INFLUENCE OF USING EMULSIFIED PALM BIODIESEL FUEL ON THE PERFORMANCE AND POLLUTANTS EMITTED FROM DIESEL ENGINE

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ABSTRAK

Semasa peningkatan penduduk pesat, global penggunaan tenaga juga akan meningkat terutamanya dalam pengangkutan peribadi, kenderaan. Untuk menyelesaikan masalah sumber tenaga, biodiesel adalah minyak yang dipilih kerana ia boleh diperbaharui, mampan dan sesuai untuk digunakan pada enjin diesel semasa tanpa mengubahkan enjin tersebut. Para penyelidik sebelum ini juga mendapati bahawa bahan bakar biodiesel lebih bersih dan lebih efisien daripada diesel. Tesis ini difokuskan untuk menyiasat ciri-ciri, prestasi enjin dan pelepasan biodiesel emulsi dengan alkohol. 8 minyak sampel iaitu B5Bu5, B5Bu10, B5Bu15, B5Bu20, B10Bu5, B10Bu10, B10Bu15 dan B10Bu20 telah bersedia untuk menyiasat sifatnya. Kemudian, 3 minyak yang sesuai iaitu B5Bu5, B5Bu10 dan B10Bu5 telah diteruskan dengan prestasi enjin dan ujian pelepasan gas ekzos dan berbandingkan dengan minyak diesel. Parameter yang diukur untuk prestasi enjin dan ujian pelepasan gas ekzos ialah tork, kuasa enjin (BP) dan penggunaan bahan bakar tertentu (BSFC), nitrogen oksida (NOx), karbon monoksida (CO) dan hidrokarbon (HC). Kondisi operasi untuk kedua-dua ujian ini adalah sama, iaitu 50% beban malar pada pelbagai kelajuan enjin (1000rpm, 1500rpm dan 2000rpm). Dari segi ciri, kepadatan 8 sampel minyak tidak berbeza dengan D100 (100% diesel) kerana bahan tambah mempunyai kepadatan yang hampir sama seperti D100. Walau bagaimanapun, nilai kalori D100 adalah 4.3% hingga 8.7% lebih tinggi daripada 8 minyak sampel. Dari segi prestasi enjin, BP daripada minyak sampel dikurangkan 4 hingga 14% berbanding dengan D100. B5Bu5 menunjukkan purata BSFC yang paling rendah berbanding keseluruhan kelajuan enjin. Dari segi pelepasan, pelepasan NO_x purata hanya sedikit lebih tinggi daripada D100 dengan 7%. Walau bagaimanapun, pelepasan CO daripada B5Bu5 berkurangan sebanyak 30.2% berbanding dengan D100, manakala CO_2 menghasilkan cara bertentangan yang mana B5Bu5 meningkat sebanyak 28.8% berbanding dengan D100. Ini disebabkan oleh kawasan kaya oksigen yang membawa bahan api beroksigen dan letupan mikro yang mempromosikan pembakaran lengkap. Oleh itu, B5Bu5 adalah bahan bakar terbesar di antara 8 bahan bakar sampel dalam ciri-ciri keseluruhan, prestasi enjin dan pelepasan gas ekzos.

ABSTRACT

As the population growth rapidly, the global energy consumption also increases especially in personal transportation, vehicles. To solve the problem of energy sources, biodiesel is chosen as it is a renewable, sustainable and suitable to use on current diesel engine without modified the engine. Previous researchers also found that biodiesel fuels are cleaner and even more efficient than diesel fuel. This thesis is focused on investigate the characteristics, engine performance and emission of emulsified biodiesel with alcohol. 8 sample fuels which are B5Bu5, B5Bu10, B5Bu15, B5Bu20, B10Bu5, B10Bu10, B10Bu15 and B10Bu20 are prepared to investigate the fuel properties. Then, 3 suitable fuels which are B5Bu5, B5Bu10 and B10Bu5 are continued with engine performance and emission testing and therefore compared with diesel fuel. The parameters that measured for engine performance and exhaust gas emission testing are torque, brake power (BP), brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), nitrogen oxide (NO_x), carbon monoxide (CO) and carbon dioxide (CO_2). The operating condition for both testing are same which is constant 50% load at various engine speeds (1000rpm, 1500rpm and 2000rpm). In term of characteristic, the density of 8 samples fuels has not significant different with D100 (100% diesel) due to the additive has similar density as D100. However, the calorific value of D100 is 4.3% to 8.7% higher than 8 sample fuels. In term of engine performance, BP of sample fuels is reduced 4 to14% as compared to D100. B5Bu5 shows a lowest average of BSFCs over entire engine speeds. In term of emission, the average emission of NO_x is slightly higher than D100 with 7%. However, the CO emission of B5Bu5 is significantly reduced by 30.2% as compared to D100, whereas CO_2 resulted opposite way which B5Bu5 increased by 28.8% as compared to D100. This is because of the oxygen-rich regions brings by oxygenated fuels and micro-explosions that promote the complete combustion. Therefore, B5Bu5 is the greatest fuel among the 8 sample fuels in overall characteristics, engine performance and exhaust gas emission.

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LIST OF SYMBOLS

D100	100% Diesel
B5	95% Diesel + 5 % Biodiesel
B10	90% Diesel + 10% Biodiesel
B5Bu5	5% Water + 1% surfactant + 5% Butanol + 89% B5
B5Bu10	5% Water + 1% surfactant + 10% Butanol + 84% B5
B5Bu15	5% Water + 1% surfactant + 15% Butanol + 79% B5
B5Bu20	5% Water + 1% surfactant + 20% Butanol + 74% B5
B10Bu5	5% Water + 1% surfactant + 5% Butanol + 89% B10
B10Bu10	5% Water + 1% surfactant + 10% Butanol + 84% B10
B10Bu15	5% Water + 1% surfactant + 15% Butanol + 79% B10
B10Bu20	5% Water + 1% surfactant + 20% Butanol + 74% B10

LIST OF ABBREVIATIONS

ASTM	American Society of Testing
BP	Brake Power
BTE	Brake Thermal Efficiency
BSFC	Brake Specific Fuel Consumption
PM	Particulate Matter
NO_x	Nitrogen Oxide
HC	Hydrocarbon
DI	Direct Injection
CI	Compression Ignition
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CN	Cetane Number
rpm	Revolution per minute
ppm	Parts per million
kW	kilowatt
EGT	Exhaust Gas Temperature
POME	Palm Oil Methyl Ester

CHAPTER 1

INTRODUCTION

1.1 Background

As the population growth rapidly, the global energy consumption also will be increasing. Therefore, people are looking for new renewable resources to meet the global energy demand and replace the current limited resource. Researchers highlighted the possible of renewable energy in Malaysia is via palm oil biomass because of the huge feedstock and Malaysia is one of the production countries of the palm oil biomass (Ong, Mahlia et al. 2011).

One of renewable resources is biodiesel which produce from crude oil, plant oil and some of additives. Biodiesel is a biodegradable and some researchers even claimed that it has better performance than diesel fuel in term reducing air pollution (Abu-Hamdeh and Alnefaie 2015, Phoon, Mustaffa et al. 2017). However, there are several issues with biodiesel in term of the overall engine performance.

Biodiesel can reduce the air pollution since the biodiesel produce lesser exhaust gas emissions as compared with diesel fuel. Previous researchers such as Zhang and Balasubramanian had proved that biofuel can highly reduce the impact of emissions such as particulate matter from exhaust gas toward the environment (Zhang and Balasubramanian 2014).

Biofuel such as bio-alcohol also can be added into the biodiesel to improve the fuel performance. Alcohol is enriching in oxygen content which able to improve both premixed and diffusive combustion stage. Therefore, alcohol can be used to improve the fuel properties. However, it will cause the lower self-ignition temperature, vaporization latent heat and knock tendency(Campos-Fernández, Arnal et al. 2012). Some researchers also introduced water to emulsify with biodiesel to reduce the NO_x from the exhaust gas(Elsanusi, Roy et al. 2017).

In this study, emulsified biodiesel with alcohol will be the combination of diesel, palm oil biodiesel, water, butanol and NP-9 as surfactant. Various formulations will be tested to produce this emulsified biodiesel to obtain the optimum stability. After that, the fuels are proceeding with the data analysis on engine performance and exhaust gas emission.

1.2 Problem Statement

Diesel is the main fuel for the diesel engine and it produces the emission such as particular matter, hydrocarbon, carbon monoxide and nitrogen oxide. These exhaust gas emissions can bring the harmful effect to human health and environment in the long term. Therefore, biodiesel is one of the solutions for the air pollution from the diesel engine as it is the fuel that can work as diesel and reduce the harmful exhaust gas emission.

Diesel also is a non-renewable energy that will be used up one day. With the limited resources and increasing demand of the diesel, the global fuel price is expected to be increasing dramatically until a new representative fuel is found. Therefore, a replacement alternative fuel for diesel is a must for the diesel engine.

Currently, there are many types of biodiesel such as B5 (95% diesel and 5% biofuel) and B20 (80% diesel and 20% biofuel) can be commonly seen on the market. But different type of blend method, formulation, or additive used can affect the biodiesel in term of fuel properties, stability, engine performance and the exhaust gas emissions.

1.3 Objective

1. To investigate the characteristics of emulsified biodiesel with alcohol.
2. To investigate the performance of emulsified biodiesel with alcohol at different engine speeds.
3. To investigate the exhaust gas emission of emulsified biodiesel with alcohol.

1.4 Scope of Project

The scopes for this project are:

1. To study the characteristics of emulsified biodiesel with alcohol.
2. To study the effect of the butanol with variation of volume on emulsified biodiesel.
3. To study the emulsified biodiesel on the performance of diesel engine at different engine speeds.
4. Data analysis of emulsified biodiesel with alcohol on the exhaust gas from the diesel engine.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, there is a literature review from journals with related topic. Basically, this chapter will discuss the details about the biodiesel properties, formulation, method, fuel performance and emissions concentration from the previous researchers or scholars. These reviews are very useful as references in this study. Subchapter 2.2 is explained about the biodiesel and its possible additives. Subchapter 2.3 is some emulsion methods of previous researchers used in preparing their fuels. Subchapter 2.4 and 2.5 are the results from engine performance and exhaust gas emission testing that previous researchers had done.

2.2 Biodiesel

Biodiesel is a renewable and biodegradable fuel which manufactured domestically from vegetable oils, restaurant waste oil or animal fats. Biodiesel is a liquid fuel often referred as B100 to represent its pure and unblended form. It can be said that biodiesel is a cleaner-burning replacement for petroleum diesel fuel. However, biodiesel has several deficiencies such as lower heating value (LVH), higher viscosity, lower volatility, lower oxidation stability, higher pour point and poorer cold flow properties as compared with mineral diesel (Aghbashlo, Tabatabaei, Khalife, Najafi, & Khounani, 2017)

2.2.1 Properties of biodiesel

The chemical and physical properties of neat diesel, pure biodiesel, biodiesel blends and biodiesel-alcohol blends are having their own chemical and physical properties.

Researchers also experimentally found that those properties can effectively affect the parameters such as spray features, fuel droplet and emissions (Abu-Hamdeh & Alnefaie, 2015).

Density is an important property of fuel for compression ignition engines. As the fuel density increases, the percentage in volume of biodiesel increases as well because the density of biodiesel is higher than diesel. Preheating of biodiesel before injection could be done to overcome the problem of higher fuel density by taking advantage of the high temperature of the engine exhaust gas.

From table 2.1, the kinematic viscosity was measured for biodiesel from $4.3mm^2/s$ – $5.6mm^2/s$ @40^oC which more than the kinematic viscosity of diesel. A decrease in the blending percentage of both biodiesels reduced the kinematic viscosity of the mixture. The shape of the fuel droplets and atomization are affected by the fuel viscosity. A higher viscosity of the fuel may cause starting problems and smoky exhaust. This requires higher spraying pressure to obtain the desired spray pattern inside the cylinder. In contrast, a very low viscous fuel would prevent accurate metering of the fuel especially in older engines due to the leakage from piston walls of the injection pump (Abu-Hamdeh & Alnefaie, 2015). Preheating of biodiesel before injection either in the fuel tank or in the fuel lines could be done to overcome the problem of higher viscosity of biodiesel oils by taking advantage of the high temperature of the engine exhaust gas.

Table 2.1 shown the heating value of the biodiesels was measured and found to be 35 MJ/kg – 41 MJ/kg which lower than the heating value of diesel. Diesel fuel has higher values of carbon and hydrogen content than biodiesels. However in terms of ash, diesel fuel contains higher percentage than both biodiesels and higher carbon and hydrogen content indicates higher calorific value.

The flash points of biodiesels are within the range of 85^oC – 196^oC, while diesel fuel has a flash point of 50^oC -70^oC. As the higher flash point, it can be easier in transportation and safe storage, but at the same time, it will have negative effect in combustion. Meanwhile, blending biodiesel with diesel fuel could reduce the value of the flash point.

Table 2.1 Properties of researchers found.

Researchers	Fuel	Density (kg/m^3)	Kinematic viscosity @40°C (mm^2/s)	Calorific value (MJ/kg)
(Gad et al., 2017)	Diesel	827	2.28	44.85
	Palm oil biodiesel	877	4.56	40.56
(Hafizil et al., 2017)	Diesel	837	4.24	49.96
	Palm oil biodiesel	878	5.68	39.92
(Basha, 2016)	Diesel	830	2.10	42.30
	Jatropha biodiesel	895	5.25	38.88
(Hua et al., 2017)	Diesel	830	2.5	44.8
	Biodiesel cooking oil	900	5.0	35.0
(Aydın & Öğüt, 2017)	Diesel	830	3.3	47.6
	Safflower biodiesel	880	4.3	40.8
	Bioethanol	790	1.2	29.6
(Yang et al., 2015)	Diesel	835	2.66	45.7
	Biodiesel	881	4.47	41.0
	Butanol	810	2.24	33.5

Source: (Gad et al., 2017), (Hafizil et al., 2017), (Basha, 2016), (Hua et al., 2017), (Aydin & Öğüt, 2017) and (Yang et al., 2015).

