PERFORMANCE AND EMISSION CHARACTERISTICS OF A DIESEL ENGINE OPERATING WITH BIODIESEL

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature ....

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DEDICATION

Specially dedicated to my beloved family:
Rabain Bin Dahalan
Gholiah Binti Haji Mad Ladzim
Nadiatul Munirah Binti Rabain
Nurul Amera Aina Binti Rabain
and my supervisor Dr. Rizalman Mamat
for their greatest support and care
.

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Assalamualaikum W.B.T. Alhamdulillah, firstly I would like to stand our greatest gratitude to Allah the most gracious and most merciful, I was fell so proud and glad because I have been able to finish my thesis within the time given with successfully. I think that I have accomplished what I set out to do, and that was improving a successful of my project.

I would like to express my deepest appreciation and gratitude to my supervisor, Dr. Rizalman bin Mamat for his germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. He has always impressed me with his outstanding professional conduct and the time waste to guide me. A great appreciation is acknowledged to the Faculty of Mechanical Engineering for the funding under the final year project.

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ABSTRACT

The use of biodiesel as an alternative diesel engine fuel is increasing rapidly. However, due to technical deficiencies, they are rarely used purely or with high percentages in unmodified diesel engines. Therefore, in this study, biodiesel is used as alternative fuel in a diesel engine. The tests were conducted on a typical four-stroke, four cylinders, water-cooled, direct-injection diesel engine. The effect of test fuels on engine torque, power, brake specific fuel consumption, brake mean effective pressure, and CO, CO2, NOx and HC emissions was investigated. The experimental results showed that the performance of diesel engine was improved with the use of the biodiesel compared to diesel fuel. Besides, the exhaust emissions for biodiesel were fairly reduced.

ABSTRAK

Global biodiesel sebagai bahan bakar enjin diesel alternatif meningkat dengan cepat. Namun, kerana kekurangan teknikal, ia jarang digunakan secara asli atau dengan peratusan yang tinggi pada enjin diesel diubahsuai. Oleh kerana itu, dalam kajian ini, biodiesel digunakan sebagai bahan bakar alternatif di dalam enjin diesel. Ujian dilakukan pada empat-stroke khas, empat silinder, mesin air-cooled, direct injection diesel. Pengaruh bahan bakar uji pada torsi enjin, daya, penggunaan bahan bakar khusus rem, rem bererti tekanan berkesan, dan CO, CO2, NOx dan pembebasan HC diteliti. Keputusan kajian menunjukkan bahawa prestasi enjin diesel dipertingkatkan dengan penggunaan biodiesel berbanding diesel. Selain itu, pembebasan gas buang untuk biodiesel sudah cukup berkurang.

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$P = 2(\pi) \times (N) \times (T)$

Fuel consumption rate = $\rho \times Q$

BSFC = Fuel consumption rate / Power

BMEP = $4 (\pi) \times (T) / Vd$

Φ = Stoichiometric fuel to air ratio / actual fuel to air ratio

LIST OF SYMBOLS

Φ	Equivalence ratio
B100	Neat biodiesel
B20	20% of biodiesel
CO	Carbon monoxide
CO_2	Carbon dioxide
HC	Hydrocarbon
N_2O	Nitrous oxide
N	Engine speed
NO_x	Nitrogen oxide
P	Power
p	Fuel density
Q	Fuel volume flow rate
T	Torque
Vd	Engine displacement volume

LIST OF ABBREVIATIONS

BDC	Bottom dead centre
BMEP	Brake mean effective pressure
BSFC	Brake specific fuel consumption
CI	Compression ignition
DI	Direct injection
EVC	Exhaust valve closing
HHVs	Higher heating values
IDI	Indirect injection
IVO	Inlet valve opening
TDC	Top dead centre

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Global air-pollution is a serious problem. Much of this pollution is caused by the use of fossil fuels for transportation. Therefore, engine manufacturers have designed alternatively fueled engines and fuel systems, which provide sufficient power while staying within regulatory emission-limits. At the same time, a great deal of research and development on internal-combustion engines has taken place in finding an appropriate fuel. Many researchers have concluded that biodiesel holds promise as an alternative fuel for diesel engines. Therefore, biodiesel can be used in diesel engines with few or no modifications. Diesel-fuel blends with biodiesel have superior lubricity, which reduces wear and tear on the diesel engine and makes the engine components last longer.

Biodiesel has a higher cetane number than petroleum diesel fuel, no aromatics, and contains 10–11% oxygen by weight. These characteristics of biodiesel reduce the emissions of carbon monoxide (CO), and hydrocarbons (HC), in the exhaust gas compared with diesel fuel. However, NOx emissions of biodiesel increase because of combustion and some fuel characteristics. The fuel properties of biodiesel such as cetane number, heat of combustion, specific gravity, and kinematic viscosity influence the combustion and so the engine performance and emission characteristics because it has different physical and chemical properties than petroleum-based diesel fuel.

