CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Diesel engine is the most efficient internal combustion engine among all known types of engines. Heavy trucks, urban buses, and industrial equipment are powered almost exclusively by diesel engines all over the world. Currently, diesel powered cars have been increasingly popular compare to gasoline powered engine cars. The diesel engine is a major candidate to become the power plant of the future. Before that happens, however, further progress in diesel emission control is needed. Internal combustion engines are significant contributors to air pollution, which has a damaging impact on our health and the environment and is suspected to cause global climate changes. Environmental benefits of diesel, such as low greenhouse gas emissions, are balanced by growing concerns with emission of nitrogen oxides (NO_x), diesel particulates and harmful gases.

As possible solutions for this diesel emission crisis, the world bodies have came out with many measures such as diesel engine retrofitting, implementation of Diesel Oxidation System (DOC) and Diesel Particulate Filter (DPF) to be used with current diesel engines, exploration in hybrid technologies and also efforts in finding alternative fuels [14]. Although the Environmental Protection Agency (EPA) had set the standards to reduce emissions from on-road vehicles by as much as 90%, it will go a long way towards controlling the diesel emission in the future and primarily will impact new engines but older uncontrolled diesel engines, due to their durability and long life, will be continuing to make up a significant portion of the heavy-duty vehicle fleet for the years to come [15]. Hence, the best preferred solution is to replace the diesel fuel with alternative fuels without needs for any modification of the current diesel engines.

Emulsification of bio-oil and diesel is one of the potentially effective techniques to reduce exhaust emission from diesel engines. Bio-oils also referred to, as biomass pyrolysis liquids, pyrolysis oils, or bio-crude oils, are dark brown, free flowing liquids with an acrid or smoky odor. They are complex mixtures of compounds that are derived from the depolymerization of cellulose, hemicelluloses and lignin. Chemically, they comprise quite a lot of water, more or less solid particles and hundreds of organic compounds that belong to acids, alcohols, ketones, aldehydes, phenols, ethers, esters, sugars, furans, nitrogen compounds and multifunctional compounds [10].

Emulsified bio-diesel formulations are reported to reduce the emissions of NO_x, SO_x, CO and particulate matter (PM) without compensating the engine's performance [14]. In the current Malaysian market, B5 biodiesel fuel, which comprises of 5% palm methyl ester (PME) mixed with 95% diesel fuel is being used to replace diesel fuel usage. This fuel is proven to have better emission quality and at the same time has almost similar engine performance to diesel fuel. Hence, in this project, palm methyl ester (PME) bio diesel fuel will be used to prepare B10 and B20 biodiesel fuel to check whether does this higher proportion of PME emulsified diesel fuel has better characteristics than B5 emulsified fuel and diesel fuel.

However, through research, its claimed that emulsified diesel fuel with higher bio-oil percentage will lead to few drawbacks, such as corrosion problems and lack of engine performance. So, this project is aimed to investigate these drawback issues of B10 and B20 emulsified biodiesel fuel.

1.2 PROBLEM STATEMENT

As explained above, there are few drawbacks that needed to be taken into account before commercializing this emulsified diesel fuel. The problems are as below:

- Bio-oil contains water components in its molecular structure. This could cause corrosion if in contact with metal surface. So at what rate will this water component affect corrosion characteristics of emulsified diesel?
- Bio-oil also reported to have high viscosity and density compare to diesel fuel, which will lead to ignition difficulties and burning problems. So, how these bio-oil characteristics will affect the engine performance when emulsified with diesel fuel?

Explaining in detail the above stated problems; actually bio-oil is known as a low-grade liquid fuel. Many problems have been encountered when bio-oil is employed alone in diesel engines and gas turbines, such as ignition difficulty and formation of char deposits on engine walls. Hence, after bio-oil emulsified with diesel fuel, it also found to raise some issues about the compatibility and the characteristics. Claimed that bio diesel emulsified fuel has higher corrosion rate and has higher gas emission rates compare to neat diesel fuel. Besides that, this emulsified diesel fuel also have problems as explained below:

1.2.1 Stratification

Research claims that even stable emulsions of pyroltic bio-oil and diesel fuel forms stratification after a certain induction time. The presence of stratification is undesirable in fuel because it has different characteristics and properties, which could damage the engine after, stratify.

1.2.2 Viscosity

Emulsified diesel is claimed to have higher viscosity than neat diesel fuel. This is due to neat bio-oil characteristics, which has high viscosity and density value. This viscosity problem has to be handled in order to reduce damages to engine fuel spray nozzle, which cannot function on high viscosity fuels.

1.2.3 Water contain

The structural water in bio-oil makes it immiscible with hydrocarbon based diesel fuel. So, this complicates the emulsification process as it fractions automatically after certain time. Water in bio-oil results from the original moisture in the feedstock and as a product of the dehydration reactions occurring during pyrolysis. Therefore, the water content varies over a wide range (15-35%) depending on the feedstock and process conditions.

1.3 OBJECTIVES

The objectives of this project are as below:

- To study temperature and time interval influence on B10 and B20 biodiesel fuel corrosiveness.
- To study the engine performance of B10 and B20 biodiesel fuel.

1.4 SCOPE OF STUDY

Table 1.1: Scope of study

ASPECTS	SCOPE OF STUDY
Corrosion	• Influence of temperature (25^oc and 70^oc) and time interval (24hours & 48 hours) on emulsified diesel corrosiveness. • Comparison study between neat bio-oil, neat diesel fuel, 10%wt and 20%wt bio-oil emulsified diesel fuel. • Study corrosiveness on stainless steel and mild steel only as these metals are widely used for engine parts.
Engine Performance	• Study on the specific fuel consumption (SFC), power and torque of engine. • Comparison between diesel fuel, 10%wt and 20%wt bio-oil emulsified diesel fuel only.

These scopes of study are feasible because all the necessary equipments are available in the labs. In this study, diesel fuel characteristics will be set as benchmark for comparison purpose with the B10 and B20 emulsified biodiesel fuels.

CHAPTER 2

THEORY / LITERATURE REVIEW

2. THEORY

2.1 DIESEL ENGINES: EMISSIONS & HARMS

2.1.1 Diesel Engines Emissions

At present, diesel engines are used in most industrial sectors overwhelmingly because it provides more power per unit of fuel and its lower volatility makes it safer to handle, fuel economy, efficient power and also durability. Its application conquers most giant and vital sectors of the world such as transportation, manufacturing, commercial/industrials and even medical sectors [2]. As an example, considering only worlds transportation sector, the vast majority of modern heavy road vehicles like trucks and buses, ships, long-distance trains, large-scale portable power generators, and most farm and mining vehicles have diesel engines. In the agricultural field, tractors, irrigation pumps and threshing machines and other equipment are predominantly diesel powered. Construction is another sector that relies heavily on diesel power. All concrete pavers, scrapers, rollers, trenchers and excavators run on diesel [2] and [3].

These diesel engines are widely used in the world due to many major reasons. Such as, in some countries, where tax rates make diesel fuel much cheaper than petrol, diesel vehicles are very popular. The continuous revolutions in diesel engines technologies like the newer designs and its improvised performance have significantly narrowed differences between petrol and diesel vehicles and also the enhanced benefits in using these engines. Currently, diesel engines are also known as the most fuel-efficient combustion engines in the world [3].

Petroleum-derived diesel is composed of about 75% saturated hydrocarbons (primarily paraffins including *n*, *iso*, and cycloparaffins), and 25% aromatic hydrocarbons (including naphthalenes and alkylbenzenes). The average chemical formula for common diesel fuel is $C_{12}H_{23}$, ranging approximately from $C_{10}H_{20}$ to $C_{15}H_{28}$. [1]

The current commercialize diesel fuel is a high cetane index fuel designed for use in low and high speed self-ignited compression engine to provide efficient, dependable and smooth operation. It has the proper viscosity suitable for critical fuel injection system to provide maximum protection against wear and leakage. Properties of the commercialize diesel fuel are as in Table 2.1 below:

Table 2.1: Properties of Diesel Fuel [3]

Properties	Guaranteed Level		Test Method
	Minimum	Maximum	
Cetane Index	45	-	ASTM D4737
Density @ 15°C, kg/m3	815	870	ASTM D1298 / D4052
Kinematic Viscosity @ 40°C, cSt	2.0	5.0	ASTM D445
Sulphur, % m/m	-	0.35	ASTM D2622
Distillation, recovery @ 300°C, % vol	40	-	ASTM D86
Final Boiling Point, °C	Nil		
Pour Point, °C	-	18	ASTM D97
Flash Point, °C	60	-	ASTM D93
Conradson Carbon Residue, % m/m	-	0.1	ASTM D4350
Water, mg/kg	-	500	ASTM D1744
Cooper Corrosion	-	1	ASTM D130
Ash, % m/m	-	0.01	ASTM D482
Sediment, % m/m	-	0.01	ASTM D473
Strong Acid No., mgKOH/g	-	0	ASTM D664
Total Acid No., mgKOH/g	-	0.6	ASTM D664
Particulate, mg/l	Report		ASTM D2276
Appearance	Bright & Clear		Visual
Colour ASTM	-	3	ASTM D1500

Diesel exhaust is a mixture of harmful gases and solids, including particulate matter, nitrogen oxides (NO_X), toxic metals, and toxic organic substances such as acrolein, polycyclic aromatic hydrocarbons (PAHs), and formaldehyde. Diesel emissions contain 40 hazardous air pollutants (HAPs) listed by EPA, 15 of which are listed by the International Agency for Research on Cancer (IARC) as known, probable, or possible carcinogens. These emissions account for one-quarter of the ozone and Particulate Matter (PM)-forming nitrogen oxides emissions. Diesels contribute more PM than gasoline-powered engines; two thirds of mobile source PM emitted is from diesels. Heavy-duty diesel engines are the dominant source of diesel emissions including 95 percent of emissions from on-road diesels and 85-90 percent of all diesel particulate matter. Diesel PM typically has hundreds of chemicals ("soluble organics"), many carcinogenic, adsorbed onto their surfaces. Gaseous diesel emissions also contain toxic chemicals and irritants. Summary of some of the most harmful diesel emissions are as in the A-Figure 1 and A-Figure 2 (Appendices) [8] and [15].

2.1.2 Diesel Engine Emission Harms

There are vast disadvantages that the mankind and the mother of nature have to bare due to this extreme usage of diesel engines. This dangerous air pollutants that make up diesel exhaust contribute to a host of public health and environmental hazards, including cancer risk greater than that posed by any other air pollutant; premature death; both chronic and acute respiratory injury; asthma attacks; ground-level ozone formation; acid deposition; and particulate haze and visibility impairment. Diesel engines produce far more harmful particulate pollution than gasoline engines [4]. These fine particles are breathed deep into the lungs where they can cause very serious health effects including hospitalization and death. Fresh diesel particulate matter emitted by diesels includes "ultrafine" particles—less than one tenth of a micron giving them the ability to bypass the lung's natural defenses and enter the bloodstream causing cardiovascular effects. Ultrafine particulate matter is particularly concentrated within 100 meters of busy roadways according to a recent California study [4] and [15].

Organizations including the National Institute for Occupational Safety and Health, International Agency for Research on Cancer, Health Effects Institute, World Health Organization, U.S. Department of Health and Human Services National Toxicology Program, and the U.S. Environmental Protection Agency have determined that diesel exhaust is a probable or likely human carcinogen. A study conducted by California's South Coast Air Quality Management District in 1998 and 1999, found that 70 percent of the cancer risk from air pollution for those living in the Los Angeles air basin was due to diesel particulate emissions [15].

2.1.3 Diesel Emission Solutions

Hence, to reduce and avoid further destructions done to the world by these diesel engine emissions, there are many approaches suggested or taken into action by the world bodies. Environmental Protection Agency (EPA) announces plans to reduce sulfur in on-road diesel fuel by 97 percent by mid-2006 [5] and [15]. EPA also issues final rule to address emissions of hazardous pollutants (air toxics) from mobile sources. The rule identifies 21 mobile source air toxics and sets new gasoline toxic emission performance standards [15]. Although this new EPA standards will go a long way towards controlling the diesel emission in the future and primarily will impact new engines but older uncontrolled diesel engines, due to their durability and long life, will be continuing to make up a significant portion of the heavy-duty vehicle fleet for the years to come. Hence, to control the harms from the older diesel engines, currently Diesel Oxidation System (DOC) and Diesel Particulate Filter (DPF) implemented to be used for these engines [14]. A DOC is a device, which utilizes a chemical process, in order to break down pollutants from diesel engines in the exhaust stream, turning them into less harmful components. DOC's reduce emissions of particulate matter by typically 20%-40%+. While DPF is a device designed to remove diesel particulate matter or soot from the exhaust gas of a diesel engine [6] and [14].