2.2.2 Role of alcohol in biodiesel

The high viscosity of biodiesel reduce the engine torque and engine power resulted in the increase of specific fuel consumption and decrease in combustion temperature (Balamurugan & Nalini, 2014; Hafizil, Yasin[a], Mamat[a], Yusop[a], & Rahim[a], 2013). Therefore, the oxygen contents of alcohol can improve the fuel properties of biodiesel such as viscosity, cetane number and lubricity through the higher alcohol-biodiesel blends as mentioned by Zaharin et al. (Zaharin, Abdullah, Najafi, Sharudin, & Yusaf, 2017).

Pentanol and n-butanol are long chain alcohols which has five carbons and four carbons respectively in their molecular structure. Researchers reported that long chain alcohol can be utilised as blending component in diesel-biodiesel blend to improve the low-temperature fluidity of biodiesel as the long chain alcohol have better miscibility, higher LVH, higher catane number and higher energy density than the short chain alcohol such as methanol and ethanol (Balamurugan & Nalini, 2014; Imdadul et al., 2016; Z. H. Zhang & Balasubramanian, 2014). However, the lower LHV and cetane index of the alcohols leads to the increase ignition delay and inefficient combustion.

Most researchers mentioned that adding alcohol into diesel-biodiesel blend could decrease the CO, NOx, PM and HC emissions (Y. Chang, Lee, Son, Wu, & Chen, 2014; Imtenan, Masjuki, Varman, Arbab, et al., 2014; Raj, Subramanian, & Manikandaraja, 2017; Yang et al., 2015; Yerrennagoudaru & Manjunatha, 2017). Meanwhile, some researchers argued that NO_x emission will be increasing by adding alcohol into the blends (Atmanli, Yüksel, & Ileri, 2013; Yilmaz & Atmanli, 2017).

2.2.3 Role of water in biodiesel

Basically, Baskar and Senthil Kumar were listed four method to diminish the NO_x emission from diesel engine which are water injection into the cylinder using a separate injector, spraying water into the inlet air, intake manifold fornication and water-diesel emulsion (Baskar & Senthil Kumar, 2017). Through these four method, water-diesel emulsion is the most effective method to reduce the emission of NO_x and smoke from engine emissions (Aghbashlo et al., 2017). By introducing water in combustion chamber, water-diesel emulsion not only reduces the harmful pollutants but also improves the combustion efficiency by ‘micro-explosion’ phenomena due to the varied volatility of the diesel fuel and water as indicated by Ithnim et al. This phenomenon will cause the second atomization by breaking the injected fuel droplets into the fine ones and therefore the fuel can has better mixing with the intake air (Ithnin, Noge, Kadir, & Jazair, 2014).

2.3 Type of Emulsion Method

In this section, there are some emulsions methods are used as references. Each method was using different source of diesel, different type of biodiesel, or different type of additive. Therefore the results for stability and fuel properties are different from each research even some of them were using the same emulsion method.

2.3.1 Two-Stages Emulsification Method

According to the method used by Hua et al., Hua et al. used a two-stage emulsification method to prepare the three-phase diesel-biodiesel-bioethanol emulsion of oil droplets – dispersed in water-in-oil (Hua et al., 2017). To form a kinetically stable emulsions fuels, two commercialized surfactants, Span 80 (a lipophilic surfactant with hydrophilic-lipophilic balance, HLB = 4.3) and Tween 80 (a hydrophilic surfactant with HLB = 15), were chosen to prepare the emulsions. Span 80 was used as the main emulsifiers of the oil medium; while, Tween 80 was for bioethanol medium.

First stage is mix the surfactant with a present quantity of alcohol by using an electromagnetic and heating machine prior to mix with the biodiesel. Second stage is stir and agitated the biodiesel-alcohol emulsion by a mechanically homogenizing machine with propeller speed of 6000 rpm for 15 min.

Hua et al. used this two-stage emulsification method with the surfactants of Tween 80 and Span 80, and the result that obtained is 17 days for the longest stability(Hua et al., 2017). The emulsions tend to break down and separate over time at motionless through a variety of physicochemical mechanism. They might undergo gravitational separation, droplet aggregation or droplet growth. According to Stokes' Law, it states that generally, emulsification stability decreases with an increase in droplet size in the dispersed phase. This phenomenon slowly leads to a greater separation rate from the continuous phase (diesel) and fasten the deterioration process of diesel-biodiesel-bioethanol emulsion (Miklasz and Denny 2010).

2.3.2 External Force Method

Elsanusi et al. used external force method to prepare the emulsified fuel. Firstly, a blend of Span 80 and Tween 80 was stabilized at HLB 8.25, was added to the fuel in a volumetric percent of 2. The fuels used were diesel and biodiesel-diesel blends, namely B0, B10, B20, B30, and B40. Three different levels of water concentration in emulsion were investigated (5%, 10%, and 15%). Secondly, using the mixer at a speed of 4000 rpm for 15 min, the water was added to the fuel, after which the emulsifiers were added slowly at a rate of 1.25 ml/min. The results were milky emulsified fuels. Elsanusi et al. used this method to prepared 15 samples and as a result, the sample which contain 95% diesel and 5% water show the highest stability which able to stable for 87 days (Elsanusi, Roy et al. 2017).

2.3.3 Two-Stage Ultrasonic Bath Sonication Emulsification Method

Chintala et al. used two-stage ultrasonic bath sonication emulsification method to prepared their corn stalk bio-oil-diesel emulsions (Chintala, Kumar et al. 2017). Researchers used Span 80 and Tween 80 as the surfactants, n-heptanol as a co-surfactant and $Ce_{0.7}Zr_{0.3}O_2$ nanoadditive as a fuel borne catalyst.

On the first stage, the lipophilic surfactant, Span 80, n-heptanol and $Ce_{0.7}Zr_{0.3}O_2$ nanoparticles (50 ppm in ppm level) were loaded into the base oil and the resulting mixture was evenly stirred and fully mixed or blended by using an electromagnetic heating stirrer at 1000 rpm for 15 min. The hydrophilic surfactant Tween 80 was added with measured quantity of bio-oils and stirred with the help of an electromagnetic heating stirrer at 1000 rpm for 15 min.

Thereafter, the continuous phase, i.e. diesel with Span 80, n-heptanol and $Ce_{0.7}Zr_{0.3}O_2$ nanoadditive was poured into a tank and placed in a sonication machine. The Tween 80 mixed bio-oils were slowly injected into the diesel/Span 80 mixture and sonicated for 3 h. For complete mixing and no deposition of sediments, CBD emulsions were examined at time intervals of 30, 60, 90, 120, 150 and 180 min. After 180 min of sonication, almost no deposition was observed. Finally, the CBDEs with 2.5% of surfactant (The volume ratio of Tween-80 and Span-80 was 1:7), 2.0% of n-heptanol, 50 ppm of Ce0.7Zr0.3O2 nanoparticles and various bio-oil concentrations of 10%, 15%, 20% and 25% were prepared, which were denoted as CBDE10, CBDE15, CBDE20 and CBDE25, respectively.

2.3.4 High Shear Force Blending

Li et al. prepared hydrous ethanol diesel emulsified fuels with high shear force blending method (Li, Zhang et al. 2017). This method used two type of mixer machine which are electric mixer and the high shear disperse mill.

First, hydrous ethanol was prepared by the combination of anhydrous ethanol and distilled water. Second, diesel fuel was blended with the emulsifier (Span 80) by a glass rod. Then, the co- emulsifier (n-butanol) was added to diesel mixture and stirred with an electric mixer. Lastly, the hydrous ethanol was added to diesel mixture drop by drop and stirred with a disperse mill of high shear force.

Several factors should be considered to be important to prepare a stable emulsion, including the Hydrophile-Lipophile Balance (HLB) value of the emulsion, selection and addition quantities of the emulsifier and co-emulsifier in the emulsions. For typical water-in-oil (W/O) emulsion, HLB value is usually in a range of 3–6. Therefore, performances of several emulsifiers with HLB value in this range were tested with a target of the stable time as long as possible. Finally, Span80 was determined to be used as the emulsifier to prepare the emulsions and n-butanol as co-emulsifier to promote the stability of the emulsions. As a result, Li et al. able to produce HE10 which the emulsion containing 10% of hydrous ethanol in volume with the stability of 60 days (Li, Zhang et al. 2017).

2.4 Engine Performance

2.4.1 Torque

Torque is the expression of rotational or twisting force around an axis which is measured in unit of force multiple with distance from the axis of rotation. In compression ignition engine, torque is the measure of rotational effort applied on engine crankshaft by the piston.

Researchers such as Ali et al., Atmanli et al., Hua et al., Leeviit et al., Sharon et al. reported that engine torque was reduced with the butanol addition into the biodiesel fuel as compared to diesel fuel (Ali, Mamat, Abdullah, & Adam, 2016; Atmanli, Ileri, & Yilmaz, 2016; Atmanli, Ileri, & Yüksel, 2015; Atmanli et al., 2013; Atmanlı, İleri, & Yüksel, 2014; Hua et al., 2017; Leevijit, Prateepchaikul, & Maliwan, 2017; Sharon, Jai Shiva Ram, Jenis Fernando, Murali, & Muthusamy, 2013). Meanwhile, there are the researchers claimed that there is increase in engine torque by adding butanol into the biodiesel as compared with diesel fuel (Abu-Hamdeh & Alnefaie, 2015; Ibrahim, 2016; Imtenan, Masjuki, Varman, Kalam, et al., 2014; Phoon et al., 2017; Yerrennagoudaru & Manjunatha, 2017).

Abu-Hamdeh & Alnefaie and Srinivas et al. claimed that torque was increase as adding the biodiesel into the diesel fuel (Abu-Hamdeh & Alnefaie, 2015; Srinivas, Naik, & Radha, 2017). However, Habibullah et al. and Yasin et al. mentioned that torque was reduced as biodiesel added into the diesel fuel (Habibullah et al., 2014; Yasin et al., 2015). This is because the biodiesel has higher density and viscosity that result in uneven combustion and poor atomization.

Ithnin et al. found that emulsion fuel has lower torque that diesel fuel due to emulsion fuel had lower heating value and reached peak pressure before top dead center (Ithnin et al., 2014).

2.4.2 Brake Power (BP)

Ali et al. and Rizwanul et al. claim that biodiesel-diesel blend has lower brake power can attributed to the combined effect of their lower energy content which are lower calorific value and higher viscosity as compared to diesel fuel (Ali et al., 2016; Rizwanul Fattah, Masjuki, Kalam, Mofijur, & Abedin, 2014).

Ileri et al., Atmanli et al. and Hua et al. reported diesel-biodiesel-alcohol blends have lower brake power than the diesel fuel due to higher density and viscosity that caused poor atomization and lower heating value and cetane number of blend (Atmanli et al., 2013; Atmanlı et al., 2014; Hua et al., 2017; Ileri, Atmanli, & Yilmaz, 2016). However, Imadadul et al. claimed that additions of alcohol into biodiesel-diesel blends could improve the brake power (Imdadul et al., 2016). Alcohol can decrease density and viscosity of the blends and their evaporative nature permits good atomization even at higher speed. Therefore, alcohol has higher oxygen content, good atomization, low density and viscosity contribute to higher combustion efficiency which result higher power as well.

Ali et al. and Imdadul et al. researched that engine brake power decreased when biodiesel added into the diesel fuel (Ali et al., 2016; Imdadul et al., 2016). Biodiesel which has higher density and viscosity caused atomization at higher speed is hindered.

Ithnin et al. reported that there is a slightly drop in brake power due to the water emulsion fuel which has lower heating value than diesel fuel, thus less energy released in combustion (Ithnin et al., 2014).

2.4.3 Brake Thermal Efficiency (BTE)

Brake thermal efficiency is the ratio of the power output to the energy from fuel supplied. The energy supplied is mass flow rate of the fuel multiple with the lower heating value. The brake thermal efficiency can be affected by the calorific value. The lower the calorific value, the thermal efficiency will be reduced as well (Sharon et al., 2013).

Balamurugan & Nalini and CamposFemandez et al. found that additional of alcohol in diesel can increase the BTE at all load as compared to neat diesel due to presence of oxygen which involves higher combustion efficiency and reduction of heat losses due to lower boiling point of alcohol (Balamurugan & Nalini, 2014; Campos-Fernández, Arnal, Gómez, & Dorado, 2012). Phoon et al. claimed that there is no change in BTE as the alcohol added into the diesel fuel (Phoon et al., 2017).

Yoshimoto et al., Babu & Anand, Sharon et al. and Atmanli et al. observed that biodiesel-alcohol blend has lower BTE than diesel fuel (Atmanli et al., 2016, 2013; Atmanlı et al., 2014; Babu & Anand, 2017; Sharon et al., 2013; Yoshimoto, Kinoshita, Shanbu, & Ohmura, 2013). Meanwhile, most authors argued that additional of butanol into the biodiesel blend could increase the BTE because alcohol will reduce viscosity and cause better atomization (Y. C. Chang, Lee, Lin, & Wang, 2013; Y. Chang et al., 2014; Ibrahim, 2016; Imtenan, Masjuki, Varman, Kalam, et al., 2014; Rao, Ravisankar, & Raju, 2017; Yerrennagoudaru & Manjunatha, 2017; Z. H. Zhang & Balasubramanian, 2014).

Debnath et al. and Elsanusi et al. researched that water content in emulsion fuel of diesel could increase the BTE of the engine as compared to diesel fuel (Debnath, Sahoo, & Saha, 2013; Elsanusi, Roy, & Sidhu, 2017). This is because of the presence of the occurrence of micro explosion in the emulsion fuel and therefore improve the atomization in the combustion.

