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Properties Modification of Crude Jatropha Oil for Utilization as Fuel in Direct Injection Diesel Engine

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Abstract – *Renewable energy sources from plant appeared to be an alternative source of fuel for diesel engine. Jatropha oil is one of the promising alternative choices. The aim of this research is to study the effect of modification of Jatropha oil fuel properties on direct injection diesel engine performance and exhaust emissions. Modification of Jatropha oil fuel properties such as transesterification process to produce biodiesel, addition of water to produce emulsion fuel and blended with diesel fuel have been conducted. However, due to high free fatty acid contents of Jatropha oil, transesterification process alone is unable to produce Jatropha biodiesel and this fuel has been omitted as test fuel from this study. The engine performance and exhaust emissions of 20% of Jatropha oil blends with diesel fuel (J20), and Jatropha emulsion fuel (J20 Emul) are measured and has been compared with conventional diesel fuel. A 600cc single cylinder direct injection diesel engine was used. The experiment was conducted at 1500rpm with variable engine loads. The results indicated that J20 Emul showed the highest brake thermal efficiency. There is no significant difference of brake thermal efficiency produced by J20 and diesel fuel. Brake specific fuel consumption (BSFC) for J20 Emul is the lowest at low load and do not exhibit much difference with other test fuel at high loads. For the exhaust emissions, J20 Emul produced lowest emission of nitrogen oxide (NOx) and smoke number while diesel fuel produced the highest smoke number for all loads and emission of NOx for low loads. J20 on the other hand, showed the highest NOx emission at high loads. For the emission of carbon monoxide (CO), both J20 Emul and J20 show slight increment compared with diesel fuel.*

Keywords: Jatropha oil, fuel properties, diesel engine, NOx emission

1.0 INTRODUCTION

Biodiesel is an alternative fuel which was developed a few decades ago to substitute diesel fuel. Biodiesel is a variety of ester-based oxygenated fuels derived from natural, renewable biological sources such as vegetable oils. The name indicates the use of this fuel in diesel engine as an alternative to diesel fuel. Biodiesel operates in compression ignition engines like petroleum diesel thereby requiring no essential engine modifications. Moreover, it can maintain the payload capacity and range of conventional diesel. Biodiesel can be made from new or used vegetable oils and animal fats. Unlike fossil diesel, pure biodiesel is biodegradable, nontoxic and essentially free of sulphur and aromatic.

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Biodiesel are made from different sources. Most commercialized biodiesel are made from the source that is also being used as foods. This will give impact on food supply and rise the demand as well as price of particular oil. Therefore, this research will make use of Jatropha oil which is not a source for food and being grown specifically as fuel.

Pure vegetable oil can also be used directly into diesel engine, but it will create some problems to the engine. According to Prasad et al. [1], they observed major differences between diesel fuel and vegetable oil such as the significantly higher viscosities, moderately high densities, lower heating values, rise in the stochiometric air–fuel ratio due to the presence of molecular oxygen and the possibility of thermal cracking at the temperatures encountered by the fuel spray in the naturally aspirated diesel engines. These characteristics often resulted in poor atomization, carbon deposits and wear. The high viscosity of vegetable oils will cause problems in the injection process leading to an increase in smoke levels and the low volatility of the vegetable oils resulting in the oil sticking to the injector or cylinder walls, causing the deposit formation which interferes with the combustion process. In order to improve the engine performance modification of the vegetable oil must be done to improve their properties.

On the other hand, modification of vegetable oil properties can be made by the addition of water to produce emulsion fuel. The term emulsion is a mixture of two or more immiscible liquids. One liquid is dispersed in the other. There are 2 types of emulsion which are oil in water (O/W) also known as direct emulsion and water in oil (W/O) which is known as inverse emulsion. According to Antonov [2], the emulsion types of W/O can be used as an alternative fuel. This is due to the reliability of ignition and the nearly complete and fast combustion when the emulsion fuel is sprayed through the nozzles as the water remained within the drops under the emulsifier layer, while the fuel remained outside. If O/W type emulsion is use, the water comes into direct contact with the fuel feed system and the cylinder-piston group, this will result in failure of these parts and increasing wear.

During the combustion, the droplets of diesel and biodiesel are huge, the combustion time available are not sufficient for them to burn completely. But, for emulsion fuel, their droplets are relatively small due to the micro explosion, so the fuel can be burn completely. According to Dryer [3], the micro-explosion combustion induce the generation of more fuel particles, promote complete combustion, and reduce the generation of soot, NOx, CO and other pollution materials without deteriorating combustion efficiency.

