STUDY THE CORROSION BEHAVIOUR OF ALUMINIUM ALLOY 5052 IN CROTON MEGALOCARPUS AND COCONUT BIODIESEL

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Field of Study: **Corrosion Engineering**

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ABSTRACT

Biodiesel has become more attractive as alternative fuel for engines because of its environmental benefits and the fact that it is made from renewable sources. However, corrosion of metals in biodiesel is one of the concerns related to biodiesel compatibility issues. This study aims to characterize the corrosion behaviour of aluminium alloy 5052 commonly encountered in the fuel system in diesel engine. The biodiesel was tested in this study is croton megalocarpus biodiesel and coconut biodiesel. Static immersion tests in B0, B10, B20 and B30 fuels were carried out at room temperature for 1200 h for both of the biodiesel. At the end of the test, corrosion behaviour was investigated by weight loss measurements and changes in surface morphology. The surface morphology was analysed using SEM images. Viscosity of the fuel was also analysed using Anton paar viscometer to co-relate the viscosity of the blends towards the corrosion. Results showed that under the experimental conditions, aluminium alloy 5052 is more corrosion resistant in presence of coconut biodiesel and its blends compare to croton megalocarpus biodiesel and its blends. All the objective as per listed earlier of the study was clearly achieved for this study.

ABSTRAK

Biodiesel telah menjadi lebih menarik sebagai bahan api alternatif untuk enjin kerana faedah alam sekitar dan fakta bahawa ia dibuat daripada sumber yang boleh diperbaharui. Walau bagaimanapun, kakisan logam dalam biodiesel adalah salah satu masalah yang berkaitan dengan isu keserasian biodiesel. Kajian ini bertujuan untuk mencirikan tingkah karat aloi aloi aluminium 5052 yang lazim ditemui dalam sistem bahan api dalam enjin diesel. Biodiesel diuji dalam kajian ini adalah croton megalocarpus biodiesel dan biodiesel kelapa. Ujian rendaman statik dalam bahan api B0, B10, B20 dan B30 telah dijalankan pada suhu bilik selama 1200 h bagi kedua-dua biodiesel tersebut. Pada akhir ujian, tingkah laku kakisan diselidiki oleh pengukuran berat badan dan perubahan morfologi permukaan. Morfologi permukaan dianalisis menggunakan imej SEM. Kelikatan bahan api juga dianalisis menggunakan viscometer Anton untuk mengaitkan kelikatan campuran ke arah kakisan. Keputusan menunjukkan bahawa di bawah keadaan eksperimen, aloi aluminium 5052 adalah lebih tahan kakisan di hadapan biodiesel kelapa dan campurannya berbanding dengan croton megalocarpus biodiesel dan campurannya. Semua objektif seperti yang disenaraikan di awal kajian jelas dicapai untuk kajian ini.

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LIST OF SYMBOLS AND ABBREVIATIONS

CC	:	Coconut
CM	:	Croton megalocarpus
AA	:	Aluminium alloy
B0	:	100 % Commercial diesel
B10	:	Commercial diesel 90% mix with biodiesel 10%
B20	:	Commercial diesel 80% mix with biodiesel 20%
B30	:	Commercial diesel 70% mix with biodiesel 30%
B100	:	100 % Biodiesel
CSTR	:	Continuous stirred tank reactor
PFR	:	Plug flow reactors
COME	:	Croton oil methyl ester
ASTM	:	American society of testing and materials
ICP	:	Inductively coupled plasma
EIS	:	Electrochemical impedance spectroscopy
SET	:	Static emersion tests
CS	:	Carbon steel
HDPE	:	High density polyethylene
FTIR	:	Fourier transform infra-red
TAN	:	Total acid number
SEM	:	Scanning electron microscopy

CHAPTER 1: INTRODUCTION

1.1 Brief Introduction

Biodiesel could be a sustainable various fuel that is quickly obtaining a lot of popularity in automobile section. it's made from renewable sources (Deng X, 2011) and has abundant potential to fulfil the considerations associated with fuel depletion and environmental degradation (Deng X, 2011) (Karavalakis G, 2011). However, corrosion of automotive metals in biodiesel is one in all problems} associated with biodiesel compatibility issues. The variability in oil process has shown a clear need for new opportunities of fuel generating based on renewable resources. But there are many researches and studies going on to find the possible substitution of the petroleum fuels by cleaner fuel such as biodiesel as biodiesels mostly from vegetal origin.

Acetic acids need to be taken into corrosion consideration. Although aluminium contains a sensible resistance to acetic acid solution at room temperature, aluminium will corrode in nearly any concentration of acetic acid at any temperature if the acid is contaminated with the correct species (Tadala akhil, 2016). Corrosion is a naturally occurring phenomenon usually outlined because the deterioration of a material of construction or its properties because of a reaction with the atmosphere (Tadala akhil, 2016). There are many industrial applications of aluminium such as constructions, electrical engineering, transport and etc. Aluminium and its alloys is a good choice of material which can be easily applicable at any working environment as consider the good properties of aluminium.

On the opposite hand, because of the unsaturated molecules present in biodiesel, some adverse effects were reportable by numerous authors. Most of them are centred on the corrosive character as a result of its additional oxidative and causes increased corrosion and material degradation. However, at low concentrations, no serial issues were rumored to elements of the engine. the right material choice minimizes the corrosion drawback bestowed by biodiesel. as an example, the material accustomed biodiesel transportation and storage is usually stainless-steel as a result of it's an honest corrosion resistance, similarly as edges price relation. It had been cited that they need a wonderful compatibility with corrosive fluids.

Some metallic substrates are employed in automotive systems like tanks and carbon steel plates (covered or not by zinc), iron Zn alloys, aluminium-zinc or nickel-zinc, lead, and tin (A. R. P Ambrozin, 2009) (Susuki, 2007) (A. S. M. A.Haseeb T. S., 2011). Studies regarding the biodiesel compatibility with the opposite sorts of materials are some vital, particularly due to their injection method within the automotive application. during this step, it gets in touch with completely different materials like metallic, ferrous, and even elastomeric.

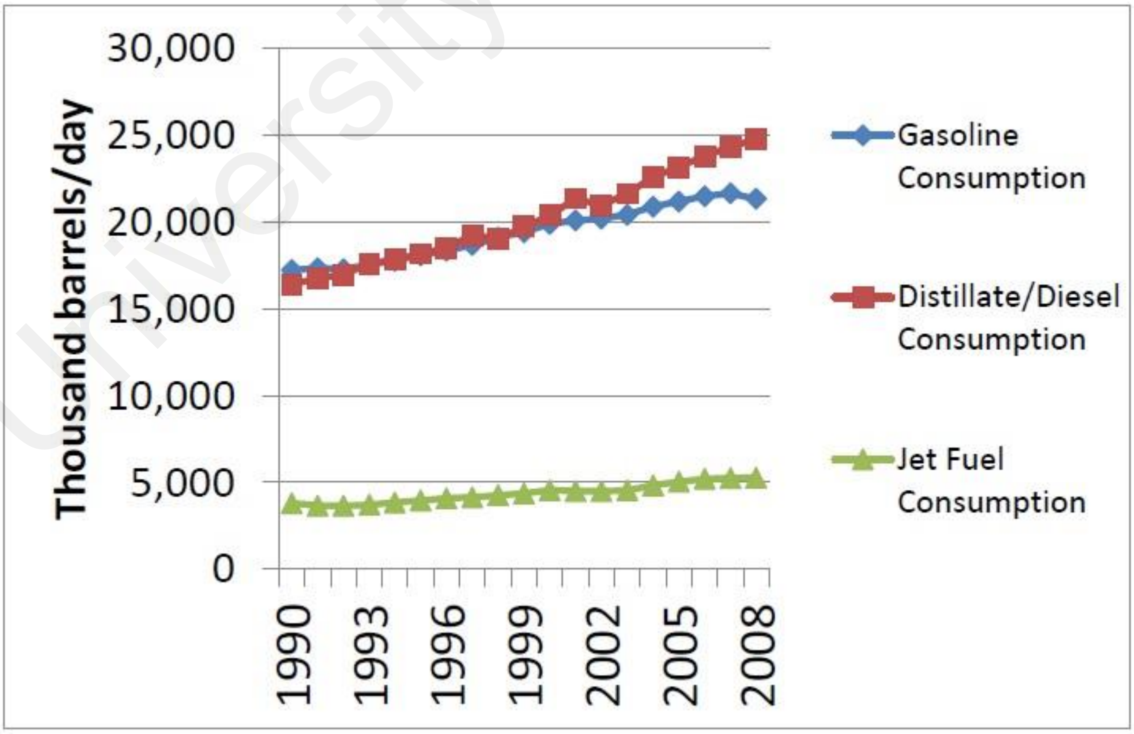


Figure 1.1: Worldwide consumption of Diesel, Gasoline and Jet Fuel (Npa, 2014)

1.2 Problem Statement

Aluminium alloys are suitable substitutions for heavy ferrous alloys in diesel engines. Biodiesel has become a rapid growing liquid biofuel across the world as a substitute for fossil fuel. Corrosion of metals in biodiesel poses a great threat as this can affect durability of engine parts with which it comes in contact. Previously there was no study was done to investigate the effectiveness of Croton Megalocarpus (CM) biodiesel and Coconut (CC) biodiesel with different mixing composition (blends). Therefore, this research of corrosion behaviour in aluminium alloy due to the compositions of biodiesel are highly beneficial for its applications prevention in future.

1.3 Research Objectives

The main objective of this study is:

1. To investigate the effect of composition (blends) of Croton megalocarpus (CM) biodiesel and Coconut (CC) biodiesel towards corrosion response of aluminium alloy 5052.
2. To compare the both croton megalocarpus biodiesel and coconut biodiesel on which is more corrosion resistant.

1.4 Scope of Study

The study of this research is to analyse and understand the corrosion behaviour of aluminium alloy 5052 in presence of croton megalocarpus biodiesel and coconut biodiesel of different compositions of blends. The samples are prepared as per standard and was performed static immersion at room temperature for 1200 hours. The samples later will be later study on the weight loss before and after and corrosion rate will be calculated as for quantitative analysis. For qualitative analysis, the surface microstructure will be analysed using SEM images. With all the data a proper discussion and conclusion will be drawn

CHAPTER 2: LITERATURE REVIEW

In this chapter, will be elaborate the comprehensive view on the types of biofuel and material selected for this project and elaborate on the previous work or project that have been done related to this project.

2.1 Aluminium and Aluminium Alloy

2.1.1 Aluminuim

In nature, aluminium exists as the mineral bauxite, rich in alumina. Because of its high reactivity with oxygen, aluminium requires a large amount of energy to be extracted from its ore. In 1885 aluminium was isolated as a pure element by Hans Christian Oerstedand. Its commercial production started in 1886 (Polmear, 2006). Nowadays bauxite production has reached 200 million tonnes worldwide; where Australia and China are the largest producers. To produce one tonne of aluminium requires four tonnes of bauxite (Hughes A.E., 2011).

Aluminium is silver-white with an atomic number of 13, an atomic weight of 27 and a melting point 683°C. It is a soft, ductile, non-toxic and paramagnetic material, with a high electric and thermal conductivity and has an excellent resistance to corrosion (Hussey, 1998) (Schweitzer, 2003) (I.J., 2015). When aluminium reacts with oxygen, it will produce coherent thin oxide aluminium (Al_2O_3) layer of 1-5 nm on its surface that protects the metal from further corrosion. It can be easily extruded to form bars and tubes and rolled to foils, sheets and plates and is suitable for low cost recycling processing (Polmear, 2006) (Hussey, 1998). Additionally, it can be cast, mainly by sand and/or die casting, and machined. It is widely used in both mechanical and electrical conducting applications in modern industry. (Aburas, 2013)

2.1.2 Aluminium Alloy

High light, heat reflectivity and having a silvery-white surface is the characteristics of a pure aluminium. The density of aluminium at room temperature is 2.7 g/cm^3, yet it can reduce to 2.6 g/cm^3 at the temperature of 660˚C, near the melting point, and 2.4 g/cm^3 for the molten metal (Davis, 1993). Its thermal conductivity is 209 W/m.K, however a little measure of polluting influences has antagonistic impact on its conductivity. The noticeable properties of aluminium alloys which make them alluring for an extensive variety of uses are light weight, great formability, satisfactory mechanical properties and incredible consumption protection (Davis, 1993). Aluminium combinations are arranged in two primary gatherings in view of the way they are handled or created, specifically: cast and wrought alloys (Davis, 1993).

Wrought aluminium alloys are used for numerous forming processes like rolling, extrusion and formation. The forged grades are used for castings. forged alloys are unreal in numerous ways in which as well as sand casting, mould casting, and die casting. the most distinction between moulded and forged metal alloys is that the structure and texture, that are primarily identical for forged alloys (Davis, 1993). The chemical composition of forged alloys is totally different from moulded alloys of constant grade because of the various technique of producing. The forged metal alloys are used in engine components, room appliances and craft body structures. moulded alloys are unreal within the style of worked product like sheets, plates, foils, tubes, rods, bar and wires (Davis, 1993).

Both moulded and solid Al alloys square measure divided into 2 groups: heat treatable and non-heat treatable. The strength and hardness of warmth treatable alloys are often improved through a three-stage heat treatment, namely: resolution heat treatment, termination and age hardening. Non-heat treatable alloys gain strength by either strain hardening or primary solid solution strengthening (Association, 1984).

Table 2.1: Aluminium wrought and cast alloys and their typical applications (Kaufman, 2000).

	Alloy series	**Composition**	**Ultimate tensile strength (Mpa)**	**Heat treatable**	**Properties**	**Applications**
Wrought	1xxx	Al	70 - 185	No	Exceptionally high formability, corrosion resistance and electrical conductivity	Packaging, chemical equipment, electrical applications
	2xxx	Al-Cu	190 - 430	Yes	Low resistance to atmospheric corrosion	Aircraft, space shuttle
	3xxx	Al-Mn	110 - 285	No	High formability and corrosion resistance	Cooking utensils, heat exchanger, beverage cans
	4xxx	Al-SI	175 - 385	Yes	Low melting point, excellent flow characteristics	Forging, weld filler
	5xxx	Al-Mg	125 - 350	No	Excellent corrosion resistant, toughness and weld ability	Building and construction, highway structures, marine application

	6xxx	Al-Mg-Si	120 - 400	Yes	High corrosion resistance, excellent extrudability	Architectural and structural parts
	7xxx	Al-Zn-Mg (Cu)	220 - 610	Yes	High strength and toughness	Aircraft
Cast	2xx.x	Al-Cu	130 - 450	Yes	High strength at room at elevated temperatures, high toughness	Aerospace industry, machine tools, engine blocks or bearings
	3xx.x	Al-Si (Cu/Mg)	130 - 275	Yes	Flexibility provided by the high silicon content	Aircraft, car wheels
	4xx.x	Al-Si	120 - 175	No	Excellent cast ability and weld ability	Complex cast parts for computer housings and dental equipment
	5xx.x	Al-Mg	120 -175	No	Good resistance to corrosion	Door and window fittings
	6xx.x	Al-Zn	210 - 380	Yes	Excellent finishing characteristics	Furniture, garden tools, office machines and farming and mining equipment
	7xx.x	Al-Tin	105 - 210	Yes	Excellent Machinability	Bushings and bearings

2.1.3 5052 Aluminium Alloy

One in every of the alloy with higher strength, non-heat-treatable alloys, that contains magnesium as its major alloying element, with very little measures of manganese, iron, silicon, chromium, zinc, and copper is aluminium alloy 5052. 5052 alloys cannot be heat treated, nevertheless is hot and funky worked (States, 2016).

The properties of 5052 aluminum incorporate nice workability, creating it very valuable in shaping operations. it's nice erosion protection, notably to salt water, and may be effectively welded (States, 2016). Its high fatigue strength makes it an implausible alternative for structures that require to resist intemperate vibrations. Compound 5052 is usually utilized as a section of sheet, plate and tube form. nevertheless, this compound is evaluated not out of the question for machinability, therefore it's not the most effective call for broad machining operations while not oil material (States, 2016).

Due to the good corrosion resistance, aluminum alloy 5052 widely used for ship manufacturing and marine industry. The components which used AA 5052 for fabrications is marine components, fuel tanks and oil lines (States, 2016). Smaller, thinner parts, which most commonly used in electronics industry also manufactured by AA 5052 because of AA 5052 having high strength, light weight and best finishing capabilities (States, 2016). AA 5052 most commonly used for mobile devices, laptop computers, electronics casings, and televisions (States, 2016). There are other common applications for aluminum alloy 5052 includes pressure vessels, fuel and oil lines, heat exchangers, kitchen cabinets, hydraulic tubes, fencing, lighting, appliances like home freezers, rivets and wiring. AA 5052 is always a preferred material for general sheet metal work (States, 2016).

Table 2.2: Chemical Composition of AA 5052

MATERIAL	COMPOSITION (%)
Aluminium (Al)	95.7 – 97.7
Chromium (Cr)	0.15 – 0.35
Copper (Cu)	Max 0.1
Iron (Fe)	Max 0.4
Manganese (Mn)	Max 0.1
Magnesium (Mg)	2.2 – 2.8
Silicon (Si)	Max 0.25
Zinc (Zn)	Max 0.1
Other, each	Max 0.05
Other, total	Max 0.15

Table 2.3: Physical Properties of AA 5052

Property	Value
Density	2.68 g/cm^3
Melting Point	605 ºC
Thermal Expansion	23.7 x 10^{-6}
Modulus of Elasticity	70 GPa
Thermal Conductivity	138 W/m.K
Electrical Resistivity	0.0495 x 10^{-6} Ω . M

Table 2.4: Mechanical Properties of AA 5052

Property	Value
Proof Stress	130 Min MPa
Tensile Strength	210 - 260 MPa
Hardness Brinell	61 HB

2.2 Biodiesel and It's Properties

2.2.1 Production of Biodiesel

Biodiesel is that the name of a clean burning mono-alkyl ester-based aerated fuel made of natural, renewable sources like new/used vegetable oils and animal fats (Salvi B.L., 2012). The renewable raw materials for biodiesel are mainly vegetable oils, seeds and lignocelluloses (Hassan M. Hj., 2013).

Transesterification is one amongst the ordinarily adoptable ways to convert those vegetable oils as fuel (Salvi B.L., 2012). Transesterification is that the reaction of a fat or edible fat with an alcohol to create esters and glycerin. Among the alcohols that may be utilized in the transesterification method are methyl alcohol, ethanol, propanol, butyl alcohol and alcohol. Since the reaction is reversible, excess alcohol is needed to shift the equilibrium to the merchandise facet. to boost the reaction rate and yield sometimes a catalyst is employed. Alkali-catalyzed transesterification is way quicker than acid-catalyzed transesterification and is usually used commercially (A.K.Agarwal, 2007) (Garcia C.M., 2008).The transesterification is often performed at around 80 °C and at this temperature a catalyst is needed. The catalyst is often an alkali but it is also possible to use an acid catalyst or an enzyme. Alkali catalysts are mostly preferred since they give higher reaction rates than acid catalysts and enzymatic processes are considered too expensive (Van, 2005)

Methyl route is the main industrial process used to produce biodiesel. This chemical reaction (Figure 2.1) is also known as metanalysis, and one mole of triglyceride reacts with three moles of methanol in the presence of sodium hydroxide (catalyst) to form the methyl ester (Biodiesel) as product and glycerol (glycerin) as byproduct (Salvi B.L., 2012).