Habibullah et al., Phoon et al., Yasin et al. and Leevijit et al. reported that thermal efficiency of biodiesel-diesel blends are lower as compare to neat diesel (Habibullah et al., 2014; Leevijit et al., 2017; Phoon et al., 2017; Yasin et al., 2015). This is because of the higher density and viscosity of biodiesel caused poor atomization and low calorific value lead to lower combustion efficiency. However, Abu-Hamdeh & Alnefaie, B. Li et al. and Srinivas et al. proved that BTE of biodiesel-diesel blend is higher than diesel fuel (Abu-Hamdeh & Alnefaie, 2015; B. Li et al., 2017; Srinivas et al., 2017).

Ali et al. and Hafizil et al. claimed that biodiesel-diesel fuel has no change in brake thermal efficiency as compared to diesel (Ali et al., 2016; Hafizil, Yasin, Paruka, Mamat, & Fitri, 2015).

2.4.4 Brake Specific Fuel Consumption (BSFC)

From the result obtained by Kumar & Saravanan, Nabi et al. and Atmanli et al., the higher the brake specific fuel consumption with the higher n-butanol blends at all operating engine speeds and loads (Atmanli et al., 2016; Kumar & Saravanan, 2016; Nabi et al., 2017).On the other hand, Y.C.Chang et al. found that BSFC was increased as adding alcohol into the diesel fuel (Y. C. Chang et al., 2013).

Elsanusi et al. researched that water content in emulsion fuel of diesel could increase the BSFC of the engine as compared to diesel fuel (Debnath et al., 2013; Elsanusi et al., 2017). Meanwhile, Debnath et al. claimed that water content in emulsion fuel has lower BSFC than diesel (Debnath et al., 2013). This is because the water content in emulsion fuel could increase the atomization through the micro explosion of water content.

Babu & Anand, Atmanli et al., Yang et al. and Yoshimoto et al. and Sharon et al. observed that additional of biodiesel-alcohol blend has higher BSFC than diesel fuel because of higher viscosity and density of blend caused longer ignition delay and reduce combustion efficiency (Atmanli et al., 2013; Babu & Anand, 2017; Sharon et al., 2013; Yang et al., 2015; Yoshimoto et al., 2013). Yerrennagoudaru & Manjunatha and Ibrahim claimed that biodiesel-alcohol blend can decrease the BSFC of the diesel fuel (Ibrahim, 2016; Yerrennagoudaru & Manjunatha, 2017)

However, Phoon et al., Yoshimoto et al., Hafizil et al., Ali et al, Yasin et al., Leevijit et al. and Ileri et al. indicated that BSFC of biodiesel-diesel blends are higher as compare to neat diesel. This is because of lower calorific value compare to diesel and poor atomization due to higher density and kinematic viscosity of the biodiesel (Ali et al., 2016; Hafizil et al., 2015; Ileri et al., 2016; Leevijit et al., 2017; Phoon et al., 2017; Yasin et al., 2015; Yoshimoto et al., 2013). However, Abu-Hamdeh & Alnefaie and B. Li et al. mentioned BSFC was decreased by adding the biodiesel into the diesel fuel (Abu-Hamdeh & Alnefaie, 2015; B. Li et al., 2017).

İleri & Koçar mentioned the biodiesel which contain a high viscosity and density can decrease the combustion efficiency due to longer physical ignition delay and an adverse effect on achieving homogeny mixing before combustion of fuel (İleri & Koçar, 2014).

2.4.5 Exhaust Gas Temperature (EGT)

Ileri et al reported that exhaust temperature of biodiesel-alcohol decrease as compared to diesel fuel at a function of engine speed (Ileri et al., 2016). The higher latent heat of evaporation of n-butanol and higher oxygen content in the blend that causes a cooling effect and lower exhausts gas temperature. However, Yilmax & Davis and a review by Zaharin et al. showed that alcohol could increase the EGT as compared to neat diesel (Yilmaz & Davis, 2016; Zaharin et al., 2017)

Leevijit et al. and Abu-Hamdeh & Alnefaie found that the addition of biodiesel fuel has slightly lower exhaust gas temperature than the diesel fuel (Abu-Hamdeh & Alnefaie, 2015; Leevijit et al., 2017). The reason is due to higher cetane number of biodiesel reduce pre-mixing time and move the combustion passing earlier in compression stroke. Meanwhile, Srinivas et al. reported the EGT of biodiesel-diesel blend was higher as compared to diesel (Abu-Hamdeh & Alnefaie, 2015; Srinivas et al., 2017).

Elsanusi et al. researched that water content in emulsion fuel of diesel could increase the EGT of the engine as compared to diesel fuel because water content in emulsion fuel resulted in absorption of the combustion heat (Elsanusi et al., 2017).

2.5 Exhaust Gas Emissions

2.5.1 Nitro Oxide Emission (NO_x)

Phoon et al., Nabi et al., Odziemkowska et al. and Zaharin et al. found that NO_x is slightly increase for the alcohol blends compared to those of the reference diesel. This is because more oxygen molecules from alcohol attributed more NO formation as large amount of oxygen delayed combustion produce higher exhaust gas temperature and therefore NO_x emission formed (Nabi et al., 2017; Odziemkowska, Matuszewska, & Czarnocka, 2016; Phoon et al., 2017; Zaharin et al., 2017). However, Sharon et al., Y.C.Chang et al. and Hansdah observed that the NO_x emission decreased with increasing butanol content as compared with diesel fuel (Y. C. Chang et al., 2013; Hansdah, 2013; Sharon et al., 2013) .

Ibrahim, Imtenan et al. and Rakopoulos et al. pointed that there is slightly increase in NO_x emission with biodiesel-alcohol blends as compared to neat diesel. This is because these blends have higher cetane number and lead to shorter ignition delay (Ibrahim, 2016; Imtenan et al., 2015; Rakopoulos, Rakopoulos, & Giakoumis, 2015). Qi et al. mentioned that there is no changes in NO_x emission by adding alcohol into the biodiesel-diesel fuel (Qi et al., 2017). Babu & Anand, Raj et al., Kumar & Saravanan, Imtenan et al. and Yerrennagoudaru& Manjunatha reported that the NO_x reduced by additional alcohol into the biodiesel-diesel blend (Babu & Anand, 2017; Imtenan, Masjuki, Varman, Kalam, et al., 2014; Kumar & Saravanan, 2016; Prabakaran & Udhoji, 2016; Raj et al., 2017; Yerrennagoudaru & Manjunatha, 2017).

Phoon et al., Yasin et al. and Leevijit et al. reported that NO_x emission from exhaust gas of biodiesel-diesel blends are higher as compare to diesel fuel (Habibullah et al., 2014; Leevijit et al., 2017; Phoon et al., 2017; Yasin et al., 2015). The biodiesel blends are expected to combust earlier with an improved combustion efficiency because biodiesel is an oxygenated fuel that possesses short ignition delay due to high cetane number. On the other hand, Abu-Hamdeh & Alnefaie, B. Li et al. and Hafizil et al. claimed that addition biodiesel can effectively reduce the $NO_{x.}$ Due to diesel has higher cetane number and reduce pre-mixing time, hence better combustion behaviour in diesel and then richer NO_x concentration produced (Abu-Hamdeh & Alnefaie, 2015; Hafizil et al., 2015; B. Li et al., 2017).

Lin et al., Atmanli et al., Nour et al., Basha and Elsanusi et al. observed that water addition to alcohol-diesel blend reduce the flame temperature and consequently reduce the NO_x emission (Atmanli et al., 2016; Basha, 2016; Elsanusi et al., 2017; Lin, Lee, Lee, & Wu, 2012; Nour et al., 2017).

Mofiur et al. and Debnath et al. reported that water content in emulsion biodiesel can effectively reduce the NO_x emission as compared to diesel fuel (Debnath et al., 2013; Mofijur, Masjuki, Kalam, Shahabuddin, & Hazrat, 2012). The reason is water in emulsified blend lowers peak combustion temperature of burnt gas because of its high latent heat vaporisation and researchers also justified by exhaust gas temperature curve.

NO_x emission is one of the major emissions from the CI engine. NO_x emission included nitric oxide (NO) and nitrogen dioxide (NO_x). Higher cetane number leads to reduce the ignition delay which results in shorter premixed combustion time and lower the formation of NO_x (Ileri et al., 2016). High combustion temperature also can affect the NO_x formation. At high combustion temperature, the nitrogen and high local oxygen concentrations in cylinder cause high NO formation rate (Rizwanul Fattah et al., 2014).

2.5.2 Carbon Monoxide (CO)

Carbon monoxide (CO) is a poisonous emission that produces from incomplete combustion

Imtenan et al., Phoon et al., Hafizil et al., Srinivas et al., Yasin et al. and Leevijit et al. reported that CO emission from exhaust gas of biodiesel-diesel blends are lower as compare to neat diesel (Abu-Hamdeh & Alnefaie, 2015; Hafizil et al., 2015; Imtenan, Masjuki, Varman, Kalam, et al., 2014; Leevijit et al., 2017; Phoon et al., 2017; Srinivas et al., 2017; Yasin et al., 2015).

Babu & Anand, Atmanli et al., Z.Zhang et al., Yerrennagoudaru & Manjunatha, Rao et al. and Sharon et al. observed that biodiesel-alcohol blend has lower CO emission than diesel fuel (Atmanli et al., 2016; Babu & Anand, 2017; Rao et al., 2017; Sharon et al., 2013; Yerrennagoudaru & Manjunatha, 2017; Z. Zhang, Chua, & Balasubramanian, 2016). Meanwhile, Ileri et al., Yoshimoto et al. and Qi et al. showed that additional alcohol into diesel biodiesel blends increase the CO emission due to higher density and viscosity of blend which reduce atomization (Ileri et al., 2016; Qi et al., 2017; Yoshimoto et al., 2013).

Kumar & Saravanan mentioned that CO emission was increased by adding alcohol into the diesel fuel (Kumar & Saravanan, 2016). Odziemkowska et al. claimed that there is no change in CO emission by adding alcohol into the diesel fuel (Odziemkowska et al., 2016; Yilmaz & Davis, 2016). Meanwhile, Phoon et al. and Balamurugan & Nalini found that alcohol-diesel blend could reduce the CO emission at medium and high load (Balamurugan & Nalini, 2014; Phoon et al., 2017). Alcohol content improve the fuel air mixing procedure, particularly in the fuel-rich region of the combustion chamber by providing more oxygen and improve combustion.

Elsanusi et al. researched that water content in emulsion fuel of diesel could increase the CO emission from exhaust gas as compared to diesel fuel because lower combustion temperature and combustion efficiency environment resulted in addition CO emission (Elsanusi et al., 2017). However, Debnath et al. showed that there is a reduction in CO emission by using water content emulsified biodiesel (Debnath et al., 2013). This is because the proper mixing by micro explosion has better combustion and reduce the CO emission.

2.5.3 Hydrocarbon Emission (HC)

Hydrocarbon is one of the exhaust gas emissions due to incomplete combustion. Hydrocarbon emissions are significantly affected by the fuelling system, engine load, ambient condition and turbocharging (Nabi et al., 2017).

Phoon et al., Z.Zhang, et al., Fitri et al., Hansdah and Nabi et al. and found that hydrocarbon emission are significantly reduced with additional butanol as compare to diesel fuel (Fitri, Hafizil, Yasin, & Adam, 2013; Hansdah, 2013; Nabi et al., 2017; Phoon et al., 2017; Z. Zhang et al., 2016). Alcohol is an oxygen content fuel so that it will provide a more complete combustion. Meanwhile, Kumar & Saravanan and Odziemkowska et al. reported that additional alcohol to diesel fuel caused increasing in HC emission (Kumar & Saravanan, 2016; Odziemkowska et al., 2016)

Atmanli et al., Yerrennagoudaru & Manunatha and Zhang and Balasurbramanian pointed that there is slightly reduction of HC with biodiesel-alcohol blends as compared to neat diesel (Atmanli et al., 2016; Prabakaran & Udhoji, 2016; Yerrennagoudaru & Manjunatha, 2017; Z. H. Zhang & Balasubramanian, 2014). However, Imtenan et al., Ra et al., Qi et al. and Yoshiomoto et al. researched that HC emission increased as the addition of alcohol in biodiesel-diesel blend (Imtenan, Masjuki, Varman, Kalam, et al., 2014; Qi et al., 2017; Raj et al., 2017; Yoshimoto et al., 2013)

Habibullah et al., Abu-Hamdeh & Alnefaie, Phoon et al., Hafizil et al. and Yasin et al. investigated that HC emission from exhaust gas of biodiesel-diesel blends are lower as compare to neat diesel (Abu-Hamdeh & Alnefaie, 2015; Habibullah et al., 2014; Hafizil et al., 2015; Phoon et al., 2017; Yasin et al., 2015). The better conversion of HC is resulting from higher cetane number and also the oxygen content from the biodiesel.

Debnath et al. proposed there is decreasing in HC emission with water content emulsified biodiesel as compared to diesel (Debnath et al., 2013). Researchers explained water depress the temperature of the combustion products of emulsified fuel and reduction in BSFC also resulted lower HC emission.

2.5.4 Particulate Matter (PM)

Particulate matter in exhaust gas increased at higher content of biodiesel blends due to the higher viscosity of biodiesel and this may cause the over penetration of the fuel, which could cause wall-quenching. Meanwhile, water content in emulsion fuel which can cause mirco-explosion and secondary atomization contribute to a reduction of PM (Elsanusi et al., 2017).

