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Characterization of Biodiesel for Use as a Fuel in Compression Ignition Engine

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ABSTRACT: Biodiesels are fuels that are made from renewable oils that can usually be used in diesel engines without modification. These fuels have properties similar to fossil diesel oils and have reduced emissions from a cleaner burn due to their higher oxygen content. The present work investigates the performance of three types of biodiesel and diesel fuels in a Mitsubishi 4D68 4 in-line multi cylinder compression ignition (CI) engine using transient test cycle. The test results that will obtain are brake power, specific fuel consumption (SFC), brake thermal efficiency and exhaust emissions. An instrumentation system also will be developed for the engine testing cell and controlled from the control room. Biodiesel was also tested against diesel fuel in Exhaust Gas Recirculation (EGR) system. Thus it is possible that biodiesel fuels may work more effectively than fossil diesel in certain applications.

KEYWORDS: Biodiesel, CI engine, transient, Instrumentation, EGR

I. INTRODUCTION

Biodiesel, is the generic terms for all types of Fatty Acid Methyl Ester (FAME) as one among other organic renewable alternative fuel that can be used directly in any conventional diesel engine without modification. They are transesterified vegetable oils that have been adapted to the properties of fossilized diesel fuel and considered to be superior since they have a higher energetic yield been combusted in the diesel engine. Current compression ignition (diesel) engines are able to operate upon a wide range of fuels due to its specific characteristic which is internal combustion under a variety of operating conditions. In a world of resources, it seems prudence to focus upon fuels which are potentially efficient and renewable, like bio-fuels. Besides this advantage in fuel flexibility, compared to those of spark ignition (petrol) engine, diesel engine can offer better engine durability, higher thermal efficiency and more economical fuel consumption. Through centuries, diesel engine was used in many sectors such as in transportation and industries. Diesel engine is used in heavy industries, automotive, ships, locomotive, transportation such as truck and buses, and also farm equipment such as lawnmowers and tractors. The latter relates to fuel economy savings that can potentially produce less carbon dioxide (CO₂) emission. Diesel engines are therefore, part of a long-term solution to global warming Diesel engine use fossilized fuel in its combustion process. However, it is estimated that the fossil fuel supply will decrease in the future. This is happening due to maximum production of the fuel which cause fuel reserve been decrease drastically to a minimum level. Eventually it leads to demand succeed supply and finally increase the fossil fuel price. Beside that fossil fuel use also leads to environmental problems such as toxic emission and releasing of harmful particles. This particulate matter (PM) generated from the unburned hydrocarbon which forms black soot. It is found that the particulates can result cancer, respiratory diseases and others that can affect the health of human [1-8]. In order to solve those problems, many researchers trying to discover new technology such as solar cars, hybrid cars, hydrogen fuel cell cars and such on to replace most of the internal combustion engine including diesel engine. Even though many successful findings been recorded years ago, but still expensive in terms of cost, impractical and need better research to improve it.

The most preferred solution is using the renewable alternative fuels that can support the diesel engine. Those alternative fuels are not been produced by the fossil fuel distillation but been extracted through a chemical process called transesterification process to produce methyl ester or ethyl ester that fueled the diesel engine without any modification. Those fuel properties similar to diesel fuel but produce less emission and same or higher performance than the diesel fuel itself.

Internal Combustion Engine Background

Internal combustion engine has been developed since 1876 when Nicolaus Otto introduce spark ignition engines and in 1911 when Rudolf Diesel presented the world with the compression ignition engine, which at that time did not have a

specific fuel. Diesel claimed that the engine could be fed by vegetable oils which his engine running on peanut oil. According to [9], internal combustion engine development is evolving due to increase knowledge on the engine operation, new technology, and the demand on new engines that less affecting the nature. In an internal combustion engine, mechanical power is generated due to fuel combustion reaction that converts chemical energy into heat energy. Mechanical energy will rotate the output shafts which will be used to move loads. One of the internal combustion engine applications was used in automobiles where the engine is the power train for the automobile. Engine type that been used in automobiles are called reciprocating engine and it use fuel derived from fossil oil distillation. Engine that use gasoline as fuel called spark ignition engines while compression ignition engine consumed diesel fuel. Other application includes stationary engine in generators or pumps and portable engine in equipment such as lawn mowers and chain saws.

Beside reciprocating engine, wankel engines or rotary engine also known as an internal combustion engine. Instead of using reciprocating piston, it use a rotor to deliver power for automobiles, small aircraft, go-karts, personal water craft and auxiliary power units for aeroplane. Other types of internal combustion engine can be found in jet engines, rockets, and gas turbines which might have different type of combustion process but still burn fuels in a confined space. In this research, compression ignition engine or diesel engine which is a reciprocating engine will be emphasized.