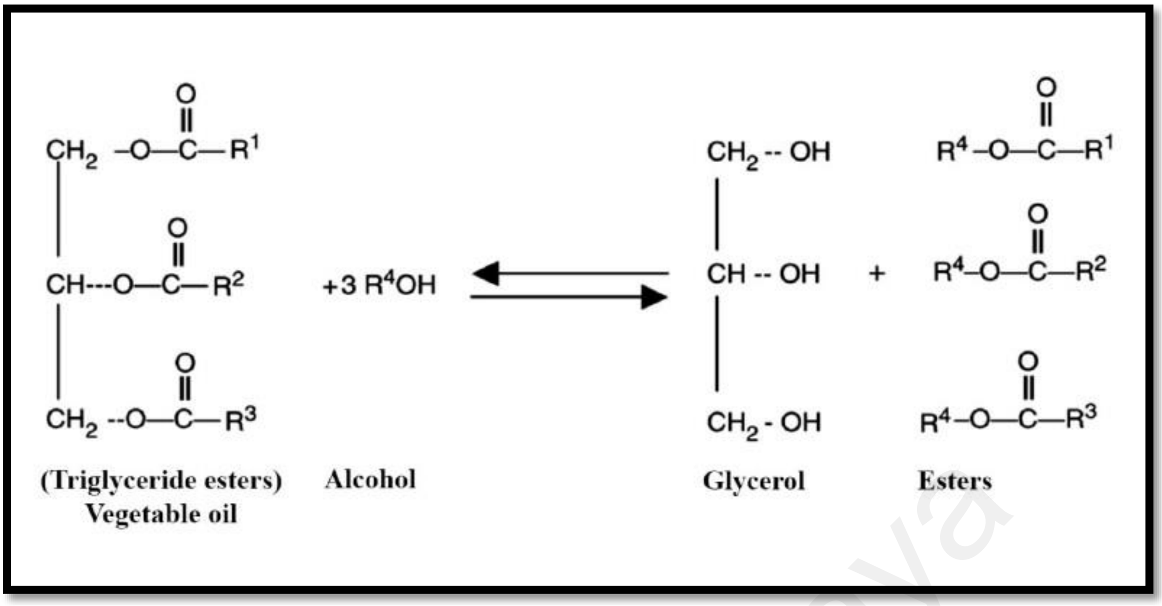


Figure 2.1: Representation of transesterification reaction (A.K.Agarwal, 2007)

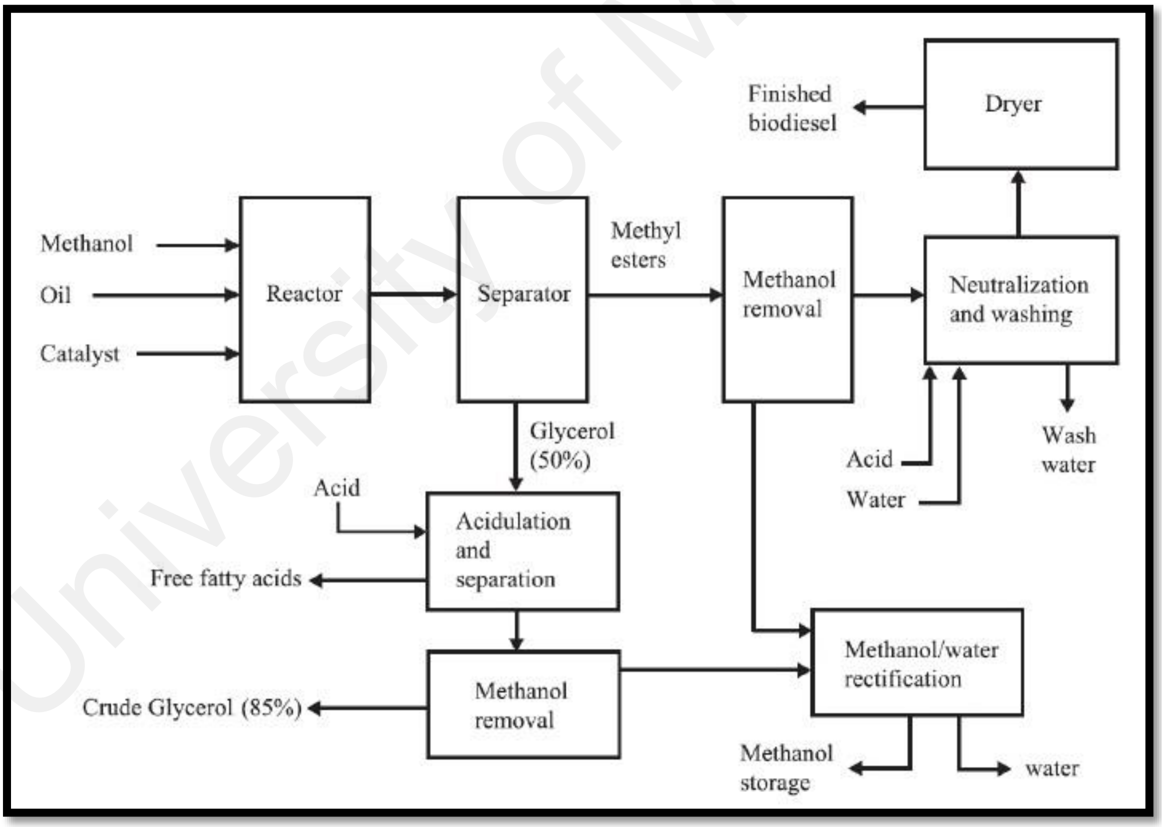


Figure 2.2: Schematic overview of process for biodiesel production (Van, 2005).

The type of chemical reactor used, will depend on the size of the plant's production. Small producers often have batch reactors while large scale (>4 million liters/year) often use continuous. Preferred types of continuous reactors are continuous stirred tank reactor (CSTR) and plug flow reactors (PFR) (Van, 2005). An example of a continuous reactor can be seen below in Figure 2.3 (Fangrui Ma, 1999). This reactor also has an integrated first step separation process with an addition of acid and then settling of esters and glycerol. The alcohol is separated by evaporation, for warming, steam in a heat exchanger is used (Lindstrom, 2015).

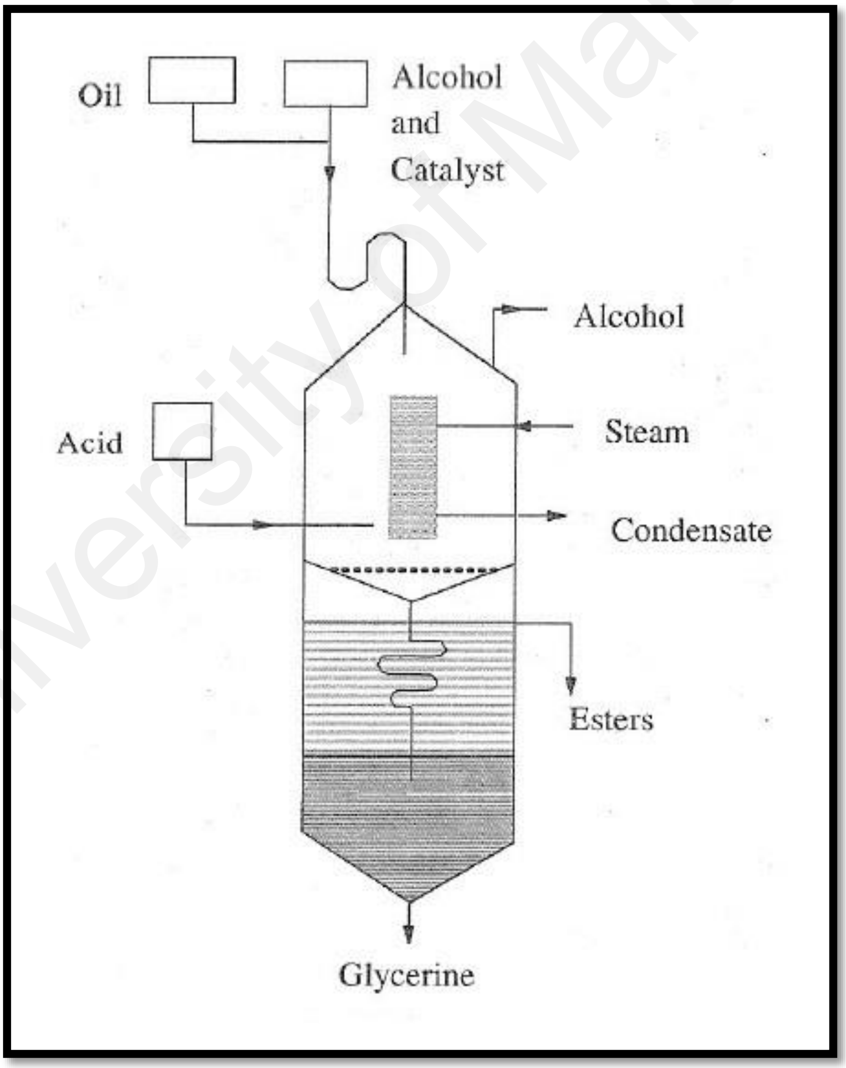


Figure 2.3: A continuous transesterification reactor (Lindstrom, 2015).

2.2.2 Croton Megalocarpus (CM) and It's Biodiesel

Croton megalocarpus plants are origin from East Africa, and are broadly found in the mountains of Uganda, Tanzania and Kenya (Aliyu B S. D., 2010) (Kafuku G M. M., 2010). Croton megalocarpus tree is a member of Euphorbiaceous family (Samoita, 2014). The tree can be found in natural forests margins or as a canopy tree (Samoita, 2014). Croton megalocarpus is origin from East Africa and has been broadly grown in mountainous regions as ornamental for generations (Samoita, 2014). It occurs in tropical East Africa, with an altitude range of 1,400 m to 2,300m; it is mainly planted as a shade tree in coffee plantations (Chudnoff, 1984).

The fruit of Croton megalocarpus contains three ellipsoid ovoid or rectangular ellipsoid seeds two.2-3.4 cm long and one.2-1.4 cm wide (Chudnoff, 1984). The tree produces up to 50kgs of seeds and a square measure produces 5-10 plenty of seeds each year (Makayoto, 1985). geographical region Croton megalocarpus seed has been reported to yield forty ninth oil that is hemolytic and purgative, of that seventy-eight is octadeca-9,12-dienocic acid (C18:2) (Munavu, 1983b). The plant merely drops its seed pods once they become ripe, over the course of simply some weeks (Samoita, 2014). These will be caught in inverted "umbrellas," or additional merely raked along and picked up (Samoita, 2014). The extremely unsaturated oil will be used as oil in paint formulations and as fuel since it's like sunflower-seed oil, that has been shown to be appropriate diesel substitute (G. Antolin, 2002). Croton seed contains malignant neoplastic disease carboxylic acid esters of phorbol, and toxic alkaloids (Samoita, 2014).

Croton megalocarpus are wont to build a decent and secure environment. For medications, the leaves are used for mulch and manure and also the oil (Aliyu B A. B., 2010). As of late, Croton megalocarpus seeds oils can be a potential supply for biodiesel generation (Aliyu B A. B., 2010). Croton megalocarpus seeds contain roughly forty to forty fifth of oil on mass premise once disentangled automatically utilizing a hydraulic press (Aliyu B A. B., 2010).

Figure 2.4: Croton megalocarpus seed, fruit and tree

So far, many studies have been done on creation of biodiesel from croton crude oil within the writing (Aliyu B S. D., 2010) (Kafuku G M. M., 2010) (Kafuku G L. M., 2010) (Kafuku G T. K., 2011). within the overwhelming majority of the investigations, it's been accounted for croton oil methyl ester (COME) is wealthy in unsaturated fat methyl group esters. an experiment disclosed that return has 72.7% linoleic unsaturated fats which since it's wealthy in unsaturated fats, return has astonishingly cold flow properties (Kafuku G

M. M., 2010). COME have been identified that having a cloud and pour point of −4 °C and −9 °C, severally (Kafuku G M. M., 2010). These predominant low remperature properties showed in return demonstrate where by it is possible to be used in cold regions (Kafuku G M. M., 2010).

One of the analysis examined the impact of various antioxidants on the chemical reaction steadiness of repeat (Kivevele TT, 2011). the right come back recorded a chemical reaction reliability of 4.04h, that failed to meet the bottom necessity of chemical reaction strength supported in nut 14214 and SANS 1935 of 6 h (Kivevele TT, 2011). Availability of unsaturated fatty acid methyl group esters of concerning 78.5% is the explanation of the repeat data lower chemical reaction stability (Kivevele TT, 2011).

Table 2.5: Properties of crude Croton megalocarpus oil (A.E. Atabani I. B., 2013)

Properties	**Unit**	**Crude Croton Oil**
Kinematic viscosity at 40 °C	mm^2/s	29.84
Kinematic viscosity at 100 °C	mm^2/s	7.28
Dynamic viscosity at 40 °C	mPa.s	27.15
Flash point	°C	235
Cold filter plugging point	°C	10
Density	kg/m^3	910
Acid value	mg KOH/g oil	12.07
Calorific value	MJ/kg	39.33
Oxidation value	h at 110 °C	0.14
Viscosity index	-	224.2
Transmission	% T	87.5
Absorbance	Abs	0.06
Refractive index	-	1.47

Table 2.6: Physio-chemical properties of Croton megalocarpus methyl ester and its blends with diesel (A.E. Atabani I. B., 2013)

	B0	**B10**	**B20**	**B30**	**B40**	**B50**	**B60**	**B70**	**B80**	**B90**	**B100**
Dynamic viscosity at 40 °C	2.69	2.89	2.92	3	3.05	3.13	3.2	3.28	3.34	3.44	3.52
Kinematic viscosity at 40 °C	3.23	3.46	3.5	3.57	3.61	3.69	3.75	3.83	3.88	3.97	4.05
Kinematic viscosity at 100 °C	1.24	1.34	1.37	1.42	1.45	1.48	1.52	1.55	1.58	1.62	1.66
Density 40 °C	827.2	831.2	835.6	840.3	844.1	848.1	852.7	855	861.6	866	867.2
Viscosity index	90	119.3	139.8	183.7	197.4	202	228.1	238.9	245.8	255.2	266.4
Cloud point (CP)	8	6	5	5	4	4	3	-1	-1	-4	-4
Pour point (PP)	0	0	0	0	3	2	2	2	-1	-1	-3
Cold filter plugging point (CFPP)	5	7	7	6	6	5	4	0	-4	-6	-4
Oxidation stability	N/D	19.5	17.5	N/D	7.91	N/D	3.96	N/D	2.4	N/D	1.1
Calorific stability	45.3	44.9	44.23	43.48	42.81	42.37	41.89	41.17	40.88	40.06	39.53
Flash point	68.5	83.5	86.5	N/D	92.5	N/D	100.5	N/D	N/D	N/D	N/D

Table 2.7: Fatty acid composition for Croton Megalocarpus biodiesel (A. E. Atabani, 2013)

No.	Fatty acid	Molecular weight [g mol¯1]	Structure	Systematic name	Formula	%
1	Caprylic	144	8:0	Octanoic	$C_8H_{16}O_2$	0
2	Capric	175	10:0	Decanoic	$C_{10}H_{20}O_2$	0
3	Lauric	200	12:0	Dodecanoic	$C_{12}H_{24}O_2$	0
4	Myristic	228	14:0	Tetra decanoic	$C_{14}H_{28}O_2$	0.1
5	Palmitic	256	16:0	Hexadecenoic	$C_{16}H_{32}O_2$	6.3
6	Palmitoleic	254	16:1	Hexadec-9-enoic	$C_{16}H_{30}O_2$	0.1
7	Stearic	284	18:0	Octadecanoic	$C_{18}H_{36}O_2$	3.7
8	Oleic	282	18:1	Cis-9-octadecenoic	$C_{18}H_{34}O_2$	10.6
9	Linoleic	280	18:2	Cis-9-cis-12-octadeca-dienoic	$C_{18}H_{32}O_2$	75.7
10	Linolenic	278	18:3	Cis-9-cis12	$C_{18}H_{30}O_2$	3.1
11	Arachidic	312	20:0	Eicosanoic	$C_{20}H_{40}O_2$	0.4
12	Gondoic	310	20:1	11-eicosenoic	$C_{20}H_{38}O_2$	0
13	Erucic	338	22:1	(Z)-docos-13-eboic acid	$C_{22}H_{42}O_2$	0
Saturated						10.5
Monounsaturated						10.7
Polyunsaturated						78.8
Total						100

2.2.3 Coconut and It's Biodiesel

Coconut belongs to Palmaceae (Wagutu, 2010). it's said as Nazi in Bantu (Wagutu, 2010). It is mostly cab be found at the highlands and also the coastal tropics (Child, 1974). Static coconut manufacturing area unitas are South and Central America, East and West Africa, Philippines and Indies (Satyabalan, 1982). In Kenya, coconut tree is being a multipurpose plant for the peoples over there. The tree is being use for create including: coconut, hot toddy (mnazi), leaves (makuti), brooms, coconut shell, shell charcoal, baskets, recent coconut juice and handcrafts (Wagutu, 2010).

The approached people's economic system which depends on a coconut tree "tree on life". It also has a tremendous value into phrases over food, shelter yet service (H. Harries, 2004). Cocos nucifera whereby scientific fame on coconut, is a substantial palm, perform grow upon after 30 m tall, together with pinnate leaves as is 4– 6 m lengthy yet pinnae which is 60– 90 cm long, the historical leaves intention break up outside fair yet fade off the tree conveniently. Coconuts are typically categorized among 2 usual category which is great and dwarf (T. Pradeepkumar, 2008).

The cocoanut tree can survive at bad sandy soils with saline water and even cyclones (Wagutu, 2010). The tree has a ball on crop plants each month because in relation to 65 of their 70 in imitation of 80-year life span yet requires minimal renovation (Wagutu, 2010). The estimated yield is in relation to hundred forty-nine million nuts through an annual (Laichena, 1989). Dried clean (the white flesh) of coconut, is local manufacture so much which going to the world trade. The oil ingredients is within 65% or 72% oil together with an excessive content material over lauric acid (44%) (E.Pryde, 1979). The oil has each safe to eat yet manufactured makes use of (Wagutu, 2010).

Coconut is majorly used to manufacture soap and cosmetic, production of plasticizers, polymer and rubber (Erhan, 2005). Coconut bushes which is left over once the oil has been extracted contains regarding 18-25% supermolecule and it is so largely used to feed animals (piggery, poultry and cattle), baking foods such as cookies or produce organic fertilizers (Thampan, 1981).

The first mature coconuts can be produced after 5-6 years following plantation, and about 50 to 80 fruits per year are produced from a fruit bearing palm with each endosperm yielding up to 40% oil (E. Chan, 2006). Approximately 8-10 coconuts are requested to prepare 1 litre of coconut oil (Tupufia, 2012). The productive lifespan of such palms is about 80 years (Tupufia, 2012). The use of coconut oil has not been widely reported in the literature of biodiesel production although it is considered to be one of the most suitable (Tupufia, 2012).