From the experiment done by Y. C. Chang et al, Balamurugan & Nalini, Kumar & Saravanan, Z.Zhang et al., Nabi et al., Hansdah and Odziemkowska et al., the PM was reduced as the substantial reduction in PM emissions with n-butanol blends in mainly associated with the absence of aromatics, sulphur and fuel oxygen in the blends(Balamurugan & Nalini, 2014; Y. C. Chang et al., 2013; Hansdah, 2013; Imtenan et al., 2015; Kumar & Saravanan, 2016; Nabi et al., 2017; Odziemkowska et al., 2016; Z. Zhang et al., 2016).

Babu & Anand, Rakopoulos et al., Rao et al., Zhang and Balasurbramanian pointed that there is slightly reduction of PM with biodiesel-alcohol blends as compared to neat diesel (Babu & Anand, 2017; Rakopoulos et al., 2015; Rao et al., 2017; Z. H. Zhang & Balasubramanian, 2014). This is because fuel-bonded oxygen atoms in alcohol and biodiesel that remove carbons from the pool of hydrocarbons forming precursors of PM. Meanwhile, Qi et al. claimed that there is no change in PM when the alcohol is added into the biodiesel-diesel blends(Qi et al., 2017)

Y. Chang et al, Lin et al., Li et al., Change et al. and Nour et al. researched that the addition of water to alcohol-diesel fuel lead to reducing the PM as compared to fully diesel (Y. Chang et al., 2014; T. Li et al., 2017; Lin et al., 2012; Nour et al., 2017). The reason is micro-explosion which has better mixing and enhanced atomization and chemical effect by the concentration of OH radicals which leads to the oxidation of soot precursors.

Abu-Hamdeh & Alnefaie, B. Li et al. and Yasin et al. reported that additional biodiesel in diesel fuel can reduce the PM emission (Abu-Hamdeh & Alnefaie, 2015; B. Li et al., 2017; Yasin et al., 2015).

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the chosen methods and procedures in this study is discussed in details. Basically, it is divided into 3 sub chapter which are 3.1 (introduction), 3.2 (Fuel test) and 3.3 (Engine performance and exhaust gas test). Subchapter 3.1 is the introduction to chapter 3. Subchapter 3.2 is the methods and procedures to prepare the fuels, stability tests, and fuel properties test. Subchapter 3.3 is the methods and procedures for the engine performance and exhaust gas emissions at various operating conditions.

3.2 Fuel preparation and stability testing

In subchapter 3.2.1 and 3.2.2, the preparation of 8 sample fuels are explained in detail such as fuel combination of each sample, blending equipment , method and rotating speed used and the raw material used.

3.2.1 Fuel combination

In this study, emulsified biodiesel with alcohol is the combination of diesel, palm oil biodiesel, 1-butanol, distilled water and NP-9 as surfactant. Eight samples were prepared by various volume of diesel-biodiesel blend and various volume of 1-butanol added. The volume of each emulsified biodiesel with alcohol is tabulated as in table 3.1.

Table 3.1 8 Samples of emulsified biodiesel with alcohol.

Fuel	Diesel-biodiesel blend		1-butanol (%)	Distilled water (%)	NP-9 (%)
	B5	B10			
B5Bu5	89	0	5	5	1
B5Bu10	84	0	10	5	1
B5Bu15	79	0	15	5	1

B5Bu20	74	0	20	5	1
B10Bu5	0	89	5	5	1
B10Bu10	0	84	10	5	1
B10Bu15	0	79	15	5	1
B10Bu20	0	74	20	5	1

3.2.1.1 Blending equipment

The first blending equipment is electric mixer or RW20 digital mixing stirrer as shown in figure 3.1. This electric mixer isrobust, slimline and ergonomic design with digital display. It can be adust the turning speed which between 60 to 2000 rpm. Electric mixer is used to blend the diesel with palm oil biodiesel in this study.

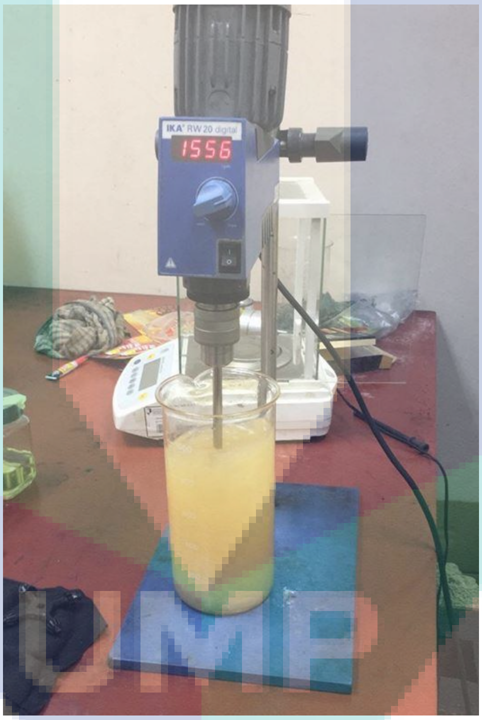


Figure 3.1 Blending sample fuel.

Second blending machine is ultrasonic homogeneisator or ultrasonic processor UP400S (400 watts, 24 Hz) as shown in figure 3.2. Ultrasonic homogeneisator has the sonotrodes which has the diameter range between 3 to 40mm. Each sonotrode suited different range of sample volume. The power control of ultrasonic homogeneisator can be adjustable between 20 – 100% amplitude and 0 – 1 cycle per second. In this study, ultrasonic homogeneisator is used to mix the diesel-biodiesel blend, water, butanol and surfactant emulsion.

Figure 3.2 Ultrasonic homogeneisator

3.2.1.2 Materials used

The diesel used in this study is the neat diesel that provided by University Malaysia Pahang and it is same as the diesel fuel that available in public fuel station. The palm oil biodiesel is supplied from the local industrial company in Selangor, Malaysia. The alcohol used is 1-butanol that produced from German company with 99.5% purity. The water used is car battery distilled water that available in public market. The surfactant used is Tergitol™ NP-9 surfactant that produced from USA company with 12.9 HLB value. Figure 3.3 is the surfactant Tergitol NP-9 and its data sheet is available at APPENDIX A.

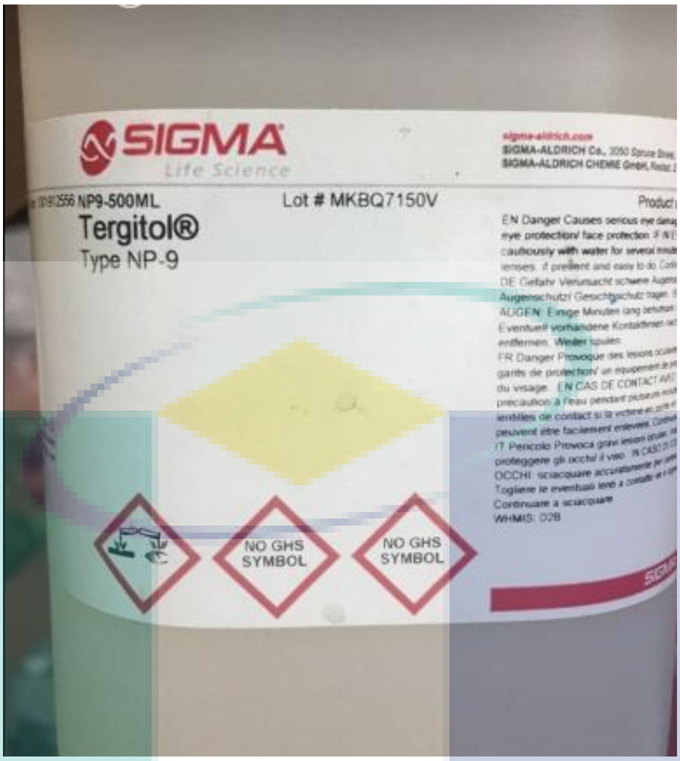


Figure 3.3 Surfactant Tergitol NP-9

3.2.2 Emulsion method

The emulsion method in this study is high shear force blending method which has some similarity with the method of T. Li et al. (T. Li et al., 2017). There are some reasons to choose this method. First, the combination of emulsified biodiesel with alcohol is almost same as T. Li et al. which are the combination of diesel, biodiesel, alcohol, water and surfactant. Second, T. Li et al. showed an excellent stability of the emulsified biodiesel with alcohol which the highest stability of the test fuel able to stable for 30 days. Third, the equipment needed is available in UMP laboratory. Therefore, the whole fuel preparation is able to carry out at laboratory.

The first stage to prepare the emulsified biodiesel with alcohol is by preparing the diesel-biodiesel blend. The palm oil biodiesel is blended with diesel with 500 rpm at room temperature to form B10 (contain 90% diesel and 10% palm oil biodiesel) and B20 (contain 90% diesel and 10% palm oil biodiesel).

The second stage is adding diesel-biodiesel blend, butanol, water and surfactant into beaker Then, the ultrasonic processor UP400S (400 watts, 24 kHz) is used for emulsion and to form the emulsified biodiesel with alcohol. In this study, the ultrasonic processor is set with 25% amplitude and 0.5 cycle for 5 minutes for each sample. The total volume for each sample was 100ml.

3.3 Properties test

There are 5 properties are tested which are density, kinematic viscosity, calorific value, cetane number and stability time.

3.3.1 Density

Density can be measured by using the mass divided by volume. In this project, the density is measured by weighting the 3 millilitres of fuel sample. Each sample is measured under the room temperature 25°C and repeated 3 times to get the average data. As the weighting machine is available in laboratory, so the density of each sample fuel is measured.

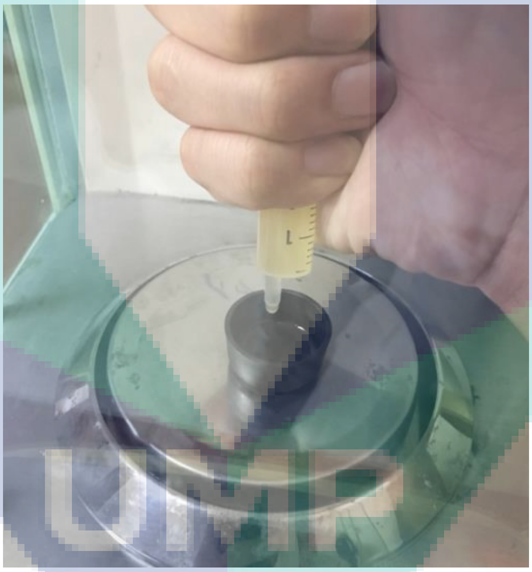


Figure 3.4 Measure density of sample

3.3.2 Kinematic viscosity

In this project, kinematic viscosity of the sample fuel is measured by the Cannon-Fenske type viscometer tubes. The Cannon-Fenske size that used to measure the sample fuel is 100 which having a constant of 0.015120 at 40°C and suitable to measure the viscosity range between 3 to 15 cSt. Based on the ASTM D445 Standard, the measurement is repeated twice to get the average result. As the Cannon-Fenske viscometer is not available in laboratory, so only one chosen sample is sent to the FKKSA Consultation & Services Unit for measurement.

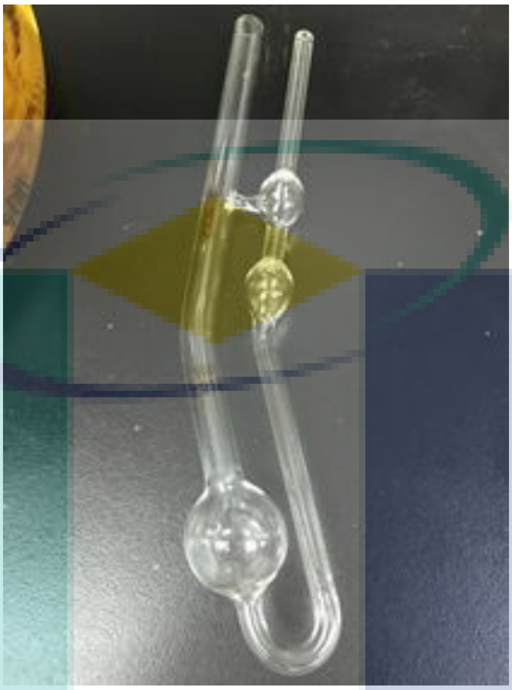


Figure 3.5 Cannon-Fenske viscometer

3.3.3 Calorific value

Calorific value can be measure by using oxygen bomb calorimeter. In this project, model 6772 calorimeter is used to measure the calorific value of the samples and it is following the standard ASTM D240. As the oxygen bomb calorimeter is available in laboratory, therefore the measurement is repeated twice to get the average data for each sample fuel.

Figure 3.6 Oxygen bomb calorimeter

3.3.4 Cetane number

Cetane number is an indicator to measure the ignition quality or combustion speed of the diesel fuel. Generally, a higher cetane number of the diesel fuel has a shorter ignition delay and better combustion process in combustion chamber, which means the fuel with higher cetane number has better performance and more engine power.

Cetane number can be measured by using the portable octane analyser. The measurement of cetane level by this device is according to the ASTM D 613 which standard test method for cetane number of diesel fuel. As this portable octane analyser is also not available in laboratory, so only one chosen sample is sent to the FKKSA Consultation & Services Unit for measurement.

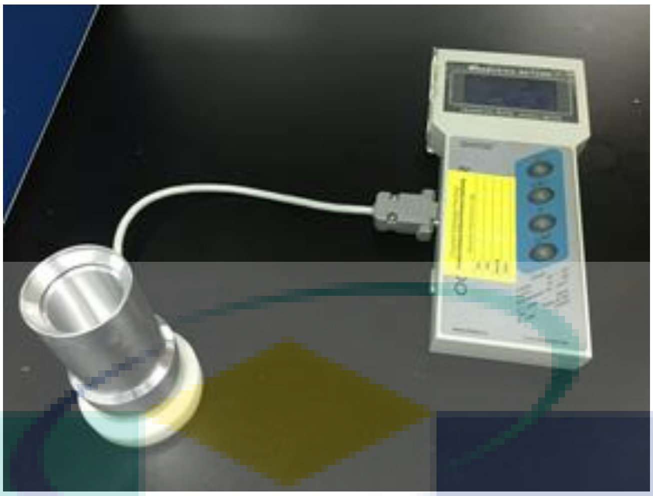


Figure 3.7 Portable octane analyser

3.3.5 Stability test with various volume of 1-butanol

Various volume of butanol with emulsified biodiesel is the main propose of this study. Therefore the 8 samples which are B5Bu5, B5Bu10, B5Bu15, B5Bu20, B10Bu5, B10Bu10, B10Bu15 and B10Bu20 were undergoing the stability test to observe the stability change through the different percentage volume of 1-butanol. Table 3.3 showed the volume distribution of emulsified biodiesel with alcohol for stability test with various volume of 1-butanol.