Diesel Engine Type

Diesel engine can be divided into several categories such as cycles, cylinder arrangement, displacement, method of fuel input, cooling systems and applications. There are two type of diesel engine according to cycles which is two stroke cycles and four stroke cycles. Most of the large diesel engines run on two stroke engines while medium and small diesel engines operate on four stroke engines. There are two methods that cooling the engine which are using liquid or air. Liquid cooling is the common type using in the automotive industry. Diesel engine can be available in various sizes depending on the engine block configuration and cylinder arrangements. Single cylinder or multi-cylinder contains from two until eight cylinders and arranged in various patterns. The most common is in-line design where cylinders been positioned in a straight line along the crankshaft length. The V- type cylinder arrangement uses two banks at an angle of 15° - 120° with each other banks along a single crankshaft. The most common V type engines for automobile is V6 and V8 at an angle of 60° - 90° . The diesel engine also been differentiate by the displacement volume it can produce. Engine displacement is the air volume displaced by the piston when it moves from bottom dead center (BDC) to top dead center (TDC) during compression stroke. The displacement volume depends on the cylinder bore size, piston stroke length and number of cylinders.

Diesel engine can also be classified according to fuel input method. One of the methods is Indirect Injection (IDI) which divides combustion chamber into two segments. Fuel will be injected into pre-combustion chamber that situated at upper part of the engine block. The pre combustion chamber connected to the main combustion chamber by a nozzle. Another method is Direct Injection (DI) where fuel been injected into the main combustion chamber to react with the hot air inside the cylinder during the compression stage. There is also homogeneous charge compression ignition which some fuel added during the intake stroke.

Diesel Engine Application

Diesel engine is widely used due its efficiency, power delivered, low cost, environmental friendly, and easy to design [10-15]. Most of the applications require diesel engine reliability and high torque output. Diesel engine application can be divided according to the speed generated from the engine. High speed engines generates speed from 1200 rpm upwards are used in buses, trucks, tractors, compressors, cars, pump and small electrical generators. Medium speed engines use in large electrical generators can run speed from 300 rpm to 1200 rpm. While for ships, large compressors, and pumps also use medium speed engines. Medium speed engine can be available in two strokes or four strokes types. Low speed engine normally used by large ships and power generation units. The large two strokes engines usually operate within range 60 rpm to 120 rpm at engine speed. Diesel engine is been used to produce high torque and run smoothly for automobile. Automobiles powered by diesel engine can capable reaching maximum speed until 5500 rpm. For heavy transportation vehicles such as trucks, diesel engine provides advantage in fuel consumption due to the DI fuel input method. Agricultural and construction machinery also use diesel engine because it provides durability, reliability and easy to maintain. For heavy duty application such in railway locomotives and marine ships which run continuously, it needs higher thermal efficiency and better fuel consumption that can be provided by diesel engine (Bauer et al. 2004).

Diesel Engine Technology

From years to years, modifications and improvements has been done to the diesel engines in order to maximize the performance that generated from the engine to run efficiently. According to [16-24], during the initial stage in producing high speed engines, problem in supplying fuel was encountered. Usually for lower speed engines, air blast method was used at that time. This method sprayed fuel into the combustion chamber by using compressed air and not suitable for high speed engine. Robert Bosch has tried to create fuel injection system for diesel engine and succeeded designing fuel injection pump [25-34]. New diesel engines are cleaner compare to earlier version of the diesel engine due to the achievement of complete fuel combustion. This also follow the regulations and standard of emission that been enforced by Environmental Protection Agency (EPA), United States with FTP (Federal Test Procedure) and Economic Commission for Europe (ECE). Nowadays direct injection fuel systems have three type of injection method which is using distributor, common rail and unit injection. Distributor pumps supply fuel to the entire cylinder in the engine within high pressure. In a common rail injection system, pressure generation and fuel injection are separated. The injection pressure depends on the engine speed and fuel is injected and controlled by a high pressure pump. The fuel will supply into the fuel rail and fuel will be injected into each cylinder through a nozzle from the rail. Fuel injected quantity is calculated by an Electronic Control Unit (ECU). In a unit injection method, fuel is also injected directly into the cylinder in the engines. However unit injection contains injector and pump in one unit positioned over each cylinder.

Technology such as fuel injection controlled electronically using Electronic Diesel Control (EDC) has improved the power and torque of the diesel engine. Besides that, diesel engine been customized with turbocharger or supercharger to produce highertorque. Turbocharger also can reduce emission and sound pollution. In reducing Nitrogen Oxide (NO_x), exhaust gas are diverted back to the engine and flows back into the cylinder. Exhaust gas reduction also can be achieved by cooling the exhaust gas withthe heat exchanger. This system is called Exhaust Gas Recirculation (EGR).