Figure 2.5: Coconut seed, fruit and tree

Coconut oil contains more than 90% saturated fatty acids with the remainder being unsaturated (J. Benzard, 1971) (Diaz, 2008) . About 62% of the saturated fatty acids are medium chain length (C8 –C18) and 29% are characterized as long chain fatty acids (above C18) (J. Benzard, 1971). Coconut oil has excellent solubility and solvency, such features make "coco biodiesel", a perfect biodiesel for developing countries (Diaz, 2008).

Table 2.8: Properties of crude Coconut oil (A.E. Atabani I. B., 2013)

Properties	Unit	Crude coconut oil
Kinematic viscosity at 40 °C	mm^2/s	4.06
Kinematic viscosity at 100 °C	mm^2/s	1.57
Dynamic viscosity at 40 °C	mPa.s	3.51
Flash point	°C	120.5
Cold filter plugging point	°C	-4
Density	kg/m^3	866.4
Cloud point (CP)	°C	0
Calorific value	MJ/kg	38
Oxidation stability	h	5.12
Viscosity index	-	180.7
Pour point (PP)	°C	-4

Table 2.9: Physio-chemical properties of Coconut methyl ester and its blends with diesel (A.E. Atabani I. B., 2013).

	B0	B10	B20	B30	B40	B50	B60	B70	B80	B90	B100
Dynamic viscosity at 40 °C	2.69	2.75	2.81	2.89	2.96	3.03	3.12	3.22	3.31	3.41	3.51
Kinematic viscosity at 40 °C	3.23	3.28	3.34	3.42	3.49	3.57	3.65	3.75	3.84	3.95	4.06
Kinematic viscosity at 100 °C	1.24	1.3	1.32	1.35	1.37	1.41	1.43	1.47	1.5	1.54	1.57
Density 40 °C	834.9	838.1	841.3	844.3	847.5	850.6	853.7	856	859.9	863.2	866.4
Viscosity index	90	144.7	153.1	155.6	155.9	166.2	168.2	175	177.8	179.8	180.7
Cloud point (CP)	8	7	7	7	7	6	6	4	0	0	0
Pour point (PP)	0	0	-15	-12	-9	-9	-6	-6	-6	-4	-4
Cold filter plugging point (CFPP)	5	7	7	7	6	5	2	1	-1	-4	-4
Oxidation stability	N/D	N/D	113.1	85.88	N/D	66.44	56.55	41.05	32.08	23.23	5.12
Calorific stability	45.3	44.53	43.74	43.08	42.2	41.46	40.82	40.04	39.39	38.62	38
Flash point	68.5	74.5	76.5	N/D	81.5	N/D	89.5	N/D	102.5	N/D	120.5

Table 2.10: Fatty acid composition for Coconut biodiesel (A. E. Atabani, 2013)

No.	**Fatty acid**	**Molecular weight [g mol¯1]**	**Structure**	**Systematic name**	**Formula**	**%**
1	Caprylic	144	8:0	Octanoic	$C_8H_{16}O_2$	8.2
2	Capric	175	10:0	Decanoic	$C_{10}H_{20}O_2$	6.6
3	Lauric	200	12:0	Dodecanoic	$C_{12}H_{24}O_2$	48.3
4	Myristic	228	14:0	Tetra decanoic	$C_{14}H_{28}O_2$	16.4
5	Palmitic	256	16:0	Hexadecenoic	$C_{16}H_{32}O_2$	9.3
6	Palmitoleic	254	16:1	Hexadec-9-enoic	$C_{16}H_{30}O_2$	0
7	Stearic	284	18:0	Octadecanoic	$C_{18}H_{36}O_2$	2.4
8	Oleic	282	18:1	Cis-9-octadecenoic	$C_{18}H_{34}O_2$	7
9	Linoleic	280	18:2	Cis-9-cis-12-octadeca-dienoic	$C_{18}H_{32}O_2$	1.7
10	Linolenic	278	18:3	Cis-9-cis12	$C_{18}H_{30}O_2$	0
11	Arachidic	312	20:0	Eicosanoic	$C_{20}H_{40}O_2$	0
12	Gondoic	310	20:1	11-eicosenoic	$C_{20}H_{38}O_2$	0
13	Erucic	338	22:1	(Z)-docos-13-eboic acid	$C_{22}H_{42}O_2$	0
Saturated						91.3
Monounsaturated						7.0
Polyunsaturated						1.7
Total						100

2.3 Corrosion

Corrosion is the degradation over a material fit to its interaction with the environment. Corrosion can take place about some feasible material, keep such metals, ceramics, polymers then composites (Singh, 2016). durability Corrosion is a naturally happening development, commonly defined namely degradation concerning the material properties as like a end result regarding its interplay along the surroundings above a length of time (Zarras P, 2014). This setting is actual because any type of fabric inclusive of plastics, on the other hand such is hourly reserved because metallic alloys. In the area 80 concerning the acknowledged chemical factors are metals permanency (Figure 2.8).

Of these metals roughly, half may be alloyed with different metals, the following composition of the alloy can confirm the physical, chemical and mechanical properties (Speight J, 2014). The literature illustrates that the corrosion resistance of alloys corresponding to stainless steels may be considerably increased by acceptable alloying (Olsson C O A, 2003).

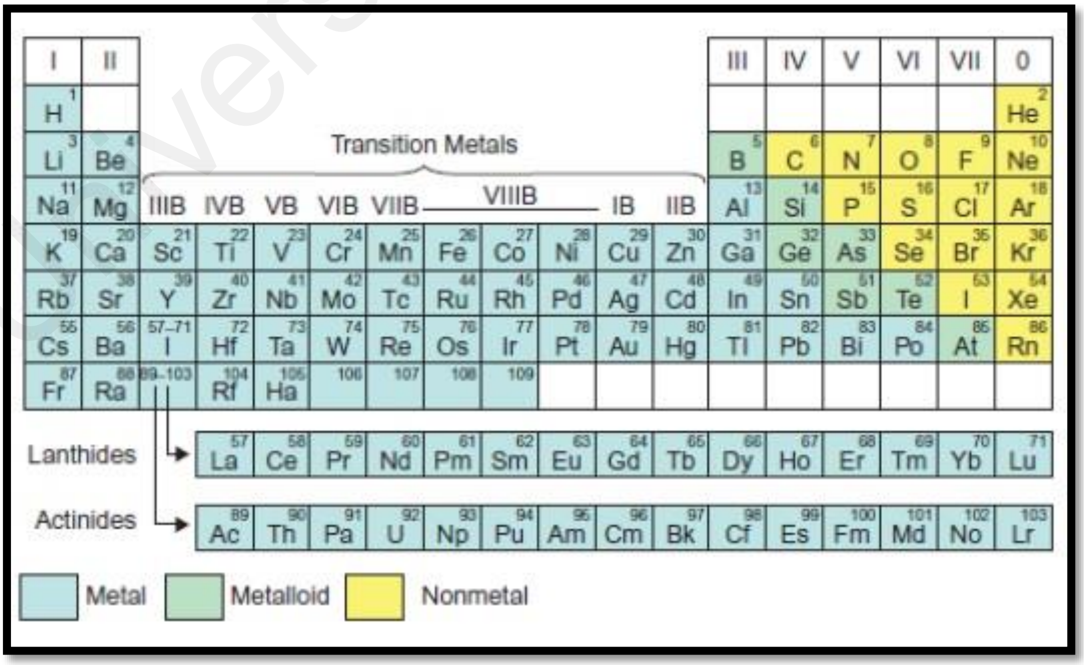


Figure 2.6: Periodic table of the elements (Speight J, 2014)

The surface of all metals with the exception of gold contain an oxide film when in air. This protective oxide film has a tendency to dissolve when submerged in an oxidizing environment, exposing the bare metal surface resulting in a susceptibility to corrosion (Hinds). However, a passive film is formed during the bare metal surface exposure 13 which will reduce the reaction rate of the corrosion by several orders of magnitude (Olsson C O A, 2003).

Figure 2.7: Corrosion phenomenon

2.3.1 Types of Corrosion

A process harm concerning materials due to chemical and/or electrochemical interactions along the working phenomenon is defined as Corrosion. Corrosion is classified as tame then moist corrosion (Obi, 2008). Dry corrosion happens together with gases so the depreciating agent then of the absence of aqueous phases concerning metallic facial (Obi, 2008). Moist corrosion happens when liquids existing on the surface over the metal. Many reasons concerning moist corrosion hold consequently recognized and labeled which is uniform, bimetallic, pitting, crevice, erosion, intergranular, filiform, and de-alloying, stress corrosion cracking, corrosion fatigue, hydrogen blistering yet embrittlement, and microbial corrosion (J.R. Davis, 1999).

Uniform Corrosion: General corrosion which attacked evenly by the aqueous solutions on the facial of the materials. (Obi, 2008).

Pitting Corrosion: Pitting corrosion is that the perforation of a metal at isolated electrode sites on the metal surface (Obi, 2008).

Crevice Corrosion: Crevice corrosion is that the corrosion harm ensuing from uneven distribution of gas on the surface of a metal. electrode sites develop at oxygen-deficient sites, notably among crevices, whereas cathodic sites at the same time occur at oxygen-rich areas. Crevice corrosion typically happens at flanges, bolt holes, gaskets, washers etc (Obi, 2008).

Galvanic Corrosion: Galvanic corrosion is that the corrosion attack on a active metal with a coffee conductor potential that's electrically connected to a metallic element with a high conductor potential (Obi, 2008).

Erosion Corrosion: Erosion corrosion is that the erosion caused or accelerated by relative motion between the metal surface and its atmosphere (Obi, 2008).

Intergranular Corrosion: Intergranular corrosion is that the corrosion attack that is confined to the depletion or deterioration of the grain boundaries of a fabric (Obi, 2008).

In uniform corrosion, the full surface of the alloy exposed to the corrosive surroundings is uniformly and equally corroded over time leading to a standardized reduction of dimensions. Having the material subjected to around a similar rate of corrosion over time. Uniform corrosion is chemical science in nature, the foremost wide best-known sort of corrosion, and it's the relevant kind for this investigation (Obi, 2008).

The behaviour about a material including its environment is the controlling factor into corrosion resistance. There are primary 3 material characteristics. There are materials as are greater preventive to corrosive environments, i.e., in that place is no reaction with the surroundings observed. Those materials are referred to as primitive materials certain as like gold, silver, or platinum (Obi, 2008). The 2nd class includes materials that are regarded in conformity with react along their environments constantly in accordance with form corrosion products. Those materials are categorized namely active due to the fact their corrosion merchandise is either soluble within the surroundings and bear less structural fidelity which leads according to non-stop assault over the base material. An instance on certain conduct is the rusting seen over carbon steel or forged metal (Obi, 2008). In the third category, so are materials that ferment including their surroundings till close and insoluble response merchandise structure (Obi, 2008). Those consumption merchandise act as much a protecting barrier preventing further reactions concerning the surroundings together with the base material. Those materials are regarded namely passive materials certain so aluminium, titanium, or stainless steels (Obi, 2008).

2.3.1.1 Pitting Corrosion

Pitting corrosion is that commonest kind localized corrosion impact of field materials and constitutes terribly a serious material degradation mechanism thanks to the very fast, insidious and unpredictable nature by that confined points, little areas (that usually take the shape of little cavities) on metals sections becomes perforated (International A., 1987) (Roberge, 2008). prevalence of pitting corrosion within the oilfields may be manifested as follows;

1. Pitting within materials is brought on by way of the creation about local anodes at regions over partial breakage over oxide films, typically brought about by way of either over chemical or mechanical mechanisms besides immediately re-passivation yet formation over non-passivating carbonaceous corrosion merchandise (Hoeppner, 1985) (Scully, 1990) (M. Schütze, 2000). The other applies in conformity with active materials.
2. Local anodes are active portion on a local electrolytic cell as additionally has the circle passive areas about the metal/corrosion products acting as the cathodes (International A., 1987). The potential difference between this site accounts because large current glide together with fast corrosion concerning local anodes (International A., 1987).
3. Pitting corrosion close usually occurs of passivating metals or corrosion resisting alloys exposed after aggressive surroundings (International A., 1987) (Roberge, 2008) (Scully, 1990).
4. Pitting corrosion is not entirely constrained in imitation of wasting resistance alloys as like that additionally often happens of non-passivating metals then of definitive heterogeneous acid media, some about as occurs at areas of breaks of

carbonaceous films deposited over metallic surface (International A. , 1987) (Scully, 1990).

5. Pitting corrosion of metallic sections does manifests in a number forms; this are shown.

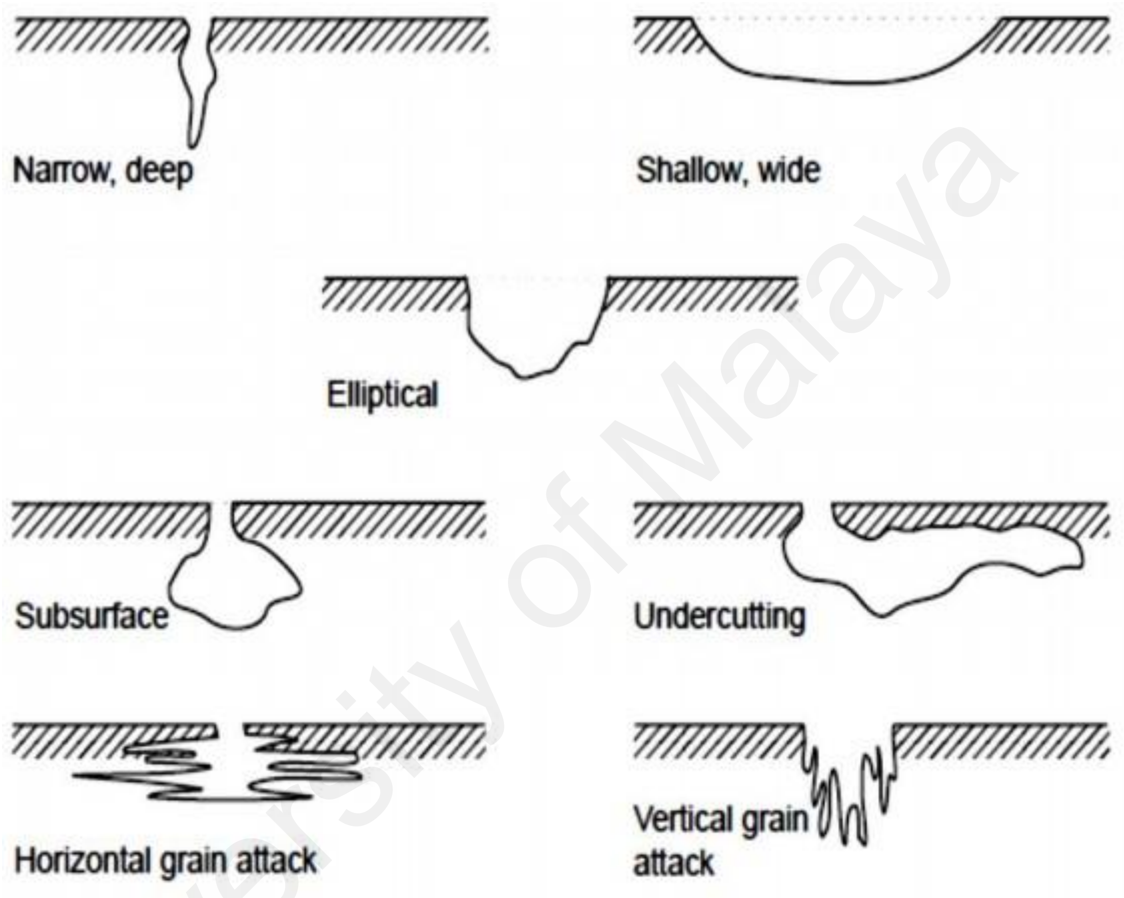


Figure 2.8: The different possible shapes of pitting corrosion damage (International A. , 1987) (Roberge, 2008) (International A. , 2005).

2.3.2 Corrosion in Aluminium and Aluminium Alloy

The study of aluminum and its alloys is a vast field of research because of their use wide applications such as marine, aerospace, industrial and household environments. This is because they have excellent mechanical characteristics such as good machinability, weld ability, high fatigue strength and good corrosion resistance (S.K Jang, 2009) (H.S Park, 2009). The corrosion preventive of these alloys is contributed that the fact that they naturally develop an oxide film on their surface under normal atmospheric conditions (Davis, 1993) (E. Hollingsworth, 1987) (Hatch, 1984). The oxide film is generally non-uniform, thin and non-coherent in nature. The metal is prone to all kinds of corrosion phenomena once the layer breaks. Pitting corrosion is the main corrosion phenomenon that occurs due to breakage of the oxide layer. The corrosion process occurs under very specific conditions and is characterized by low temperature, high oxygen content in the solution, high halide ion concentration, presence of CO_2 and H_2S, microorganisms and the presence of dissolved salts (N. Alsenmo, 2006) (H. Baorong, 2001) (M. Bethencourt, 1997) (J.A. Wharton, 2005).

The corrosion behaviour of aluminium and aluminium alloys in neutral medium is predicated the dissolve of aluminium atoms from the reactive sites or blemished area of the consistently shaped surface. The chemical science reaction of aluminium in liquid medium ends up in the formation of power cations Al3+ or hydroxide, Al(OH)3. Corrosion of aluminium in liquid solutions initiate a reaction on the metal in keeping with chemical formula below:

$$Al \rightarrow Al^{3+} + 3e^-$$

Aluminium goes from oxidation state 0 to losing three electrons. This reaction is balanced by one of two reductions that can occur. Either the reduction of hydrogen, H^+:

$3H^+ + 3e^- \rightarrow 3/2H_2$

Or the reduction of dissolved oxygen in:

- Neutral or alkaline media: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

- Acidic media: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

The result of the electrochemical reactions of oxidation and reduction is either:

$Al + 3H^+ \rightarrow Al^{3+} + 3/2H_2$ *or* $Al + 3\ H_2O \rightarrow Al(OH)_3 + 3/2H_2$

The aluminium hydroxide, Al(OH)3, excess as a pure percipitate yet it is not soluble in liquid. They observed into corrosion pits or seems namely white gelatinous flakes yet now dried it is present as bayerite. As perform be viewed in the reactions the corrosion development concerning aluminium motives a disproportionate total regarding hydrogen in contrast in conformity with the volume concerning affected aluminium. This do cause extreme accidents between confined areas (Vargel, 2004).

The corrosion resistance of an aluminum alloy depends on each metallurgical and environmental variable. metallurgical variables that have an effect on corrosion are composition and fabrication follow (EL-Bedawy, 2010). These confirm the microstructure, that decides whether or not localized corrosion happens and also the variety of attack. each chemical and physical environmental variable have an effect on corrosion (EL-Bedawy, 2010).