Table 3.2 Volume distribution of 8 samples

Fuel	**Diesel-biodiesel blend**		**1-butanol (%)**	**Distilled water (%)**	**NP-9 (%)**
	B5	**B10**			
B5Bu5	89	0	5	5	1
B5Bu10	84	0	10	5	1
B5Bu15	79	0	15	5	1
B5Bu20	74	0	20	5	1
B10Bu5	0	89	5	5	1
B10Bu10	0	84	10	5	1
B10Bu15	0	79	15	5	1
B10Bu20	0	74	20	5	1

3.4 Engine setup

Engine setup is conducted at Automotive Engine Centre (AEC) laboratory which located at University Malaysia Pahang Pekan campus. Setup an engine is complicated processes which need to assembly the engine with dynamometer, pump, intake manifold, exhaust manifold, control unit and etc. Therefore, the engine is setup by a team of three students which are Izuan (master student), Adam (4^{th} year Degree student) and me. We are guided by our supervisor (Dr. Ahmad Fitri).

Basically, there are few major problems in setup the engine. First, the old shaft is not fit for the new dynamometer. Shaft is the linked mechanical part between the engine and the dynamometer. The main purpose of the shaft is transfer the torsion load from the engine to dynamometer. As the dimension of the old shaft is not fit with the new dynamometer, then a new shaft is needed to fabricate in order to connect the engine and dynamometer. This problem is passed to me.

Second problem is the location of dynamometer is not flexible. The old dynamometer is located on the beam with four fixed through hole for the bolts and nut. However, due to the new dynamometer has different size and dimension, then the four fixed through hole is not suitable for the new dynamometer. In order to solve this problem, we planned to change the through holes to the slopes. So, the dynamometer can be adjustable and fixed with bolt and nuts. This also will be easier and benefit for the next batch students. This problem is passed to Adam who need to change the through holes to slopes.

Third problem is the pressure sensor in the combustion chamber of the engine. The pressure sensor is needed to install in the combustion chamber in order to measure the pressure and this parameter is important to investigate the combustion analysis. So, this problem will be in charged by Izuan.

3.4.1 Shaft

As I was in charged in shaft problem, I need to measure the dimensions at the engine and dynamometer and then redrew the shaft with solidwork. The figure below is the drawing of the shaft.

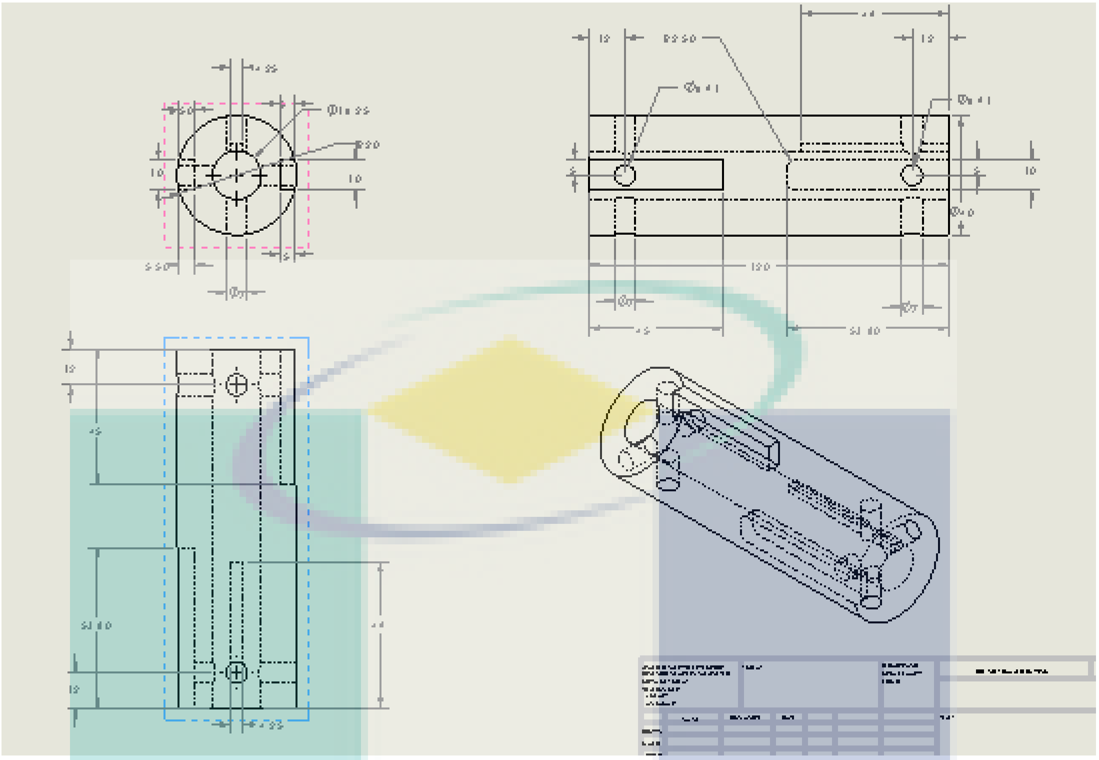


Figure 3.8 Drawing of shaft

3.5 Software setup

There are some software are used to measure and record the data in engine performance testing and emission testing. The software used are DASYlab, DAQ monitor software from Focus Applied Technologies, and PicoLog.

DASYlab is the main software to run and analysis the data. The load cell which used to measure the torque is connected to DASYlab. Then, the DASYlab also is use the torque found and engine speed to calculate brake power. Digital weight balance also connected to DASYlab and using the DASYlab to get the brake specific fuel consumption. Figure below is the DASYlab layout for engine performance testing.

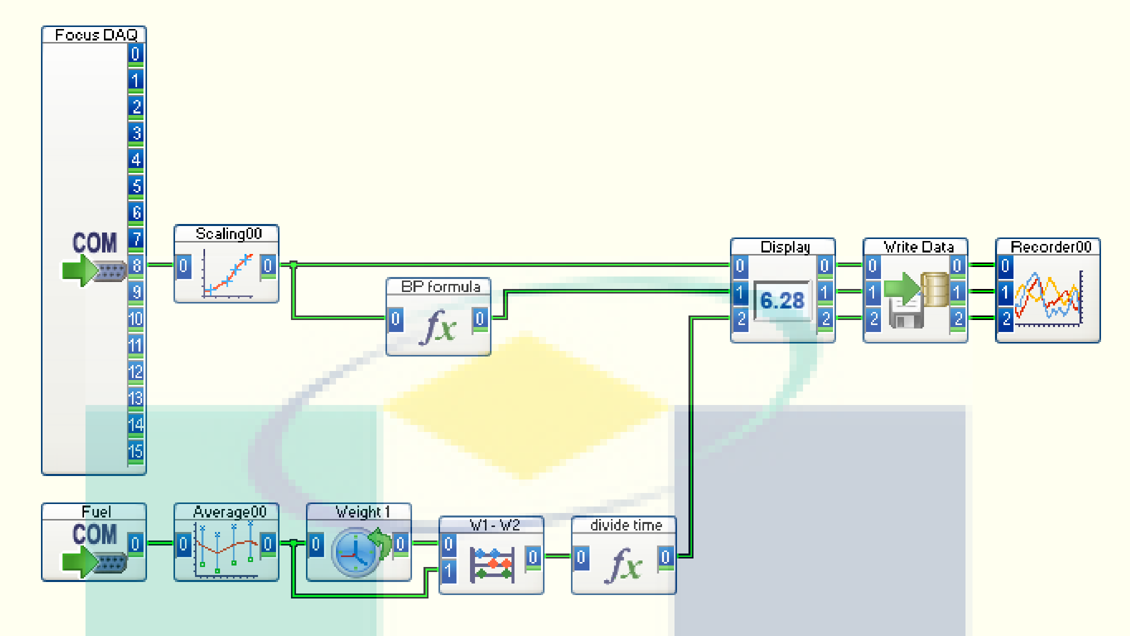


Figure 3.9 DASYlab layout

DAQ monitor software from Focus Applied Technologies is used to calibrate the load cell. The load cell used is manufactured from Focus Applied Technologies so therefore its software can be used to calibrate the load cell by following the steps from DAQ manual.

PicoLog software is used synchronise with the Pico DAQ. Pico DAQ able to connects with 8 thermocouples (maximum) at the same time. Then, PicoLog software also able to records the data from thermocouples and export them into Microsoft Excel.

3.6 Engine performance and exhaust gas test

YANMAR TF120-M is the diesel engine that conducted the experiment and run the sample fuels. YANMAR TF120-M is manufactured by Yanmar Co. Ltd. YANMAR TF120-M is a single cylinder, water cooled, 4-cycle diesel engine with direct injection (DI) and natural aspiration engine. The engine swept volume is 638 cm^3 with bore × stroke of 92 × 96 mm. The engine was coupled to an eddy current dynamometer with continuous rate output of 7.7kW at 2400 rpm.

Table 3.3 Engine specification

Description	Specification
Engine model	YANMAR TP120-M
Engine type	1-cylinder, horizontal, water-cooled, 4-cycle diesel engine
Combustion system	Direct injection
Aspiration	Natural aspiration
Cylinder bore×stroke (mm)	92 × 96
Displacement (L)	0.760
Engine dimensions (mm)	Length: 695.5 Width: 348.5 Height: 530
Engine dry weight (kg)	101.5
Continuous rate output	10.5Ps or 7.7kW @ 2400rpm
At 1-hour rate output	12.0 Ps or 8.8kW @ 2400rpm
Cooling system	Radiator cooling
Lubrication system	Complete enclosed forced lubricating system
Fuel tank capacity	11.0 L
Engine oil capacity	2.8 L
Cooling water capacity	2.3 L

The engine was first ran with diesel fuel to define the baseline parameters of other sample fuels. After the engine ran for 10 minutes for warm up to make sure the engine reached stabilized working condition, then only start taking the engine performance parameters. The taken engine performance parameters are brake power, brake specific fuel consumption and exhaust gas temperature. The engine performance test was carried out at 1000, 1500 and 2000 rpm of engine speed with constant 50% load.

The exhaust gas emission testing was run at the same time with the engine performance testing under same condition as well. Gas emissions were measured by an KANE Automotive Gas Analyser. The exhaust gas analyser is able to measure the CO, and CO_2. All data were monitored and recorded. The experiment was repeated with different fuel samples which are D100, B5Bu5, B5B10 and B10Bu5. Figure below is the schematic diagram of engine performance and emission testing.

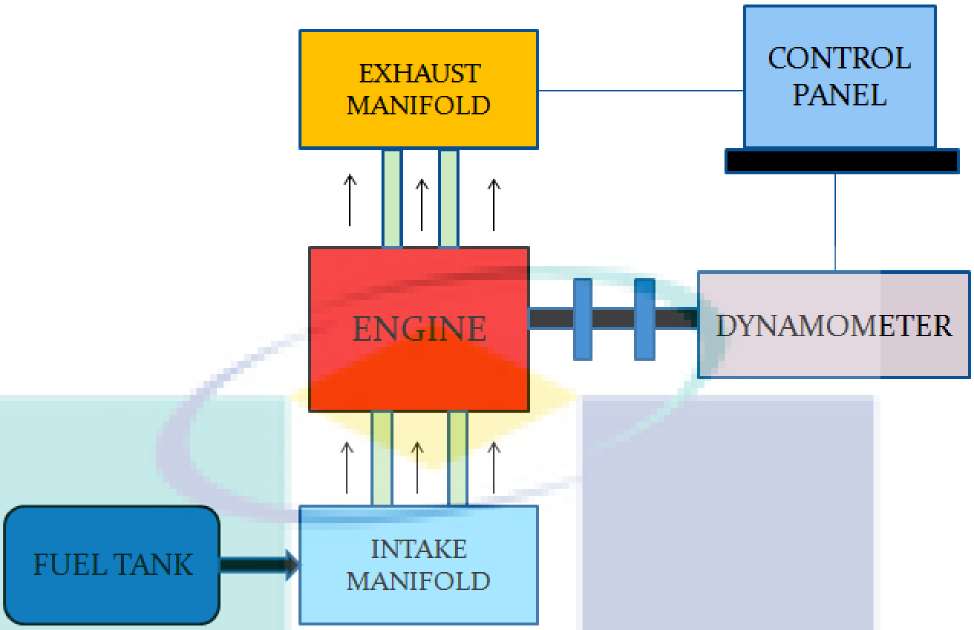


Figure 3.10 Schematic diagram.

3.7 Summary

This chapter has covered three major parts which are preparation of fuels, setup of engine and setup of software. Setup the engine part is the most difficult and challenging because the engine is not only setup from zero but also need to repair some minor defects from the engine. Then, some of the parts need special alignment tools only can do for the alignment. After the setup was done, the project will be proceeding with testing and all data will be analysed and discussed in next chapter. Figure below is the flow chart of this study.