Conventional Diesel Fuel

Diesel fuel is produced from crude oil or fossil oil distillation. Diesel fuel consists of hydrocarbon (HC) compound and has boiling temperature within range 160°C - 380°C. Diesel fuels can combust at temperature almost 350°C. Diesel fuel has density of 850 gm/liter and release 40.9 MJ/liter when burned. Since diesel fuel contains high level of pollutants, it must go through additional filtration which contributes higher cost. The diesel fuel properties enable the fuel to operate in a diesel engine. Diesel fuel properties include Cetane Number (CN), fuel density, viscosity, sulphur contents and cold behavior at certain temperatures. Even though diesel fuel is economical in fuel consumption, it still emits 69% toxic gases that contribute to the green house effect and contains high sulphur content which harmful to environment (Bauer et al. 2004).

Overview of emission regulation and controls

Increased 'dieselisation' especially in cars in combination with the ever-increasing demand for jet-fuel, leads to an unbalanced use of oil-based fuels, i.e. less gasoline consumption and significantly increased diesel fuel consumption. Diesel engines were associated with combustion noise, engine vibration, and the problem of nitrogen oxides (NO_x)-particulate matter (PM) trade-off emissions. Currently, the EURO 6 emission legislation for an introduction in 2012/13 is in discussion. Particulates limits will be reduced to enforce the use of diesel particulates traps and it is likely that the NO_x standards will be further reduced while maintaining other conditions such as OBD (On- Board Diagnostics), emission limits and emission stability will remain. According to Knecht (2008), it is expected, that more stringent regulations with respect to off-cycle emissions including an NTE (not-to-exceed)-concept will be introduced. Furthermore, a world-harmonised test procedure including the WHSC (World Harmonised Steady-state Cycle) and the WHTC (World Harmonised Transient Cycle) will be the base for emission testing. The choice of a test cycle can affect the engine technology significantly. It is well known that the average cycle speed and the average cycle load of today's transient cycles (Europe, Japan, USA) vary quite considerably.

Efforts have been made by researchers to reduce toxic and greenhouse gases emitted from these engines. Several advanced technologies for clean diesel engines have been introduced and categorised into four strategies: (1) fuel and fuel additive, (2) fuel injection systems including in-cylinder technology, (3) lubricant oil development, and (4) exhaust gas after-treatment devices. All these approaches have been developed to varying degree since internal combustion (IC) engines were invented.

Project Overview

The use of renewable alternative fuels to replace the conventional fossil fuels and its potential was well known and been studied many years in other continents such as Europe and America. This been proved by the certified significant results from the many research that been conducted and the regulations and standards enforced by various agencies. However in Malaysia, alternative fuel usage is still doubtful stage due to lack support from the public and also the government agencies. Many people are uncertain of the performance generated by the diesel engine using the alternative fuels. This research determines the performance and emission generated by four stroke diesel engine to gather more technical data that useful for the research field enhancing the use of alternative fuels rapidly. The alternative fuels used in this research are Palm Oil Methyl ester B100 (100% palm oil) that been produced by three method of transesterification process and also conventional diesel fuel provided by Petronas. The engine performance test will be performed using the alternative fuels and conventional diesel fuel in order to obtain engine performance characteristics and also exhaust emission based on transient mode of cycles. Among the characteristics considered are brake power, maximum torque, engine speed, fuel consumption, performance index, thermal efficiency, torque and crank angle. The data obtained throughout the research will be converted to graphical form in order to study the patterns of torque-power curve and determine the engine performance with different fuels. Besides that, level of emission and also its content been compared with different fuels to determine which alternative fuels has better and environmental friendly.

Problem Statement

The purpose of this research is to determine engine performance and level of exhaust emission generated by palm oil methyl ester and conventional diesel from Petronas. Several objectives are aimed in order to achieve the research goals and performing there search smoothly. Among the objectives are:-

- a) To commission an engine test rig fully equipped with the instrumentations system.
- b) To determine engine performance and exhaust gas emissions during combustion of diesel and biodiesel fuel with transient mode of cycles.

This research work is initiated by the recent interest in the use of biodiesel as a part-substitute for diesel fuel. There is a need to extend research on engine performance and emission effects of such fuels in order to obtain the data required by motor industry. The research was performed on the engine test rig which comprised of a Mitsubishi 4D68 SOHC Direct Injection 2.0L diesel engine coupled on ECB eddy current dynamometer. The test engine is equipped with cylinder pressure data acquisition equipment, exhaust gas emission measurement devices, an exhaust gas extraction system, an engine cooling system (turbocharger intercooler, engine cooler, and fuel cooler), fuel/air-flow measuring instruments, and an engine management system (EMS). The engine dynamometer set includes: the brake cooling systems (both air and water), measuring devices, and load control systems (mechanical and electrical). Furthermore, it requires a ventilation system in the test cell. The Mitsubishi diesel engine was tested at different engine operating condition points by using the aforementioned of biodiesel fuels with conventional diesel fuel in order to determine the quantitative impact on engine performance and emissions. The tests were based on the engine dynamometer over a sequence of steady-state modes and were operated for the prescribed time in each point for specific speeds/loads. Emissions were measured during each mode and averaged over the cycle using a set of weighting factors. Regulated emissions: HC, NO_x, CO, and smoke, as well as other major gases: carbon dioxide (CO₂) and oxygen (O₂) were measured. Several engine combustion performance indicators have been determined such as: cylinder pressure trace, heat release pattern, fuel consumption, and thermal efficiency.