Dr. Rudolf Diesel invented the first diesel engine in 1892 and it was designed to run on a number of fuels including vegetable oil. He developed the diesel engine to run on vegetable oil and commented that it would help considerably in the development of agriculture of the countries that use it. He demonstrated his engine at the World Exhibition in Paris in 1900 and described an experiment using peanut oil as fuel in his engine.

Biodiesel has actually been around for around 100 years but the cheap availability of petroleum fuel has made it the choice for diesel fuel. But now that petrodiesel prices have risen to such a high level, it’s becoming affordable to use biodiesel. And it’s becoming very popular in many countries across the globe.

1.2 PROBLEM STATEMENT

There are two problem statement in that has to be solved in this research. First is the prediction of the engine performance and exhaust emissions of diesel engine using biodiesel fuel and second is how the inputs affect the outputs of engine.

1.3 PROJECT OBJECTIVES

There are two main objective in that has to be achieved in this research. First is to investigate the performance and emission characteristic of a diesel engine operating with biodiesel and second is to investigate the different performance of biodiesel and diesel fuel.

1.4 PROJECT SCOPES

There are four main scopes in this research. First is four cylinder diesel engine installations. Second is installation of required instrumentation. Third is engine testing at various engine speed and lastly is collect all the performance and emission characteristic from the literature.

1.5 THESIS ORGANIZATION

This thesis consists of five chapters raging from chapter 1 to chapter 5. Chapter 1 gives an overview of the study conducted. It also included with objective, scope of the project and problem statement. Chapter 2 reviews the previous research works that was conducted by other people. All the relevant material including technical paper, journals, and books taken from those researches will be discussed in this chapter. Chapter 3 is the methodology. This chapter is about the method used and the progress of the project. It will discuss about the experiment conducted and flow in details of this research. Result of the experiment conducted and discussion of it will be discussed in chapter 4. Chapter 5 which is the last chapter concludes the entire thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter covers the recent review of diesel engine powered with biodiesel research activities are presented here. All the studies are mainly focus on the performance and emissions characteristic for the diesel engine operating with biodiesel and comparison to conventional diesel engine.

2.2 DIESEL ENGINE

2.2.1 History

Although the history of the diesel engine extends back into the closing years of the 19^{th} century when Dr Rudolf Diesel began his pioneering work on air blast injected stationary engines, and in spite of the dominant position in now holds in many application, it is today the subject of intensive development and capable of improvements.

Before 1914, building on the work of Dr Rudolf Diesel in Germany and Hubert Akroyd Stuart in the UK, the diesel engine was used primarily in stationary and ship propulsion applications in the form of relatively low speed four-stroke normally aspirated engines.

The 1914-18 war gave considerable impetus to the development of the high speed diesel engine with its much higher specific output, with a view to extending its application to vehicles. Although the first generation of road transport engines were undoubtedly of the spark ignition variety, the somewhat later development of diesel engines operating on the self or compression ignition principle followed soon after so that by mid 1930s the high speed normally aspirated diesel engine was firmly established as the most efficient prime mover for trucks and buses.

2.2.2 Classification

The major distinguishing characteristic of the diesel engine is the compression-ignition principle, i.e. the adoption of a special method of fuel preparation. The compression ignition (CI) engine operates with heterogeneous charge of previously compressed air and a finely divided spray of liquid fuel. The latter is injected into the engine cylinder towards the end of compression when, after a suitably intensive mixing process with the air already in the cylinder, the self ignition properties of the fuel cause combustion to be initiated from small nuclei. These spread rapidly so that complete combustion of all injected fuel, usually with air-fuel ratios well in excess of stoichiometric, is ensured. There are two broad categories of combustion systems:

(a) Direct Injection (DI) Systems

The fuel is injected directly into a combustion chamber formed in the cylinder itself, i.e. between a suitably shaped non-stationary piston crown and a fixed cylinder head in which is mounted the fuel injector with its single or multiple spray orifices or nozzles.

(b) Indirect Injection (IDI) Systems

Fuel is injected into a prechamber which communicates with the cylinder through a narrow passage. The rapid transfer of air from the main cylinder into the prechamber toward top dead centre (TDC) of the firing stroke promotes a very high degree of air motion in the prechamber which is particularly conducive to rapid fuel-air mixing.

Two-stroke engines

In two-stroke engines combustion occurs in region of top dead centre (TDC) of every revolution. Gas exchange also has to be affected once per revolution in the region of bottom dead centre (BDC) and with minimum loss of expansion work of the cylinder gases following combustion. This implies that escape of gas from the cylinder to exhaust and charging with fresh air from the inlet manifold must occur under the most favourable possible flow conditions over the shortest possible period.