According to Abu Zaid [4], he found that the emulsion fuel gave better performance relative to diesel. The engine torque, power and brake thermal efficiency increased by using the emulsion fuel. Besides increasing the water content in the emulsion fuel will increase the performance. Using diesel emulsion will decrease the brake specific fuel consumption and gas exhaust temperature. From Sii et al. [5], they found that the best performance of the machine with respect to efficiency and NOx and soot emissions was when operating at 40% water by volume. Besides, there was no obstacle using emulsion fuel with 5% to 10 % of water content to run the diesel engine.

According to Bidyut and Satya [6], the micro-emulsion-based fuels are able to increase the octane number of gasoline and the corresponding octane number for diesel oils. Micro-emulsions in fuels are also found to improve air–fuel contact and increase the flash point of fuel.

Ballester et al. [7] concluded that the use of water in oil emulsions is an effective method for the reduction of the particulate emission in heavy oil combustion. Similarly Kadota, and Yamasaki [8], observed that during the combustion of the emulsion fuel, the dilution of water vapor would suppress the chemical reaction in the gas phase due to the reduced rate of heat release in the flame. As a result, it will decrease the production of NOx. The addition of water would cause an increase in OH radicals which is very effective in the oxidation of the soot precursors. The enhanced oxidation of soot by the additional OH radicals might also be one of the significant factors to reduce the soot formed in the gas phase.

For the percentage of water content in emulsion fuel, higher percentages of water content have also been investigated relative to 5-10% of water content normally use by most researchers. It has been claimed that the optimum water content for PM reduction is between 10 and 20% [9]. Samec et al. [10] studied the effect of 10 and 15% water in the diesel on emission levels of NOx, hydrocarbons and soot, as well as on the specific fuel consumption. The values obtained, were relative to the values for neat diesel. They found a considerable reduction in both hydrocarbons and soot at 10% water. The NOx reduction seems to be more water dependent and a 15% level is needed in order to obtain a significant effect.

This study attempt to modify the Jatropha oil fuel properties by using transesterification process, water addition and diesel fuel blend methods in order to have improved diesel combustion performance and exhaust emissions.

2.0 TEST FUELS

Jatropha is a genus of approximately 175 succulent plants, shrubs and trees, from the family Euphorbiaceous. It is cultivated in Central and South America, South-east Asia, India and Africa and commonly used to prevent and control erosion, as well as grown as hedges. A picture of the Jatropha fruits is shown in figure 1.

Figure 1: Jatropha Fruits

The Jatropha fruit is a suitable source for alternative fuel because:-

- Approximate 33% oil yield from the fruit.
- Grow well in tropical climates.
- Produced fruits after 6 months of cultivation.
- Low maintenance, the use of pesticides and other polluting substances are not necessary.

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- Not an edible oil.

The Jatropha oil is extracted from the fruits and after filtration is brown in color. Table 1 shows the properties of Jatropha oil compared with diesel fuel.

Table 1: Properties of Jatropha oil [11]

Specification	Jatropha oil	Diesel fuel
Specific Gravity	0.9186	0.82
Flash Point(°c)	110	50
Carbon Residue (%)	0.64	0.15 or less
Cetane number	51	>50.0
Distillation Point(°c)	295	350
Kinematics Viscosity(cs)	50.73	>2.7
Sulphur(%)	0.13	1.2% or less
Calorific Value(KcaL/kg)	9470	10170
Pour point(°c)	8	10

From table 1, the kinematics viscosity for Jatropha oil is significantly high relative to the diesel fuel. Since the Jatropha oil is highly viscous, resulting in the reduction of volatility and causing problem during combustion process. High viscosity has a negative effect on atomization quality, engine performance and exhaust emission are affected badly, and this causes failure of engine parts [12]. According to Nasser [13], fuel with high viscosity will result in an incomplete combustion and produced residue in the fuel injector and engine oil contamination. Unburned particle will result in an increase in the emission gases like hydro carbon because the unburned particle will be released from the combustion chamber through the exhaust manifold as exhaust gases into the environment.

This study is aimed towards the production of biodiesel from Jatropha oil to become Jatropha Oil Methyl Ester (JOME). Biodiesel made from vegetable oil generally has significant lower kinematic viscosity and density compared with its original condition. The common method to produce biodiesel from vegetable oil is through transesterification process which is a chemical reaction between triglycerides and alcohol. The alkaline liquid can be used as catalyst together with sodium or potassium oxide. The long and branched chain triglyceride molecules are transformed to biodiesel and glycerin [8]. In this study, not all of the Jatropha oil can be converted to JOME. The reason being due to the high FFA contents in Jatropha oil. For crude Jatropha oil, its FFA content is 14.9% and transesterification process is only effective when there is 2% or less FFA content in the vegetable oil [14]. Jatropha oil with high content of FFAs cannot be directly used in an alkali catalyzed transesterification process because FFAs react with alkali catalyst to form soaps, resulting in serious emulsification and separation problems. Pre-esterification catalyzed by homogeneous acids, such as sulfuric acid, phosphorous acid, or sulfuric acid, is a conventional and useful method to reduce the content of FFAs, which converts FFAs to valuable fatty acid methyl esters [15]. Due to the complexity and ineffectiveness of producing biodiesel from Jatropha oil, the study of using JOME was abandoned.

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Another modification of Jatropha oil properties has been done by the addition of water to produce emulsion fuel. Several types of surfactant or emulsifier had been tested to produce W/O emulsion. None of these surfactants can produce a stable emulsion using 100% Jatropha oil. However, blended fuel between 20% volume of Jatropha oil and 80% volume of diesel fuel (J20) was successful in producing a stable emulsion fuel by using "Span 80" as surfactant and named as "J20 Emul". Diesel engine performance and exhaust emissions using this fuel have been tested together with J20 and diesel fuel as comparison. Fuel properties of these three fuels are shown in Table 2. From Table 2 it can be seen that the density of J20 and J20 Emul were respectively 1.76% and 7.16% higher compared with diesel fuel. The reason for the higher density of J20 Emul is due to the presence of water. The kinematic viscosities of the test fuel were measured at temperature of 40°C by using the kinematic viscometer device. J20 Emul has 10 times and J20 has 1.36 times higher kinematic viscosity compared with the diesel fuel. For the kinematic viscosity, J20 Emul has the highest value (39.833 cST). This might be due to the sediment of J20 Emul solution which became more difficult to flow through the capillary tube.

Table 2: Test Fuels Properties

Test fuel	Density, g/ml	Kinematic Vicosity, cST
Diesel	0.852	3.979
J20	0.867	5.42
J20 Emul	0.913	39.833

Fuel distillation curve for diesel fuel, J20 and crude Jatropha oil has been measured and is shown in Figure 2. Distillation curve for J20 Emul could not be measured because the fuel has separated into J20 and water at high rate when heated at high temperature normally used in the distillation measurement method.

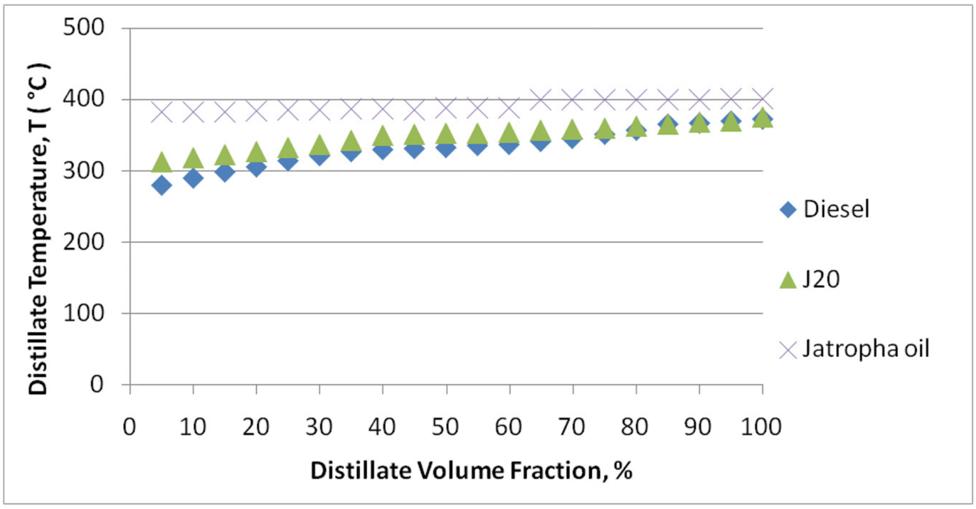

Figure 2: Distillation Curve for Diesel Fuel, J20 and Jatropha Oil

Generally, distillation temperature of fuel component will affect fuel evaporation inside combustion chamber. From Figure 2 it can be seen that distillation temperature for diesel fuel ranged from 280°C to 373°C. Low-end distillation component of diesel fuel is important to start the engine. Jatropha oil has high temperature distillation component ranged from 383°C to 401°C. High temperature distillation components are difficult to evaporate inside the combustion chamber and can cause problems such as dilution of lubrication oil in crank case, uneven fuel distribution during fuel injection and deposit formation on the injector nozzle tip. Blending fuel to become J20 has equipped the fuel with low-end distillation component and lower the overall temperature of distillation component in Jatropha oil

3.0 EXPERIMENTAL SET UP

The test engine is a four-stroke single cylinder naturally aspirated direct-injection diesel engine (Lister ST1). The base engine specifications are given in Table 3. The engine is 94.8 mm cylinder diameter and 90 mm stroke. The compression ratio is 16.

Table 3: Engine Specifications

Parameter	Specification
Engine type	DI diesel engine
Model	Lister ST 1
Number of stroke	4 stroke
Number of cylinder	1
Bore	94.8 mm
Stroke	90.0 mm
Power	10.5bhp
Maximum speed	3000rpm
Volume displacement	600cc
Compression ratio	16:01

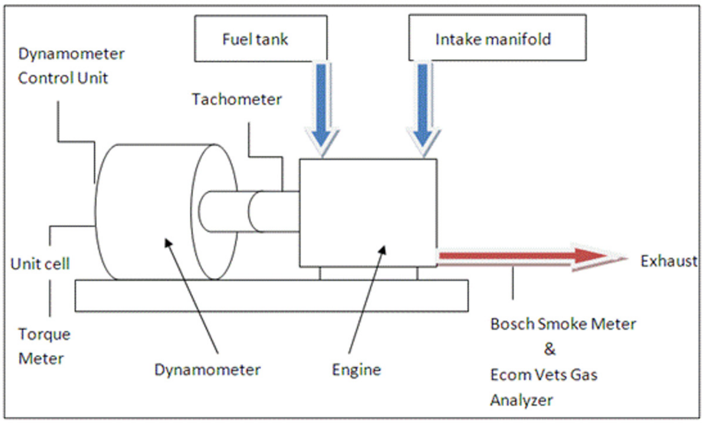

Figure 3: Schematic Diagram of Experiment Apparatus

Figure 3 shows the schematic diagram of the experimental apparatus. Engine performance and emissions data are obtained under stable operating conditions at engine speed of 1500rpm. Carbon Monoxide (CO) and Nitrogen Oxides (NOx) concentration are measured with a diesel exhaust gas analyzer (Ecom Vets Gas Analyzer) and smoke density is measured with a Bosch smoke scale.

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4.0 RESULTS AND DISCUSSION

Figure 4 shows the graph of Brake Specific Fuel Consumption (BSFC) versus load. All fuels showed a similar trend where BSFC decreased with increment of engine load. At 0% of engine load, BSFC for Diesel, J20, and J20 Emul are 7.35 kg/kW.h, 12.9 kg/kW.h, and 4.18 kg/kW.h respectively. BSFC for each test fuel decrease greatly from 0% to 20% of engine loads. BSFC for each test fuel had almost the same value after 40% of engine load. BSFC are lowest while operating at approximate 65% of engine load for all test fuels.

At low load engine condition, BSFC for J20 is 80% higher than diesel fuel while BSFC for J20 Emul is 47% lower than diesel fuel. J20 has higher kinematic viscosity than diesel fuel. Higher kinematic viscosity will cause lower volatility of fuel when injected into the combustion chamber and reached the wall of combustion cylinder especially at low load engine condition. Low temperature at low load engine condition will increase unburned fuel as well as BSFC.