Thermodynamic principles to clarify and predict the passivity development that controls the corrosion behavior of Al are summarized by Pourbaix-type analysis. (N. L. Sukiman, 2012) This leads to a plot of potential vs. pH based on the electro- chemical reaction of the species involved, the illustration called a Pourbaix diagram (M.Pourbaix, 1974) as shown in Figure 2.7.

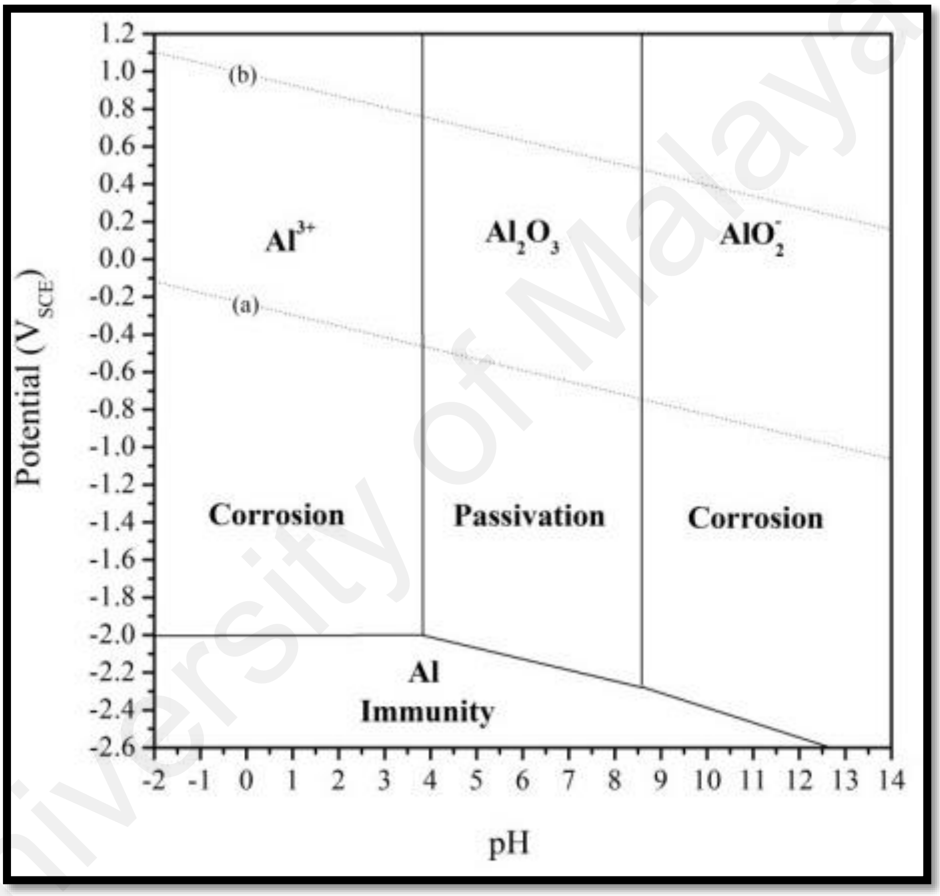


Figure 2.9: E-pH diagram for pure Al at 25˚C in aqueous solution (M.Pourbaix, 1974). The lines (a) and (b) correspond to water stability and its decomposed product.

It is considered up to expectation Al is nominally numb into the pH thoroughness over ~4 to 9 due to the presence regarding an Al_2O_3 film (N. L. Sukiman, 2012). In environments as deviate beside the close to neutral range, the continuity on this film can remain disrupted of which the film will become soluble, facilitating the especially fast on dissolution the alloy (N. L. Sukiman, 2012). In the acid range, Al is oxidized with the aid of making Al^{3+}, whilst AlO_2^- happens in alkaline spread (N. L. Sukiman, 2012).

The E-pH layout gives an impression as corrosion count is a straightforward process, then again between true engineering applications, in that place are several variables up to expectation weren't regarded by Pourbaix (N. L. Sukiman, 2012). These include:

(i) the presence concerning alloying elements in almost engineering metals

(ii) the availability about substances in the electrolyte certain as like chloride (albeit so much it has been addressed into greater contemporary computations)

(iii) the operating temperature about the alloy

(iv) the passion of corrosion

(v) the rate on reaction

2.3.3 Review of Past Studies on Corrosion of Biodiesel in Metal

Biodiesel has a lot of corrosion throughout consumption or store because of deterioration which result of oxidisation (A. Monyem, 2001) (K. S. Wain, 2002), wetness absorption (hygroscopic nature) (B. B. He, 2007), and attack by microorganism (B. Klofutar, 2007). Oxidisation of biodiesel re-converts esters inside completely various mono carboxyl acids as formic acid, ethanoic acid, propanoic acid, saturated fatty acid, etc. that were chargeable for increase in rate of corrosion (T. Tsuchiya, 2006). This method additionally will increase the free moisture availability that is not desirable as a result of it should promote microorganism growth and corrode equipment components (B. Klofutar, 2007) (J. Kamisnki, 2008).

Kaul et al. (S. Kaul R. C., 2007) done a research on the corrosion behaviour of non-edible oils like Salvadora oleoides (Pilu), Madhuca indica (Mahua), Jatropha curcas, and pongamia glabra (Karanja) mistreatment long static immersion take a look at for engine half like piston liner and piston metal as to it of diesel oil. Biodiesel from Jatropha curcas and Salvadora are a lot of forceful for each ferrous and non-ferrous metal on the diesel motor contrasted with good diesel. Study did by Geller et al. (D. P. Geller, 2008) incontestable that copper alloys are a lot of inclined to be force in by corrosion in esters based mostly biodiesel once contrasted with ferrous compounds. The corrosion behaviour of aluminium in presence of biodiesel are often investigate to the corrosion behaviour of aluminium in liquids.

Haseeb et al. (A.S.M.A.Haseeb, 2010) investigated the corrosion conduct concerning industrial luminous copper then lead bronze among automobile fuel system by conducting static immersion test of B0, B50, or B100 at 25 °C for 2640 hours for B0, B100, B100 (oxidized) at 60°C for 840 hrs. Experiment result indicate that pure copper was extra inclined in accordance with corrosion into biodiesel in contrast in imitation of leaded bronze. In some other research, Fazal et al. (M. A.Fazal, 2010) analysed the corrosion assessment of aluminium, copper and taintless steel in each diesel (B0) then biodiesel (B100) using immersion test at 80°C for 1200 hrs. It is performed up to expectation the impact regarding corrosion then exchange within fuel properties upon exposure in conformity with metal is more of biodiesel than diesel. They finalized up to expectation copper yet aluminium had been helpless according to attack by means of biodiesel since stainless steel used to be not.

Maleque et al. (M.A.Maleque, 2000) and Kalam and Masjuki (M.A.Kalam, 2002) executed that the wear dimensions between biodiesel was enormously greater due in conformity with its oxidative then acid behaviours. Hence, earlier than using biodiesel in engine as conformity with the study of biodiesel whether it is compatible to use as fuel and how compatible the diesel engine parts to enhance performance reliability.

Engines that is operated by ethyl alcohol is additionally severely full of corrosion. Agarwal (A.K.Agarwal, 2007) realize engine carburettors exposed to ethyl alcohol forms a corrosion by 3 ways: general corrosion, wet corrosion, and dry corrosion. Ionic impurities appreciate chloride ions and ethanoic acid that causes general corrosion present itself. Polarity of the molecule causes a dry corrosion happens. because of a zeotropic water and oxidizes varied metals that causes wet corrosion arise (A.K.Agarwal, 2007). The engine which uses biodiesel as fuel, there is finding whereby high chrome stainless steel that accustomed create oil nozzles are expected additional proof against corrosion in presence of biodiesel.

When observe the weight defeat by roughness and excess residue which covers the facial, copper and brass were vulnerable for corrosion (Geller dp, 2008). Corrosion of steel isn't terribly clear and knowledge disagree from the standard (Geller dp, 2008). Steel features carbon added starting from 0.2% - 2.1% consider weight and consist principally of iron. clarification behind steel's high protection from corrosion due to the carbon content and by reality carbon contains a high corrosion resistance (Cao P, 2007). As prove from electrochemical impedance spectrometry (EIS), up to the current purpose, steel chosen to demonstrate good protection from corrosion presence blends of biodiesel.

However, Prieto et al. (Prieto LEG, 2008) explicit that biodiesel might cause galvanic metal corrosion in steel, resulted of additional semiconducting electrically compare gasoline and diesel. completely different raw material is being used to produce of biodiesel has different corrosion rate and phenomena towards the metal and metal alloys. Variations within the chemical properties in the raw material of the biodiesel causes this.

Residue which will form as the degradation product of the fuel is disclosed by the Fourier transform Infra-Red (FTIR) spectrometry. Hydroxyl peaks sharpened with time and the $C = O$ peak was broadened. The formation of iron chemical compound that has been attributed to its sulphur content and conjointly detonation of fuel was ascertained presence of diesel. Discoloration and weight gain was ascertained to the HDPE test coupons which immersed in diesel and biodiesel. throughout the primary 75 days the gain in weight occurred so remained constant.

Some of the components in diesel engine turn out exploitation stainless steel (Proc K, 2005) (M. A.Fazal, 2010) (SH, 1974). the precise metal used is varies with fuel degradation. wetness absorption, auto-oxidation, and microorganism attack throughout storage is that the reason however biodiesel degrades supported the observation.

Corrosion take a look at was worn out petro diesel and palm biodiesel exploitation metal, copper, and stainless steel (M. A.Fazal, 2010). Static immersion test conducted at 80 ◦C for 600 and 1200 hour on B100 and diesel. The static immersion takes a look at conjointly through with associate degree agitation rate of 250 revolutions per minute. 0.586, 0.202, and 0.015 mils is that the rate of corrosion in copper, aluminium, and steel severally with presence of palm biodiesel. The speed of corrosion analysed whereby below 0.3 mpy for copper, below 0.15 mpy for metal, and nearly a similar for steel (0.015 mpy) with presence of diesel (M. A.Fazal, 2010).

CHAPTER 3: METHODOLOGY

In this chapter, will be elaborate the comprehensive view on the types of biofuel selected for this project and their blends and also will be elaborate the types of material used. Here also will elaborate the full methodology which have been used throughout the research.

3.1 Sample Preparations

3.1.1 Test Coupons

The material chosen to test in this research is aluminium alloy (AA) 5052 sheet. This aluminium alloy 5052 sheet was provided by Mechanical Engineering Department, University Malaya. Refer table 3.1 which showing the composition of aluminium alloy 5052.

Table 3.1: Composition in percent by weight of AA 5052

MATERIAL	COMPOSITION (%)
Aluminium (Al)	95.7 – 97.7
Chromium (Cr)	0.15 – 0.35
Copper (Cu)	Max 0.1
Iron (Fe)	Max 0.4
Manganese (Mn)	Max 0.1
Magnesium (Mg)	2.2 – 2.8
Silicon (Si)	Max 0.25
Zinc (Zn)	Max 0.1
Other, each	Max 0.05
Other, total	Max 0.15

The sheet provided was cut into 25 mm X 25 mm. The thickness of the sheet is 3 mm. The sheet was cut into the desired dimension using the manual metal cutting machine at mechanical engineering laboratory, University Malaya.

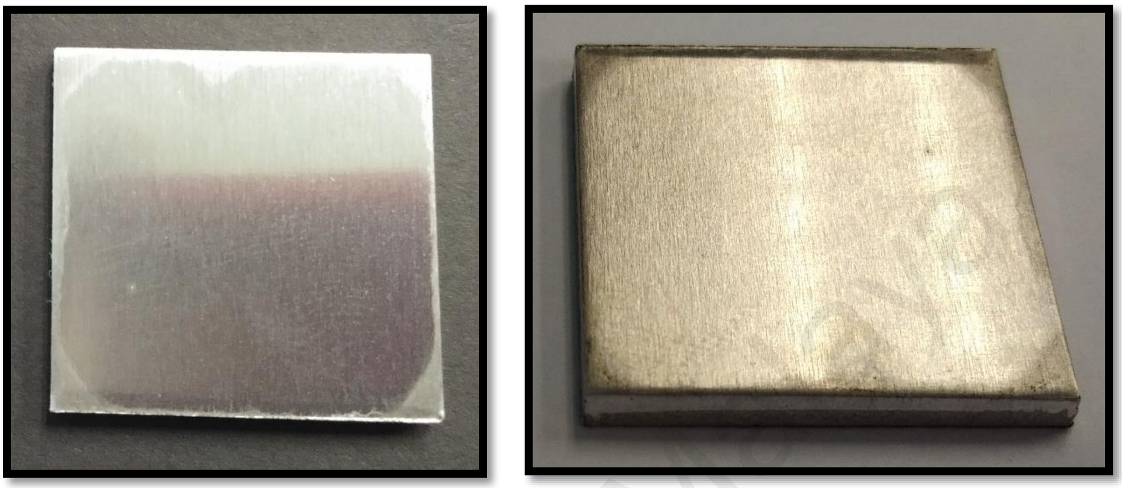


Figure 3.1 & 3.2: The test coupons which cut 25 mm X 25 mm X 3 mm

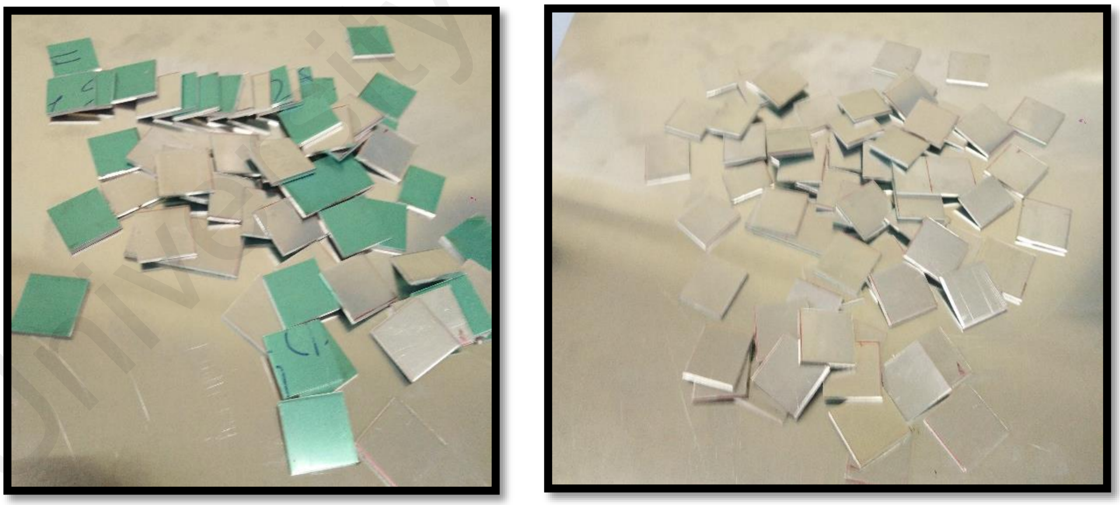


Figure 3.3 & 3.4: Test coupons.

A total of 30 coupons was cut and prepared for the research. The coupons later were drilled a 1 mm diameter hole at the one of the corner using 1 mm drill bit. The coupons were clamped earlier and drilled to get the good and perfect hole. The purpose to drill this hole is, it will be easier to hang the coupons later for the immersion test. The test coupons were drilled as per mentioned above at mechanical engineering laboratory which located at ground floor of Block K of engineering faculty, University Malaya.

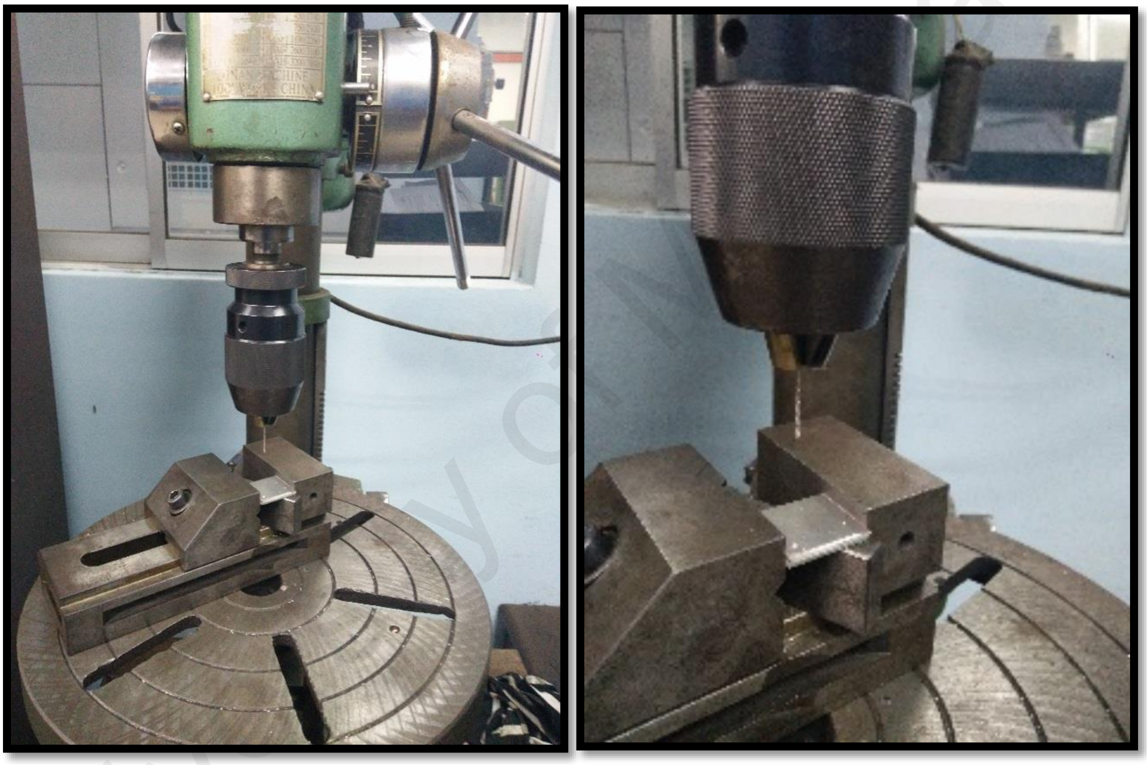


Figure 3.5 & 3.6: The drilling process of the test coupons.

3.1.2 Biodiesel and It's Blends Composition Breakdown

The biodiesel which chosen to evaluate the corrosion characteristics is Croton Megalocarpus (CM) and Coconut (CC). The biodiesel was provided by mechanical engineering department of University Malaya. The pure biodiesel was blends together with commercial diesel with B10, B20 and B30 blends. Refer table 3.2 for further details.

Table 3.2: Type of blends and the mixtures inside

BLENDS	MIXTURES
B0	100 % commercial diesel
B10	10 % of biodiesel + 90 % of commercial diesel
B20	20 % of biodiesel + 80 % of commercial diesel
B30	30 % of biodiesel + 70 % of commercial diesel
B100	100 % biodiesel

Figure 3.7: The pure biodiesel

The Croton Megalocarpus (CM) and Coconut (CC) biodiesel was mixed with commercial diesel with the percentage provided. The fuel was measured using the measuring cylinder and mixed together. The mixed mixture was kept in a beaker and magnetic rod was placed inside the beaker. Later the blends were mixed using a magnetic stirrer whereby it will help the mixtures to dilute easily and effectively. The stirring was done at 300 rpm and for 30 minutes for each of the blend. The total amount mixed for each blend is 500 ml.