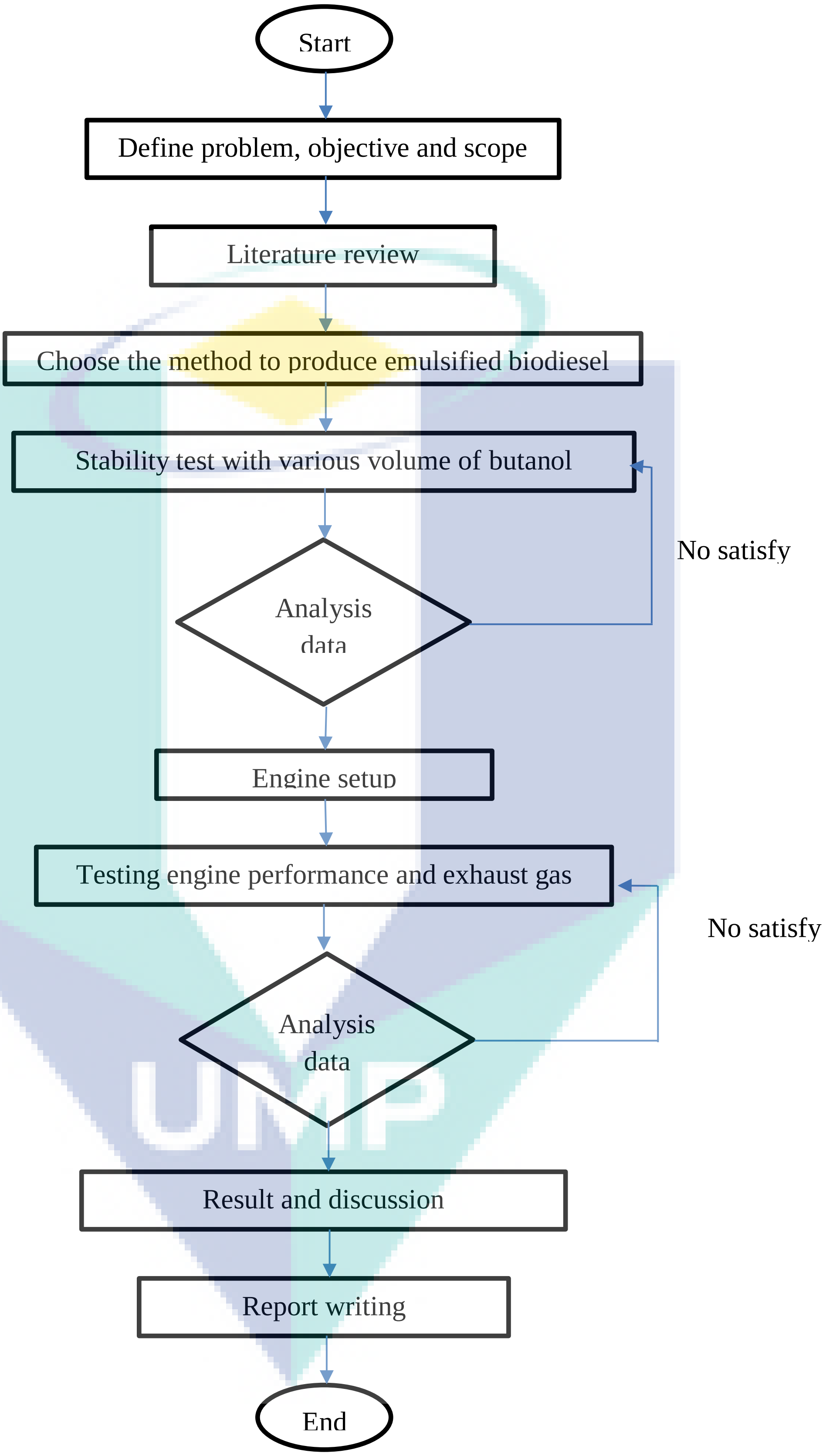


Figure 3.11 Flow chart of the project

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the obtained results throughout the experiment will be discussed. In subchapter 4.2, the fuel properties of 8 samples are tabulated and explained in details. In subchapter 4.3, the result obtained from engine performance testing is discussed. Whereas the subchapter 4.4 discussed about the result obtained throughout the emission testing. Lastly, subchapter 4.5 is a summary for the chapter 4, which is overall results and discussion.

4.2 Fuel Properties

In this study, the density of emulsion was obtained by measuring the volume and weight of the samples. Kinematic viscosity was determined by Cannon-Fenske type viscometer tube which following the ASTM D445 Standard. Calorific value is determined by the Oxygen Bomb Calorimeter and following standard ASTM D240. Cetane number was measured by the portable octane analyser and following the standard ASTM D613. Stability time was calculated from the fresh emulsion until first layer formed. The obtained results are shown as tables below.

Table 4.1 Properties of raw materials

Properties	Diesel (D100)	Palm oil biodiesel	Butanol	Distilled water
Density (kg/m^3)	855.7	919.3	825.0	998.2
Calorific value (MJ/kg)	46.00	39.62	35.15	-

Table 4.2 Properties of B5 fuels

Properties	B5Bu5	B5Bu10	B5Bu15	B5Bu20
Density (kg/m^3)	844.3	841.8	867.7	860.0
Calorific value (MJ/kg)	42.46	43.92	43.69	41.98
Kinematic Viscosity @40°C (mm^2/s)	3.891	NA	NA	NA
Cetane number	55.1	NA	NA	NA
Stability (hour)	21.2	4.7	2.2	0.3

Table 4.3 Properties of B10 fuels

Properties	B10Bu5	B10Bu10	B10Bu15	B10Bu20
Density (kg/m^3)	882.7	870.0	872.2	869.8
Calorific value (MJ/kg)	41.93	41.53	40.83	40.55
Kinematic Viscosity @40°C (mm^2/s)	NA	NA	NA	NA
Cetane number	NA	NA	NA	NA
Stability (hour)	13.1	2.9	1.5	0.4

4.2.1 Stability

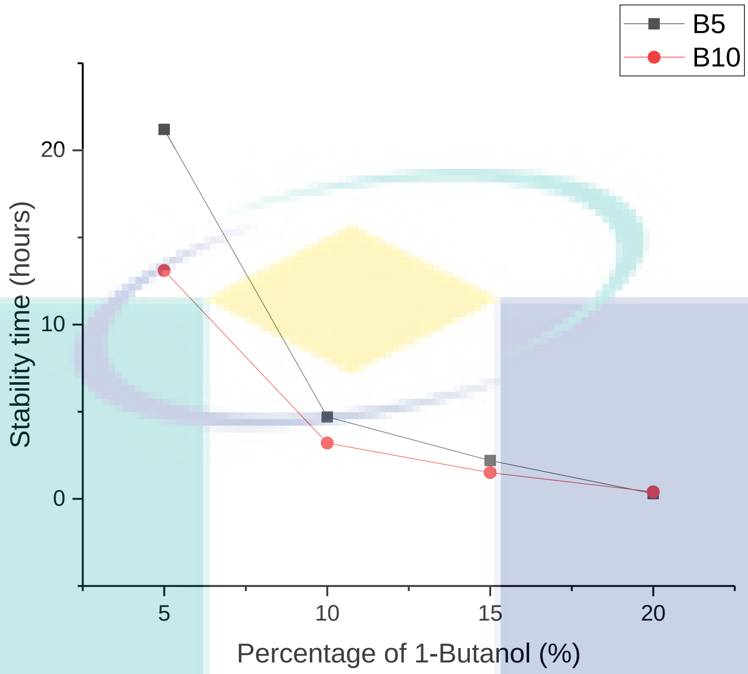


Figure 4.1 Stability time various percentage of 1-butanol.

The stability time for B5 fuels which are B5Bu5, B5Bu10, B5Bu15 and B5Bu20 are 21.2, 4..7, 2.2 and 0.3 hours respectively whereas the stability time for B10 fuels which are B10Bu5, B10Bu10, B10Bu15 and B10Bu20 are 13.1, 2.9, 1.5, and 0.4 hours respectively. The highest stability time in B5 fuel is 21.2 hours (B5Bu5) whereas the highest stability time in B10 fuel is 13.1 hours (B10Bu5).

As the volume of butanol increased to 20%, the stability for both B5 and B10 are decrease inversely. This result is same as the researchers T. Li et al., they reported that the diffusion coefficient in the emulsion increases with the fraction of alcohol contains and this will obviously decrease the stability of the emulsion (T. Li et al., 2017). Meanwhile, the stability period is very critical to the emulsion method because emulsion methods affect the droplet sizes of the dispersed phase. Homogenizer machine breaks down the butanol, diesel, biodiesel and water into smaller droplet in dispersed phase. However, this dispersed phase is unstable and therefor they merged with its neighbour droplets to form larger droplets (O et al., 2017). Because of this unstable state, the emulsion fuel formed layers after a period. As the speed of homogenizer increases, smaller droplets in dispersed phase will be formed and longer time taken for the emulsion fuel to form the layer. M.Zhang & Wu also concluded that the acceleration on bio-oil phase separation can be reason by the emulsion with water, salt or alkaline catalyst. Therefore, this is again proved in this study which higher concentration of water resulted fastest separation time and low stability (M. Zhang & Wu, 2017).

B10 sample fuels which contain higher percentage of palm oil biodiesel also resulted a shorter stability time as compared to B5 fuels when both fuels were having a same volume of butanol.

From this study, only B5Bu5, B5BU10 and B10Bu5 met the standard ASTM D6751 which require at least 3 hours of oxidation stability. Therefore, only these fuels proceed with engine performance testing to avoid the fuel damage the engine such as rusting. Although these 3 fuels are proceed with engine testing, but further improvement in stability time is needed. In real life application, stability time of fuel need to be much longer to avoid the layer formed in the oil tank. Figure 4.2 and figure 4.3 show begin and end of the emulsified biodiesel with alcohol.

Figure 4.2 Start stability test

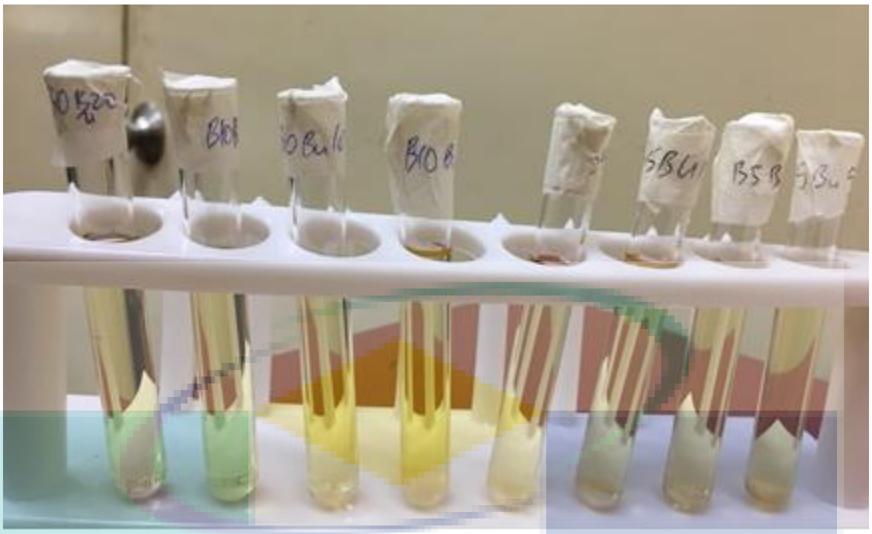


Figure 4.3 Finish separation

4.2.2 Density

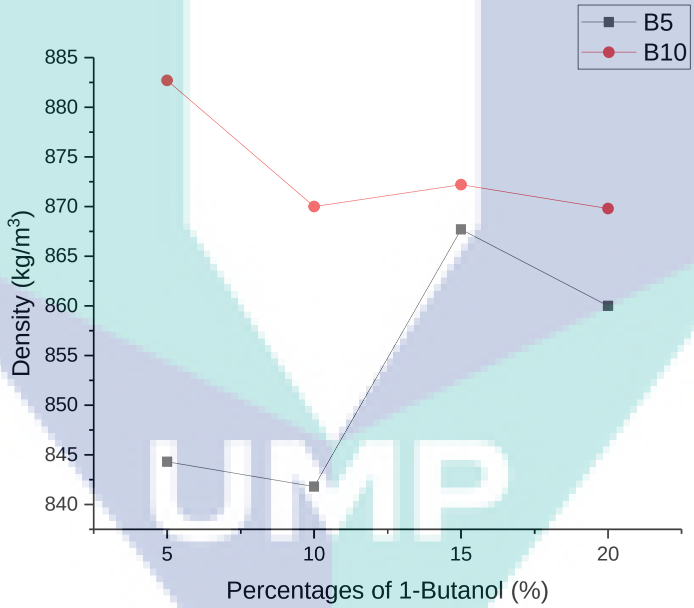


Figure 4.4 Density of sample fuels versus 1-butanol volume

From this study, the density of the fuels for B5 is within the range of 41.98kg/m^3 to 43.92kg/m^3. Meanwhile, the density of the fuels for B10 is within the range of 869.8kg/m^3 to 882.7 kg/m^3. B5 is accepted to be denser than the B10 is due to the percentages contain of the biodiesel. Palm oil biodiesel has higher density than diesel. Therefore, B10 which contain higher percentage of biodiesel has higher density than B5 as shown in graph above. However, as the butanol contains increase to 20%, both B5 and B10 trends cannot be clearly seen due to the butanol density and major raw material (diesel) has almost similar density. As a result, D100 which has the density of 855.7 kg/m^3 is laid in the range of density B5.