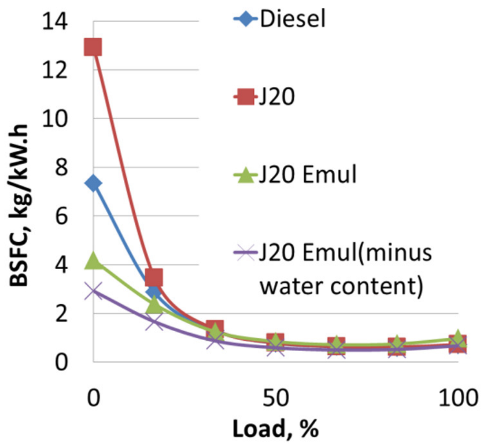

Figure 4: Brake Specific Fuel Consumption versus Load

Despite of having significantly high kinematic viscosity compared with J20 and diesel fuel, J20 Emul has the lowest BSFC at low load. This is due to the formation of a finer fuel droplet formed from micro-explosion (see Figure 5) and rapid evaporation of water. These will enhance complete combustion and increase fuel consumption efficiency Since water is not a fuel, actual amount of fuel burned for J20 Emul can be shown as “J20 Emul minus water” curve demonstrated in Figure 4. It can be concluded that, J20 Emul has the lowest fuel consumption at all loads compared with J20 and diesel fuel.

Figure 6 shows Carbon Monoxide (CO) emission versus load. Emission of CO for J20 and diesel fuel will decrease until a certain engine load before it increased greatly at full engine load.

At 0% engine load, the emissions of CO are the same for each test fuel which is 615ppm. During 35% of engine load, CO emission for Diesel and J20 is 567ppm and 570ppm respectively. But for J20 Emul is 671ppm. The CO of J20 Emul kept increasing to 4767ppm at full engine load. The emission of CO for diesel and J20 decreased to about 400ppm before it increases again to 3839ppm and 4451ppm at full engine load.

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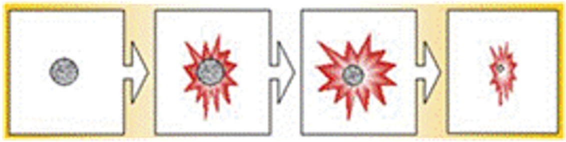
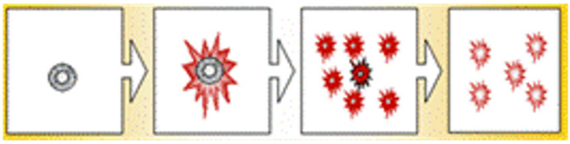


Combustion process of fuel droplet



Micro-explosion occurs during combustion of emulsion fuel
Figure 5: Illustration of micro-explosion

CO emission increased greatly at full engine load due to the lower AF (Air-Fuel) ratio. When the engine operates at higher loads, the AF ratio will decrease. Incomplete combustion occured in the combustion chamber, thus some residual fuel will be emitted with the exhaust gas. It will thus increase the CO emission.

The J20 Emul has shown slightly higher CO emission compared with the other two test fuels due to the water content. During combustion, the water was used to absorb the heat for vaporization hence resulting in the shortening of the oxygenating time for the CO. As a result, the CO emissions increased. The formula for calculating the CO oxygenating rate K_CO is:

$$CO+OH \leftrightarrows CO2+H$$

where, K_CO=6.76 x1010 exp [T/1102] cm3/gmol [16].

According to this formula, when the temperature T rises, the CO oxygenation rate rises. However, the increment percentage of CO when using J20 Emul is not significant.

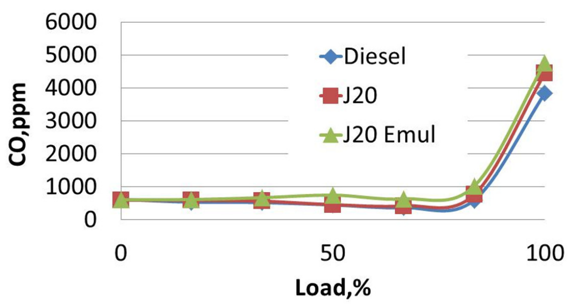


Figure 6: Carbon Monoxide versus Load

Figure 7 shows the NOx emission versus engine load. A positive slope was obtained for each of the test fuels. NOx emission increased at higher engine loads. At 0% of engine load, NOx emission

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for Diesel, J20, and J20 Emul is 225ppm, 185ppm, and 173ppm respectively. Diesel fuel had shown the highest NOx emission from 0-60% of engine load. However, after 60% engine load, NOx emission emitted from J20 had surpassed the diesel fuel NOx emission. NOx emission for J20 Emul is the lowest for all loads.

The formation of NOx originated from the nitrogen bearing fuel, excess oxygen, high exhaust gas temperature and the excessive time in the reaction zone [17].