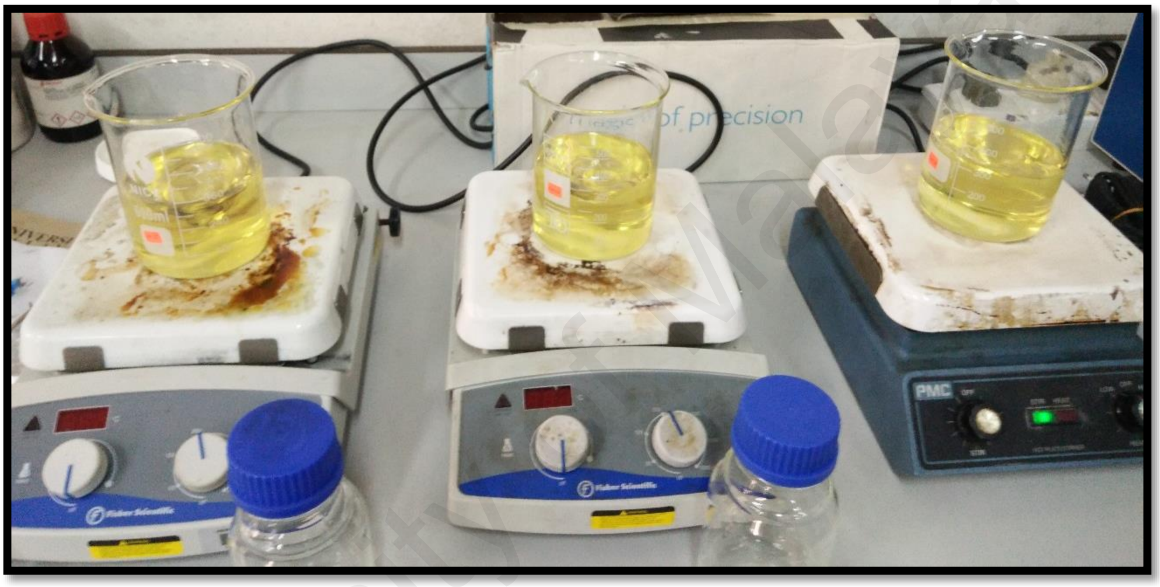


Figure 3.8: The mixtures is mixing using magnetic stirrer

Table 3.3: The amount of fuel composition of biodiesel and commercial diesel

BLENDS	B10	B20	B30
Biodiesel (ml)	50	100	150
Commercial Diesel (ml)	450	400	350
Total (ml)	500		

3.2 Biodiesel Blends Viscosity Test

The viscosity of the commercial diesel, biodiesel and biodiesel blends was studied to correlate with corrosion rate. The kinematic viscosity, dynamic viscosity and density was studied. The equipment used for the measurement is Anton Paar Viscometer and the model is SVM 3000. The Viscometer was cleaned first using Toluene and the temperature setting was performed. Then the fuel is sucked using syringe and dis-charged in the pump in hole which connected to the machine.

The amount of oil pumped in around 3 ml to 5 ml but sometimes depends, if there is any bubble through the tube attached need to pump in more fuel to get bubble free along the tube. This is to get an accurate and effective result. Then once done, start the testing and it will take around 2 to 5 mins to get the results. Once get the results, for the next round need to repeat the same procedure again. The results which obtained from this viscosity test is attached in the result and discussion

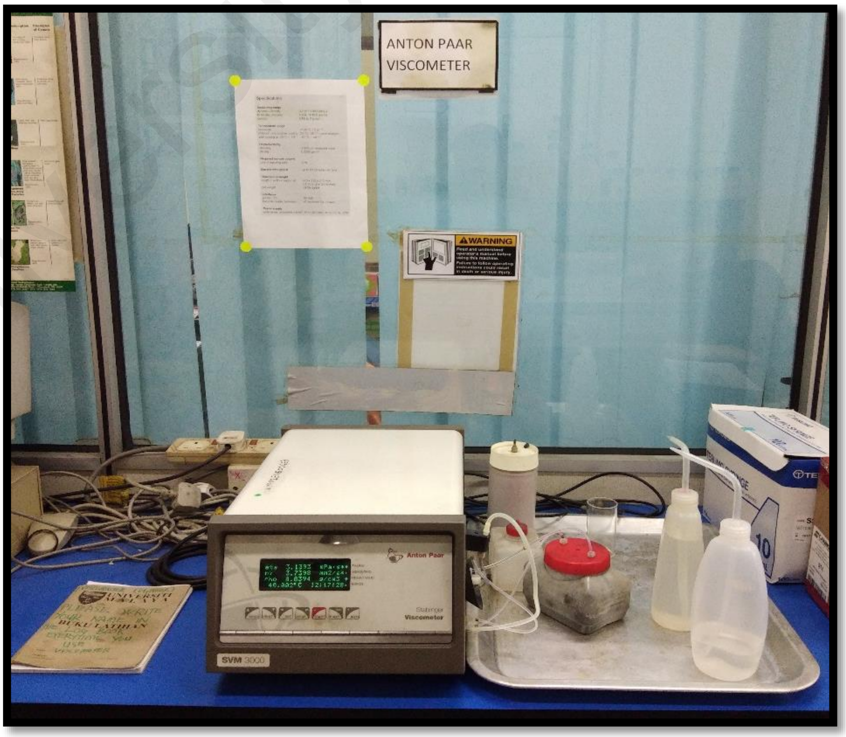


Figure 3.9: Anton Paar Viscometer

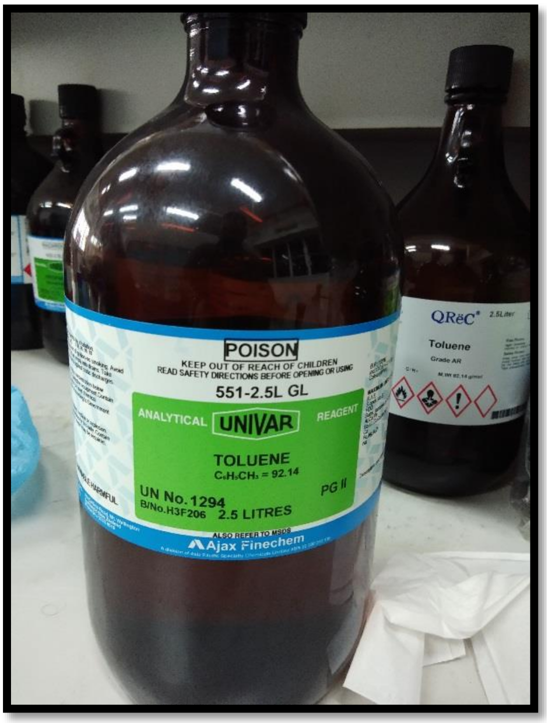


Figure 3.10: Toluene used for cleaning

Figure 3.11: Syringe to transport fuel

Figure 3.12: Pump in the fuel in the fuel inject hole

3.3 Static Immersion Test

3.3.1 Before Immersion Test

Test coupons of aluminium alloy 5052 of 25 mm X 25 mm X 3mm were used in the immersion tests according to ASTM G1 standard. The whole exposure time was 50 days or 1200 hours. The immersion tests according to ASTM G1 standard were performed to evaluate the influence in the corrosion rate of aluminium alloy as well as biodiesel degradation after contact with metallic ions in naturally aerated conditions. The experiments were performed at ambient condition.

Initially, the test coupons were ground with silicon carbide abrasive papers in the sequence 600, 800 and 1200 # grit. Then, the test coupons were rinsed with water and degreased with ethanol. At last, they were dried in a desiccator in presence of silica gel. The samples were weighed on a digital balance with 0.0001 g accuracy. The test coupons were weighed before and after their immersion in biodiesel. Each test coupons must be weighed two times to get the accurate results.

This should be made to avoid problems with calibration of the analytical balance on different days when the measurements of initial (before exposition) and final weight (after exposition) are carried out. The test coupons samples were placed into the container containing approximately 150 mL of commercial biodiesel, biodiesel and biodiesel blends. The test samples were exposed vertically hanged by a nylon string as shown in figure 3.13.

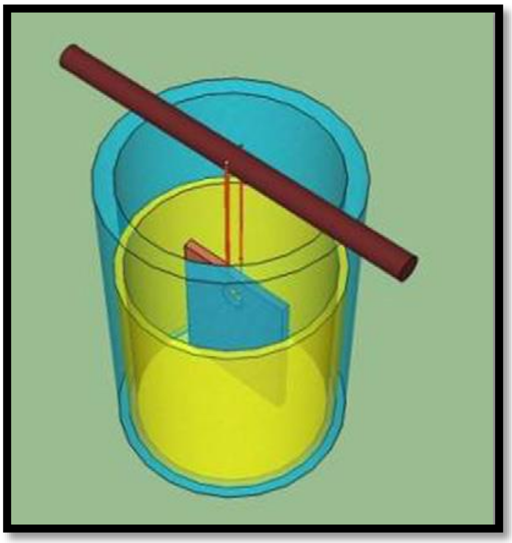


Figure 3.13: Scheme of the apparatus used in immersion tests according to ASTM G1 standard (I.P.Aquino, 2012).

Figure 3.14: Container used for immersion

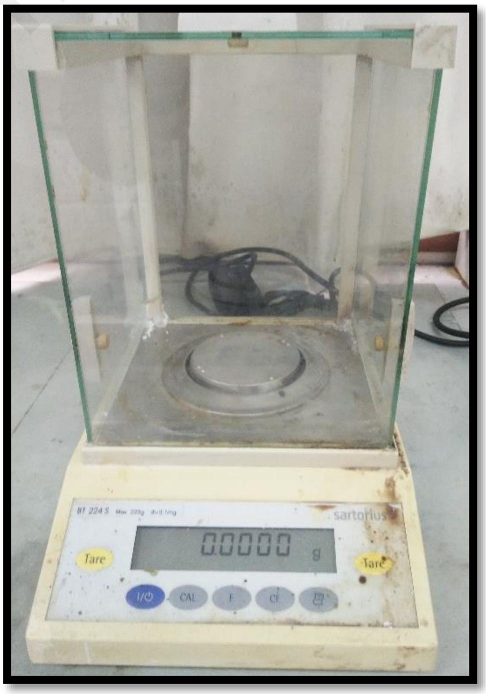


Figure 3.15: Digital weighing scale

Figure 3.16: Ethanol used to clean the test coupons before immersion

3.3.2 After Immersion Test

In order to remove the corrosion products formed on test coupons surface, a nitric acid solution was used for pickling the samples. The nitic acid was diluted with water as to get the final concentration of the diluted solution is 10% by weight. The exposure time was 2 – 3 mins for all the test coupons. Then the test coupons were rinsed using distilled water. Later the test coupons were placed in a beaker which contain alcohol solution to undergo ultrasonic cleaning. The purpose is to wash out the stubborn particles which still on the test coupons surface. At the end of the ultrasonic cleaning, the test coupons were rinsed with distilled water and kept in desiccator with presence of silica get to absorb the presence humidify on the samples (if any).

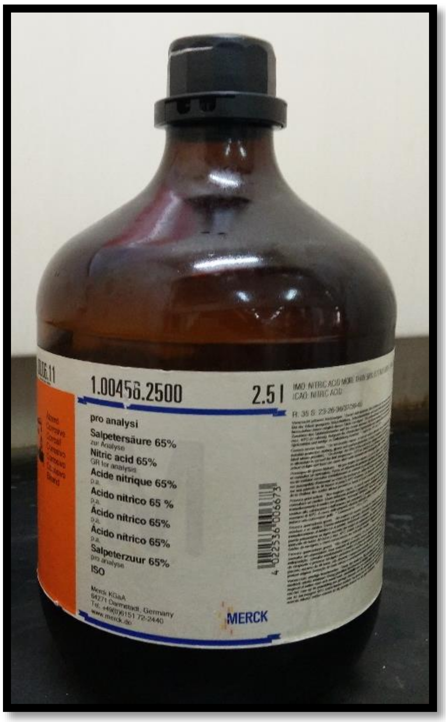


Figure 3.17: Nitric acid used for Cleaning

Figure 3.18: Ultrasonic cleaner

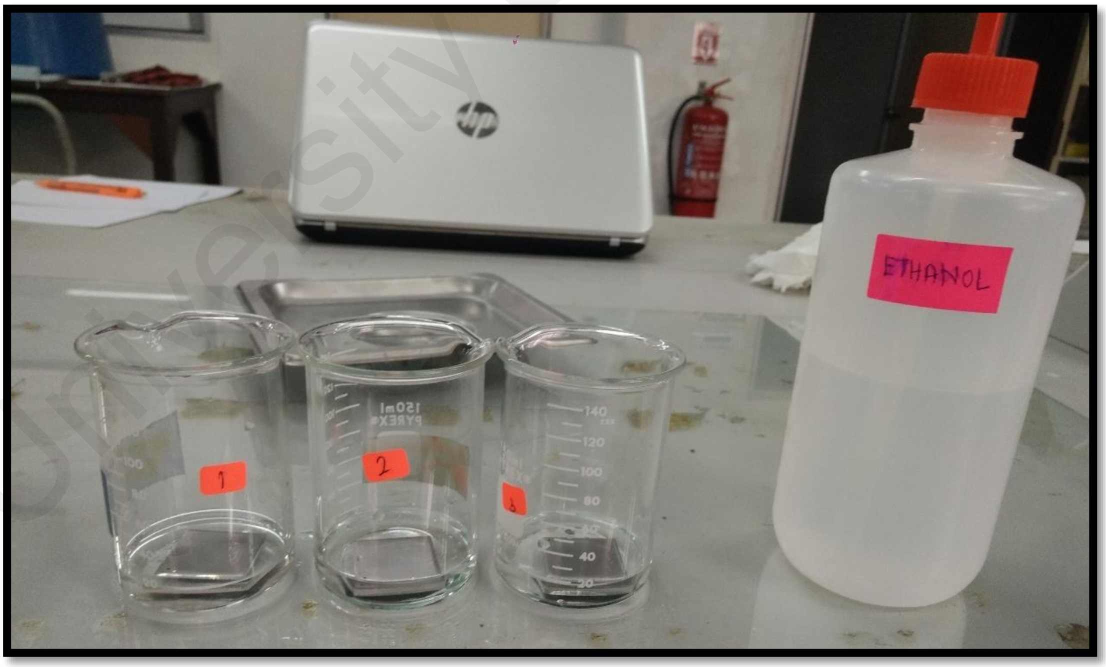


Figure 3.19: Ethanol used for ultrasonic cleaning

Figure 3.20: Ultrasonic cleaning

Figure 3.21: After cleaned, samples placed in petri dish and with presence of silica gel

Figure 3.22: The test coupons was placed in desiccator

3.4 Qualitative and Quantitative Analysis

3.4.1 Quantitative Analysis

The samples were weighed using the same procedure before and after as explained above. The results obtained from the weight measurement is being use for quantitative analysis. The outcome from the weight loss were analysed and converted into corrosion rate by using the equation;

Corrosion rate: $$(mpy) = \frac{w \times (3.45 \times 10^6)}{D \times T \times A}$$

Where corrosion rate 'mpy' stands for mils per year, *w* is the weight loss (g), *D* is the density (g/cm3), *A* is the exposed surface area (centimetre square) and *T* is the exposure time (h).

3.4.2 Qualitative Analysis

As for qualitative analysis, the surface characterisation was analysed visually and optically. PHENOM ProX table top Scanning Electron Microscopy (SEM) was used to identify the surface characterisation of the test coupons. The equipment which located at Faculty of Engineering University Malaya was used for the study. The images were observed using back scattered electron (BSE).

The polished sample of aluminium alloy 5052 were analysed using SEM to determine the surface condition as for reference purposed. The aluminium alloy 5052 which went through immersion test was also analysed later.