4.2.3 Calorific value

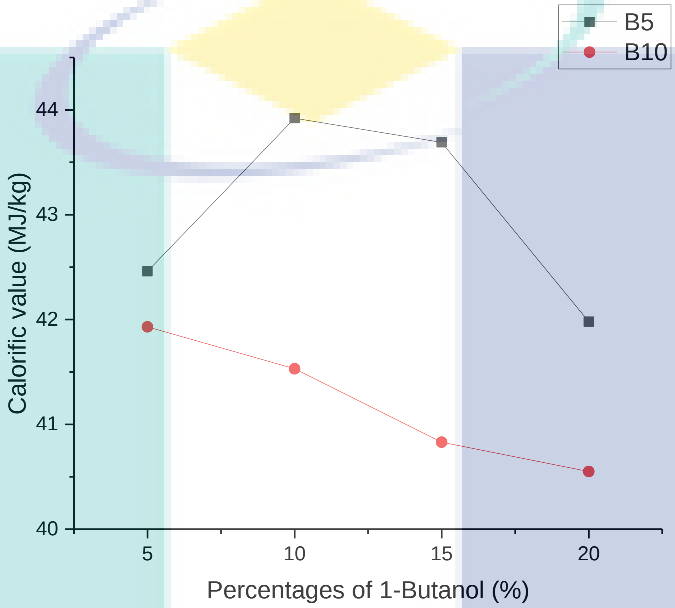


Figure 4.5 Calorific value of the samples

In this study, the calorific values of the B5 fuels are within the range of 41.98MJ/kg to 43.92 MJ/kg. However, the calorific values of the B10 fuels are within the range of 40.55MJ/kg to 41.93 MJ/kg which slightly lower than the B5 fuels. It is acceptable for B10 fuels lower than B5 fuel because diesel has higher calorific value than palm oil biodiesel.

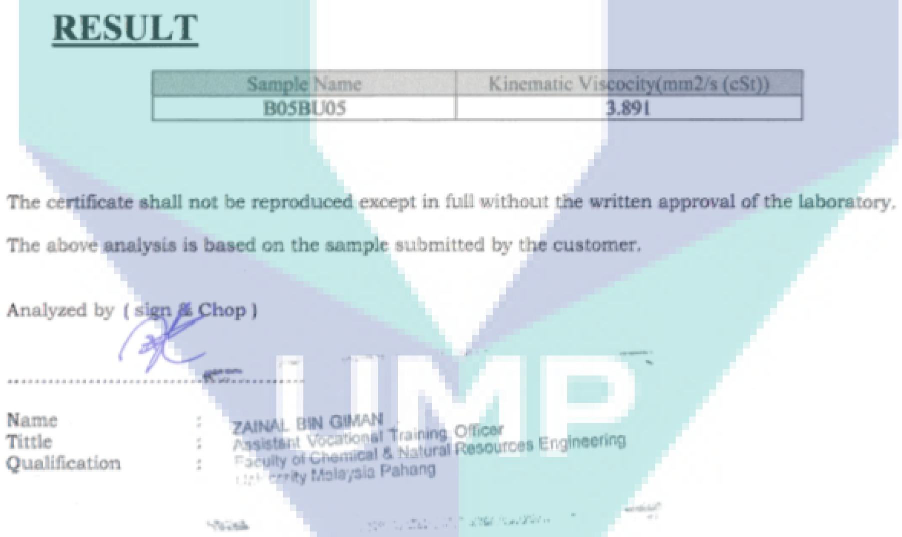
The trends for calorific value of the B5 and B10 fuels are decreasing as the alcohol (1-butanol) contains increase to 20%. This is because the calorific value of diesel is about 20% higher than 1-butanol. Therefore, as the 1-butanol contain increased and replace the diesel contain, the caloric value is dropped significantly. This result is expected and can be accept because most of the researchers such as Abu-Hamdeh & Alnefaie, Babu & Anand and Ileri etal. who were also doing the biodiesel research but using different biodiesels or alcohol get the same result as well (Abu-Hamdeh &

Alnefaie, 2015; Babu & Anand, 2017; Ileri et al., 2016). However, the diesel fuel still obviously higher than B5 and B10 fuels.

4.2.4 Kinematic viscosity

Kinematic viscosity is very important role in the fuel properties because the shape of fuel droplets and the atomization of fuel during injection are depend on the kinematic viscosity. In most of the time, the fuel with low kinematic viscosity has a better atomization as compared to higher kinematic viscosity fuel, whereas, those exceptional are due to other effects such as micro-explosion.

In this study, only sample B5BU5 was proceeded with kinematic viscosity testing because B5BU5 has a longest stability time among the sample fuels. B5BU5 has a kinematic viscosity of 3.891 mm^2s. Based on ASTM D6751, standard specification for biodiesel should between 1.9-6.0 mm^2s with testing method ASTM D445. Therefore, B5BU5 meets the requirement for ASTM D6751.



RESULT

Sample Name	Kinematic Viscocity(mm2/s (cSt))
B05BU05	3.891

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The above analysis is based on the sample submitted by the customer.

Analyzed by (sign & Chop)

Name :
Tittle :
Qualification :

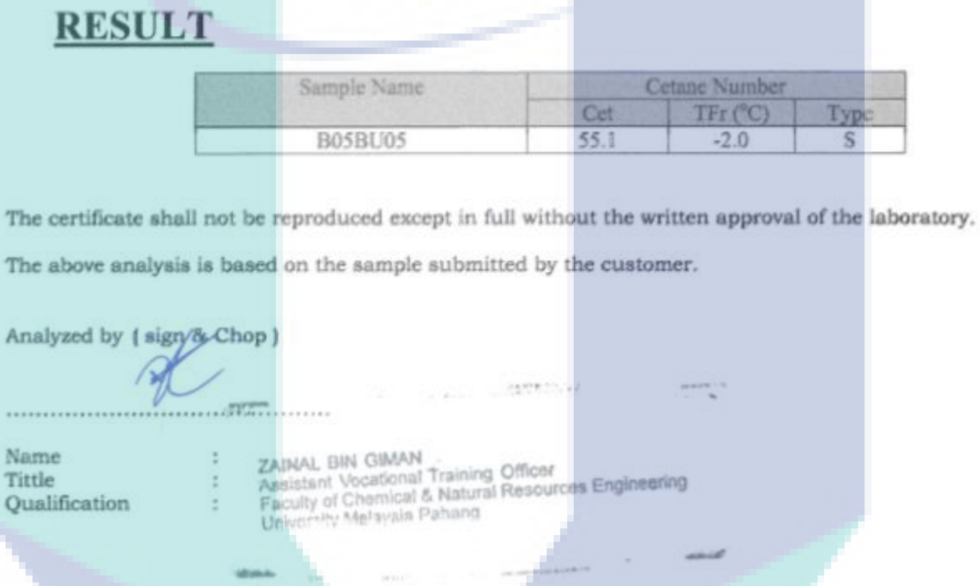
ZAINAL BIN GIMAN
Assistant Vocational Training Officer
Faculty of Chemical & Natural Resources Engineering
Universiti Malaysia Pahang

Figure 4.6 Kinematic viscosity result.

4.2.5 Cetane number

Cetane number is an indicator to measure the ignition quality or combustion speed of the diesel fuel. Generally, a higher cetane number of the diesel fuel has a shorter ignition delay and better combustion process in combustion chamber, which means the fuel with higher cetane number has better performance and more engine power.

In this study, only sample B5BU5 was proceeded with cetane number testing because B5BU5 has a longest stability time among the sample fuels. B5BU5 has a cetane number of 55.2. Based on ASTM D6751, standard specification for biodiesel should has at least 47 for the cetane number with the testing method of ASTM D613. Therefore, B5BU5 meets the requirement for ASTM D6751.



RESULT

Sample Name	Cetane Number		
	Cet	TFr (°C)	Type
B05BU05	55.1	-2.0	S

The certificate shall not be reproduced except in full without the written approval of the laboratory.

The above analysis is based on the sample submitted by the customer.

Analyzed by (sign & Chop)

Name :
Tittle :
Qualification :

ZAINAL BIN GIMAN
Assistant Vocational Training Officer
Faculty of Chemical & Natural Resources Engineering
University Malaysia Pahang

Figure 4.7 Result of cetane number

4.3 Engine performance analysis

Engine performance was tested throughout few categories which are brake power (BP), brake specific fuel consumption (BSFC) and exhaust gas consumption (EGT). In this sub chapter, the engine performance testing result will explain in detail through brake power, brake specific fuel consumption and exhaust gas temperature.

4.3.1 Brake power (BP)

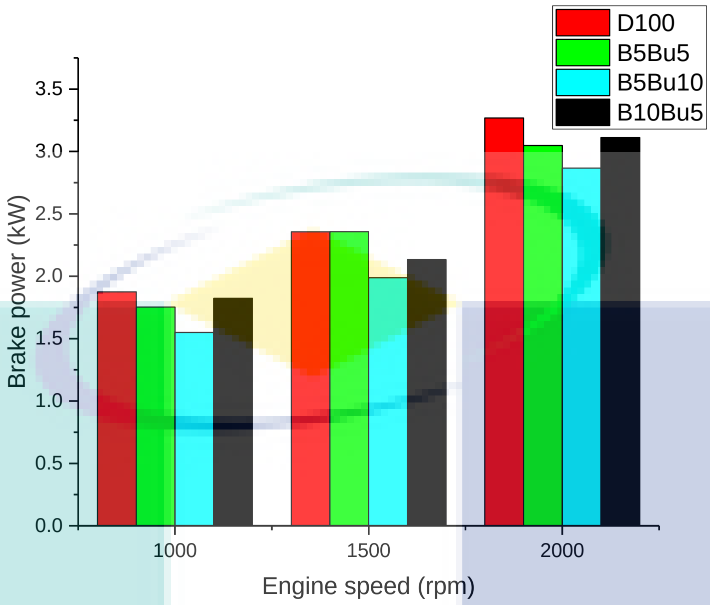


Figure 4.8 Brake power versus engine speed

Torque and brake power are likely to be linked because they are dependent each other. Brake power of the engine can be calculated by measuring the torque and rotational engine speed. As the rotational engine speed is a constant variable in this study, so, there is a linear function between torque and brake power. Brake power is dependent on the torque and engine speed also can be proved through the equation of BP.

$$BP = \frac{P_b LAN}{60000} = \frac{2\pi NT}{60000} \quad [4.1]$$

Where,
BP = brake power, kW
P_b = Brake mean effective pressure, N/m^2
L = Length of stroke, m
A = Piston area, m^2
N = Engine speed, rpm
T = Torque, Nm

As shown in figure 4.8, the brake power is increasing for each fuel with the engine speed from 1000rpm to 1500rpm. The average BPs of D100, B5Bu5, B5Bu10 and B10Bu5 are 2.50, 2.39, 2.14 and 2.36kW respectively. D100 is produced more brake power than B5Bu5, B5Bu10 and B10Bu5 by 4%, 14% and 6%. It was also clearly see that D100 has the highest BP output and B5Bu10 has the lowest BP output at each engine speed. Meanwhile, the BP output of B5Bu5 and B10Bu10 are having a close result among the engine speeds. This can be attributed to the effect of low calorific value. As subchapter 4.2.3 explained the D100 fuel is significantly higher than sample fuels, therefore the energy content of D100 is higher than the sample fuels as well. This result are same as some researchers (Habibullah et al., 2014; Ileri et al., 2016; Rizwanul Fattah et al., 2014).

4.3.2 Brake specific fuel consumption (BSFC)

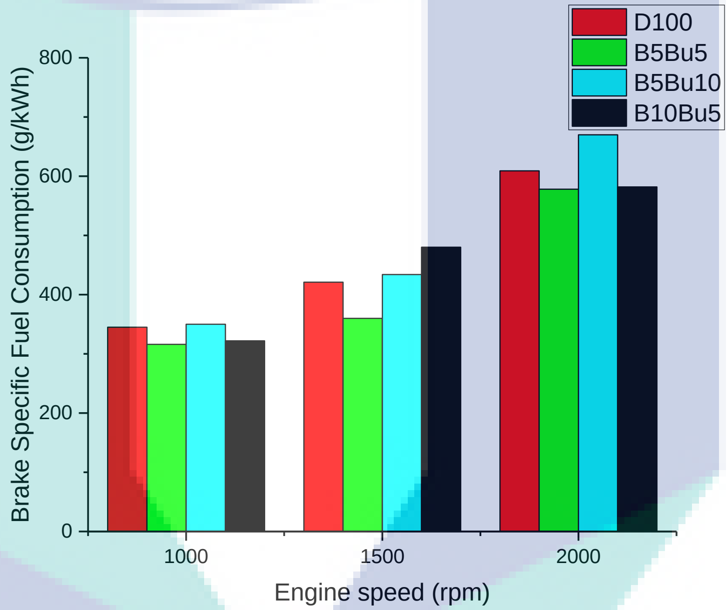


Figure 4.9 BSFC versus engine speed

In this study, BSFC is studied to investigate the each fuel consumption on the engine as load is constant at 50% and various engine speeds. The average BSFCs over entire engine speed of 1000, 1500 and 2000 rpm for D100, B5Bu5, B5Bu10 and B10Bu5 are 458, 418, 485 and 461 g/kWh respectively. Thus, B5Bu5 is 10% lower than D100 and B5Bu10 and B10Bu5 are 6% and 1% higher than D100. The highest BSFC is B5Bu10 (670 g/kWh) at 2000 rpm and the lowest is B5Bu5 (316 g/kWh) at 1000rpm. As the engine speed increases, the BSFC is increased because more fuel is needed to produce the rotating speed.

Throughout this 3 engine speeds, the BSFC of B5Bu5 are less than D100 about 9 to 12% at each speed. The BSFC of B5Bu5 supposed to be higher than D100 due to lower calorific value of B5Bu5. But B5Bu5 is water emulsified fuel, therefore it has secondary atomization due to the micro-explosion of water. As it has better atomization, then the combustion efficiency is increased as well. This result is same as some researchers who using the emulsified fuel (Debnath et al., 2013; Ithnin et al., 2014).