J20 Emul had shown the lowest NOx emission due to lowest in-cylinder temperature. As mentioned earlier, there is 30% of water content in the J20 Emul. During the combustion reaction, the water evaporated in the combustion chamber. Evaporation process of water will absorb heat from inside the combustion cylinder. This will create lower surrounding temperature within the combustion chamber hence lowered the NOx production.

J20 showed a lower NOx emission than diesel fuel at engine load lower than 60% due to higher kinematic viscosity of the fuel. As higher kinematic viscosity of J20 affected BSFC, similarly, the unburned fuel at low load will caused a lower temperature inside combustion chamber as well as NOx emission compared with using diesel fuel. However, at load 60% and above, further higher temperature within the combustion chamber can overcome the effect of higher kinematic viscosity of J20. In addition, oxygen content of J20 can enhance combustion and increase the combustion chamber temperature, hence produced a higher NOx emission than diesel fuel.

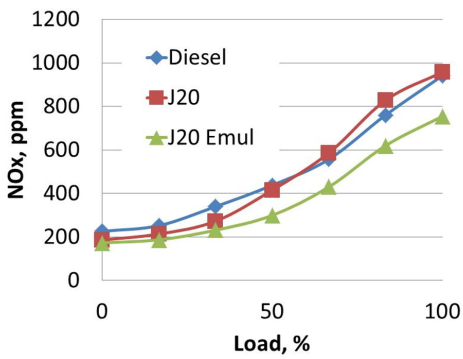

Figure 7: Nitrogen Oxide versus Load

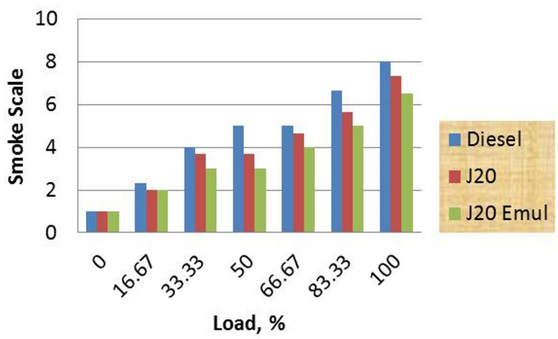

Figure 8: Smoke Scale versus Load

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Figure 8 shows the smoke scale versus engine load. From the figure it was observed that higher engine load caused higher smoke emission for all test fuels. Smoke emission is the same for each of the test fuel when the engines load were at 0%. However, significant increment of smoke emission for diesel fuel at higher engine load can be seen relative to other test fuels. Smoke emission of J20 Emul had shown the lowest for all engine loads.

At high load, high amount of fuel injected to the cylinder required high amount of oxygen for combustion mechanism. J20 has about 9% of oxygen content in fuel [18]. Oxygen in fuel contributes to improve combustion in fuel rich region where soot is formed [19]. Therefore, J20 can emit lower smoke emission than diesel fuel at high engine load.

In addition to oxygen content, the water content of J20 Emul contributed to a reduction of the smoke emission. J20 Emul can provide better combustion than diesel fuel and J20 due to the occurrence of micro-explosion as illustrated in Figure 5. Micro-explosion provides finer droplet hence enhance vaporization which reduce smoke particle formation at the end of combustion process. Furthermore, J20 Emul produced a lot of water vapor and it may dilute or dissolve some part of the black smoke particulates. This resulted in significant reduction of black smoke emission detected by Bosch Smoke Meter for J20 Emul.

5.0 CONCLUSIONS

From the results obtained in this study, it can be concluded that:

1. Biodiesel production from Jatropha oil would be costly compared to other vegetable oils due to its high content of free fatty acid (FFA) which will need an additional pre-esterification process.
2. Emulsion fuel (J20 Emul) was successfully produced from Jatropha and diesel fuel blend (J20).
3. Emulsion fuel (J20 Emul) showed the lowest Brake Specific Fuel Consumption, lowest NOx and Smoke emissions at all loads compared with J20 and diesel fuel. This is due to the positive effect of water content in fuel.
4. The higher emission of CO from J20 Emul combustion is not significant compared with the other two test fuels.

It is an economical approach to blend crude Jatropha oil with the addition of water in the conventional diesel fuel without compromising the diesel engine performance. Water addition is an effective way to reduce exhaust emissions of diesel engine.

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