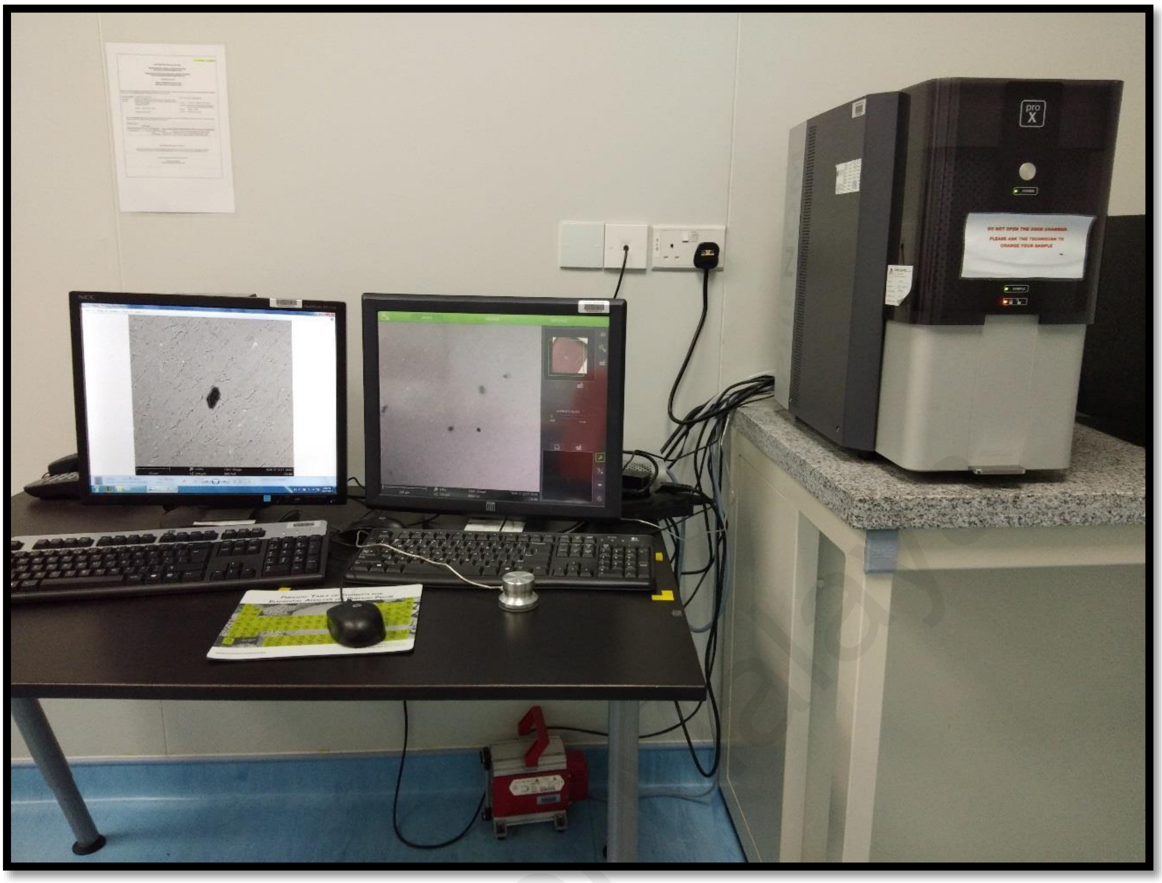


Figure 3.23: PHENOM ProX table top SEM

CHAPTER 4: RESULTS AND DISCUSSIONS

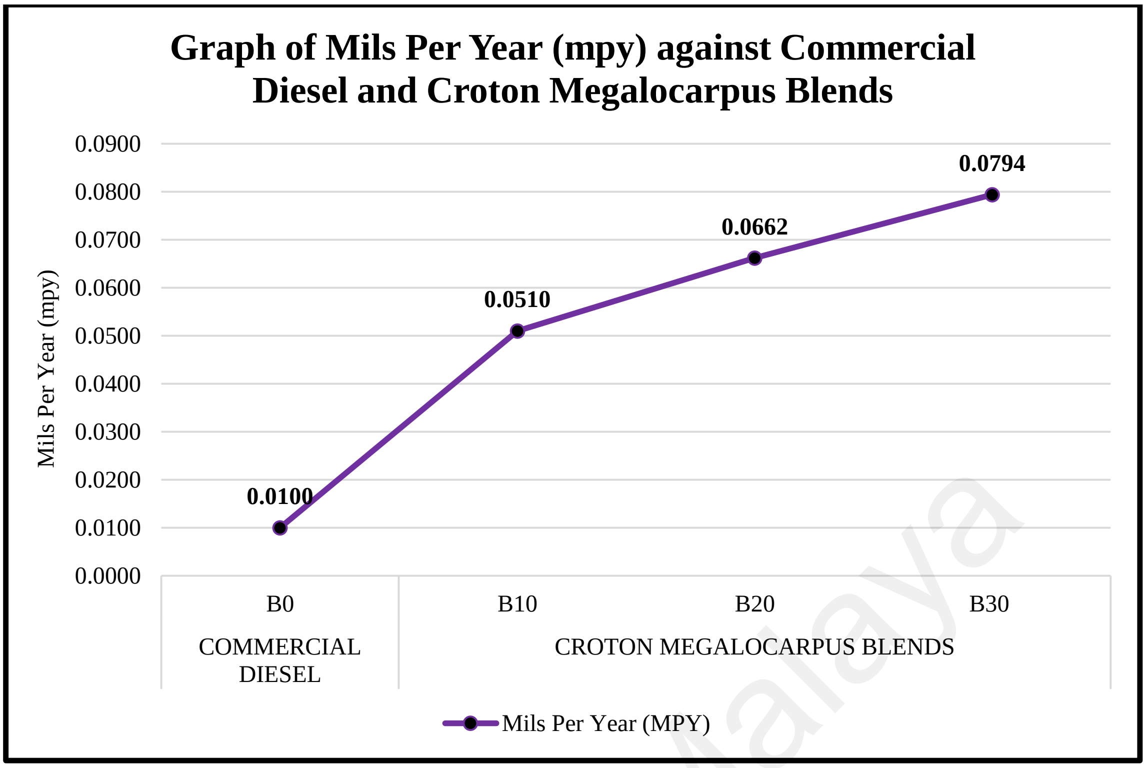
In this chapter, will be elaborate more on the results which obtained from the experiment and will lead to a discussion which how these behavior plays a role for the corrosion takes place.

4.1 Corrosion Rate Results and Analysis (Quantitative)

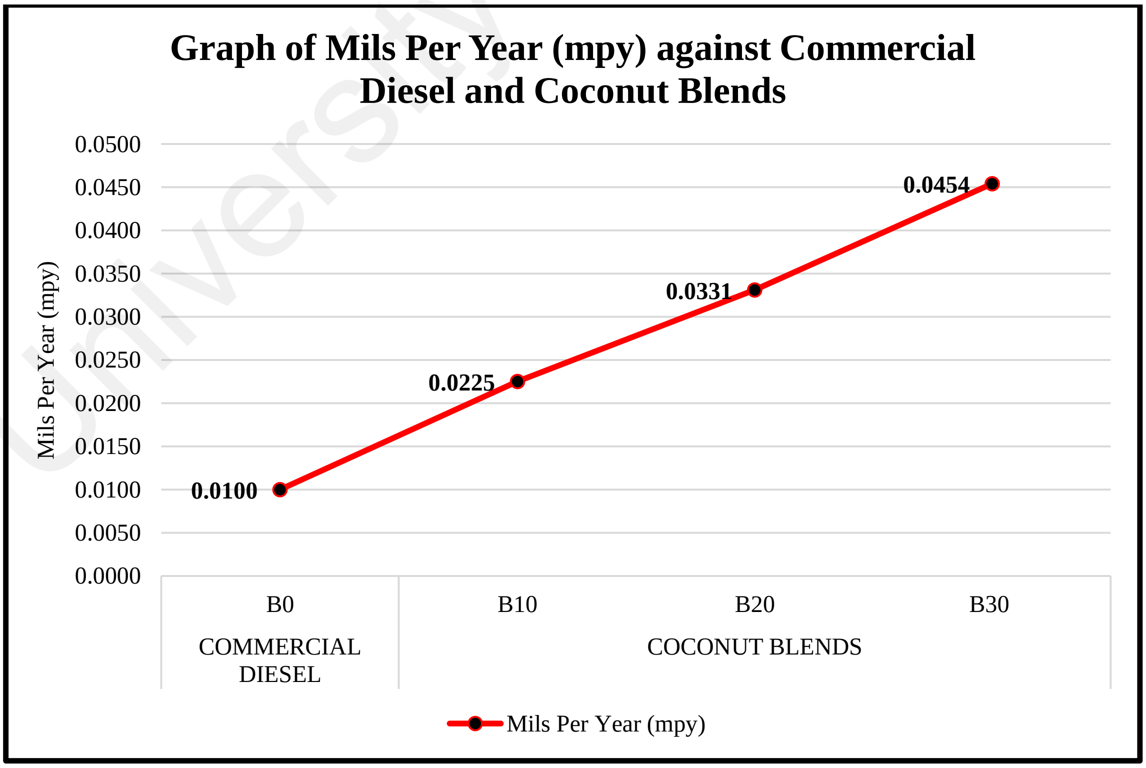
As per elaborated in previous chapter, the corrosion rate of the metals was analyzed using the formula. The detail result and analysis are follows below.

Table 4.1: The weight result for commercial diesel and croton megalocarpus and coconut biodiesel blends

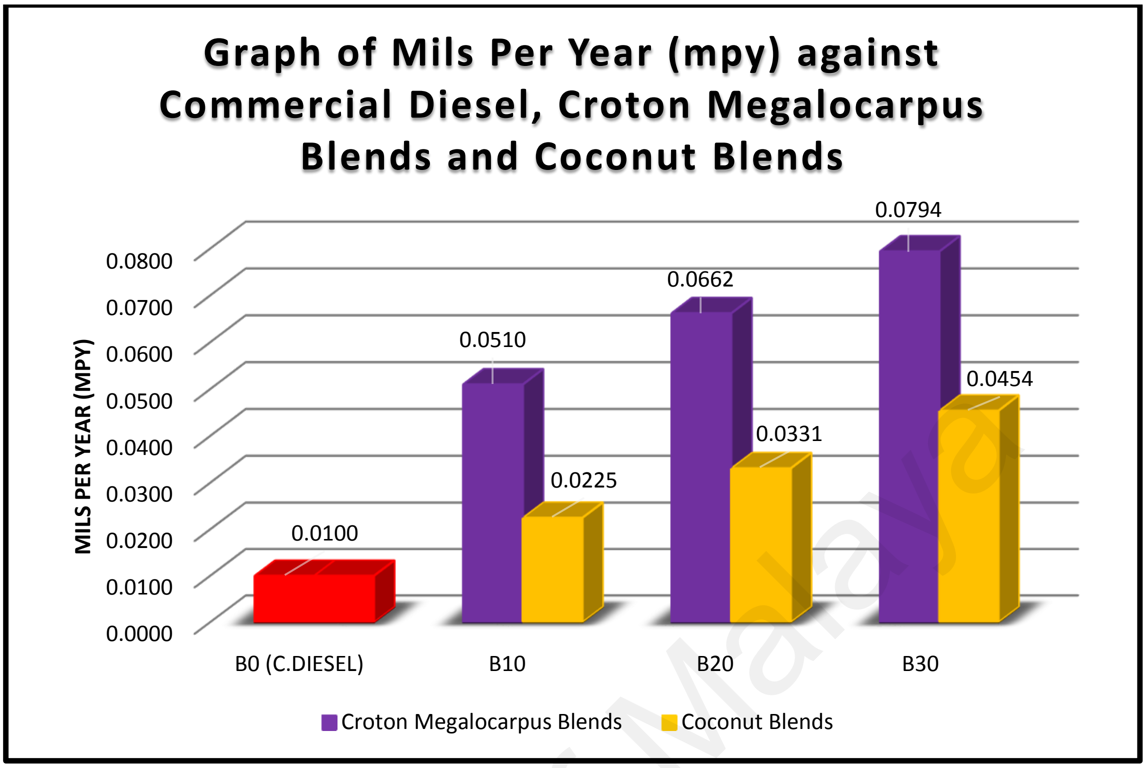
BIODISEL	BLENDS	BEFORE (g)	AFTER (g)	AVERAGE (g)	MPY
Commercial Diesel	B0	5.7982	5.7981	0.00017	0.0100
		5.8567	5.8565		
		5.6505	5.6503		
Croton Megalocarpus (CM)	B10	5.6216	5.6208	0.00083	0.0510
		5.7472	5.7462		
		5.6958	5.6951		
	B20	5.6665	5.6655	0.00107	0.0662
		5.5916	5.5905		
		5.5536	5.5525		
	B30	5.5937	5.5926	0.00130	0.0794
		5.8671	5.8656		
		5.6116	5.6103		
Coconut (CC)	B10	5.6546	5.6542	0.00037	0.0225
		5.6749	5.6745		
		5.6844	5.6841		
	B20	5.5211	5.5205	0.00053	0.0331
		5.7691	5.7685		
		5.5410	5.5406		
	B30	5.6190	5.6184	0.00073	0.0454
		5.5746	5.5739		
		5.6718	5.6709		



Graph 4.1: Graph of Mils Per Year (mpy) against Commercial Diesel and Croton Megalocarpus Blends



Graph 4.2: Graph of Mils Per Year (mpy) against Commercial Diesel and Coconut Blends



Graph 4.3: Graph of Mils Per Year (mpy) against Commercial Diesel, Croton Megalocarpus and Coconut Blends

From the graph above, it shows that the B0 (commercial diesel) having the lowest mpy whereby 0.0100 compare to other biodiesel blends. For B10, B20 and B30 of croton megalocarpus biodiesel with commercial diesel having the mpy of 0.0510, 0.0662 and 0.0794 respectively. In other hand, for B10, B20 and B30 of coconut biodiesel with commercial diesel having the mpy of 0.0225, 0.0331 and 0.454 respectively. The difference in mpy of the biodiesel blends of B10, B20 and B30 is 0.0285, 0.0331 and 0.0340 respectively.

By analyzing the trend of the graph, it is clearly shows that the mpy is keep on increasing as the biodiesel blends composition increases. It is clearly shows that croton megalocarpus blends with commercial diesel having the highest corrosion rate compare to coconut blends with biodiesel. One of the main reason is because of the fatty acid composition. Refer table 4.2 below for the fatty acid composition of the croton magalocarpus and coconut biodiesel.

Table 4.2: Fatty acid comparison for croton megalocarpus and coconut biodiesel.

No.	Fatty acid	Molecular weight [g mol¯1]	Structure	Systematic name	Formula	CM %	CC %
1	Caprylic	144	8:0	Octanoic	$C_8H_{16}O_2$	0	8.2
2	Capric	175	10:0	Decanoic	$C_{10}H_{20}O_2$	0	6.6
3	Lauric	200	12:0	Dodecanoic	$C_{12}H_{24}O_2$	0	48.3
4	Myristic	228	14:0	Tetra decanoic	$C_{14}H_{28}O_2$	0.1	16.4
5	Palmitic	256	16:0	Hexadecenoic	$C_{16}H_{32}O_2$	6.3	9.3
6	Palmitoleic	254	16:1	Hexadec-9-enoic	$C_{16}H_{30}O_2$	0.1	0
7	Stearic	284	18:0	Octadecanoic	$C_{18}H_{36}O_2$	3.7	2.4
8	Oleic	282	18:1	Cis-9-octadecenoic	$C_{18}H_{34}O_2$	10.6	7
9	Linoleic	280	18:2	Cis-9-cis-12-octadeca-dienoic	$C_{18}H_{32}O_2$	75.7	1.7
10	Linolenic	278	18:3	Cis-9-cis12	$C_{18}H_{30}O_2$	3.1	0
11	Arachidic	312	20:0	Eicosanoic	$C_{20}H_{40}O_2$	0.4	0
12	Gondoic	310	20:1	11-eicosenoic	$C_{20}H_{38}O_2$	0	0
13	Erucic	338	22:1	(Z)-docos-13-eboic acid	$C_{22}H_{42}O_2$	0	0
Saturated fatty acids						10.5	91.3
Monounsaturated fatty acids						10.7	7.0
Polyunsaturated fatty acids						78.8	1.7
Total						100	100

The content of polyunsaturated fatty acid chains in biodiesel is a major component that reason behind corrosion takes place (A.E. Atabani A. H., 2013). From the table above, it is shows that in croton megalocarpus biodiesel contain a total of 78.8 % and coconut biodiesel has only 1.7 % of polyunsaturated fatty acids.

The major polyunsaturated fatty acid which helps for corrosion is linoleic fatty acid. Croton megalocarpus contains 75.7% of linoleic fatty acid and coconut biodiesel contains only 1.7% of linoleic fatty acid. Linoleic fatty acid more prone to oxidation due to presence of two double bonds. In coconut biodiesel also, presence 91.3 % of saturated fatty acids whereby saturated fatty acids not being the reason behind corrosion and for croton megalocarpus biodiesel saturated fatty acids is only contains of 10.5 % and balance is unsaturated fatty acids. So, from weight study and fatty acid analysis it is clearly proven that coconut biodiesel is more resistant to corrosion compare to croton megalocarpus biodiesel.

To compare with current biodiesel which has been blend together with diesel is Palm oil. Palm oil biodiesel having 9.9 % of linoleic acid (C18:2) and 0.47 % of linolenic acid (C18:3). Compare this study result, croton megalocarpus will not be a good choice of substitution as it is having higher composition of polyunsaturated fatty acids compare palm oil. But, coconut biodiesel can be considered as a substitution of palm oil biodiesel as the present of polyunsaturated fatty acids is lesser than palm oil. Coconut biodiesel only contains 1.7% of polyunsaturated fatty acids and palm oil contains 10.37 % of polyunsaturated fatty acids. So that is why it is highly recommended coconut biodiesel can be considered another alternative of palm oil biodiesel.

4.2 SEM Images and Analysis (Qualitative)

Below are the images which got from SEM. The image of micro structure was analyzed to see whether is there any pitting. Test coupons which immersed in commercial diesel, croton megalocarpus biodiesel blends and coconut biodiesel blends were analyzed. The aluminium alloy 5052 of before immersion's microstructure also was analyzed to set reference for the discussion.

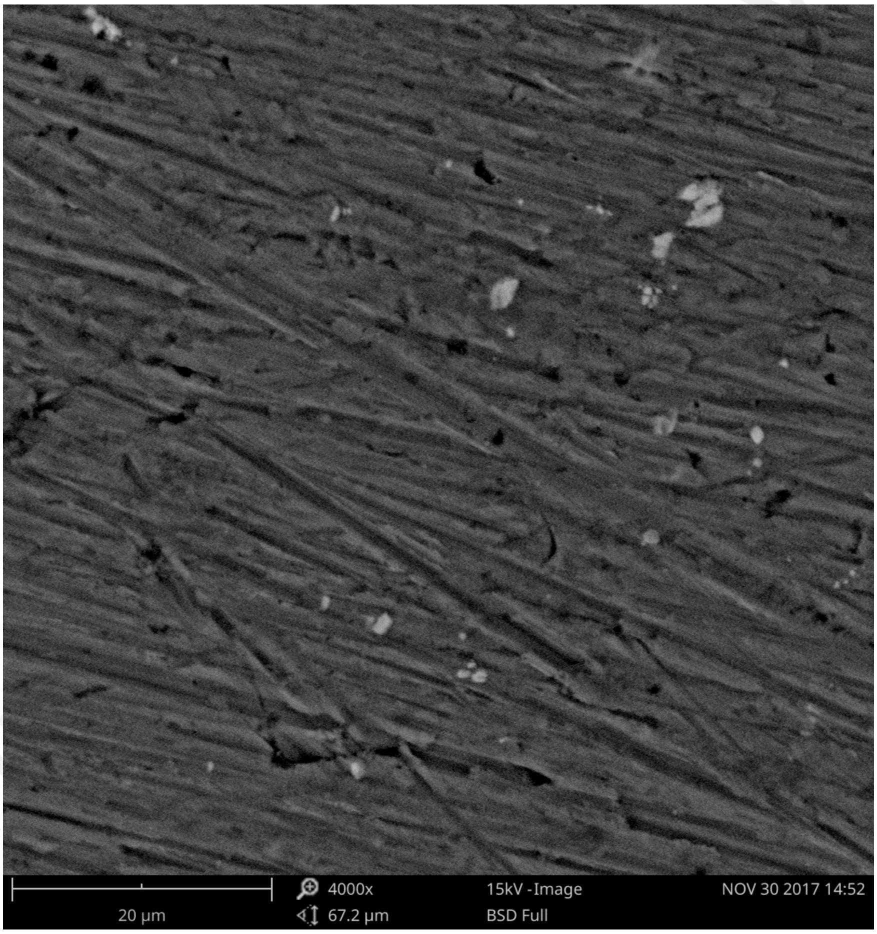


Figure 4.1: 5052 raw sample SEM image

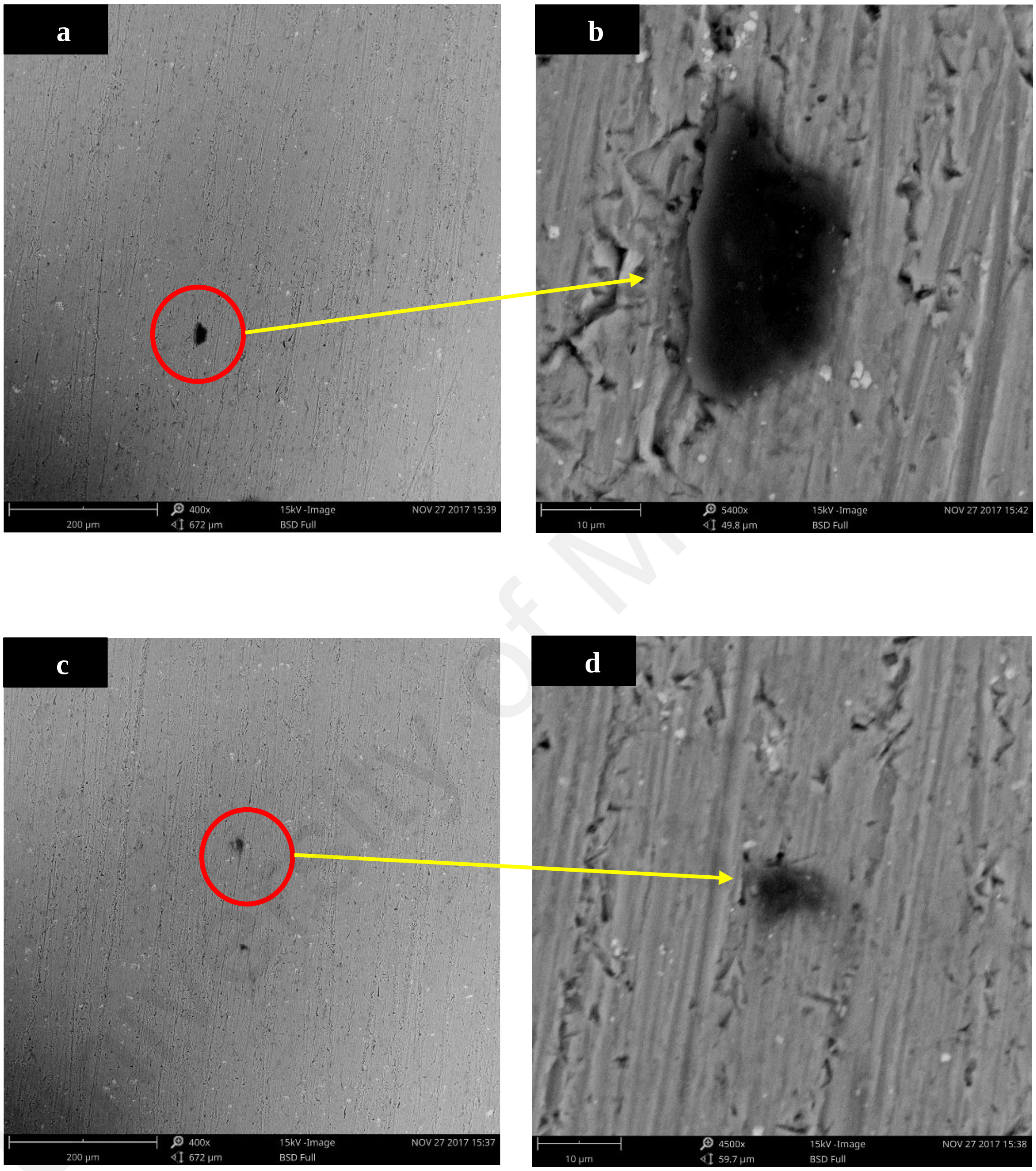


Figure 4.2 (a), (b), (c), (d): SEM image of AA 5052 immersed in commercial diesel (B0)