III. MATERIALS AND METHODS

Engine specifications

The apparatus used for conducting the emission testing and analysis of the engine exhaust sample is located in Automotive Lab, Universiti Malaysia Pahang at Pekan. The first thing to start with was an engine and a dynamometer set up, the automotive engineering lab already consisted of a 150 KW eddy current dynamometer model ECB which was previously being used for engine testing as shown in Figure 1. The distributor pump in the Mitsubishi 4D68 engine was equipped with a centrifugally controlled timing device for correction of start of delivery. Moreover, the distributor pump was also equipped with a boost control device, a boost pressure actuated diaphragm mechanism that

adjusts the maximum fuel delivery from the pumping element relative to the boost pressure. The delivery of fuel to the cylinders in a distributor pump always ends at the same stroke travelling independent of fuel quantity injected (Bosch 1996). The power unit was self contained in itself and came along with all the necessary components like vibration dampers, engine control unit and exhaust muffler mounted already. The specifications of the test engine are shown in Table 1.



Figure 1: Mitsubishi 4D68 SOHC 2.0 L Diesel Engine Testing rig

Performance of any fuel can be judged by the power and torque output that it can generate. Biodiesel has a higher cetane number than conventional diesel, but has a lower energy content per volume. Because of the lower energy content, using biodiesel without any change in the fuel injection system would result in a slight loss of engine power. Numerous studies have been undertaken to test these theoretical results. It should be noted that power and torque is difficult, if not impossible, to accurately measure in-use; therefore, power testing has occurred in controlled laboratory environments with specific duty cycles that are designed to stress engines. For example, the 200-hour Engine Manufacturers Association (EMA) test includes significant time where the tested engine is operating at full throttle [35-42].

Table 1: Specifications for a Mitsubishi 4D68 Diesel engine Model 1995

Descriptions	Specifications
Number of cylinders	4 in-line
Combustion chamber	Swirl chamber
stroke mm	Total displacement cm 1.998 cc (121.925 cu in) Cylinder bore mm x Piston 82.7 x 93 Bore/stroke ratio 0.89
Compression ratio	22.4:1
(JIS) 88.2 PS (87 bhp) (64.9 kW) @	
Maximum Power	
Maximum Torque	
4500 rpm	
Specific output 43.5 bhp/litre 0.71bhp/cu in	
(JIS) 177.0 Nm (131ft.lb) (18 kgm) @	
2500 rpm	
Bmep 1113.2 kPa (161.5 psi) Specific Torque: 88.59 Nm/ litre	
EGR type	Single type
Fuel system	Electronic control distributor-type injection

Instrumentation System

Instrumentation is about measurement and control. Instrumentation can refer either to the field in which instrument technicians and engineers work, or to the available methods of measurement and control and the instruments which facilitate certain project. In this research, the instrumentation system also will be developed according to the specifications that been developed by the previous study. Modifications to the engine and components were made as necessary to equip the engine with all the sensors, without compromising the functionality of the engine as shown in Figure 2. The engine was instrumented with sensors to record and monitor temperatures, pressures, flows, emissions, speed and torque. The location of these sensors were strategically placed to ensure the quality and accuracy of the measurements since these measurements were used for the combustion model and real time monitoring to stay within testing constraints and engine limitations