Besides above solutions, alternative fuels or fuel technologies that can offer PM benefits are including biodiesel, natural gas, diesel/water emulsions and diesel/electric hybrids. Natural gas, biodiesel and diesel/electric hybrid technologies are currently being used in heavy-duty engine applications. However, in these alternative fuel solution technologies, the demand is concentrated on fuels that can be used without the need to modify the existing engines. In this sense, the high potential solutions are the biodiesel and W/D emulsions which are direct fuel substitutes that can be utilized with little or no modifications to existing diesel engines.

2.2 Biodiesel Fuel Emulsion

An **emulsion** is a mixture of two or more immiscible (unblendable) liquids. One liquid (the dispersed phase) is dispersed in the other (the continuous phase). An emulsifier (also known as an emulgent) is a substance, which stabilizes an emulsion, frequently a surfactant. Nowadays emulsions are widely used in many intermediate and consumer products, such as cosmetics and skin lotions, pharmaceutical ointments, varnishes, paints and lubricants and fuels [1].

2.2.1 Surfactant

Surfactants are wetting agents that lower the surface tension of a liquid, allowing easier spreading, and lower the interfacial tension between two liquids. There are two forms of emulsions, which are oil-in-water (O/W) emulsion in which oil droplets are dispersed and encapsulated within the water and water-in-oil (W/O) emulsion in which droplets of water are dispersed and encapsulated within oil. Surfactants are usually organic compounds that are amphiphilic, meaning they contain both hydrophobic groups (their "tails") and hydrophilic groups (their "heads"). Therefore, they are soluble in both organic solvents and water. Figure 2.1 below shows the schematic diagram of a surfactant molecule [14] and [16].

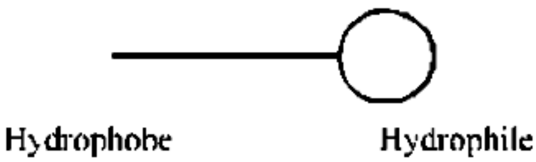


Figure 2.1: Schematic diagram of a surfactant molecule

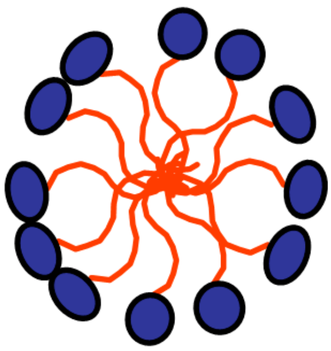


Figure 2.2: A micelle - The lipophilic ends of the surfactant molecules dissolve in the oil, while the hydrophilic charged ends remain outside, shielding the rest of the hydrophobic micelle

When micelles form in water, their tails form a core that can encapsulate an oil droplet, and their (ionic/polar) heads form an outer shell that maintains favorable contact with water. When surfactants assemble in oil, the aggregate is referred to as a reverse micelle. In a reverse micelle, the heads are in the core and the tails maintain favorable contact with oil. Surfactants are also often classified into four primary groups; anionic, cationic, non-ionic, and zwitterionic (dual charge) [16].

There are wide studies and researches done on the current surfactants to improvise the characteristics and the existing properties. This has led to the synthesis of new generation surfactants such as gemini, viscoelastic and non-migratory, etc. While conventional surfactants generally have one hydrophilic group and one hydrophobic group, recently a class of compounds having at least two hydrophobic groups and at least two hydrophilic groups have been introduced. These have become known as "gemini surfactants" in the literature (Chemtech, March 1993, pp 30-33), and J. American Chemical Society, 115, 10083-10090, (1993). Gemini has a long hydrocarbon chain, an ionic group, a spacer, a second ionic group and another hydrocarbon tail which are also known as double tailed surfactants and are considerably more surface-active than conventional surfactants. Geminis are used as promising surfactants in industrial detergency and have shown efficiency in skin care, antibacterial property, metal-encapped porphyrazine and vesicle formation**,** construction of high porosity materials, etc [14].

Hence, in mission to protect the environment from the diesel emissions, which is by fulfilling the strict standards for vehicle exhaust emissions and to provide the healthy atmospheric conditions to ever increasing urban populations, scientists all around the world are working to produce environment friendly fuels. One of the highly potential and preferred solution alternatives is to formulate emulsified bio diesel; environment friendly fuels.

2.2.2 Bio Oil

Bio oil is considered the renewable energy source with the highest potential to contribute to the energy needs of modern society. Energy from bio mass based on short rotation forestry and other energy crops can contribute significantly towards the objectives of the Kyoto Agreement in reducing the green house gases emissions and to the problems related to climate change. Fast pyrolysis is a thermal decomposition process that occurs in the absence of oxygen to convert biomass into liquid products (bio-oils). The typical properties of bio oil are as in Table 2.2 below [12] and [13]:

Table 2.2: Properties and characteristics of bio-oil [8]

Physical property	Typical value	Notes
Moisture content	25%	Water comes from moisture in the feed and reaction water and cannot be separated. Values can range from 15 to 35%
pH	2.5	The low pH comes from organic acids
Density	1.20	Very high at around 1.2 kg/l compared to light fuel oil at around 0.85 kg/l. Bio-oil has about 40% of the energy content of fuel oil on a weight basis, but 60% on a volumetric basis
Elemental analysis		Typically: C: 57%, H: 6.0%, O: 37%, N: trace; Ash; trace depending on char content
Ash	0%	All ash is associated with the char
HHV as produced (depends on water)	18 MJ/kg	Bio-oil has a higher heating value of about 18 MJ/kg as produced with about 25% wt. water that cannot be separated
Viscosity (at 40 °C and 25% water)	50 cp	Viscosity as produced can vary from 20 cSt to as high as 1000 cSt (measured at 40 °C) depending on feedstock, water content, light and ageing
Solids (char)	0.2%	0.1 wt.% is a good level and 1% is often encountered
Vacuum distillation residue	50%	Cannot be completely vaporised. Heating to 100 ℃ causes production of a solid residue of around 50 wt.% of the original liquid and distillate containing volatile organics and water
Appearance		Typically a dark brown free flowing liquid
Odour		A distinctive smoky smell
Miscibility		Water addition can be tolerated up to about 35% wt. Bio-oil is miscible with polar solvents such as methanol, but totally immiscible with petroleum-derived fuels

2.2.3 Palm Methyl Ester (PME)

Palm oil biodiesel, also known as palm oil methyl ester (PME), differs from other types of biodiesel in its grade of molecule unsaturation. PME is more saturated, which means it has a lower number of double carbon bonds in its molecules. For diesel engine applications, the degree of biodiesel molecule unsaturation represents a compromise. Saturated fuels such as PME have high-ignition quality. However, they also harden at higher temperatures, making them difficult to use in cold weather. [19] PME properties and characteristics are as in Table 2.3 below:

Table 2.3: Properties and characteristics of PME biodiesel [19]

Property	Unit	Limits		Test methods[a]
		Minimum	Maximum	
Ester content[a]	% (m/m)	96.5[b]	-	EN 14103
Density at 15 °C[c]	kg/m^3	860	900	ISO 3675 ISO 12185 ASTM D 4052 ASTM D 1298
Viscosity at 40 °C[d]	mm^2/s	3.50	5.00	ISO 3104 MS 1831
Flash point	°C	120	-	ISO 3679[e] MS 686
Sulfur content	mg/kg	-	10.0	ISO 20846 ISO 20884 ASTM D 5453
Carbon residue (on 10 % distillation residue – ISO 10370)[f] (on 100 % distillation sample – ASTM D 4530)	% (m/m)	-	 0.30 0.05	 ISO 10370 ASTM D 4530
Cetane number[g]		51.0	-	ISO 5165 MS 1895 ASTM D 6890
Sulfated ash content	% (m/m)	-	0.02	ISO 3987 ASTM D 874
Water content	mg/kg	-	500	ISO 12937 ASTM E 203 ASTM D 6304
Total contamination	mg/kg	-	24	EN 12662 ASTM D 5452
Copper strip corrosion (3 h at 50 °C)	rating	Class 1		ISO 2160 MS 787
Oxidation stability, 110 °C	hours	6.0	-	EN 14112
Acid value	mg KOH/g	-	0.50	EN 14104 MS 2011
Iodine value	g iodine/ 100 g	-	110	EN 14111
Linolenic acid methyl ester	% (m/m)	-	12.0	EN 14103
Polyunsaturated (≥4 double bonds) methyl esters	% (m/m)	-	1	EN 14103
Methanol content	% (m/m)	-	0.20	EN 14110
Monoglyceride content	% (m/m)	-	0.80	EN 14105 ASTM D 6584

Property	Unit	Limits		Test methods[a]
		Minimum	Maximum	
Diglyceride content	% (m/m)	-	0.20	EN 14105 ASTM D 6584
Triglyceride content[h]	% (m/m)	-	0.20	EN 14105 ASTM D 6584
Free glycerol[h]	% (m/m)	-	0.02	EN 14105 EN 14106 ASTM D 6584
Total glycerol	% (m/m)	-	0.25	EN 14105 ASTM D 6584
Group I metal (Na + K) [i] Group II metals (Ca + Mg) [j]	mg/kg mg/kg	-	5.0 5.0	EN 14108 EN 14109 EN 14538
Phosphorus content	mg/kg	-	10.0	EN 14107 ASTM D 4951
CFPP	°C	-	15	EN 116

PME has a short ignition delay, which is represented by its high cetane number. Thus, when compared with fuels with a lower cetane number, less fuel ignites during pre-mixed combustion. This leads to a lower peak of in-cylinder pressure and temperature. NOx is reduced since it's strongly dependent on the flame temperature. HC emissions also tend to be reduced when high cetane fuels are combusted. [16]

While the benefits of using PME to reduce emissions have been proven in laboratory tests, its operational performance is still of concern to end users and the automotive industry. Oxidation stability and low-temperature fluidity are the main concerns. PME oxidation stability has better performance than soy methyl esters and rapeseed methyl esters. PME also exceeds Europe's EN 14214 specification. Both are because PME has fewer unsaturated molecules susceptible to oxidation through its double carbon bonds. Oxidative stability is important to engine performance because oxidation byproducts can cause harmful effects such as filter plugging, deposits and corrosion.

PME is produced by transesterification process using palm oil. Simple alcohols are used for transesterification and this process is usually carried out with a basic catalyst (NaOH, KOH) in the complete absence of water. The bonding of alcohol and organic acid produces ester. An excess of alcohol is needed to accelerate the reaction. With methyl alcohol glycerol separation occurs readily. If water is present, soap is the bi-product, which results in decreasing yield of ester. In the transesterification process alcohol combines with triglyceride molecule from acid to form glycerol and ester. The glycerol is then removed by density separation. Transesterification decreases the viscosity of oil, making it similar to diesel fuel in characteristics. A block diagram illustrating the process of producing biodiesel is given in Figure 2.3.[19]