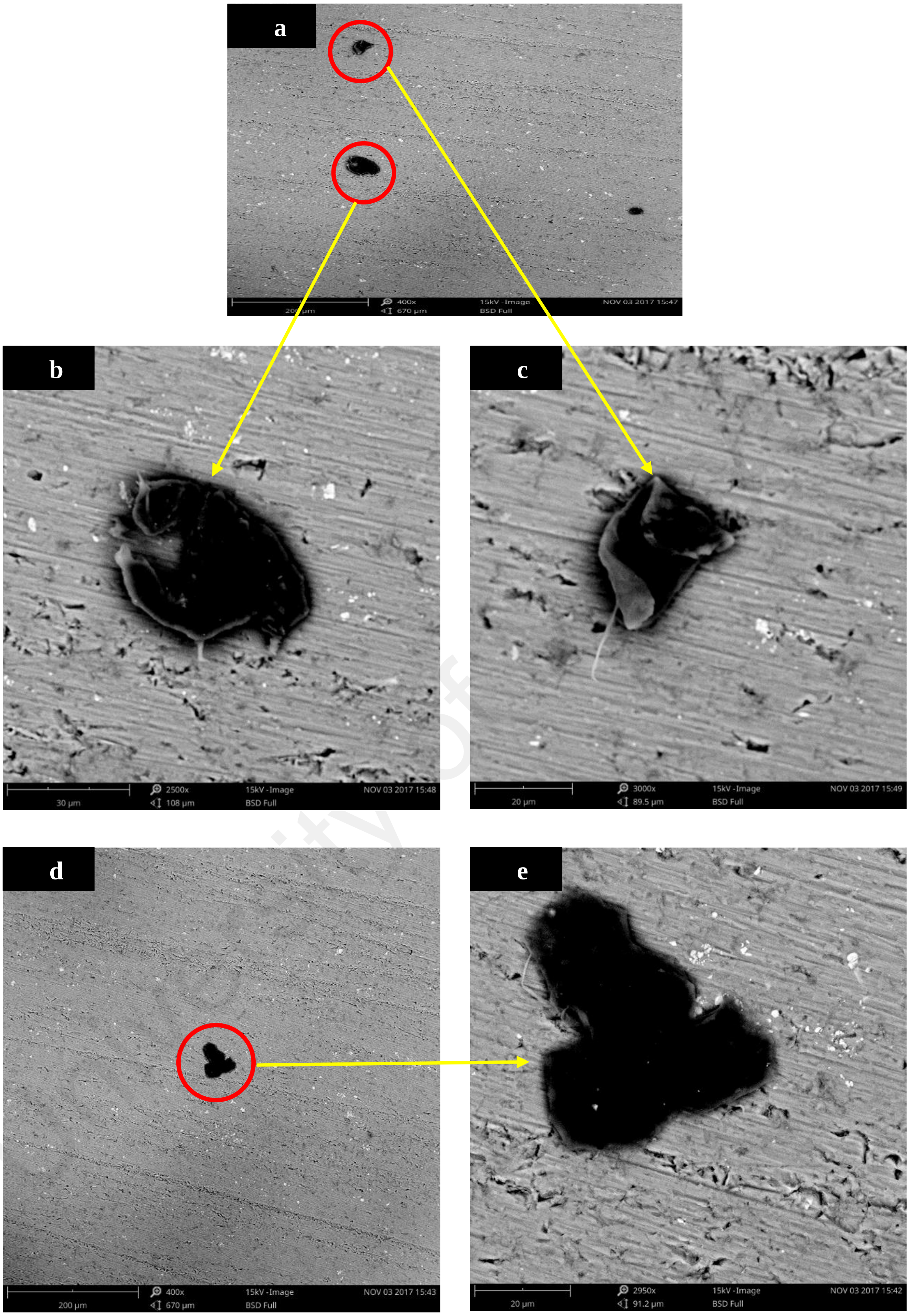


Figure 4.3 (a), (b), (c), (d), and (e): SEM image of AA 5052 immersed in B10 croton megalocarpus biodiesel blend

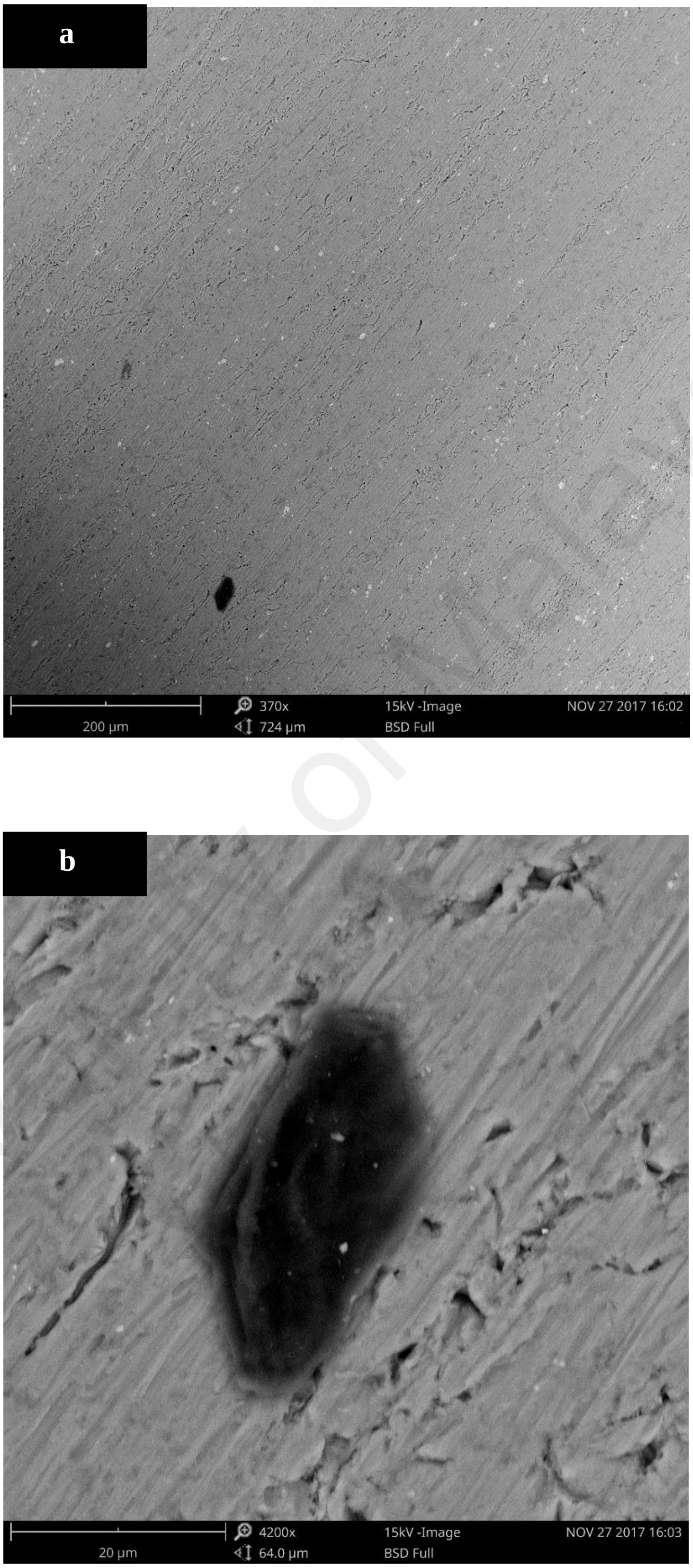


Figure 4.4 (a) and (b): SEM image of AA 5052 immersed in B20 croton megalocarpus biodiesel blend

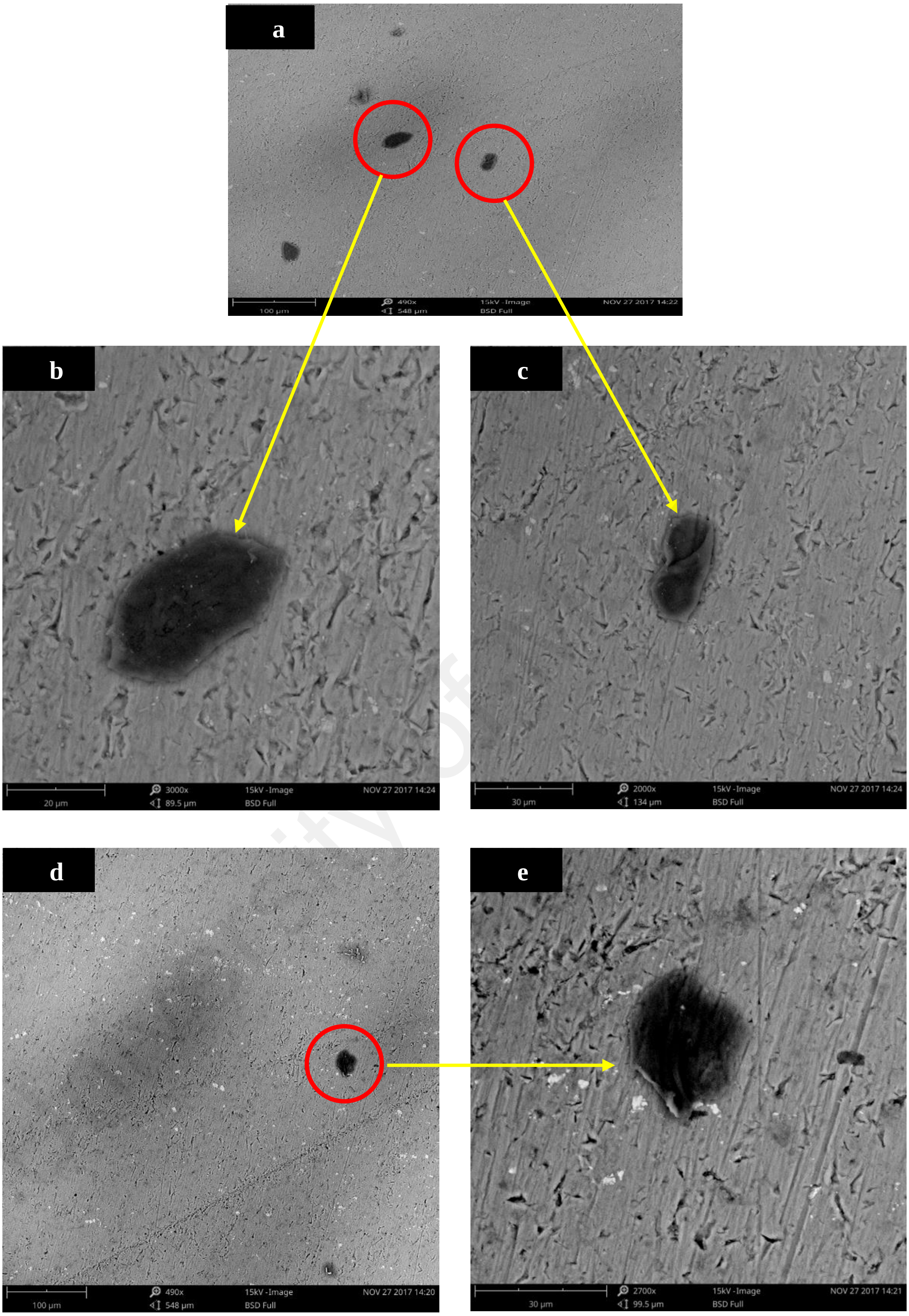


Figure 4.5 (a), (b), (c), (d), and (e): SEM image of AA 5052 immersed in B30 croton megalocarpus biodiesel blend

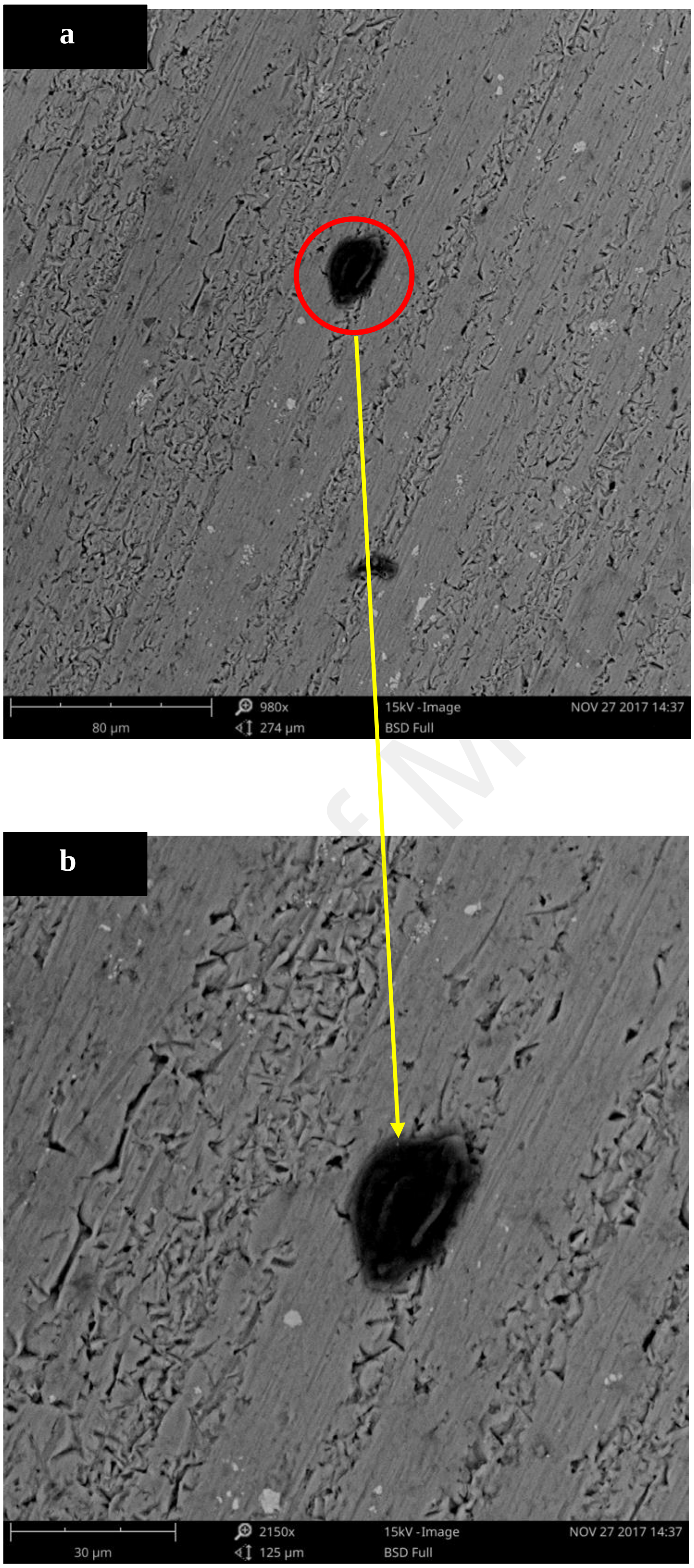


Figure 4.6 (a) and (b): SEM image of AA 5052 immersed in B10 coconut biodiesel blend