4.3.3 Exhaust gas temperature (EGT)

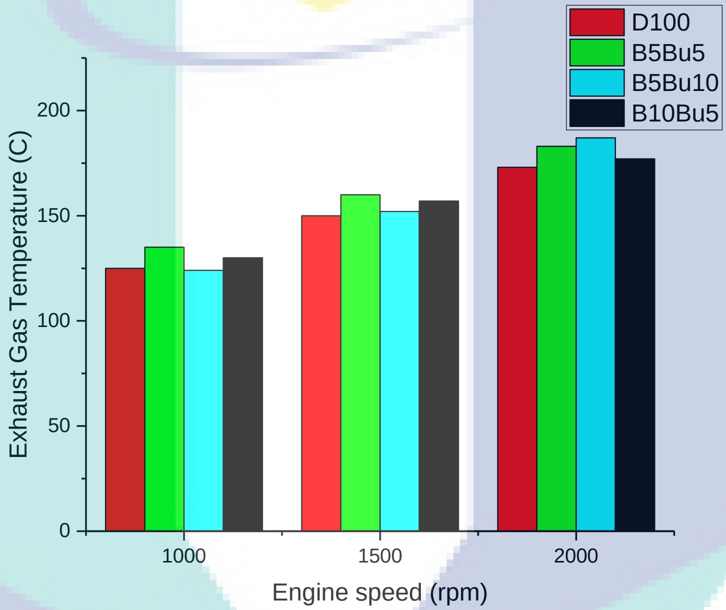


Figure 4.10 EGT versus engine speed

Exhaust gas temperature is normally used to represent or reflect the combustion temperature from the combustion chamber. By understanding the trend of EGT, it is useful to analysis the emission gases. Figure 4.10 show the EGT of each sample fuel versus to engine speed. The average EGTs of D100, B5Bu5, B5Bu10 and B10Bu5 are 149, 159, 154 and 155 ^{o}C respectively at entire engine speed. B5Bu5, B5Bu10 and B10Bu5 are 7%, 3% and 4% higher than D100. This is because of the additive of butanol and biodiesel which are oxygenated fuel. These oxygenated fuels create oxygen-rich regions where having better combustion and the temperature increased. These result of EGT are having a major similarity as the researcher Ileri et al (Ileri et al., 2016). As the engine speed increased from 1000 rpm to 2000 rpm, the trends of EGT are increased for each sample fuel.

4.4 Exhaust gas emissions analysis

In this subchapter, gas emissions such as carbon monoxide (CO) and carbon dioxide (CO_2) are analysed and explained in detail.

4.4.1 Carbon monoxide (CO)

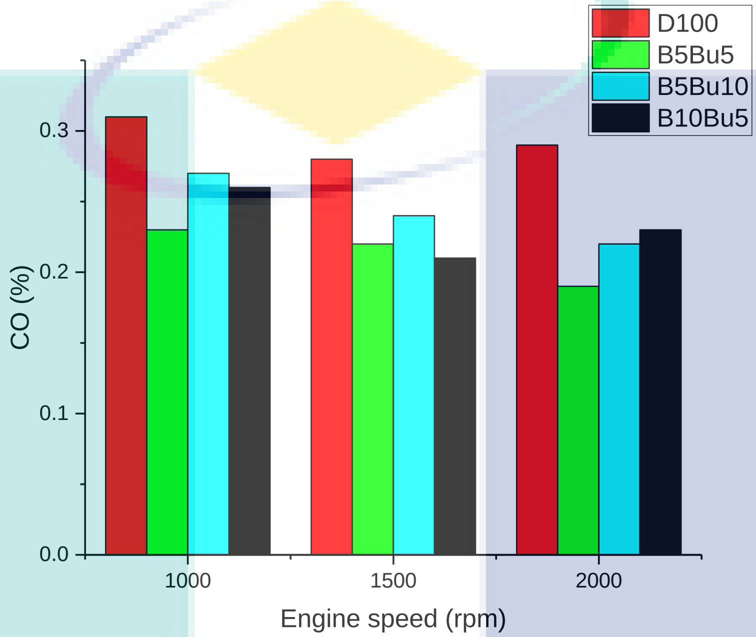


Figure 4.11 Carbon monoxide versus engine speed

From the figure 4.12, the average of CO emission from D100, B5Bu5, B5Bu10 and B10Bu5 are 0.30%, 0.21%, 0.24% and 0.23% respectively over entire engine speeds at 50% load. As compared to D100, CO emissions from B5Bu5, B5Bu10 and B10Bu5 are reduced by 30.2%, 20.3% and 23% respectively. Therefore, it can be said that B5Bu5, B5Bu10 and B10Bu5 are significantly reduce the CO emission. This can be due to two reasons. First, the oxygenated fuel such as B5Bu5, B5Bu10 and B10Bu5 which added butanol and biodiesel caused the oxygen-rich regions and increase the combustion temperature that able to promote CO to CO_2. Second, the micro-explosion that caused secondary atomization can improved the combustion efficiency and promotes complete combustion in the combustion chamber. However, the highest emission of CO of D100 is 3.1% at 1000 rpm and the lowest is 1.9% of B5Bu5 at 2000 rpm.

4.4.2 Carbon dioxide (CO_2)

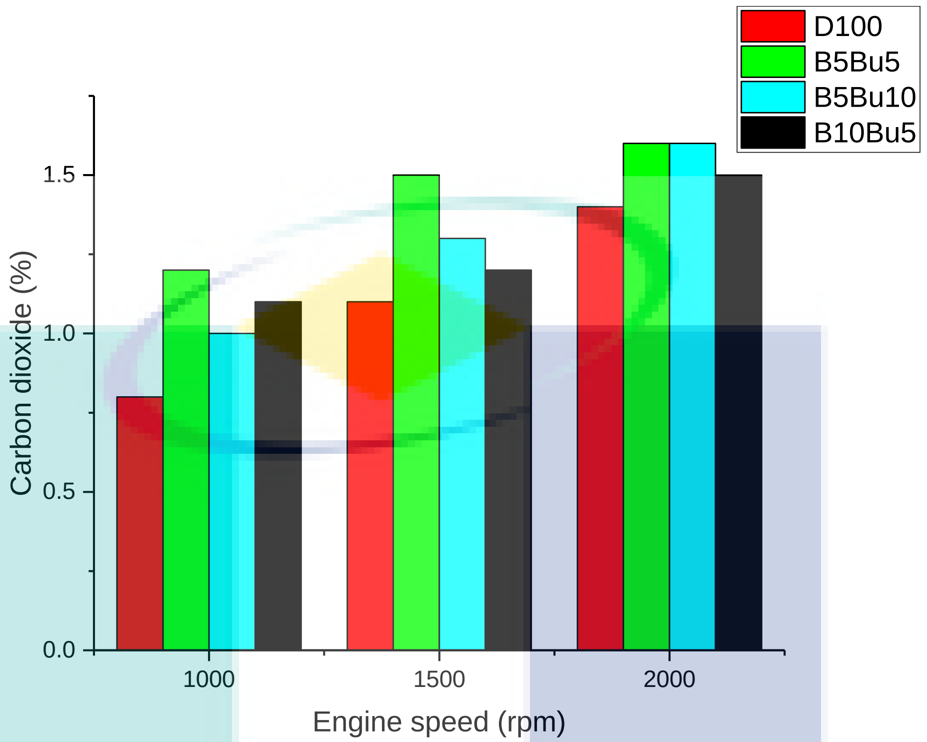


Figure 4.12 Carbon dioxide versus engine speed

Carbon dioxide is a common gas that produced by a complete combustion. Figure 4.13 shows the CO_2 emission against the engine speed of 1000rpm to 2000 rpm at 50% load. The average CO_2 emission of D100, B5Bu5, B5Bu10 and B10Bu5 are 1.11%, 1.44%, 1.36% and 1.27% respectively over entire engine speed at 50% load. The emission from B5Bu5, B5Bu10 and B10Bu5 are significantly increased by 28.8%, 24.5% and 14.2%. The highest emission of CO_2 is B5Bu5 at 2000rpm whereas the lowest emission is D100 at 1000rpm. As explained in subchapter 4.4.2, the high EGT leads to improve the combustion process promote the CO to CO_2 when the oxygenated fuel such as alcohol and biodiesel is added into the sample. Therefore, the CO emission is reduced and CO_2 emission is increased.

As engine speed is increased from 1000rpm to 2000 rpm, the CO_2 emission trends from all fuel are increased. This is phenomena can be explained by logistical thinking that the combustion process is very fast at the high engine speed.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter is provided an overview results and the recommendation throughout this thesis. This thesis is done to expand the new knowledge on emulsified biodiesel with alcohol. Therefore, subchapter 5.2 summarized the findings from this research and subchapter 5.3 is some recommendation or improvement for future work.

5.2 Summary of the thesis

In this thesis, there are three parts are done which are characteristics, engine performance and exhaust gas emission of emulsified biodiesel with 1-butanol. Among the eight fuels prepared, B5Bu5 is greatest from the overall performance in terms of characteristics, engine performance and exhaust gas emission.

5.2.1 Properties of emulsified biodiesel with alcohol

From the 8 samples of the fuels, all fuels are within the range of 841.8 to 882.7 kg/m^3 and it is acceptable. For the calorific value, the range of 8 samples lied between 40.55 - 43.69 MJ/kg as well and it was lower than diesel fuel. For the stability time, B5Bu5 has a longest stability time among 8 sample fuels. For the kinematic viscosity and cetane number, it can be conclude that B5Bu5 is met the requirement of ASTM D6751.

5.2.2 Engine performance

From this study, the brake power that produced by D100 is higher than B5Bu5 by 4%, due to higher calorific value of D100. For the BSFC, B5Bu5 is 10% lower than D100 which due to the micro-explosion that improved the combustion efficiency in the combustion chamber. The average EGTs of D100 is lower than B5Bu5 by 7% over entire engine speed.

5.2.3 Exhaust gas emission

Throughout this study, the CO emission of B5Bu5 is significantly reduced by 30% as compared to D100 due to the oxygen-rich regions brings by oxygenated fuels and micro-explosion that lead to complete combustion. However, for the CO_2 emission, the B5Bu5 is increased 28.8% which nearly to 30% as compared to D100 due to complete combustion process from CO to CO_2.

5.3 Recommendation and improvement

Throughout the study, I think that engine should be setup by the professor, manufacturer, dealer or some experienced persons. This is because setting up an engine is very complicated and need some special tool in order to align the engine. A poor alignment will caused excessive wear on bearing, premature shaft, vibration and noise, or even the failure of coupling and foundation bolts. So, the engines or parts will be damaged in a long term..

In the future work, researcher can add additive or use other surfactant to improve the oxidation time. Once the stability time is improved, then those fuels fail to reach 3 hours oxidation time can proceed to engine and emission testing to observe the performance.

Besides that, researchers also can conduct the experiment with various engine speeds or various loads on dynamometer in order to determine the engine performance or exhaust gas emission of the sample fuels. Therefore, more specific data and results can be used to analysis the trends of the sample fuel in term of engine performance and emission over the various engine speeds and various loads and then compare with the simulation result.

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APPENDIX A
DATA SHEET OF NP-9 SURFACTANT

PRODUCT DATA SHEET

PETRONAS

TERGITOL™ NP-9 Surfactant

Nonylphenol with 9 moles of ethylene oxide adducts. Produced using technology licensed by The Dow Chemical Company.

CHEMICAL DESCRIPTION:

Name : Nonylphenol Ethoxylate
CAS number : 127087-87-0
Type : Nonionic Surfactant

APPLICATIONS:

- Cleaners & degreasers
- Agrochemical
- Oil in water emulsion
- Metalworking fluid
- Paint & coatings

TYPICAL PROPERTIES:

Average Molecular Weight, g/mol (nominal)	616
Specific Gravity @ 20°C	1.052 - 1.062
pH-1% in 10/6 ISOP/H2O	5.0 - 8.0
Water, wt%	0.3 Max
Color, PtCo	70 Max
Physical Appearance	Colorless to slightly hazy liquid
Cloud Point in 1% aq., °C (nominal)	54
Critical Micelle Concentration (1% aq), ppm (nominal)	60
HLB (nominal)	12.9
Average Moles of EO	9
Pour Point, °C (nominal)	-1
Surface Tension (0.1% aq @ 25°C), mN/m (nominal)	32

FOR MORE INFORMATION

Please contact **PETRONAS Chemicals Group Berhad (PCGB)**, Level 21, Tower 2, PETRONAS TWIN TOWER, KLCC, 50088 KUALA LUMPUR, MALAYSIA.
Tel: +(603) 20515000 Fax: +(603) 20511501 or visit our site www.petronaschemicals.com

APPENDIX B
DETAIL OF ULTRASONIC HOMOGENEISATOR UP400S

Ultrasonic homogeneisator 400 watts UP400S for large samples

The ultrasonic processor UP400S (400 watts, 24kHz) is our most powerful laboratory device. With sonotrodes of a diameter range from 3 to 40mm the device is suited for sample volumes from 5 to 2000ml. In flow approx. 10 to 50 liters per hour can be treated. For example, it is used for liquid treatment methods, such as homogenizing, dispersing, extracting and degassing, or for the breaking-down of cells. For the preparation of test portions the UP400S is mainly used for bigger volumes. It is suited for the practical process development in the laboratory but also in the college of technology as well as for the production of small quantities.

For production quantities a PC-control or a connecting lead to a central control of the user's plant is recommended in order to raise the process safety. With special flow cells and flange connections liquids can also be sonicated at high temperatures and pressures.

High power generates the intensive cavitation required, but this results in unwanted noise. For operating the UP400S we recommend to use the sound protection box.

Several accessories are available for the UP400S. Below, you will find its technical specifications.

UP400S in the sound protection box

Technical Data	**UP400S**
power	400W
power control	amplitude 20-100%
pulse range	0-100%
operating frequency	24kHz
dimensions	(LxWxH) 190x200x130mm
weight	3.3kg
power supply	230V~, 4A, 50-60Hz 110-120V~, 6.3A, 50-60Hz

APPENDIX B
PICTURES OF STABILITY TEST

Before:

After: