citric acid-cysteine to produce cellulose-TPA was successfully made. It was showed by ketone functional group from FTIR at 1725 cm^{-1} .
3. Si-O-C and Si-O-Si functional groups were identified by FTIR at 1078 and 796 cm^{-1} in modified cellulose aerogel.
4. The stainless steel contained modified cellulose aerogel coating was damage less than the stainless steel without modified cellulose aerogel.
5. Inhibitor efficiency test was carried out at HCl 5%, 10%, and 15%. The result of the its were 23.37%, 21.80%, and 12.81%, respectively.

5.2. Discussion

The suggestions given for the development of this study in the future are:

1. The polishing of the stainless steel using machine and sandpaper with high number until 5000.
 2. Using Raman Spectroscopy to analyze TEOS and Silica structure.
 3. The advanced analysis of dissolved metal in HCl using Inductivity Coupled Plasma (ICP).
 4. Updating the synthesis method to obtain more optimum conditions.
- .

REFERENCES

- Aegerter, M. A., Leventis, N. and Koebel, M. M. (eds) (2011) *Aerogels Handbook*. London. doi: 10.1007/978-1-4419-7589-8_4.
- Agoes, A. (2010) *Tanaman Obat Indonesia*. Jilid 2. Jakarta: Salemba Medika.
- Aliofkhazraei, M. (2014) *Developments in Corrosion Protection, Developments in Corrosion Protection*. London: IntechOpen. doi: 10.5772/57010.
- Aliofkhazraei, M. (2018) *Corrosion Inhibitors, Principles and Recent Application*. Rijeka: InTech.
- Bartholomew, D. P., Paull, R. E. and Rohrbach, K. G. (2003) *The Pineapple: Botany, Production and Use*. New York: CABI.
- Chang-Sik Ha and Nagappan, S. (2018) *Hydrophobic and Superhydrophobic Organic-Inorganic Nanohybrids, Nucl. Phys.* Pan Stanford Publishing Pte. Ltd.
- Charles E. Carraher, J. (2013) *Polymer Chemistry: Polymer Density*. Boca Raton: CRC Press.
- Chauhan, B. P. S. (2018) *Novel Nanoscale Hybrid Materials*. New Jersey: Wiley & Sons.
- Chen, H. (2015) *Lignocellulose Biorefinery Engineering, Lignocellulose Biorefinery Engineering*. Oxford: Elsevier. doi: 10.1016/c2014-0-02702-5.
- Chen, H. *et al.* (2017) 'Citric Acid/Cysteine-Modified Cellulose-Based Materials: Green Preparation and Their Applications in Anticounterfeiting, Chemical Sensing, and UV Shielding', *ACS Sustainable Chemistry and Engineering*, 5(12), pp. 11387–11394. doi: 10.1021/acssuschemeng.7b02473.
- Cicek, V. (2017) *Corrosion Engineering and Cathodic Protection Handbook, Corrosion Engineering and Cathodic Protection Handbook*. doi: 10.1002/9781119284338.
- Cicek, V. and Al-Numan, B. (2011) *Corrosion Chemistry, Corrosion Chemistry*. Massachusetts: Scrivener Publishing LLC. doi: 10.1002/9781118232163.
- Craig, B. D. *et al.* (1994) *Handbook of Corrosion Data*. Karnataka: ASM

International.

- Crawford, R. J. and Ivanova, E. P. (2015) *Superhydrophobic surfaces, Superhydrophobic Surfaces*. doi: 10.1515/jmbm-2012-0022.
- Davis, J. R. (2000) *Corrosion: understanding the basics, Choice Reviews Online*. doi: 10.5860/choice.37-6294.
- Dhawan, S. K. *et al.* (2020) *Corrosion Preventive Materials and Corrosion Testing, Corrosion Preventive Materials and Corrosion Testing*. Boca Raton: CRC Press. doi: 10.1201/9781315101217.
- Ferry, J. D. *et al.* (1965) *Advances in Polymer Science: Fortschritte Der Hochpolymeren-Forschung*. Berlin: Springer.
- Gladysz, G. M. and Chawla, K. K. (2014) *Voids in materials: From unavoidable defects to designed cellular materials, Voids in Materials: From Unavoidable Defects to Designed Cellular Materials*. Amsterdam: Elsevier. doi: 10.1016/C2011-0-04548-9.
- Hall, M. R. (2010) *Materials for Energy Efficiency and Thermal Comfort in Buildings, Materials for Energy Efficiency and Thermal Comfort in Buildings*. Cambridge: Woodhead Publishing Limited,. doi: 10.1533/9781845699277.
- Hashmi, S. and Choudhury, I. A. (2020) *Encyclopedia of Renewable and Sustainable Materials*. Amsterdam: Elsevier.
- Henderson, J. W. (1970) *Area Handbook for Indonesia*. Washington D.C.: U.S. Government Printing Office.
- Impey, C. and Henry, H. (2013) *Dreams of Other Worlds: The Amazing Story of Unmanned Space Exploration*. New Jersey: Princeton University Press.
- Karimi, K. (2015) *Biofuel and Biorefinery Technologies (Lignocellulose-Based Bioproducts)*, Springer. London: Springer.
- Kuhad, R. C. and Singh, A. (2007) *Lignocellulose Biotechnology: Future Prospects*. Delhi: IK International Publishing House.
- Lawal, D. (2013) 'Medicinal, Pharmacological and Phytochemical Potentials of *Annona Comosus* Linn. Peel', *Journal of Pure and Applied Sciences*, Sixth Volu, pp. 101–104.
- Levy, D. and Zayat, M. (2015) *The Sol-Gel Handbook*. Weinheim: Willey Blackwell. doi: <https://doi.org/10.1002/9783527670819>.
- Li, J. *et al.* (2009) 'Microwave-assisted solvent-free acetylation of cellulose with acetic anhydride in the presence of iodine as a catalyst', *Molecules*, 14(9), pp. 3551–3566. doi: 10.3390/molecules14093551.
- Li, L. and Yang, Q. (2018) *Advanced Coating Materials*. New Jersey: John Wiley

& Sons.

- Liu, W., Budtova, T. and Navard, P. (2011) 'Influence of ZnO on the properties of dilute and semi-dilute cellulose-NaOH-water solutions', *Cellulose*, 18(4), pp. 911–920. doi: 10.1007/s10570-011-9552-9.
- Lobo, M. G. and Paull, R. E. (2017) *Handbook of Pineapple Technology*. New Jersey: John Willey & Sons.
- Lubis, E. R. (2020) *Hujan Rezeki Budi Daya Nanas*. Jakarta: Bhuana Ilmu Populer.
- Lyons, W. C. and Plisga, G. J. (eds) (2005) *Standard Handbook of Petroleum & Natural Gas Engineering*. Second Edi. Oxford: Elsevier.
- Martin, P. M. (2005) *Deposition technologies for Films and Coatings*. Second Edi. Oxford: Elsevier.
- Mekonnen, T. (2020) *Renewable Polymers, Renewable Polymers*. doi: 10.3390/books978-3-03928-767-3.
- Mile, C. (2017) 'Green agriculture in hungary: The factors of competitiveness in organic farming', in Filho, W. L., Pociovalisteanu, D.-M., and Editors, A. Q. A.-A. (eds) *World Sustainability Series*. Hamburg. doi: 10.1007/978-3-319-45081-0_5.
- Motarjemi, Y. (2013) *Encyclopedia of Food Safety, Encyclopedia of Food Safety*. doi: 10.5860/choice.52-0029.
- Nagao, D. *et al.* (2004) 'Particle formation in the hydrolysis of tetraethyl orthosilicate in pH buffer solution', *Journal of Colloid and Interface Science*, 279(1), pp. 143–149. doi: 10.1016/j.jcis.2004.06.041.
- Nishikida, K., Nishio, E. and Hannah, R. W. (1995) *Selected Applications of Modern FT-IR Techniques*. Boca Raton: CRC Press.
- Peter, K. V. (2007) *Fruit Crops*. New Delhi: New India Publishing Agency.
- Popov, B. N. (2015) *Corrosion Engineering: Principles and Solved Problems, Corrosion Engineering: Principles and Solved Problems*. Amsterdam: Elsevier. doi: 10.1016/C2012-0-03070-0.
- Portnoy, R. C. (2008) *Medical Plastics: Degradation Resistance and Failure Analysis*. Baytown: Exxon Chemical Company.
- Quraishi, M. A., Chauhan, D. S. and Saji, V. S. (2020) *Heterocyclic Organic Corrosion Inhibitors*. Amsterdam: Elsevier. doi: 10.1016/c2018-0-04237-1.
- Reddy, D. V. and Arockiasamy, M. (1991) *Offshore pipelines*. Elsevier.
- Rojas, O. J. (2016) *Cellulose Chemistry and Properties: Fibers, Nanocelluloses and Advanced Materials, Advances in Polymer Science 271*. Springer.

- Sachithanadam, M. and Joshi, S. C. (2016) *Silica Aerogel Composites, Silica Aerogel Composites: Novel Fabrication Methods*. Singapore: Springer.
- Samui, P. *et al.* (eds) (2020) *New Materials in Civil Engineering*. doi: 10.1016/b978-0-12-818961-0.00032-6.
- Sastri, V. S. (2015) *Challenges in Corrosion*. New Jersey: John Wiley & Sons.
- Thakur, V. K. (2015) *Nanocellulose Polymer Nanocomposites*. New Jersey: John Wiley & Sons.
- Thakur, V. K. and Singha, A. S. (2013) *Biomass-based Biocomposites Biomass-based Biocomposites*. Shropshire: Smithers Rapra.
- Thomas, S., Pothan, L. A. and Mavelil-Sam, R. (2018) *Biobased Aerogels*. Cambridge: Thomas Graham House.
- Timell, T. E. and Wimmer, R. (2018) *Crystalline Cellulose and Cellulose Derivates*. New York.
- Ul-Hamid, A. (2018) *A Beginners' Guide to Scanning Electron Microscopy*, \. Basel: Springer. doi: 10.1007/978-3-319-98482-7.
- Viraraghavan, T. (1991) 'Proceedings of the 45th INDUSTRIAL WASTE CONFERENCE', in Bell, J. W. (ed.). Boca Raton: Taylor and Francis.
- Watt, I. M. (1997) *The principles and practice of electron microscopy*. Second Edi, *Trends in Biochemical Sciences*. Second Edi. Melbourne: Press Syndicate of the University of Cambridge. doi: 10.1016/0968-0004(86)90057-5.
- Wüstenberg, T. (2012) *Cellulose and Cellulose Derivates in the Food Industry: Fundamentals and Applications*. Berlin: Wiley-VCH.
- Yousuf, A., Pirozzi, D. and Sannino, F. (eds) (2020) 'Lignocellulosic Biomass to Liquid Biofuels', in. Academi Press.