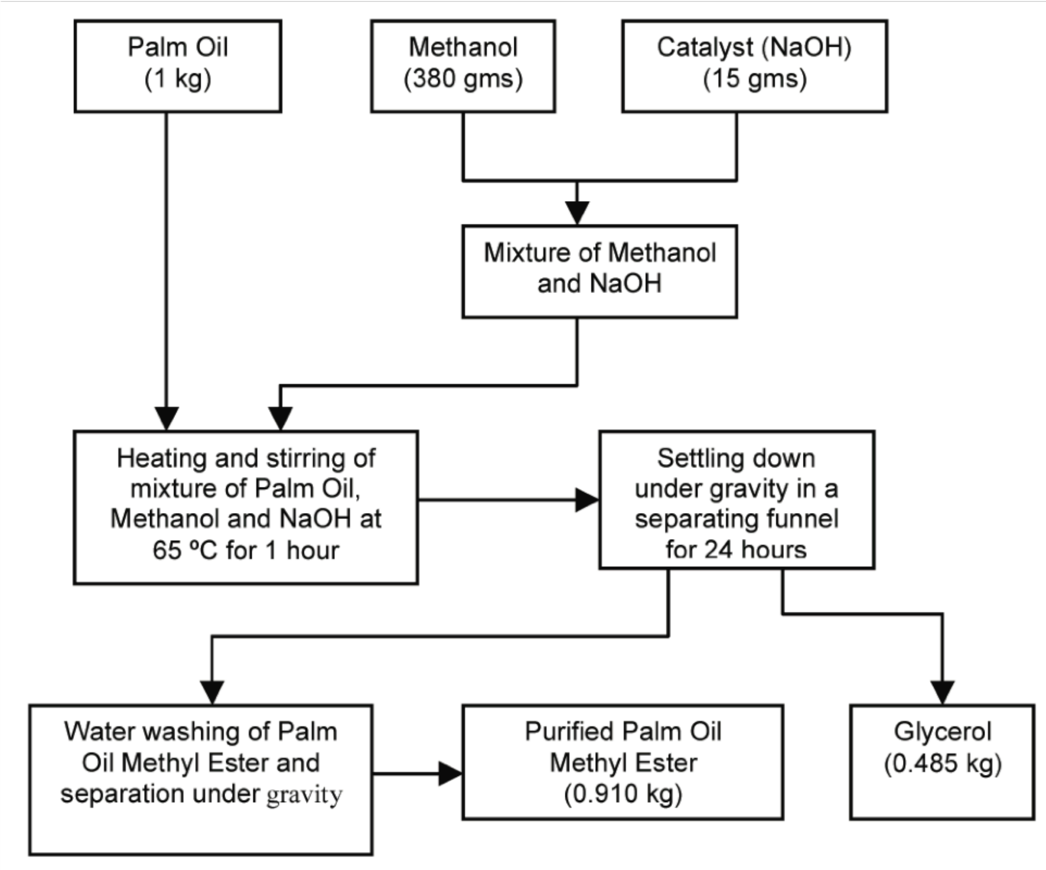


Figure 2.3: Block Diagram Illustrating the Process of Producing Palm Oil Methyl Ester (PME) [19]

The density and viscosity of the Palm oil methyl ester formed after transesterification were found to be very close to petroleum diesel oil. The flash point of PME was higher than that of diesel oil. The brake thermal efficiency is higher as compared to diesel at part and full load. The brake specific energy consumption is lower as compared to diesel at all loads. Exhaust gas temperature is higher with blends of biodiesel as diesel. The maximum cylinder gas pressure is lower for biodiesel blends and diesel.

2.2.4 Ternary Diagram

Ternary diagram are most commonly plotted as equilateral triangles. The three components (A, B, and C) which define the system are placed at the apices of the triangles. At the apex there exists 100% of that component and 0% of the other two. Moving away from the apex the proportion of the component at the apex decreases as the proportion of the remaining two increases. Hence, in bio diesel emusification process, this diagram used to determine the suitable proportion between bio-oil, diesel and surfactant to produce a stable emulsion. The diagram is as shown in Figure 2.4 below:

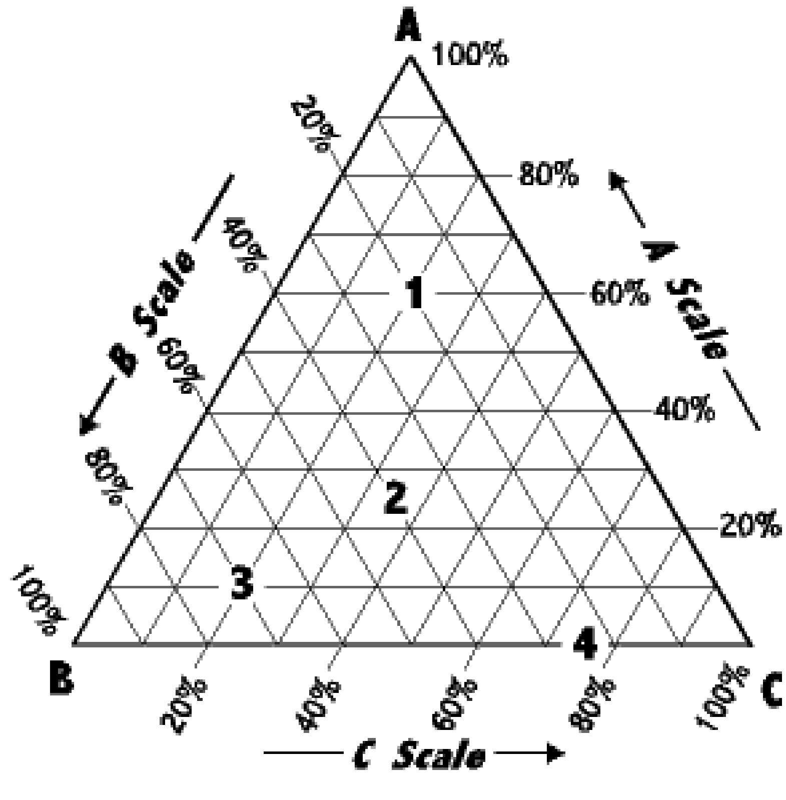


Figure 2.4: Ternary Diagram [9]

2.3 Metals in Car Engine

Car engine consists of many types of high durability and high temperature resistance metals. They are such as Stainless Steel SS321 metals and Q 235A mild steel metals. These metals are heat quenched to withstand high temperature environment and accept high lever pressure and load.

Alloys 321 (S32100) is stabilized stainless steels which offer as their main advantage an excellent resistance to intergranular corrosion following exposure to temperatures in the chromium carbide precipitation range from 800 to 1500°F (427 to 816°C). Alloy 321 is stabilized against chromium carbide formation by the addition of titanium. [17]

Alloys 321 and 347 stainless steels are also advantageous for high temperature service because of their good mechanical properties. Alloys 321 and 347 stainless steels offer higher creep and stress rupture properties than Alloy 304 and, particularly, Alloy 304L, which might also be considered for exposures where sensitization and intergranular corrosion are concerns. The general properties of this SS321 are as in Table 2.4 below [18]:

Table 2.4: SS321 General Properties [17]

	Typical	Minimum
Tensile Strength, MPa	580	515
Proof Stress (0.2 % offset), MPa	280	205
Elongation (Percent in L_o = 5.65 S_o)	60	40
Hardness (Brinell)	163	-
Endurance (fatigue) limit, MPa	260	-

LITERATURE REVIEW

According to a comparison study made by LU Qiang, ZHANG Jian and ZHU XiFeng, University of Science and Technology of China (2008), they made a study on the corrosion properties of components as in Figure 2.5 below [12]:

	HHV (MJ/kg)	Water (wt%)	Density (g/ml)	Kinematic viscosity (cSt, 40℃)	PH (–)
Bio-oil	15.4	32.3	1.13	10.2	3.2
0# diesel	44	–	0.85	2.9	–
Emulsion A	41.9	3.3	0.88	4.9	3.4
Emulsion B	35.5	9.7	0.93	8.0	3.3

*Emulsion A (10 wt% of bio-oil)

*Emulsion B (30 wt% of bio-oil).

Figure 2.5: Properties comparison if bio-oil, diesel and emulsified diesels [11]

The corrosion tests were performed by immersion of four different metals into the bio-oil and emulsion samples. The metals used were aluminum, mild steel (Q235A), brass (H62) and austenite stainless steel (SS321, 1Cr18Ni9Ti). For each metal, three metal strips were prepared for the three oil samples. All the metal strips were machined into 2 cm in length and 1 cm in width, 1.5 mm in thickness for stainless steel strips and 2 mm in thickness for the other metal strips. The metal strips were cleaned and polished by silicon carbide paper and weighed, then immersed in 50 ml glass bottles containing 30 ml oil samples. After that, the bottles were sealed and placed at room temperature (~25°C), 50°C and 70°C respectively. At specific intervals (6, 12, 24, 48, 72 and 120 h), the strips were taken out of the bottles, and washed in ethanol for two minutes. After wiped with tissue paper, the strips were weighed and then taken back to the bottles until the next weight measurement time.

This source claims that using emulsified fuels compared to neat bio-oil reduced the corrosion rate. This finding is displayed as in Figure 2.6, 2.7 and 2.8 below:

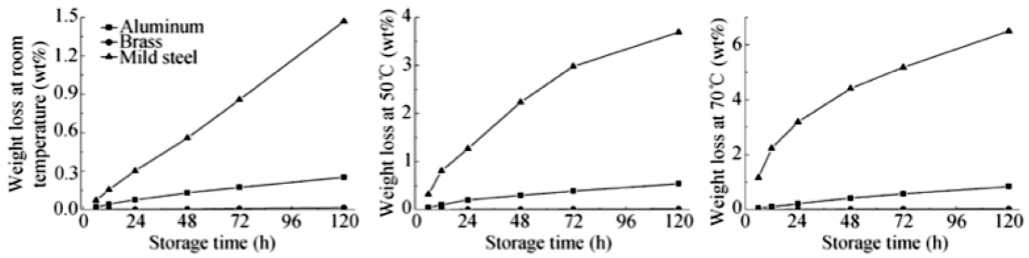


Figure 2.6: Weight loss of metals corroded by neat bio-oil [11]

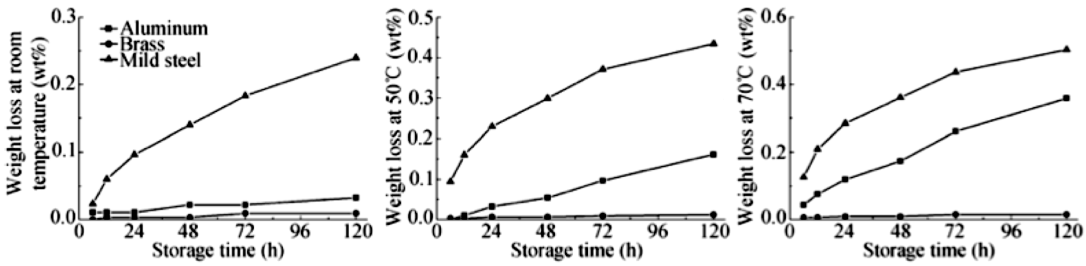


Figure 2.7: Weight loss of metals corroded by Emulsion A [11]

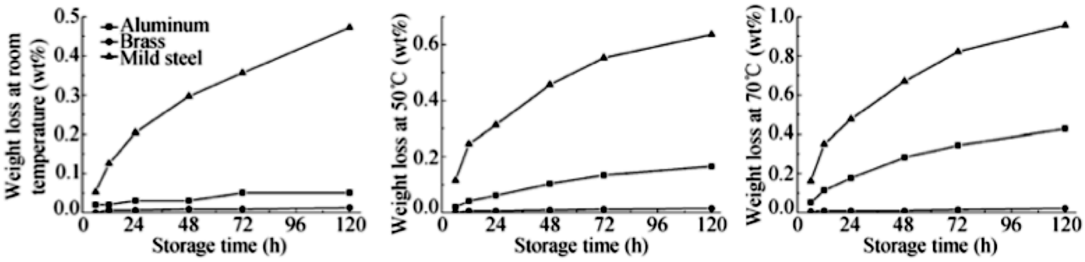


Figure 2.8: Weight loss of metals corroded by Emulsion B [11]

This result is discussed to have such effects because diesel is the continuous phase in the emulsions, and the contact area between the metal surface and bio-oil is limited. Therefore, the corrosion rates are reduced. In comparison of the two emulsions, the bio-oil concentration of emulsion B is three times higher than that of emulsion A, but the corrosion rates of emulsion B to the three metals are less than two times of those of emulsion A. Stainless steel is the only corrosion resisting metal of the four metals tested [12].

While according to M. Nadeem, C.Rangkuti, K.Anuar, M.R.U Haq, I.B.Tan and S.S Shah, University Teknologi Petronas (2009), they have done research on the diesel engine performance and emission evaluation by using emulsified fuels. The details of the fuels used in this study are as in Figure 2.9 below. The experimental methods of this study are:

- All the measurements were made under following conditions:
  - ✓ ratio of oil to water, 95:5, 90:10 and 85:15,
  - ✓ stirring intensity, 2500 rpm,
  - ✓ mixing time 15 min,
  - ✓ emulsifying temperature, 30 °C and
- Diesel engine test bed (FORD, XLD 418) was utilized to study the performance (*Engine's torque, power, brake mean effective pressure, BMEP and specific fuel consumption, SFC*) and emission (*particulate matter PM, nitrogen oxides NO_x, carbon monoxide CO and sulfur oxides SO_x*) characteristics using *neat diesel* and *emulsified fuels*, respectively.