Four-stroke engines

The vast majority of current diesel engines operate on the four-stroke principle in which combustion occurs only every other revolution, again in the region of top dead centre (TDC), and with the intermediate revolution and its associated piston strokes given over to the gas exchange process. In practice the exhaust valve(s) open well before bottom dead centre (BDC) following the expansion stroke and only close well after the following top dead centre (TDC) position is reached. The inlet valve(s) open before this latter TDC, giving a period of overlap between inlet valve opening (IVO) and exhaust valve closing (EVC) during which the comparatively small clearance volume is scavenged of most of the remaining products of combustion. Following completion of the inlet stroke, the inlet valve(s) close well after the following bottom dead centre (BDC), after which the ‘closed’ portion of the cycle, i.e. the sequence compression, combustion, expansion, leads to the next cycle, commencing again with exhaust valve opening (EVO). Figure 2.1 below shows the mechanism of 4-Stroke Engine

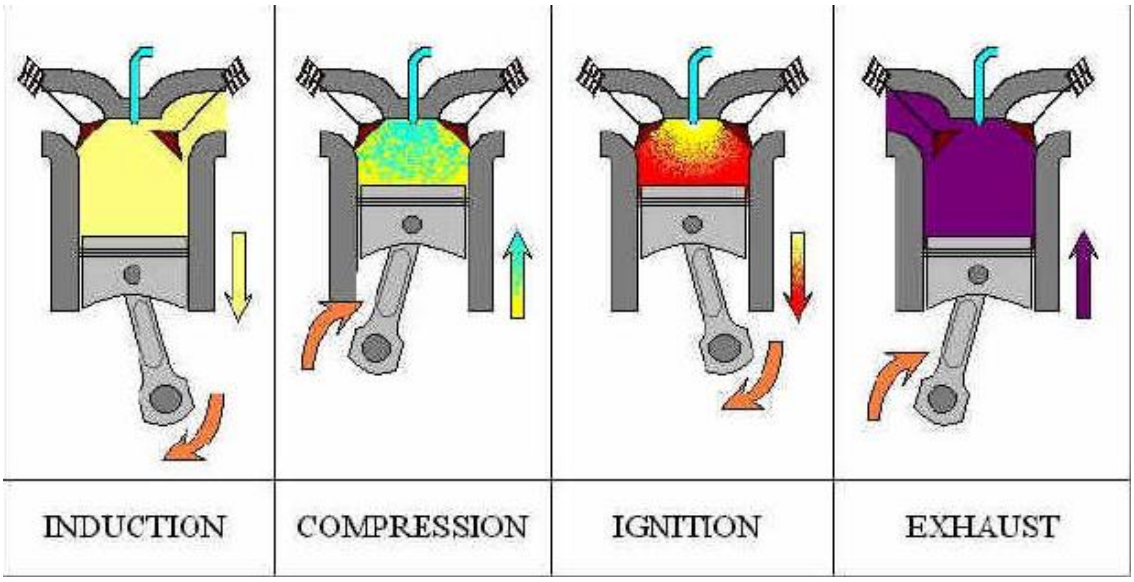

Figure 2.1: Mechanism of 4-Stroke Engine

- Induction stroke

The piston is at top dead center at the beginning of the intake stroke, and, as the piston moves downward, the intake valve opens. The downward movement of the piston draws air into the cylinder, and, as the piston reaches bottom dead center, the intake valve closes.

Compression stroke

The piston is at bottom dead center at the beginning of the compression stroke, and, as the piston moves upward, the air compresses. As the piston reaches top dead center, the compression stroke ends.

- Ignition stroke

The piston begins the power stroke at top dead center. The air is compressed. At this point, fuel is injected into the combustion chamber and is ignited by the heat of the compression. The expanding force of the burning gases pushes the piston downward, providing power to the crankshaft.

- Exhaust stroke

  As the piston reaches bottom dead center on the power stroke, the power stroke ends and the exhaust stroke begins. The exhaust valve opens, and, as the piston rises towards top dead center, the burnt gases are pushed out through the exhaust port. As the piston reaches top dead center, the exhaust valve closes and the intake valve opens.

The main advantages of the four-stroke cycle over its two-stroke counterpart are:

(a) The longer period available for the gas exchange process and the separation of the exhaust and inlet periods-apart from the comparatively short overlap-resulting in a purer trapped charge.

(b) The lower thermal loading associated with engines in which pistons, cylinder heads and liners are exposed to the most severe pressures and temperatures associated with combustion only every other revolution.

(c) Easier lubrication conditions for pistons, rings and liners due to the absence of ports, and the idle stroke renewing liner lubrication and giving inertia lift off to rings and small and large end bearings.