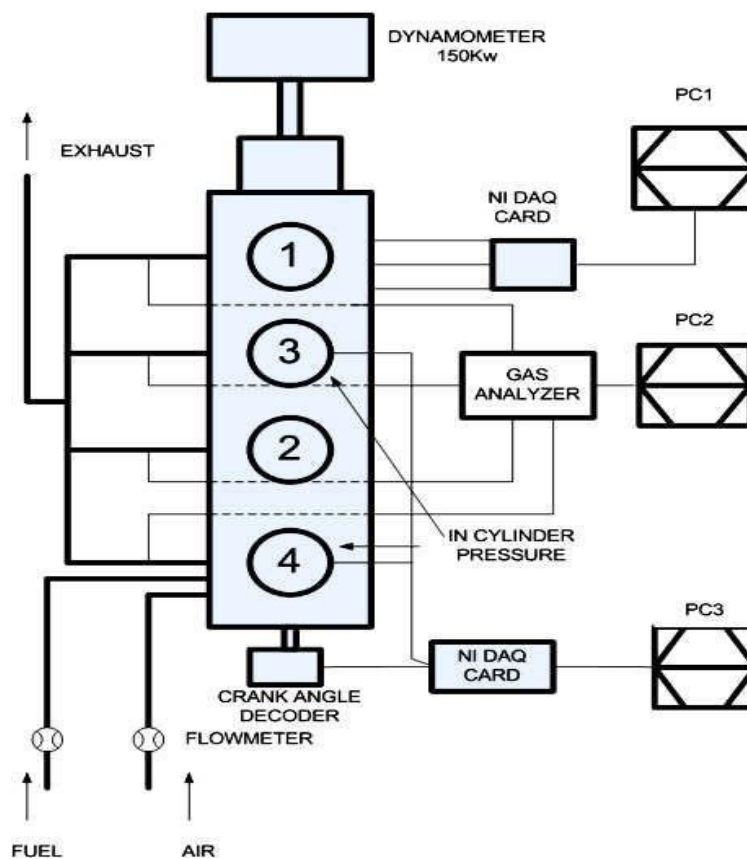


Figure 2: Measurement devices set up for Engine Testing

The instrumentation system also will integrate those physical properties into analog/digital input and can be appeared on the screen automatically and can be controlled without movement of the operator into the test cell as described in Figure 3. Fortunately National Instruments has a solution to those things with using of DAQ(Data Acquisition) card that able to interpret the data from the sensors and been monitored a LabVIEW-coded graphic user interface. According to [43-52], the role of DAQ in this research project is being a diverse and complex system of instrumentation hardware is employed to achieve the necessary level of measurement

detail and accuracy. Each piece of instrumentation hardware could be operated in isolation during a testing, being controlled and doing the measurements separately. This requires separate data files to be synchronized with respect to time involving extensive post-processing. Engine testing typically involve 1-2 hours of intensive measurements or 4-6 hours of periodic measurement with the engine operating at certain cycles, condition and rated power.

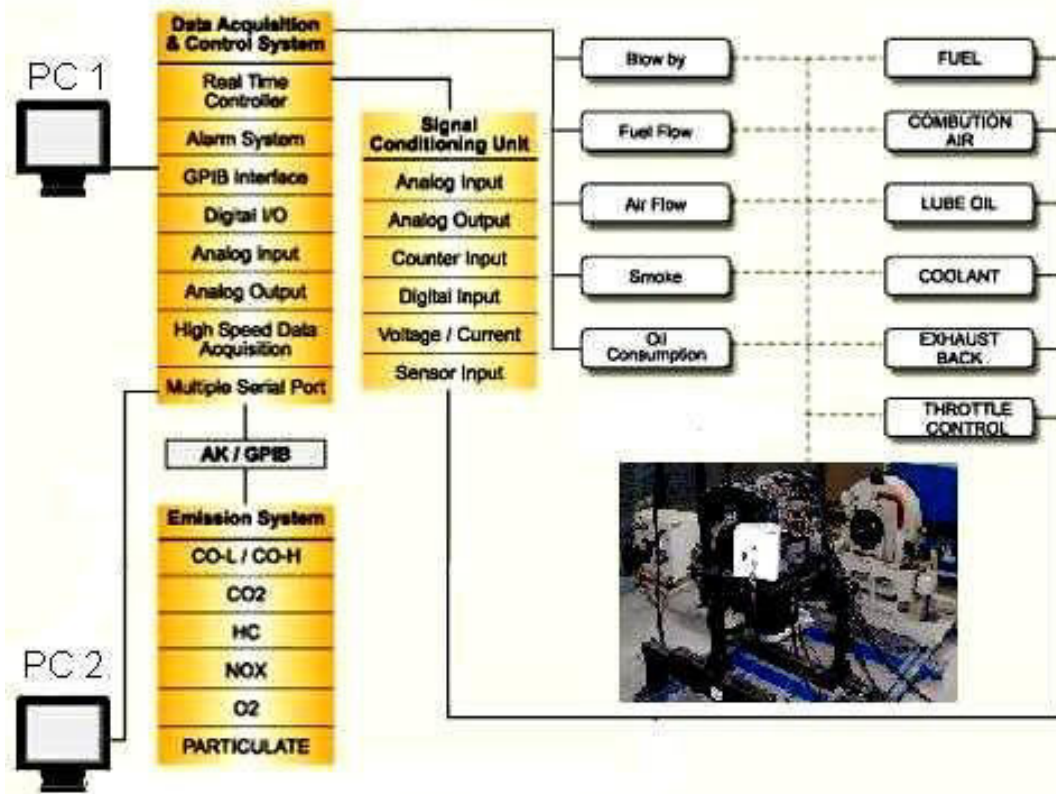


Figure 3: Description of instrumentation system function

The usage of a sophisticated DAQ system is giving the benefit to the test operator to pursue the actual project aims automatically. In this project, the challenge is how to develop a DAQ system which can be integrates a diverse collection of engine instrumentation devices and enable a highly efficient method of data post processing and analysis for accurate and rapid result interpretation that can be shown as table forms or graph forms. Other than that, this project aims to give the advantage to the test cell operator to conduct his/her testing automatically without any movement into the test cell and also trying to provide sophisticated engine monitoring and alarm systems for safety in the test cell. The solution for the project is using National Instruments LabVIEW 8.0 that highly adaptable and configurable and has been applied to exceed and meet the requirements and standard. Its function to integrate a diverse collection of engine test cell measuring devices into an efficient single point bespoke data acquisition package which also reduces operator workload and enhance test cell safety. Table 2 shows the specifications for the instrumentation system that will be used in the study.