Properties	Diesel	Emulsified fuel-1[a]	Emulsified fuel-2[b]
Density (kg m^{-3})	839.5	852.0	845.0
Cetane no.	52.6	45.5	45.9
Viscosity (cSt)	2.973	3.16	3.05
Lower heating value (MJ K g^{-1})	42.89	39.51	40.69
Sulfur content (ppm w)	410.0	345.0	321.0
C (% w/w)	85.24	72.67	73.56
H (% w/w)	13.652	11.86	11.97
N (% w/w)	0.063	0.050	0.054
O (% w/w)	–	12.689	13.782
Aromatic content (% w/w)	29.73	26.03	26.38
Poly aromatic content (% w/w)	0.51	0.45	0.48
Molecular weight (g/mol^{-1})	211.9	189.0	189.67
Adiabatic flame temperature (K)	2730.6	2704.6	2714.8

[a] Diesel containing 15% water contents stabilized by conventional surfactant.

[b] Diesel containing 15% water contents stabilized by Gemini surfactant.

Figure 2.9: Fuel types used in study [13]

This study results that nitrogen oxides (NO_x), carbon monoxide (CO) and particulate matter (PM) was reduced using the emulsified fuels instead of neat diesel. While emulsion fuels have higher specific fuel consumption (SFC) and produced less torque, power and brake mean effective pressure (BMEP) compared to neat diesel fuels but the difference is insignificant.

CHAPTER 3

METHODOLOGY

3.1 Project Flow Chart

The main objective of this project is to study the corrosion rate of the emulsified diesel and to study the engine performance of emulsified diesel fuel. The activities flow of this are as in Figure 3.1 below:

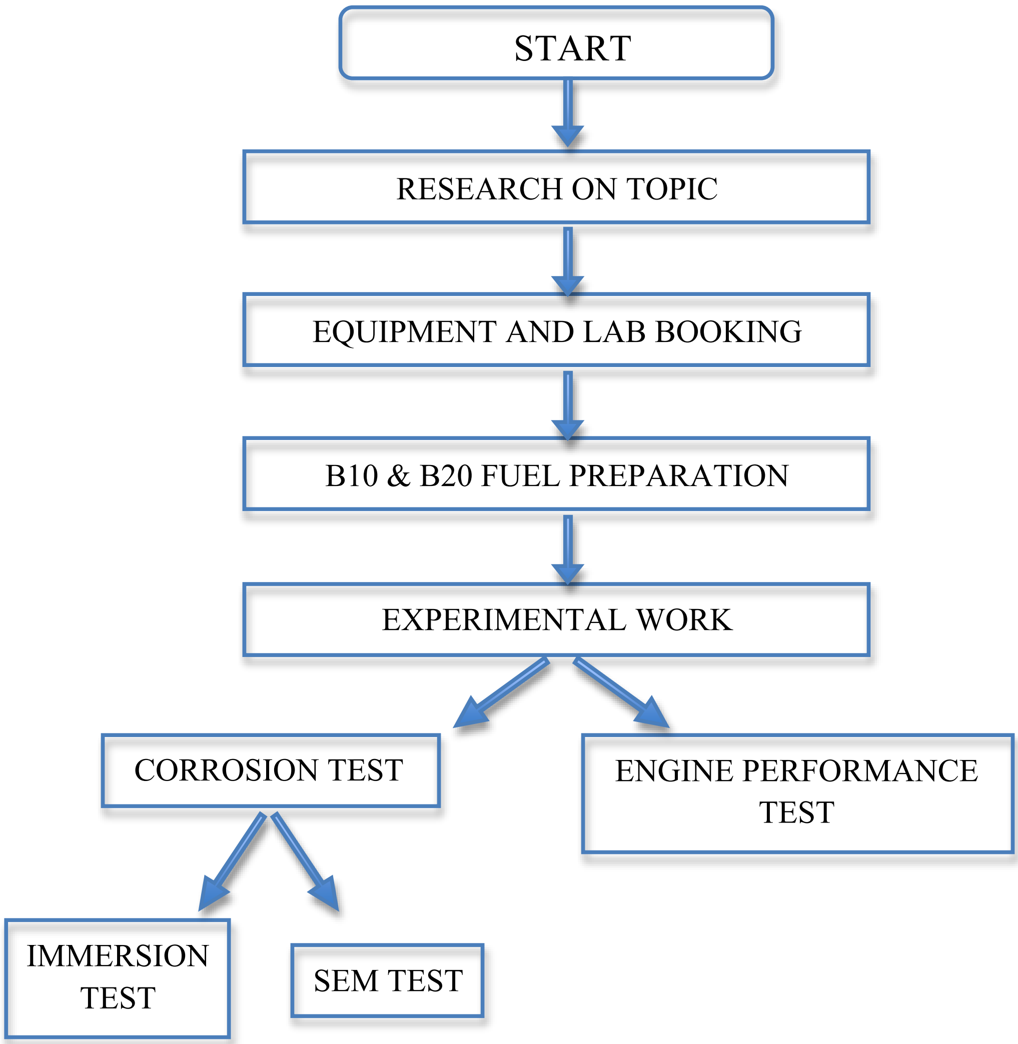


Figure 3.1: Project flow chart

Research is very important in the project to give a strong background or good basic knowledge about this project. For this research purpose, there are many methodologies applied to obtain necessary information correctly and efficiently. They are done via:

- Internet research (e.g. website, online journals, articles, thesis reports)
- Books (e.g. ASTM standards)
- Peers or lecturers

3.2 EXPERIMENTAL METHODS

In this project, there are two aspects that will be studied. Which are the corrosion, emission and engine performance. So, for these each aspects, there are respective experimental methods that will be adapted to achieve the objectives set. These experimental methods are adapted from the journals and thesis papers that obtained through the research step in this project and also by referring to the international experimental standards such as ASTM standards.

The emulsified diesel fuel for the testing purposes is being prepared by mixing palm methyl ester (PME) fuel with diesel fuel at necessary proportions. The PME bio-oil will be emulsified with diesel at proportion as below:

- 10%wt PME biodiesel and 90%wt diesel
- 20%wt PME biodiesel and 80%wt diesel

3.2.1 Corrosion Testing

The corrosion testing method in this project is adapted from the journal in the reference [12]. This testing method is also fitted to obey the rules and guidelines set in ASTM D665. The details of this corrosion testing are as in Table 3.1 below:

Table 3.1: Corrosion testing

Topic	Details
Apparatus	• Equipment (6 x 30ml glass bottles, silicon carbide paper, stopwatch) • Material (4 sets of stainless steel and mild steel metal strips (2cm x 1cm x 1.5mm) each, emulsified diesel with 10wt% and 20% biodiesel, diesel and ethanol
Issues	• Bio-oil contains water components that can cause corrosion in engine. • If emulsified bio diesel fractions by time, water will be in contact with engine surface, which will cause corrosion. • How is emulsified bio diesel corrosiveness compare to diesel fuel ? • Which material is more corrosive in emulsified bio diesel? • Does time and temperature influence the emulsified bio diesel corrosion rate?
Procedure	1. Clean the metal strips and polish them using silicon carbide paper. 2. Weigh the metal strips and record the initial mass. 3. Immerse the metal strips in the prepared testing fuels. 4. Seal the immersed beakers and place them at temperature of 25^{o}c and 70^{o}c. 5. Take out the metal strips at interval of 24 and 48 hours and wash them with ethanol for two minutes. 6. Weigh the metals strips for final mass and record them. 7. Conduct SEM & FESEM test on metal strips.
Results Display	• The result will be the weight change of the metal strips. (more weight loss signifies higher corrosion) • Results will be displayed in form of line graphs and compared among the fuel types.

3.2.2 Engine Performance Testing

Engine performance testing method is adapted from the journal in reference [14]. This testing will be done on SFC (specific fuel consumption), torque and power of engine running on these testing fuels. The details of this testing are as in Table 3.2 below:

Table 3.2: Engine performance testing

Topic	Details
Apparatus	• Equipment (Test bench engine (TECUMSEH), volumetric cylinder and stopwatch) • Material (emulsified diesel with 10wt% and 20% biodiesel and diesel)
Issues	• How bio-oil characteristics such as high density, viscosity and high water contain will affect the emulsified diesel fuel performance? • Is there significant improvisation of performance for emulsified bio diesel compare to diesel and bio-oil?
Procedure	1. Testing fuels prepared at required volume by using volumetric cylinder. 2. Make sure all the equipments and software connected properly to the testing engine. 3. Pour the testing fuel into the engine and run the engine. 4. Record the data obtained and analyze it.
Results Display	• The results will be the data produced by the equipments and software connected to the Test Bed Engine. • Results will be displayed in form of line graphs and compared among the fuel types.

Figure 3.2 below shows the test bed 4-stroke Robinson diesel engine used to run the testing fuels. This engine is connected to TEC-Equipment (Figure 3.3), which gives the readings of engine speed (RPM), power, torque, exhaust temperature, air consumption and 8ml fuel consumption gauge.

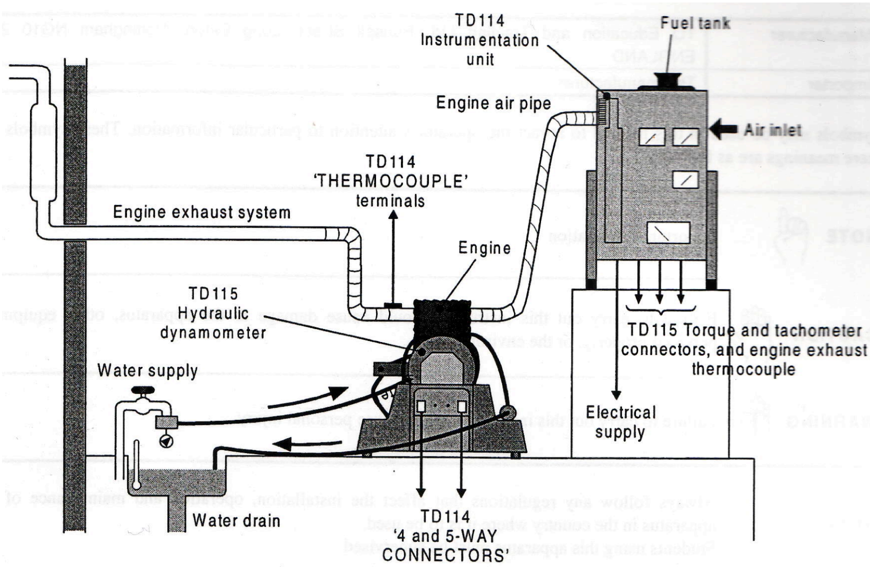


Figure 3.2: Test Bed engine assembly schematic diagram [20]

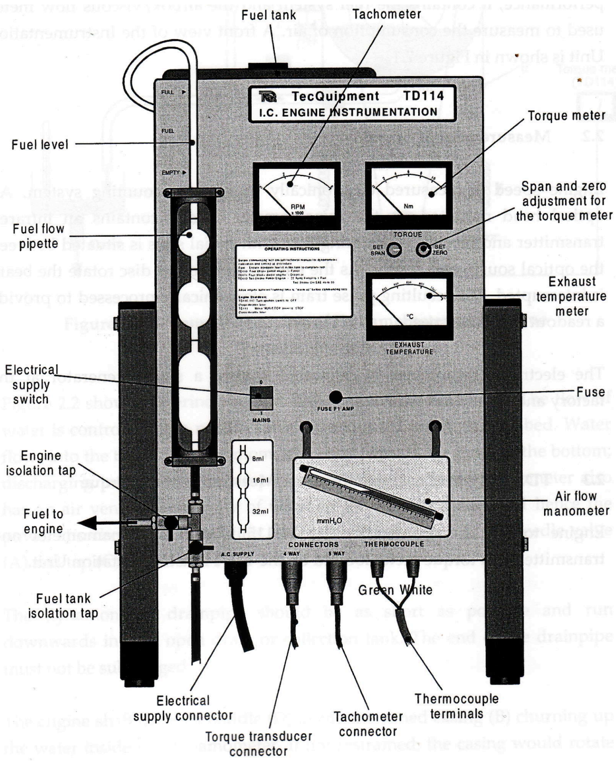


Figure 3.3: TD114 Instrumentation unit schematic diagram [20]

3.3 Gantt Chart

For this project, the workloads are divided equally between FYP1 and FYP 2.

Table 3.3: Gantt Chart FYP 1

No	Detail/Week	1	2	3	4	5	6	7	8	9		10	11	12	13	14	15
1	Project Topic Selection										Mid-semester break						
2	Topic Research																
3	Preliminary Report Submission			●													
4	Experimental Method Selection																
5	Progress Report Submission								●								
6	Seminar																
7	Lab/Material Preparation																
8	Emulsified Bio Diesel Preparation																
9	Interim Final Draft Report Submission															●	
10	Oral Presentation																

The project activities and the key milestones for FYP 1 are as in Gantt Chart below. For FYP 1, the project activities are more to research and data collection base to create a good project ground. After research stage, the emulsified bio diesel fuel will be prepared for experiments and testing process in FYP 2.

Table 3.4: Gantt Chart Fyp 2

No	Detail/Week	1	2	3	4	5	6	7	8	9		10	11	12	13	14
1	Corrosion Testing	■	■	■	■						**Mid-semester break**					
2	Progress Report 1 Submission			●												
4	Finalizing Corrosion Test				■	■	■									
5	Engine Performance Test							■	■							
6	Progress Report 2 Submission									●						
7	Engine Performance Test Finalization									■		■	■			
8	Poster Exhibition													●		
9	Oral Presentation															●

CHAPTER 4

RESULTS & DISCUSSION

4.1 RESULTS

4.1.1 Engine Performance Test

After conducting the engine performance test, the results below obtained. This test done separately for each type of fuel and each test run done by controlling the speed (RPM) of the engine. The engine performances at each speed (RPM) are recorded as in Table 4.1, Table 4.2 and Table 4.3 below. During the engine test run, the readings for speed, torque, 8ml fuel consumption, air consumption and exhaust temperature will be taken directly from the TEC-Equipment, which connected with the testing engine.

a) Diesel Fuel

Table 4.1: Diesel Fuel Test Bed Engine Results

Test Num	**1**	**2**	**3**	**4**	**5**	**6**
Speed (RPM)	1000	1500	2000	2500	3000	3500
Torque (Nm)	3.5	7.4	9.3	11.2	11.2	11.2
Brake Power (kW)	0.367	1.162	1.948	2.932	3.519	4.105
Fuel: Time for 8ml (s)	178	72	50	30	26	21
Fuel Mass Flow Rate (kg/hr)	0.136	0.336	0.484	0.806	0.930	1.152
Fuel Consumption (g/kWh)	370.813	289.060	248.405	275.020	264.442	280.632
Air (mmH_2O)	4.5	7.5	11	14.5	19	21
Exhaust Temp (°C)	140	220	280	460	470	550
Brake thermal efficiency (%)	24.893	31.934	37.160	33.564	34.907	32.893

b) 10% PME mixed Biodiesel (B10)

Table 4.2: 10% PME mixed Biodiesel Test Bed Engine Results

Test Num	1	2	3	4	5	6
Speed (RPM)	1000	1500	2000	2500	3000	3500
Torque (Nm)	6.7	7.5	8.6	11.3	11.6	11.2
Brake Power (kW)	0.702	1.178	1.801	2.958	3.644	4.105
Fuel: Time for 8ml (s)	110	72	54	36	28	26
Fuel Mass Flow Rate (kg/hr)	0.220	0.336	0.448	0.672	0.864	0.930
Fuel Consumption (g/kWh)	313.455	285.206	248.726	227.155	237.086	226.665
Air (mmH_2O)	5	7.5	11.5	16	21	24
Exhaust Temp (°C)	190	240	250	340	430	430
Brake thermal efficiency (%)	29.448	32.365	37.112	40.636	38.934	40.724

c) 20% PME mixed Biodiesel (B20)

Table 4.3: 20% PME mixed Biodiesel Test Bed Engine Results

Test Num	1	2	3	4	5	6
Speed (RPM)	1000	1500	2000	2500	3000	3500
Torque (Nm)	3.7	7	9	10.5	11.5	10.5
Brake Power (kW)	0.387	1.100	1.885	2.749	3.613	3.848
Fuel: Time for 8ml (s)	161	94	43	33	30	27
Fuel Mass Flow Rate (kg/hr)	0.150	0.257	0.563	0.733	0.806	0.896
Fuel Consumption (g/kWh)	387.807	234.059	298.471	266.686	223.204	232.821
Air (mmH_2O)	5	8	11.5	15.5	20	23
Exhaust Temp (°C)	120	170	200	330	380	400
Brake thermal efficiency (%)	23.802	39.438	30.927	34.613	41.356	39.648

The values for brake power, fuel consumption and brake thermal efficiency are calculated using equations below:

Brake Power:

$$\text{Brake power} = \frac{2 \times \pi \times \text{speed} \times \text{torque}}{60000}$$

Fuel Mass Flow Rate (kg/hr):

$$\text{Fuel Mass Flow Rate} = \frac{0.9 \times 8 \times 3.6}{\text{Time for 8ml Fuel Consumption (s)}}$$

Specific Fuel Consumption (g/kWh):

$$\text{Specific Fuel Consumption} = \frac{\text{Time for 8ml Fuel Consumption (s) x 1000}}{\text{Brake Power (kW)}}$$

4.1.2 Corrosion Test

Corrosion test conducted using two methods. They are the weight change method and Scanning Electron Microscope (SEM) image test. For the weight change method, the results obtained are as in Table 4.4 and Table 4.5 below.

Table 4.4: Weight Change Results for 24 hours

Metal	Fuel	Temp (°c)	Initial Weight (g)	Final Weight (g)	Weight change (g)
MS	B20	25	1.72873	1.72868	-0.000050
MS	Diesel	25	1.705385	1.705383	-0.000002
MS	B10	70	1.68068	1.680585	-0.000095
MS	B20	70	1.63641	1.636385	-0.000025
MS	Diesel	70	1.702145	1.702035	-0.000110
SS	B10	25	1.767815	1.767885	0.000070
SS	B20	25	1.769065	1.76911	0.000045
SS	Diesel	25	1.72721	1.727245	0.000035
SS	B10	70	1.721225	1.721235	0.000010
SS	B20	70	1.82925	1.82921	-0.000040
SS	Diesel	70	1.775185	1.77521	0.000025

Table 4.5: Weight Change Results for 48 hours

Metal	Fuel	Temp (°c)	Initial Weight (g)	Final Weight (g)	Weight change (g)
MS	B10	25	1.725575	1.72542	-0.000155
MS	B20	25	1.729595	1.729445	-0.000150
MS	Diesel	25	1.69405	1.694045	-0.000005
MS	B10	70	1.66121	1.661095	-0.000115
MS	B20	70	1.702705	1.702645	-0.000060
MS	Diesel	70	1.70978	1.709625	-0.000155
SS	B10	25	1.79826	1.798325	0.000065
SS	B20	25	1.80101	1.80105	0.000040
SS	Diesel	25	1.873545	1.873595	0.000050
SS	B10	70	1.7916	1.791585	-0.000015
SS	B20	70	1.717935	1.71792	-0.000015
SS	Diesel	70	1.818915	1.818915	0.000000

In tables above, 'MS' represents mild steel and 'SS' represents stainless steel. For this method, the initial weights of the specimens are measured using microgram calibrator before they are immersed into the specified fuels. The weight change are calculated using equation below:

$$\text{Weight Change (g)} = \text{Final Weight (g)} - \text{Initial Weight (g)}$$

The negative value of weight change shows weight loss of metal specimen while positive value of weight change shows increase of weight of metal specimen.

4.2 Discussion

4.2.1 Engine Performance

The results tabulated in Table 4.1, Table 4.2 and Table 4.3 above are plotted in line graphs as shown in figures below to conduct comparison analysis. These comparison analyses done in between B10, B20 and diesel fuel, which diesel fuel performance are set as the benchmark performance. Figure 4.1 below shows the torque performance for the 3 types of fuel at different engine speed (RPM). From the plotted graph, can be concluded that the B10 and B20 fuel has almost similar torque performance with diesel fuel.

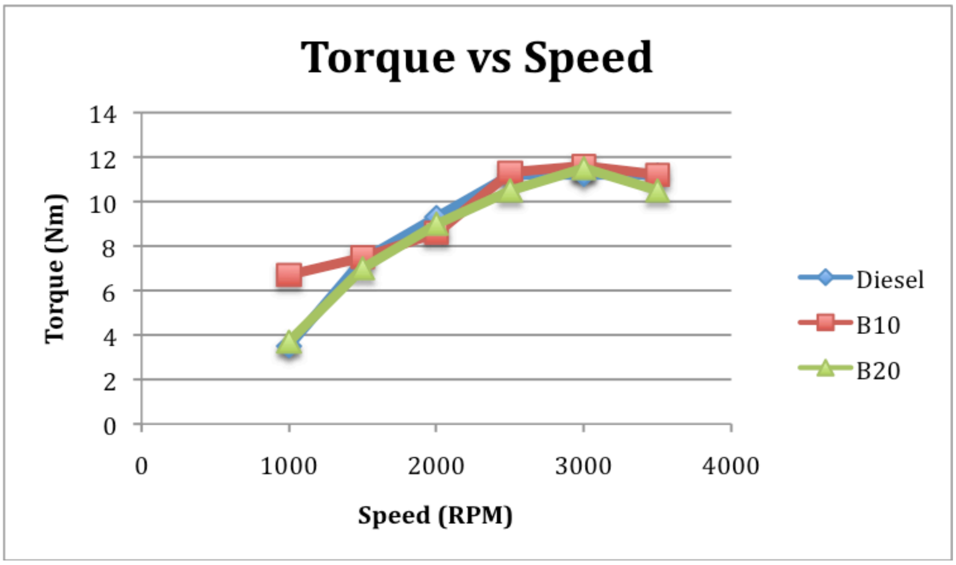


Figure 4.1: Speed (RPM) vs Torque (Nm)

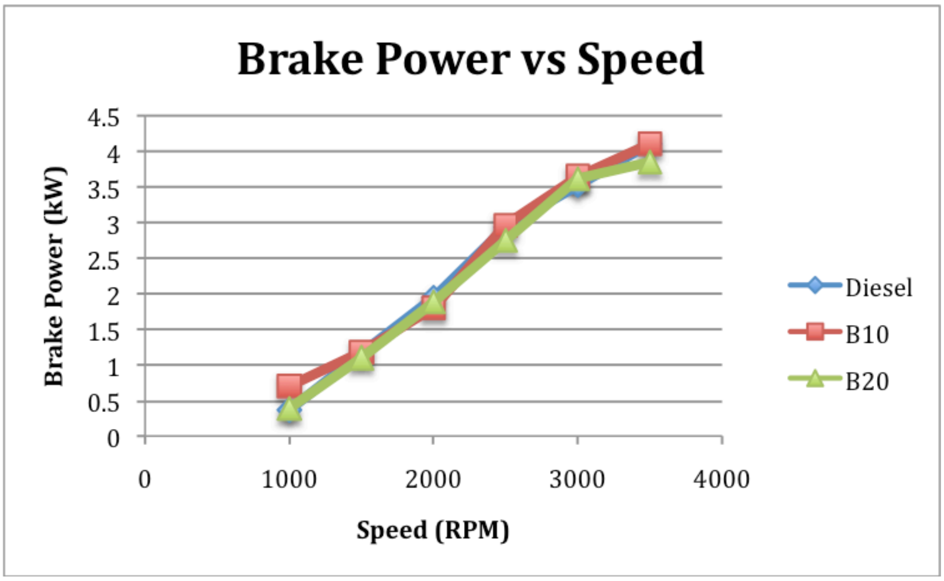


Figure 4.2: Speed (RPM) vs Brake Power (kW)

Figure 4.2 above shows the brake power (kW) produced at each engine speed (RPM) for the 3 types of fuel. From the plot trend, can be summarized that the brake power (kW) produced by B10 and B20 fuel is similar to diesel fuel.

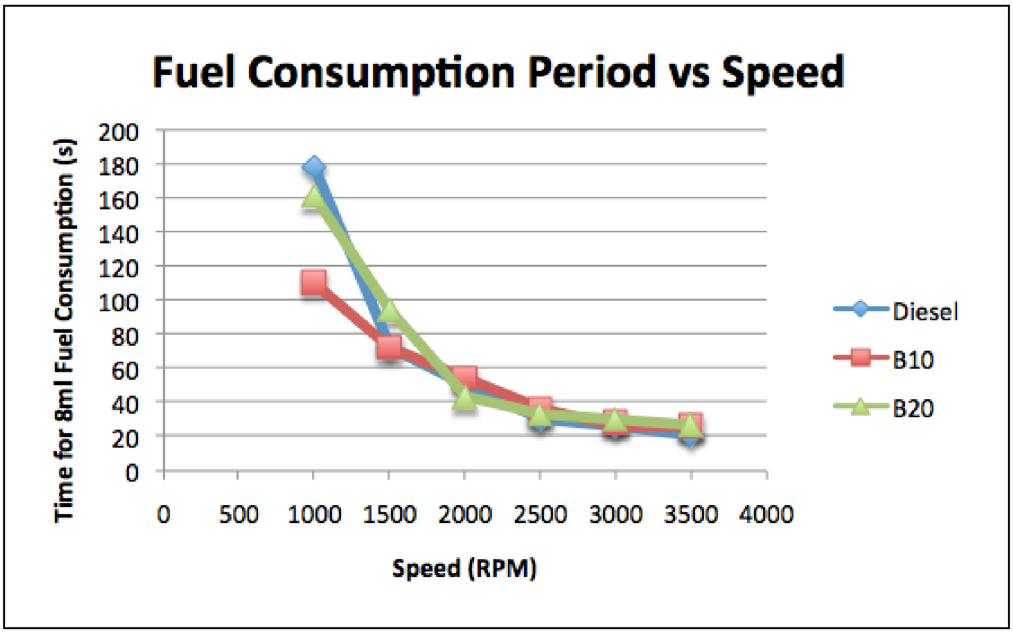


Figure 4.3: Speed (RPM) vs Fuel Consumption Period

Figure 4.3 and Figure 4.4 shows the fuel consumption of each type of fuel at particular engine speed (RPM). In Figure 4.3, the plot data shows that at low engine speed (1000-2000 RPM), diesel fuel and B20 fuel has higher fuel consumption compared to B10 fuel. After necessary calculations done, graph as in Figure 4.4 plotted. It shows that diesel fuel consumption is higher at high engine speed (RPM) compared to B10 and B20 fuel. This variation of fuel consumption can be caused by many external factors or errors such as different engine settings and conditions, which might be influenced by the changing of fuel and fuel filters. From these results and research on literature review, can be concluded that B10 and B20 fuel has insignificant increase in fuel consumption compared to diesel fuel.

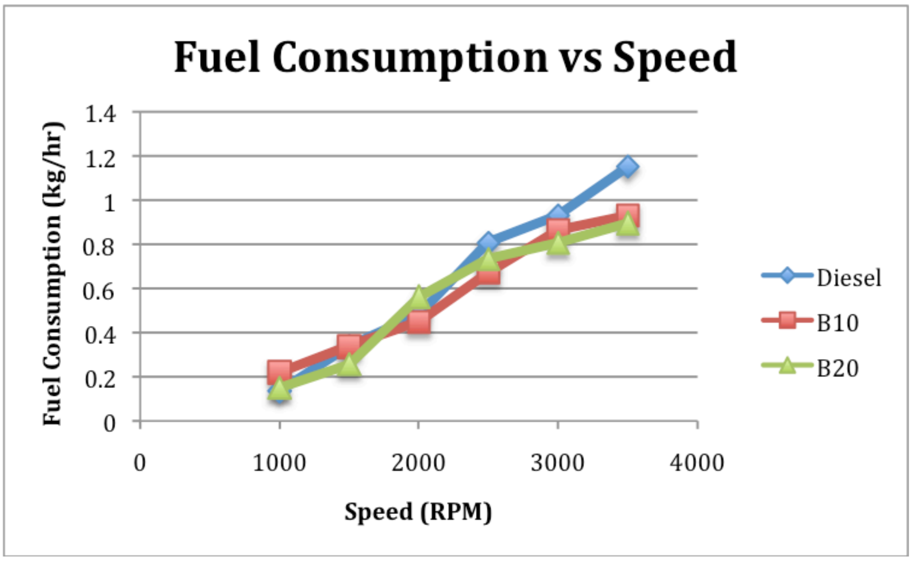


Figure 4.4: Speed (RPM) vs Fuel Consumption (kg/hr)

4.2.2 Corrosion Test

Analyzing the results data in Table 4.5 and Table 4.6, graphs as in Figure 4.5, Figure 4.6, Figure 4.7 and Figure 4.8 below produced.

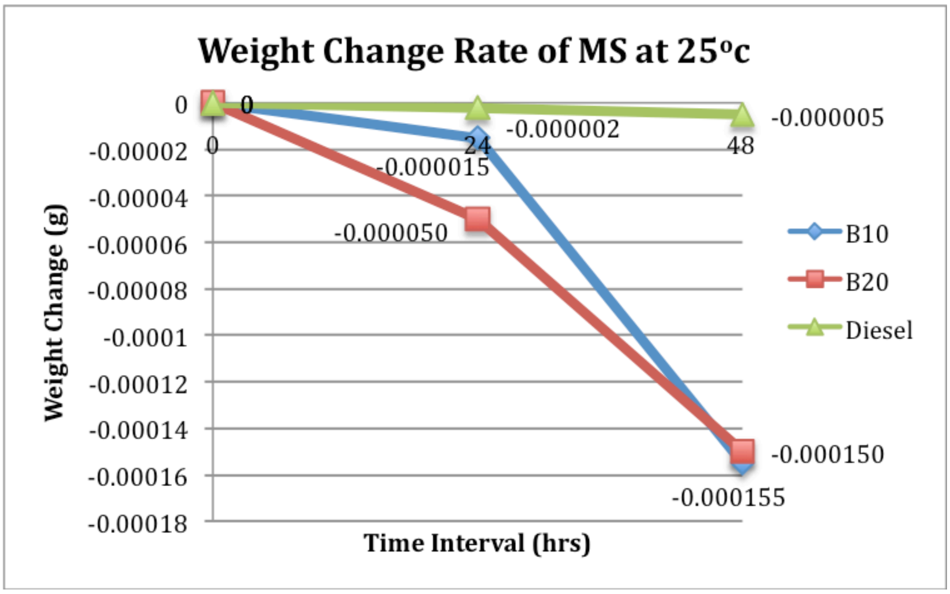


Figure 4.5: Weight change of metal in B10 Fuel at 25^{o}c

Figure 4.5 shows that mild steel experiences more weight loss in B10 and B20 fuel compared to diesel fuel. As the immersion time increases, the weight loss also increases. This proves that B10 and B20 is more corrosive than diesel fuel at room temperature condition.

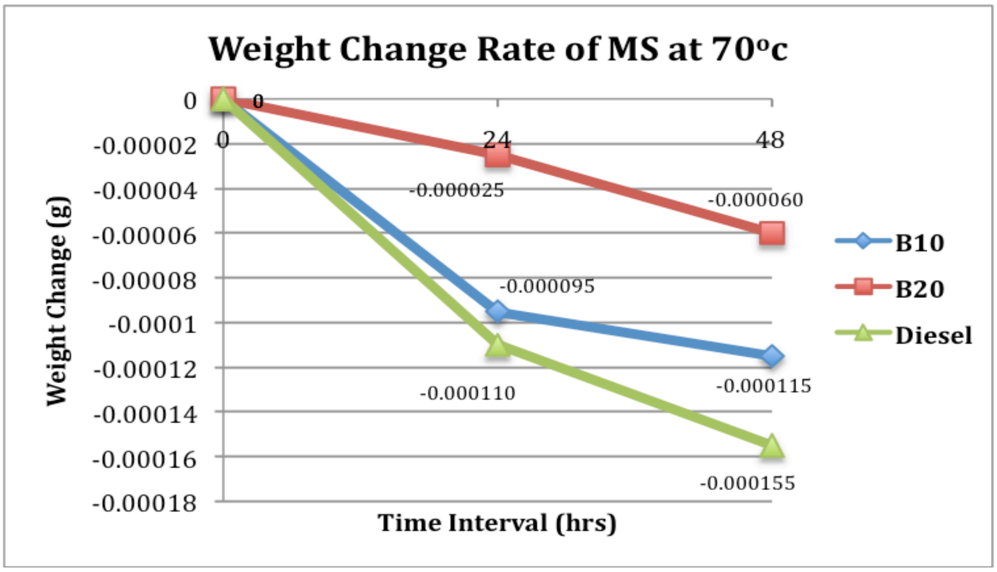


Figure 4.6: Weight change of Stainless Steel (SS) in B10 Fuel at 70^{o}c

While Figure 4.6 shows the stainless steel weight change at room temperature. The results shows that stainless steel experiences weight gain in all three types of fuel immersion and the amount of weight gain are almost at the same quantity.

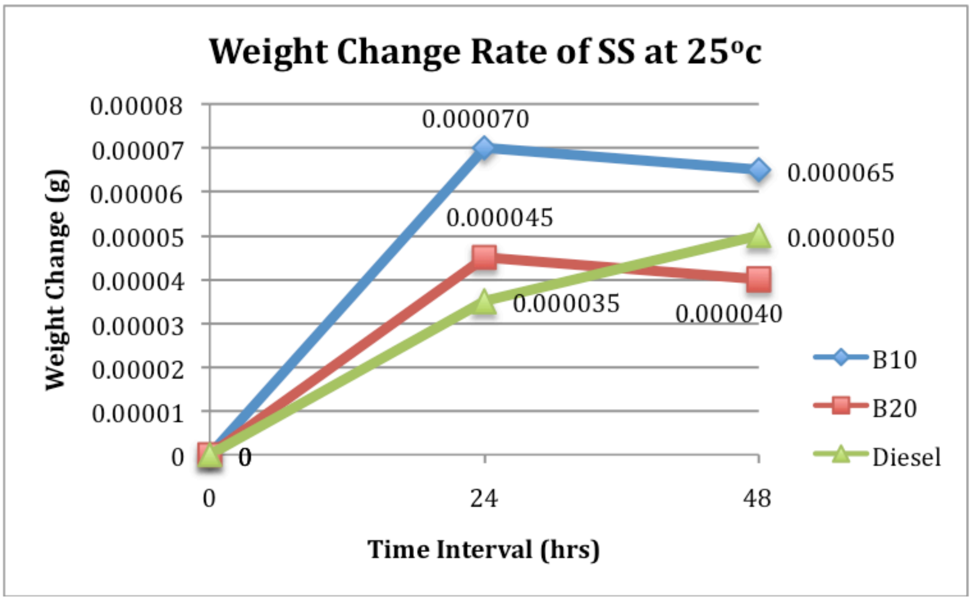


Figure 4.7: Weight change of Stainles Steel (SS) in B20 Fuel at 25^{o}c

Figure 4.7 demonstrates the trend of plot for weight change of mild steel at room temperature. The plot shows that diesel fuel experiences most weight loss, continued by B10 and B20 fuel. These results obtained is against the research claims where B20 supposed to show most weight loss, continued by B10 and the least by diesel fuel. Hence, these results might be widely influenced by errors which lead to this unprecise results. The error might occur when the metal strips being cleaned by polishing where some scrathes or damages on surface could lead to more weight loss. Besides that, comparing to Figure 4.5, the analysis shows that mild steel experiences more weight loss at 70^{o}c. Therefore, higher temperature also can lead to higher corrosion rate.

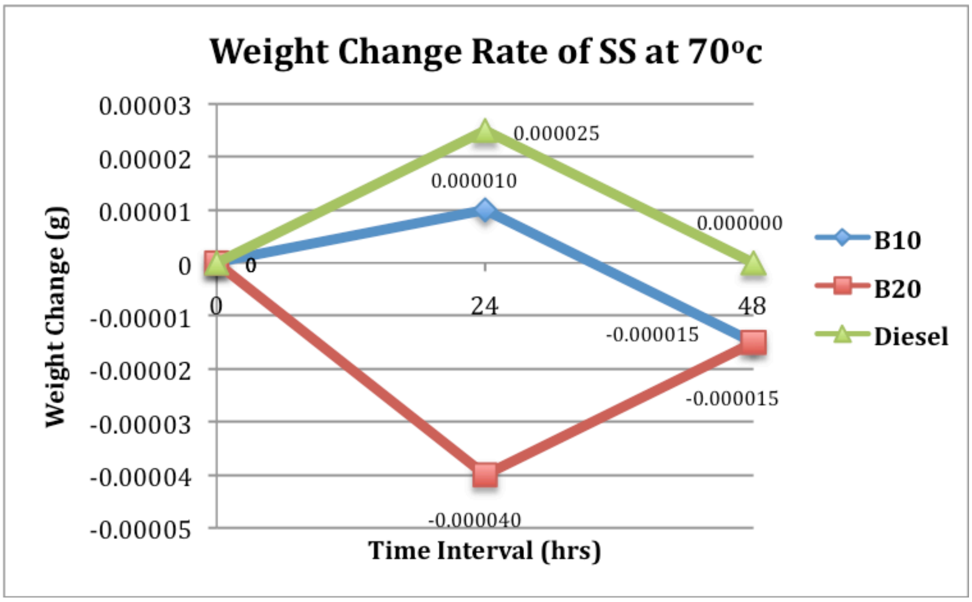


Figure 4.8: Weight change of metal in B20 Fuel at 70^{o}c

Figure 4.8 illustrates that stainless steel experiences weight gain in diesel and B10 fuel while weight loss in B20 fuel. Stainless steel is a metal which is hardly corroded and is least responsive to any chemical reactions. Hence, these characteristics cause it not to react with the water components in the bio oil which resulting it to not experience any weight loss in all kinda temperature environment. But, in this case, stainless steel strip shows some weight loss might be because influenced by errors during the experiment conducting period. However, stainless steel experiences weight gain in most conditions because sedimentation occurs on the metal surface during the immersion process.

Scanning Electron Microscope (SEM)

Corrosion of metals are also tested using Scanning Electron Microscope (SEM) images. After the metal specimens are done with immersion corrosion test, they are sent for SEM scanning. The surface images are as shown.

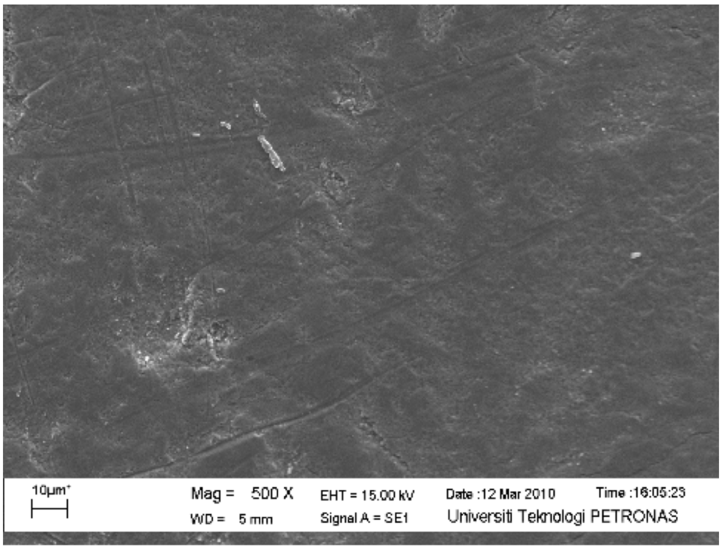
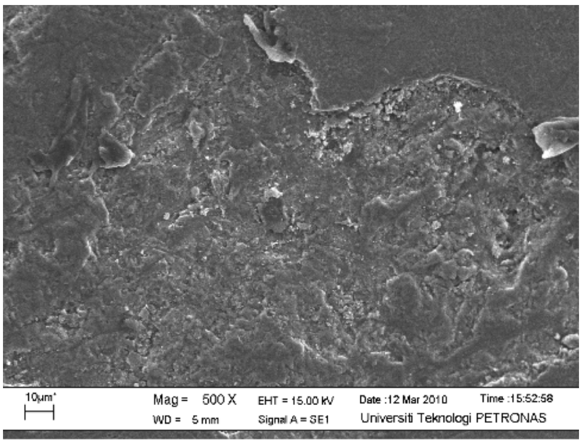
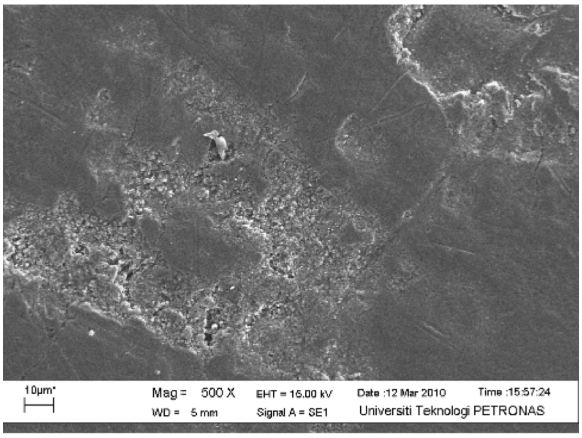


Figure 4.9: Sample of mild steel metal surface image before corrosion

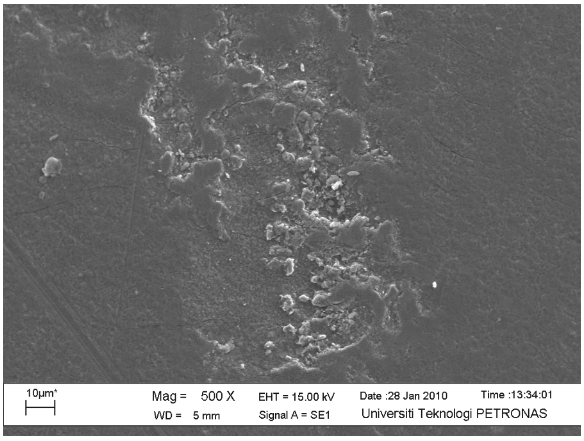
Figure 4.9 shows the initial mild steel metal strip surface conditions before the immersion test conducted. From this SEM image, its shown that mild steel have some uneven and unsmooth surface condition even before the testing. This might be because the high magnifying rate (500 X) is very precise where it reveals every detail on the metal surface.



(a)



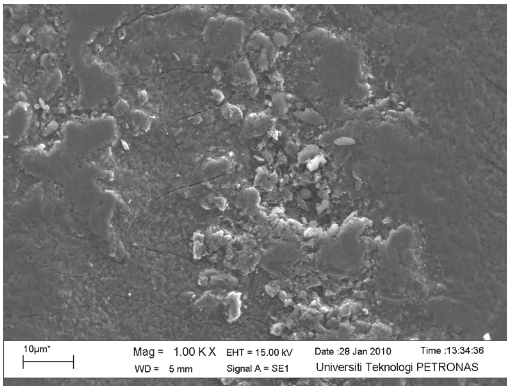
(b)



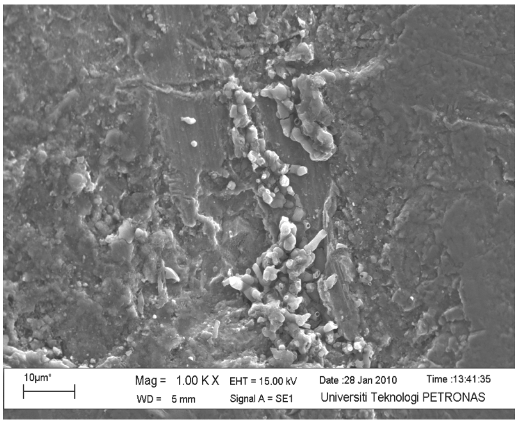
(c)

Figure 4.10 (a), (b), (c): Images of mild steel surfaces in B10(a), B20(b) and diesel fuel(c) after corrosion test at 25^{o}c for 48 hours.

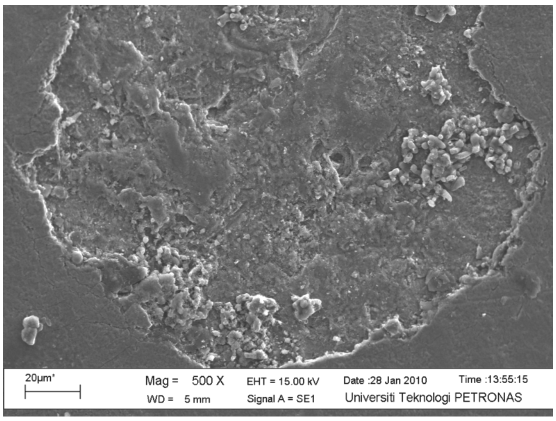
Figure 4.10 (a), (b) and (c) above shows the final surface conditions after the corrosion immersion test at room temperature, while Figure 4.11 (a), (b) and (c) shows the final conditions of test at 70^{o}c. Referring to Figure 4.10 (a), (b) and (c) above, all the three final SEM images of metal surfaces illustrate more damages and uneven surface compare to the initial image in Figure 4.9. This is due to the corrosion that occurred on the metals during the immersion test, which had lead to the weigh loss of the metals. Comparing in between three fuels, Figure 4.10 (a) and Figure 4.10 (b) shows more severe or chronic surface damages than Figure 4.10 (c). Hence, this proves that metals in B10 and B20 fuel experienced more corrosion than metal in diesel fuel. These final results also support the immersion test result, which shows metals in B10 and B20 fuel experiences more weigh loss than metal in diesel fuel.



(a)



(b)



(c)

Figure 4.11 (a), (b), (c): Images of mild steel surfaces in B10(a), B20(b) and diesel fuel(c) after corrosion test at 70^{o}c for 48 hours.

Comparing in between images of Figure 4.10 and of Figure 4.11, surface conditions of Figure 4.11 images shows more damages and more corroded surfaces. This shows that corrosion rate is higher at higher temperature. Similar results are also obtained from the immersion test above. In Figure 4.12 below, the image of stainless steel surface shows a smooth and even surface condition before immersion test.

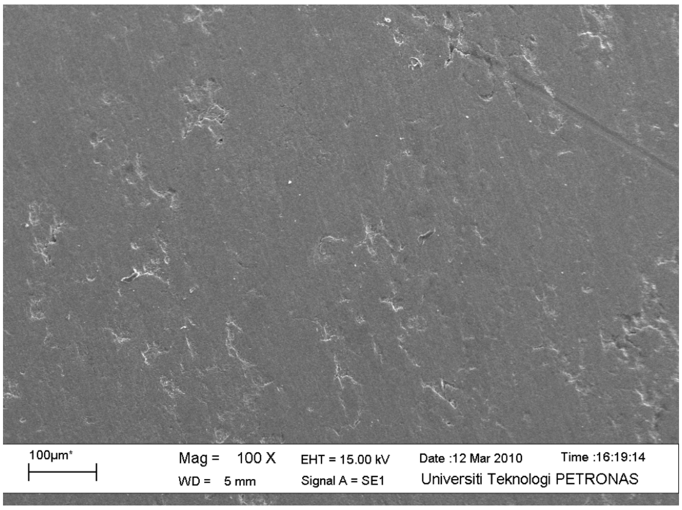
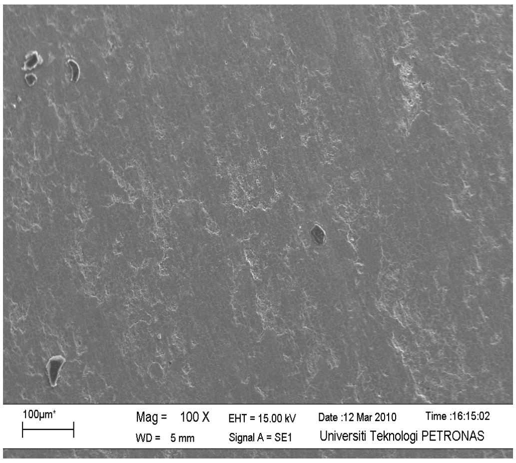
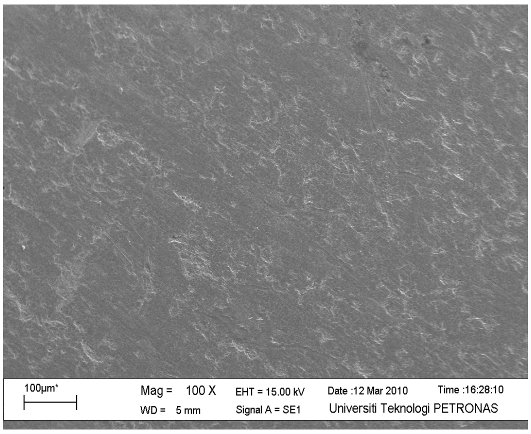


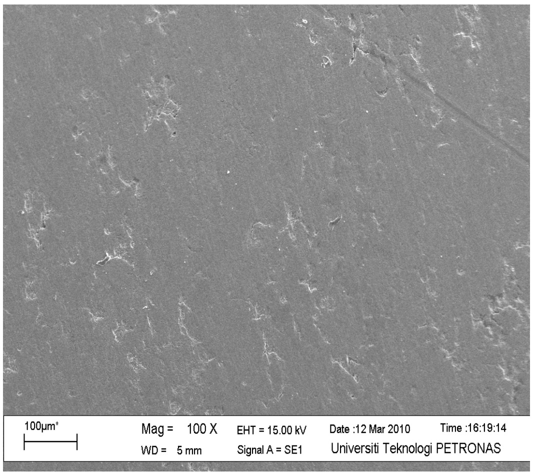
Figure 4.12: Sample of stainless steel metal surface image before corrosion test



(a)



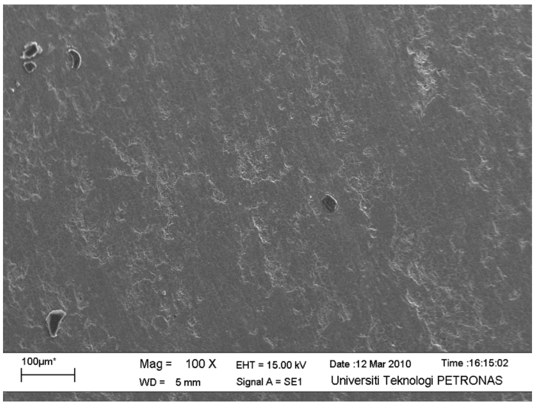
(b)



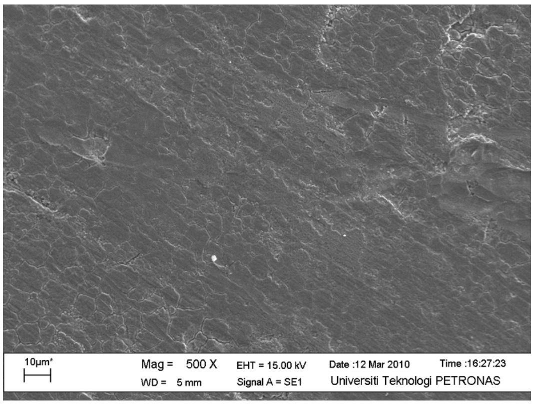
(c)

Figure 4.13 (a), (b), (c): Images of stainless steel surfaces in B10 (a), B20 (b) and diesel fuel (c) after corrosion test at 25^{o}c for 48 hours.

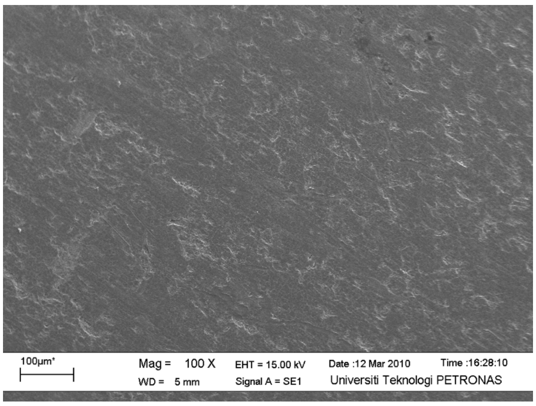
Figure 4.13 (a), (b), (c) illustrates the final image of stainless steel surface conditions after immersion test at 25^{o}c. All the three images show almost the similar surface conditions to the initial surface condition as in Figure 4.12. There are some visible stains or white marks on all the images, which is due to the sedimentation process during the immersion experiment. Figure 4.14 (a), (b), (c) illustrates the final surface conditions of stainless steel after immersion test at 70^{o}c. These Figure 4.14 images have more visible sedimentations compare to images in Figure 4.13. This might be due to more reactions has taken place in the biodiesel at higher temperature. However, these stainless steel metals still shows smooth and undamaged surface as the initial condition in Figure 4.12. Therefore, can be concluded that stainless steel is more suitable to be used as engine part compare to mild steel as it hardly get corroded and has high temperature resistance.



(a)



(b)



(c)

Figure 4.14 (a), (b), (c): Images of stainless steel surfaces in B10 (a), B20 (b) and diesel fuel (c) after corrosion test at 70^{o}c for 48 hours.

Field Emission Scanning Electron Microscopy (FESEM)

Mild Steel (MS)

FESEM test is conducted to investigate the chemical components on the metal surface. This test conducted is after the immersion test. FESEM test on mild steel (MS) shows the results below:

Table 4.6: Element percentage breakdown on Mild Steel (MS)

Element	Weight (%)	Atomic Weight (%)
C K	6.59	16.19
O K	26.13	48.23
Fe K	67.29	35.58
Totals	100.00	

Table above shows the chemical components traced on the mild steel (MS) surface and their weight percentages. Figure below shows the area positioning of the chemical components on the metal surface.

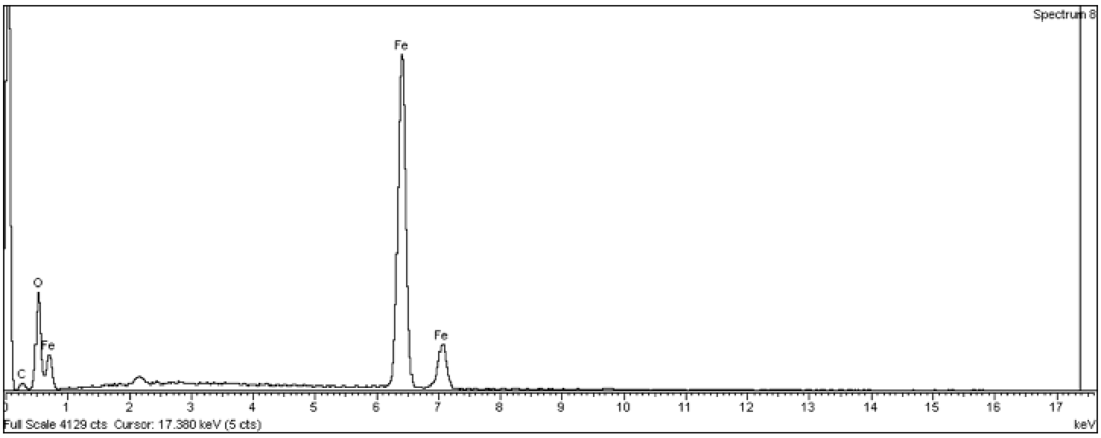


Figure 4.15: FESEM results for Mild Steel (MS)

The chemical components traced on mild steel metal surface after the immersion test is mostly oxygen (O) and Ferum (Fe). This shows that corrosion has taken place on the metal surface, which creates a layer or metal oxide on the surface. In this case, the metal oxide produced is Ferum Oxide (FeO).

Stainless Steel (SS)

FESEM test on stainless steel shows the results below. Table 4.7 shows stainless steel surface has various metallic and chemical components. This results supports the weight gain shown in immersion test above, which the sedimentation of these components are one of the major cause for the weight change for stainless steel.

Table 4.7: Elements breakdown percentage on Stainless Steel (SS)

Element	Weight (%)	Atomic Weight (%)
C K	6.81	25.17
Cr K	16.73	14.29
Mn K	0.97	0.79
Fe K	67.69	53.85
Ni K	7.80	5.90
Totals	100.00	

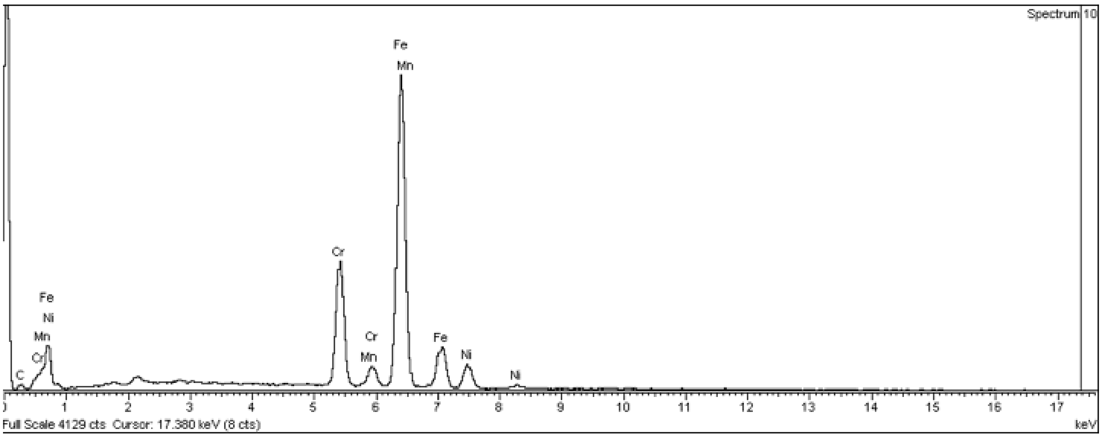


Figure 4.16: FESEM results for Stainless Steel (SS)

Figure above shows the area of the chemical components on the metal surface. The results obtained shows the Ferum (Fe) is the most component traced on the metal surface, followed by chromium (Cr), Nikel (Ni) and etc.

4.3 Errors

From the analysis above, there are some errors identified in the obtained test results, such as the fluctuations of weight loss of metal specimens and extensive weight loss of metals in certain conditions. These show that the results are widely influenced by some errors and external factors. The errors are such as:

- Specimen defect- metal specimens are corroded even before the testing done.
- Equipment error- reading fluctuations and less precise readings.
- Test fuel error- test fuel not mixed properly to the required quality.
- Human error- Recording of imprecise readings from equipments.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

CONCLUSION

From the analysis of engine performance test results, is proven that B10 and B20 biodiesel fuel have almost the same engine performance as diesel fuel. The results also show that B10 and B20 fuel has slight increase in fuel consumption compare to diesel fuel. While the torque and engine power produced by these emulsified fuels are almost similar to diesel fuel performance.

Corrosion testing for the testing fuels are done using two methods, which are the immersion test and SEM test. Both testing methods yield in positive corrosion results. From the obtained results and conducted analysis, its proven that the corrosiveness of B10 and B20 fuel is higher than the commercialize diesel fuel. Although diesel fuel shows some corrosion signs on mild steel metal specimens, they are negligible as the weight loss amount is very small. From the weight loss results, it also shows that B20 fuel is more corrosive than B10 fuel as mild steel experiences more weight loss in B20 fuel. The results also show that as temperature increases, the corrosion rate also increases. This is because; at 70^{o}c temperature, the amount of weight loss for mild steel is higher compare at the temperature of 25^{o}c. At the same time, longer immersion period leads to more weight loss too, as more corrosion takes place.

Stainless steel also does not experience weight loss in most condition, which proves that stainless steel is less corrosive or hardly get corroded compare to mild steel. In some conditions, stainless steel undergoes weight gain because of particles or external matter sedimentation on the metal surface. This weight gain also could be due to external particles deposition on the metal surface after the immersion test. From the Scanning Electron Microscope (SEM) images, it shows that the metals undergone corrosion process as the metal surfaces are rough and damaged. From this corrosion testing, it shows that the objective to study the temperature and time interval influence on emulsified diesel corrosiveness are met. Hence, this testing process is a success and the final results concludes that mild steel is not suitable to be used in engine parts as it is easily corroded.

In a whole, these B10 and B20 biodiesel fuel has high possibilities to replace the diesel fuel in market as it has almost similar characteristics and performance. Hopefully further research will be done to improvise these biodiesel fuels and introduced to the consumer world as soon as possible. This could help the environment and mankind to avoid more destruction.

RECOMMENDATIONS

From this study, these B10 and B20 biodiesel fuel have corrosion and specific fuel consumption drawbacks. Hence to overcome these drawbacks, necessary solvent or suitable additives should be added into the fuel emulsion to control and overcome the problems.

For project methodology, I would like to suggest improvising and verifying the quality of the testing fuels, as in this project the emulsified fuels are not quality tested before the corrosion and engine performance testing conducted. Besides that, the corrosion testing also should be conducted in a more engine alike environment to investigate the actual engine condition effects on corrosion. This can be done by using testing engines to run the test fuels for certain time interval continuously and conducting corrosion test on the engine parts.

For the immersion testing, I also would like to recommend that the time interval of testing to be extended to at least 3 to 4 weeks and testing temperature to be higher (maximum of $100^{o}c$). This is because; corrosion process in hydrocarbon environment is a very slow process, which requires a longer period of time to investigate the actual behavior of corrosion characteristics of the testing fuels. Referring to the obtained results, the weight change of the metal strips is only at microgram level, which is very minimal and is negligible. Hence, testing at longer time interval and higher temperature may lead to higher amount of weight change, which can give a better trend of the corrosion behavior.

Corrosion behavior of testing fuels also should be tested by conducting oxygen gas bubbling into the fuels. This is because; oxygen is one of the main components that lead to corrosion. So, in engine environment, air intake, which consists of oxygen gas can dissolve in the fuels and lead to more corrosion. Therefore, through this experiment, the effect of higher oxygen gas can also be investigated. With this measures, hopefully better and more in detail investigation can be done on this fuel before releasing it to the consumer world.