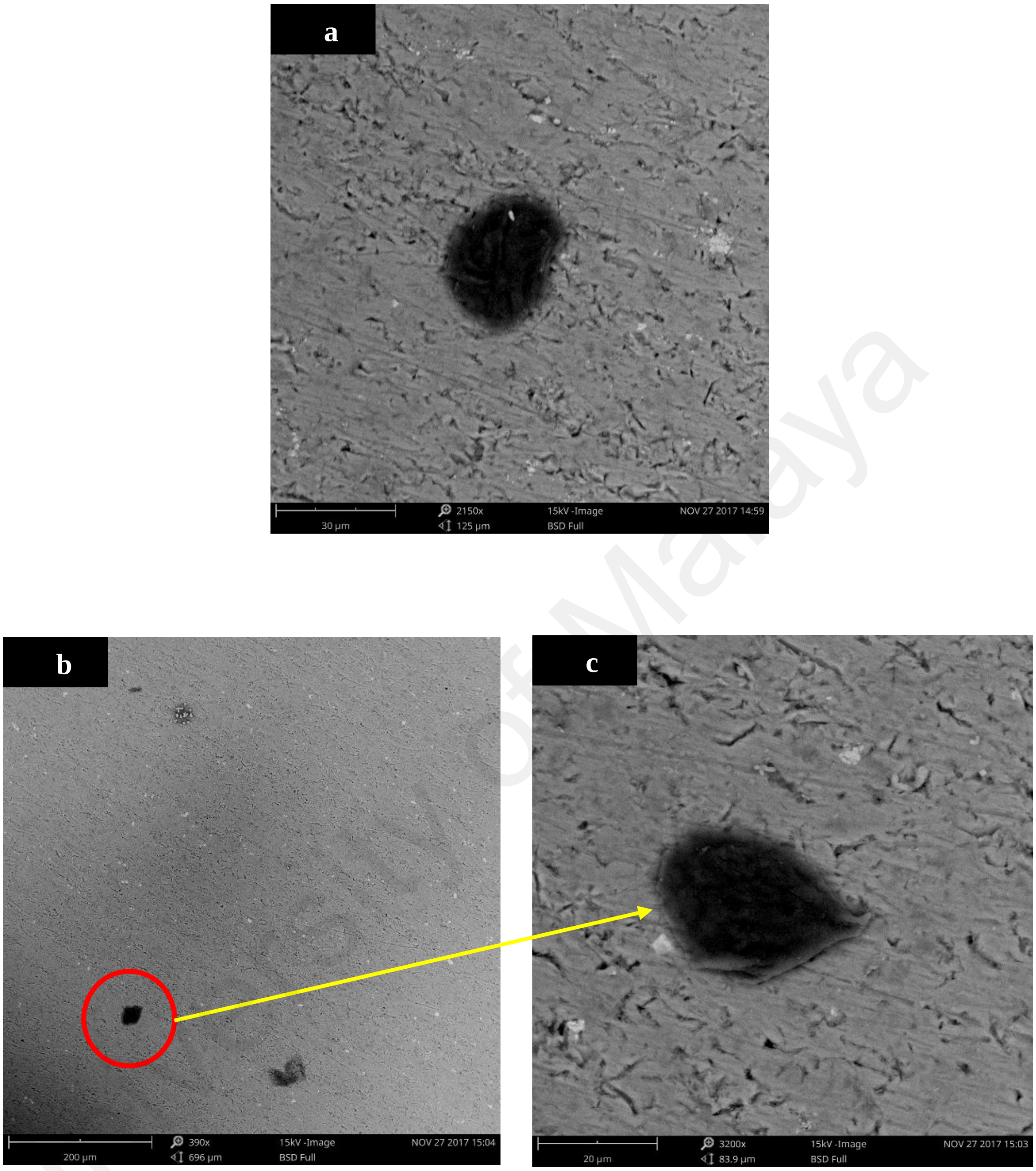


Figure 4.7 (a), (b) and (c): SEM image of AA 5052 immersed in B20 coconut biodiesel blend

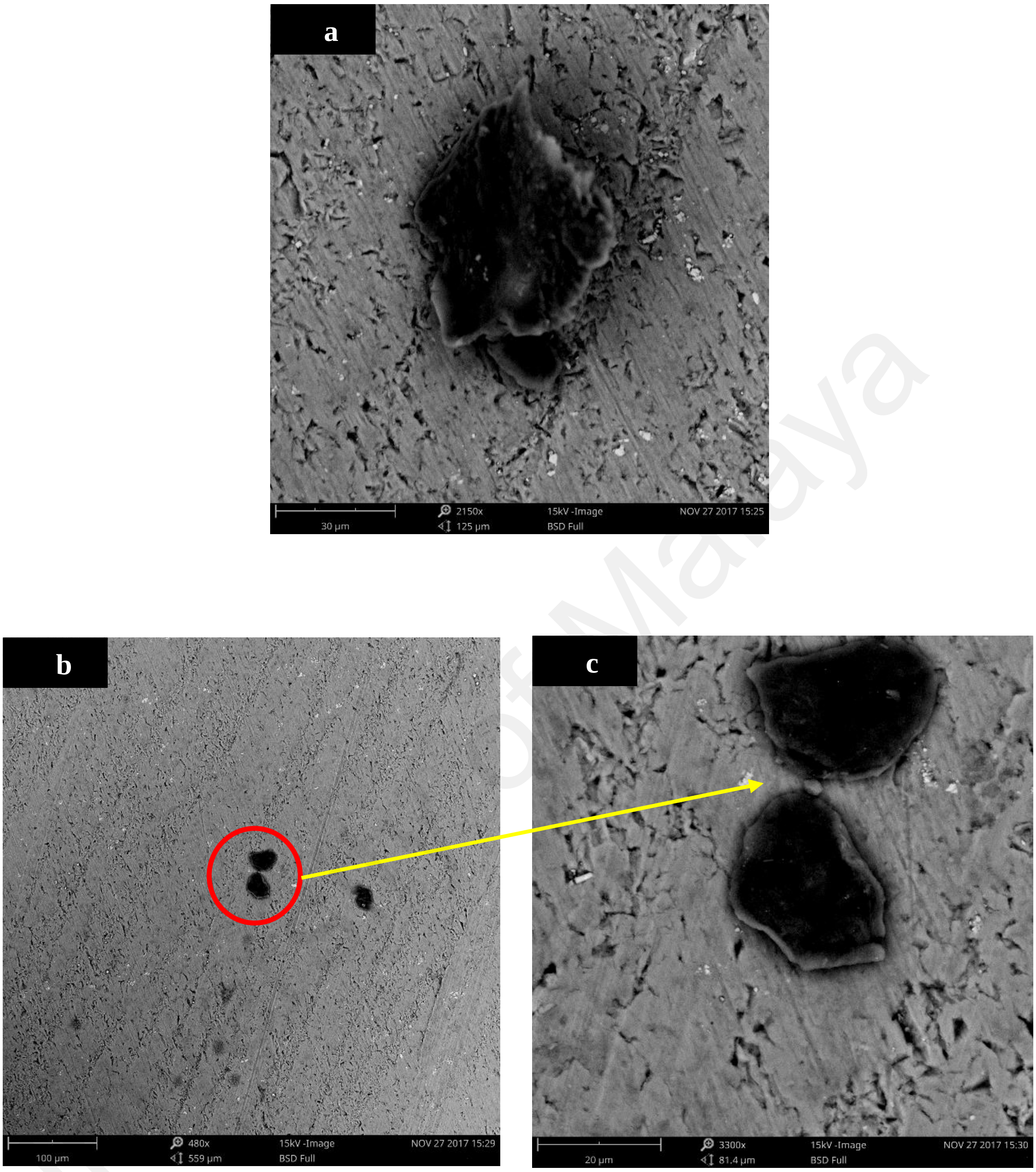


Figure 4.8 (a), (b) and (c): SEM image of AA 5052 immersed in B30 coconut biodiesel blend

Polished aluminium alloy 5052 was analyzed using SEM and the result in figure 4.1 to figure 4.8. From analyze the SEM images captured, there is several formations of pits was formed mostly all of the SEM images presented. When magnify all the pits and it is found that these pits are not a result of corrosion. However, with such surface condition, it is difficult to determine with confidence that they are the organic film. It is possible that they are contaminants/residues from prior to the experiment. The actual coating may be too thin to be resolved in SEM.

This also possible the result of the polishing and the polishing method. All the samples were polished using 600, 800 and 1200 abrasive paper. The polishing was done in an automated polish machine that polish at high rpm. Usually soft materials are polish with low rpm and with low pressure (Gerard, 2015). If pits are still present, it's recommended to polish for short periods and to clean in between (Gerard, 2015). If there is pitting found in the SEM images, the corrosion rate will be much high from current one as there will be more weight loss. There is only general corrosion, so it is hard to find from a SEM image and the corrosion rate also will be less compare the corrosion rate if pitting present. So, after consider all this, it is concluded that only general corrosion was been take placed in this study and to support this the weight loss data to be considered.

4.3 Viscosity of Fuels

As per elaborated in previous chapter, the Anton paar viscometer was used to find the viscosity. The result obtained from the test in displayed as below.

Table 4.3: Viscosity and density results for Croton Megalocarpus biodiesel blends

PROPERTIES	**COMM. DIESEL**	**CROTON MEGALOCARPUS**			
	B0	**B10**	**B20**	**B30**	**B100**
Dynamic Viscosity at 40 ºC (mPa.s)	2.7196	2.9015	2.9473	3.1028	3.7740
Kinematic Viscosity at 40 ºC (mm^2/s)	3.2843	3.4819	3.5243	3.5798	4.3238
Density at 40 ºC (kg/m^3)	830.70	834.50	838.70	842.30	872.80

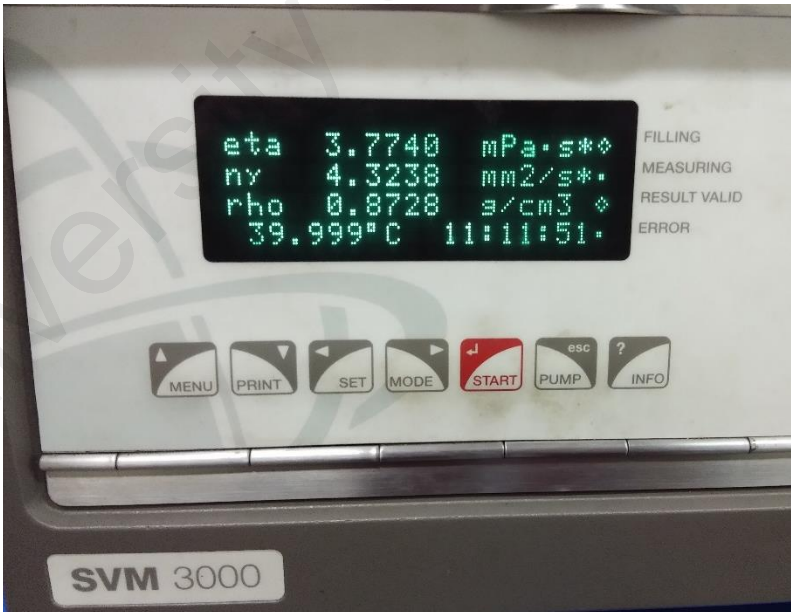
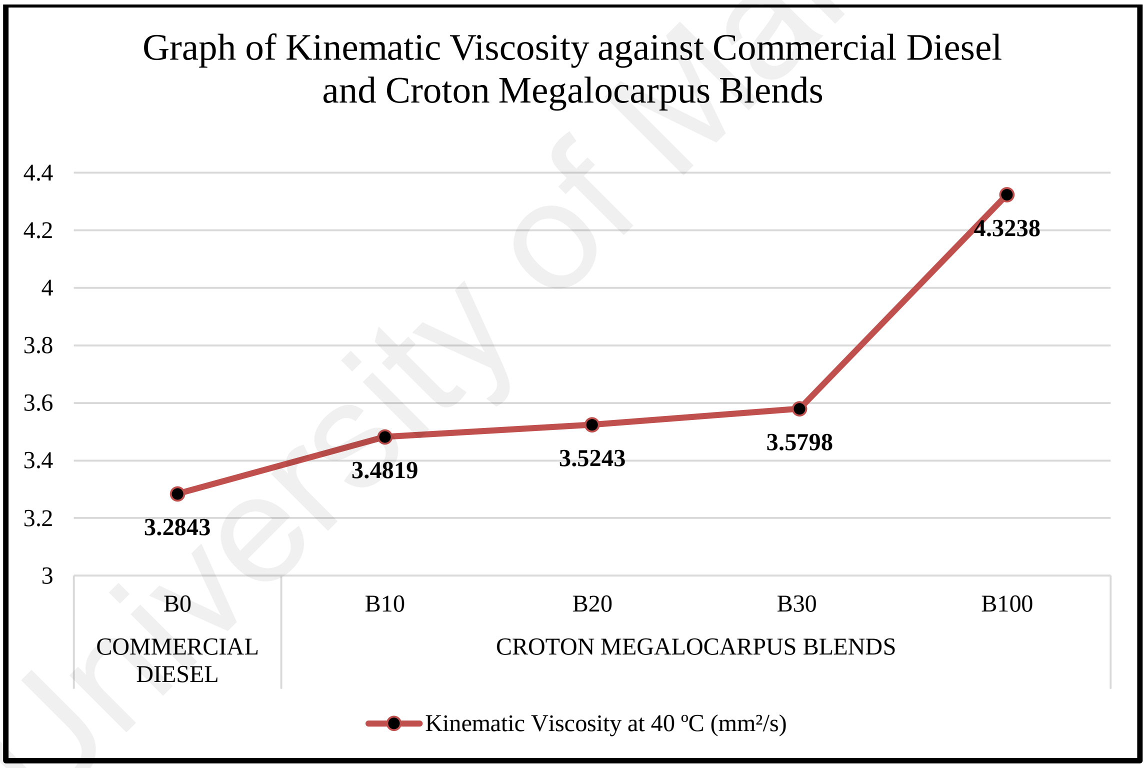


Figure 4.1: Screen shot of reading for B100 croton megalocarpus

Table 4.4: Viscosity and density results for Coconut biodiesel blends

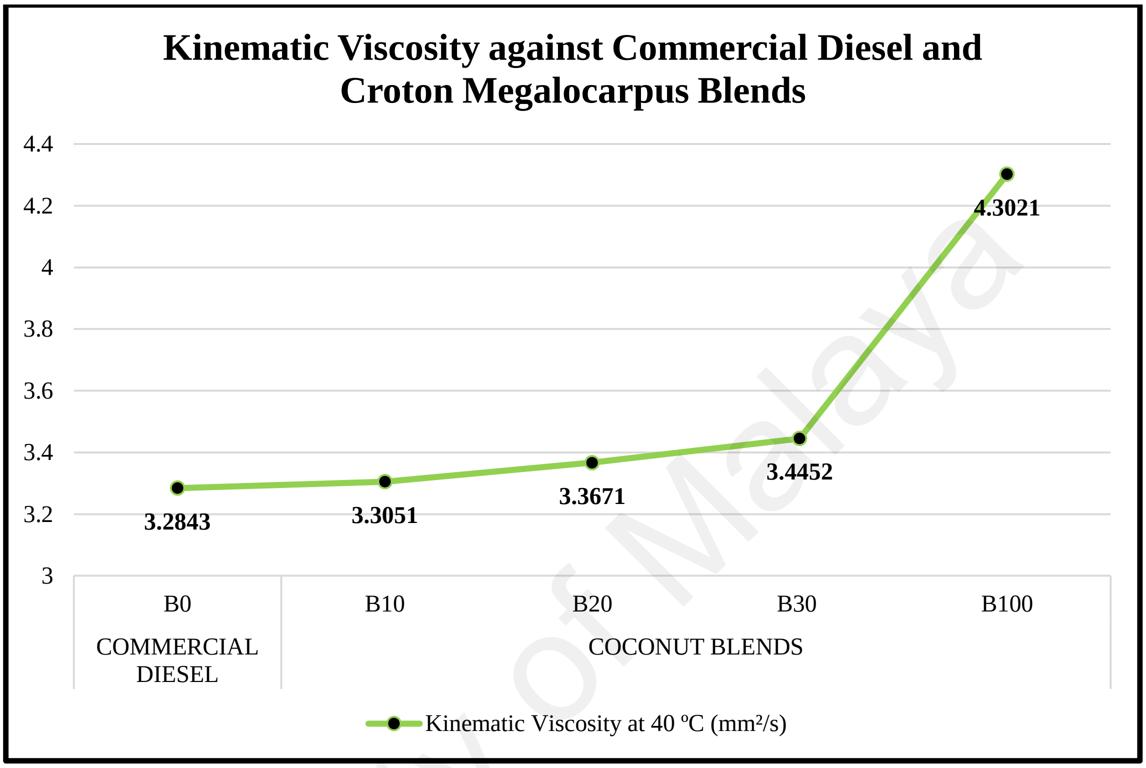
PROPERTIES	COMM. DIESEL	COCONUT			
	B0	B10	B20	B30	B100
Dynamic Viscosity at 40 ºC (mPa.s)	2.7196	2.7762	2.8395	2.9116	3.7269
Kinematic Viscosity at 40 ºC (mm^2/s)	3.2843	3.3051	3.3671	3.4452	4.3021
Density at 40 ºC (kg/m^3)	830.70	840.2	843.7	846.4	868.5



Graph 4.1: Graph of Kinematic Viscosity against Commercial Diesel and Croton Megalocarpus Blends

From the graphs above it is seen that the trend of the graph is keep increasing from B0 (Commercial diesel) to B100 pure biodiesel. This observation was observed for the both croton megalocarpus biodiesel blends and coconut biodiesel blends. Commercial diesel

Having a viscosity of 3.2843 mm^2/s. Graph 4.1 shows the kinematic viscosity against commercial diesel and croton megalocarpus biodiesel blends. It is seen that B10, B20, B30 and B100 having viscosity of 3.4819, 3.5243, 3.5798 and 4.3238 mm^2/s respectively.



Graph 4.2: Graph of Kinematic Viscosity against Commercial Diesel and Coconut Blends

Graph 4.2 shows the kinematic viscosity against commercial diesel and coconut biodiesel blends. It is seen that B10, B20, B30 and B100 having viscosity of 3.3051, 3.3671, 3.4452 and 4.3021 mm^2/s respectively. The viscosity of croton megalocarpus biodiesel and the blends is higher compare to coconut biodiesel and blends. As the blends ratio is increasing, the viscosity of the fuel also will be increasing. So, it is known that the more viscos the fuel is, the higher corrosion rate will be carried by the fuel and this was clearly observed from the above graph and corrosion rate of the blends.

CHAPTER 5: CONCLUSION

This project paper seeks to understand the corrosion behavior of aluminium alloy 5052 in presence of croton megalocarpus biodiesel blends and coconut biodiesel blends. In order to understand its behaviors, various test was conducted. One of the test was conducted is static immersion test conducted according ASTM G1 standard and was studied under room temperature for 50 days or 1200 hours. Weight loss data was calculated and it was helped to derive a good discussion from there.

The same samples that gone through immersion test was then analyzed in SEM to study the surface metallurgy. The viscosity of the commercial diesel, croton megalocarpus biodiesel blends and coconut biodiesel blends was tested and identified. A few conclusions have been made with the limited context of the project paper and it is summarized as of following:

- The weight loss data proves that as the blends composition increases, the corrosion rate also increases for both croton megalocarpus and coconut biodiesel. Here also we can conclude that croton megalocarpus biodiesel is more corrosive than coconut biodiesel because croton megalocarpus have high composition of polyunsaturated fatty acids compare to coconut biodiesel.

- The SEM data reveals that there is no any pitting corrosion was happened for all the compositions. But there is only general surface corrosion was happened and it was clearly proved by the weight loss data.

- The viscosity study shows that the more viscous the fuel is, the more weight loss will happen which will automatically result with the corrosion rate.

So, consider all the listed conclusions above, it is majorly concluded that aluminium alloy 5052 is more corrosion resistant in presence of coconut biodiesel and its blends compare to croton megalocarpus biodiesel and its blends. All the objective as per listed earlier of the study was clearly achieved.

5.1 Recommendations

In future, if any work done with similar research area or continuation of this project, the polishing method need to be monitor for each samples. The polishing method will play very important role and will affect the purity of SEM image captured. The polishing if done using an automated polish machine, than it should be done at low rpm. Usually soft materials are polish with low rpm and with low pressure. If pits are still present, it's recommended to polish for short periods and to clean in between so that it will more helpful in metallurgical study. It also recommended to get the viscosity data of the blends which already immersed earlier. This will help much to compare the data of before and after of immersion and we too can see how the viscosity important with corrosion rate.

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