Table 2: Specifications for the instrumentation system

No.	Type	Descriptions
1	Software NI LabView 8.0	Interfaced between the measurement and control hardware, analyzed data and displayed the results graphically in a real time application
2	National Instrument Data Acquisition (DAQ) Type PCI- 6220	Provide the I/O capabilities, measurement accuracy and software flexibility. 24 digital I/O; 32-bit counters; digital triggering NI PCI-6220 consists: Connector Block –Screw Terminal SCB-68 Cable shielded SHC68-68-EPM
3	Kistler CAM Crank Angle Decoder Type 2613B	An optical encoder system to provide the exact correlation between pressure measurement signal and crank angle position. CAM system 2613B consists: CAM encoder 2613B1 Signal conditioner 2613B2 Terminator 2613B4
4	Kistler Pressure sensors Type 7061 B (In cylinder pressure measurement)	Water-Cooled ThermoCOMP Measuring range 0-250 bar Equipped with : Connecting Cable Charge Amplifier Interconnecting cable
5	Kistler Thermocouple K-Type 6192B	Versions without connector for connection to temperature amplifier Type 2205A
6	Eddy current dynamometer Model ECB-200F SR No. 617	Devices used for engine testing and acts as power drive and power absorption equipment. Power 150 kW W (PAW) Max = 40 kg Dynamic constant = 9550
7	Dynalec Control Dyno Control Panel	Digital Controller for Speed and Torque for Eddy Current Dynamometer.
8	Signal Instrument Gas Analyzer	361 Prefilter 3000HM THC Analyzer 4000VM NOX Analyzer Multigas Analyzer 7000FM GFC IR Analyser Temperature Controller 200SM Series cooler
9	Kobold Fuel Flowmeter DF-HN	2.5 l/min. H205-24V DC



Fuel Samples and Properties

For the experiments with engine testing, there will be three types of fuel that been planned to be used which are first is the conventional diesel fuel itself that will providedby Petronas and represents the typical, Malaysia automotive, diesel fuel. Second, three types of biodiesel from crude palm oil (CPO) that will provided by researchers from Faculty of Chemical Engineering, Universiti Malaysia Pahang that will be used in this study conforms to the European standards the manufacture of biodiesel. Table 3 shows the standard specification of palm oil methyl ester produced by Malaysian Palm Oil Board (MPOB).

Table 3: Specifications of Palm Methyl Esters for Diesel Engine (MPOB 2008)

Property	Unit	Limits		Test Methods
		Minimum	Maximum	
Ester Contents	% (m/m)	96.5	-	EN 14103
Density at 15 °C	Kg/m3	860	900	ISO 3675 ISO 12185 ASTM D 4052
Viscosity at 40 °C	Mm2/s	3.5	5.00	ISO 3104 MS 1831 ISO 3679 MS 686
Flash Point	°C	120	-	ISO 20846 ISO 20884 ASTM D 5453
Sulfur Content	Mg/kg	-	10.0	
Carbon residue (on 10%distillation residue (on 100% distillation sample	% (m/m)	-	0.30 0.05	ISO 10370 ASTM D 4530
Cetane Number		51.0	-	ISO 5165 MS 1895
Water content	mg/kg	-	500	ISO 12937 ASTM E 203 ASTM D 1160
Oxidation stability, 110oC	Hours	6.0	-	EN 14112
Polyunsaturated (>=4 double bonds) methyl esters	% (m/m)	-	1	EN 14103
Monoglyceride content	% (m/m)	-	0.80	EN 14105 ASTM S 6584
Diglyceride content	% (m/m)	-	0.20	EN 14105 ASTM D 6584
Triglyceride content	% (m/m)	-	0.20	EN 14105 ASTM D 6584
Free glycerol	% (m/m)	-	0.02	EN 14105 EN 14106 ASTM D 6584



Petronas diesel fuel is a high cetane index fuel designed for use in low and high speed self-ignited compression engine to provide efficient, dependable and smooth operation. It has the proper viscosity suitable for critical fuel injection system to provide maximum protection against wear and leakage. Table 4 shows the specifications of Dynamic diesel fuel from Petronas.

Table 4: Specifications of Dynamic Diesel fuel (Petronas 2006)

Properties	Guaranteed level		Test Method
	Minimum	Maximum	
Cetane Index	45	-	ASTM D4737
Density @ 15°C, kg/m ³ 815 870	815	870	ASTM D1298 / D4052
Kinematic Viscosity @ 40°C, cSt	2.0	5.0	ASTM D445
Sulphur, % m/m - 0.5	-	0.5	ASTM D2622
Distillation, recovery @ 300°C, % vol 40	40	-	ASTM D86
Final Boiling Point, °C NilPour Point, °C	-	18	ASTM D97
Flash Point, °C	60	-	ASTM D93
Conradson Carbon Residue, % m/m - 0.1	-	0.1	ASTM D4350
Water, mg/kg - 500	-	500	ASTM D1744
Cooper Corrosion - 1	-	1	ASTM D130
Ash, % m/m - 0.01	-	0.01	ASTM D482
Sediment, % m/m - 0.01	-	0.01	ASTM D473
Strong Acid No., mgKOH/g - 0	-	0	ASTM D664
Total Acid No., mgKOH/g - 0.6	-	0.6	ASTM D664
Particulate, mg/l	Report		ASTM D2276
Appearance	Bright & Clear		Visual
Colour ASTM	-	3	ASTM D1500

Test Cycles and Experimental Procedure

In Europe, USA and Japan there is an obligation for manufacturers to certify new engine models to emissions performance standards. In order to control level of atmospheric pollution caused by vehicle engine emissions, the international legislation has established over the years a series of tests to evaluate the potential capability to pollute of different types of engines in order to impose restrictions to the commercialization of high polluting engines. These tests have been designed with the purpose of simulating real engine operating conditions by the performance of steady and transient test cycles. Tests cycles established by legislation specify the characteristics of the whole measurement system necessary to perform the test, including measurement configuration, devices and procedure [53]. The required specifications differ in its conditions from steady to transient tests. Non-road mobile equipment (non-



road diesel engines) is currently tested according to an eight-mode steady-state test cycle, ISO 8178 (ISO 1996). Another standard widely used is ECE Regulation No. 49 (ECE 2000) which includes 13 steady-state test modes. In a steady-state test cycle, emissions are measured at a sequence of several modes of fixed engine speed and torque. Average emission values for the whole cycle are obtained by summarising the measured emissions at the individual modes, according to different weighting factors (Hansson 2003). The procedure of the standards is one reason why most efforts in engine development recently have been directed towards improving the characteristics at static load conditions.

Transients in engine speed and torque, i.e. changes in engine speed and torque, occur frequently during the normal operation of non-road vehicles [54]. Fuel consumption and emissions of CO₂, CO, HC and NO_x were measured according to a 20-mode steady state cycle. The 20-mode steady-state cycle used was based on the 13-mode European ECE Regulation No. 49 test cycle (ECE, 2000) and extended with nine additional modes in order to increase the resolution as shown in Figure 4. The test cycle ECE Regulation No. 49 includes 11 unique engine load conditions, the remaining two modes are repetitions of the low idle mode. The fuel consumption and emissions were measured in accordance with the ISO 8178 regulation (ISO, 1996).

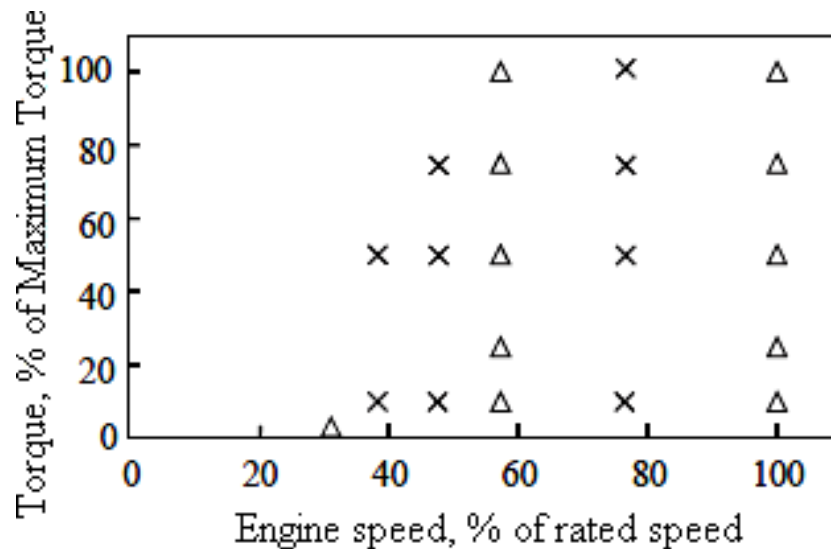


Figure 4: Twenty-mode steady-state test cycle based on ECE Regulation and extended with nine additional modes

IV. RESULTS AND DISCUSSION

All the tests and data analysis will be performed with different fuels in the Automotive Laboratory, Faculty of Mechanical Engineering, Universiti Malaysia Pahang at Pekan. In the research, there are some expecting results that can be referred from previous study. The test cycle modes will be running based on ECE (2000) 13 modes cycles which using different engine speeds and torques comparing with each fuel in the engine testing. The pattern of the graphs will indicate the performance of the engine using biodiesel and conventional diesel fuel. The correction of emission factor also will be considered to determine the best result for the study. Most of the biodiesel study is using diesel engine without any modification of any parts. Practically the performance of the engines was generally as good as on petroleum diesel. Previous studies also showed the engines were easy to start, with no knocking and smooth running. Most of the previous results showed that the exhaust emissions of the engines were much cleaner with less hydrocarbons, NO_x, CO₂ and SO₂; therefore, proven that the fuel was more environmentally-friendly.

Brake Power output

Author [55] found that the biodiesel fuel with additives produced higher brake power over the entire speed range in comparison to other fuels in his studies. It shows that the effect of fuel additive in blended biodiesel fuel influenced the conversion of thermal energy to work or increases the fuel conversion efficiency by improving the fuel ignition and

combustion.

Specific Fuel Consumption

Specific fuel consumption is totally depending which type of fuel that been used in the engine testing. Author [56] showed that the blended biodiesel with additives is produced higher fuel conversion compared with other biodiesel fuel at engine speed higher than 3500 rpm. Author [57] showed that B100 (100% soy biodiesel) had a higher brake specific fuel consumption (BSFC) when compared to fossil diesel. This reflects its lower heating value (about 12% lower than diesel).

In Cylinder Pressure

A research conducted by Spaddacini on autoignition characteristics under controlled conditions revealed that when the boost pressure increase (or pressure drop decrease), the ignition delay decrease, resulted to the higher peak pressure in engine cylinder (Heywood 1988). The ignition delays reduced associated with the reduction in premixing time when the boost pressure increase due to the increase of volumetric efficiency at constant intake oxygen. The ignition delay for RME (Rape seed Methyl ester) is shorter as compared to ULSD (ultra low sulphur diesel) due to higher bulk modulus of RME which caused an early injection event [58-60].

Oxides of Nitrogen (Nox) Emission

According to [61], NO_x that consists of nitric oxide (NO) and nitrogen dioxide (NO₂) where the nitric oxide is dominants with a small amount of NO₂ is produced from high combustion temperature and related with the individual fuel combustion temperature. The use of additives can help to reduce the combustion temperature by allowing high fuel conversion [62-72].

Carbon monoxide (CO) Emission

During the combustion process, CO is formed when the condition of insufficient oxygen to burn all the carbon in the fuel to CO₂. In eliminating effects of CO emission, a diesel engine will normally uses more oxygen (excessive air) to burn fuel and by theory, the combustion will fully complete.

Hydrocarbon (HC) Emission

Kalam (2008) also showed that the blended biodiesel fuel with additives produced the lowest HC emission compared with other fuels. The combustion of RME promotes very low unburned hydrocarbon compared to ULSD due to high burning rate estimated by heat release as reported by many researchers on biodiesel [73,74]. For the safety reason, the palm oil methyl esters did not produce an explosive air/fuel vapour. Instead, they offered enhanced safety with a higher flash point (120°C compared to 60°C of petroleum diesel). The quantity of carbon build-up in the engine nozzles was normal except that the nature of the carbon was different. For the consumer advantage the fuel consumption of palm diesel was comparable to that of petroleum diesel (e.g. 3-4km litre-1). Disadvantage of using the palm oil methyl esters as fuel attacked low grade plastic and rubber products, such as hoses, seals, etc. and also reacted with the binding material in cement floors.

V. CONCLUSION

This work contributes to the ongoing research in renewable energies, mainly the use of biodiesel as an alternative or blending additive for commercial petro diesel. In this study the effect of blending biodiesel on emissions and efficiency in a non road diesel engine was tested. The findings were compared to published results from similar experiments. It has to be said that these results are based on stationary diesel engine and hence a correlation between engine performance and emissions with road vehicles cannot be made. Furthermore, no modifications (e.g. injection time alteration, fuel pre-heating system) were made to engine to adjust for the lower viscosity of biodiesel compare to standard diesel. The quality of the palm oil biodiesel was based on MPOB standard concerning the production and no other biodiesel grades were tested in this study. Comparison also will be made according to the test results between biodiesel fuels and conventional diesel fuel based on the modes of cycle. However these results show a good usefulness for diesel powered generating systems being adjustable for biodiesel and its blend. This can be of particular interest for

farmers and other parties with easy and cheap access to biodiesel for the purpose of energy generation by reducing emissions to the environment and increase their carbon footprint. From an economical point of view, the use of biodiesel has been proven in numerous other papers and hence adds to benefits of its use.

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