2.3 BIODIESEL

2.3.1 Definition

Biodiesel is defined as the mono-alkyl esters of fatty acids derived from vegetable oils or animal fats. It’s known chemically as a 'methyl ester'. In other terms, when a vegetable oil or animal fat is chemically reacted with an alcohol to produce a new compound that is known as a fatty acid methyl ester, that product is called biodiesel.

2.3.2 Biodiesel and its properties

The use of biodiesel has grown dramatically since the US Congress first provided an incentive the 1998 Energy Conservation and Recovery Act which allows federal and state fleet managers to meet the 1992 EPACT alternative fuel vehicle acquisition requirements by using biodiesel added to petroleum diesel at blend concentrations of 20% by volume or higher.

According to the National Biodiesel Board, the US production of biodiesel grew from 500,000 gallons in 1998 to 75 million gallons in 2005 and is estimated to have reached 150 million gallons in 2006 [1].

As of late April 2006, according to the National Biodiesel Board, there are 65 biodiesel plants currently in operation with a reported total maximum annual biodiesel production capacity of 395 million gallons [2]. 58 biodiesel plants are currently under construction or expansion with a reported total annual production capacity of 714 million gallons coming on line in the next 18 months, and an additional 36 plants representing 755 million gallons of maximum annual production capacity are reportedly beyond the planning stage, but not yet under construction [3].

About two-thirds of the existing and planned biodiesel production capacity is based on the dedicated use of soybean oil as the principal feedstock. This is consistent with the fact that much of the existing biodiesel production capacity is located in Midwestern states such as Iowa, Illinois, Minnesota and Ohio which also are large agricultural producers of soybeans that have been experiencing excess production capacity, product surpluses, and declining prices [4].

It is important to place the scale of biodiesel production and usage into perspective. In 2004, total on-road diesel fuel consumption amounted to 37.1 billion gallons or 2.4 million barrels per day [5]. At 75 million gallons, current domestic biodiesel production constitutes less than 0.2% of on-road diesel demand.

In September 2005, biodiesel usage was largely limited to rural areas and to demonstration programs sponsored by government agencies and private industry. It is currently being used in transit bus and heavy-duty truck fleets operated by private organizations as well as by municipal, state, local, and federal government agencies [6].

In February 2002, ASTM International issued ASTM D6751 which established specifications that neat biodiesel (B100) must meet as a blending component in petroleum-based diesel fuel in concentrations of up to 20% by volume [7]. These specifications help to ensure minimum product qualities by setting bounds on the biodiesel production process with respect to the completeness of the esterification reaction process, the removal of glycerin, catalyst and alcohol, and the absence of free fatty acids.

Biodiesel properties are a direct function of the carbon chain length and proportion of saturated versus unsaturated fatty acids present in the fuel plus the presence of additives. Biodiesel made from feedstocks that contain highly saturated fatty acids (such as yellow grease, beef tallow, palm and coconut oil) tend to exhibit high cloud and pour points, high cetane number, and better stability. Biodiesel made from feedstocks with high polyunsaturated content (such as soy and sunflower) have low freezing points, lower cetane number and poor stability [8].

The Table 2.1 below compares selected properties of typical neat biodiesel and current, typical low sulfur diesel. In general, biodiesel has a higher cetane rating than typical petroleum diesel fuel. It also contains 11% oxygen by weight. The minimum flash point (a measure of fire safety) for biodiesel is higher than for diesel to ensure that any excess alcohol used in the manufacturing process has been removed. Furthermore, the viscosity of biodiesel tends to be higher than that for typical diesel fuel.

The energy content of neat biodiesel is 8% lower (on a gallon basis) compared to typical petroleum-derived diesel, so some reduction in fuel economy and power can be expected with fuels containing biodiesel. But, users of B20 or lower blends in fleet demonstration tests generally report little noticeable reduction in vehicle performance and fuel economy [9].

Table 2.1: Selected Properties of Diesel and Biodiesel Fuels

Fuel Property	Diesel	Biodiesel
Fuel Standard	ASTM D975	ASTM D6751
Lower Heating Value,Btu/gal	~129,050	~118,170
Kinematic Viscocity, @ 40°C	1.3-4.1	4.0-6.0
Specific Gravity kg/l @ 60°F	0.85	0.88
Density, lb/gal @ 15°C	7.079	7.328
Water and Sediment, vol %	0.05 max	0.05 max
Carbon, wt %	87	77
Hydrogen, wt %	13	12
Oxygen, by dif. Wt %	0	11
Sulfur, wt % *	0.05 max	0.0 to 0.0024
Boiling Point, °C	180 to 340	315 to 350
Flash Point, °C	60 to 80	100 to 170
Cloud Point, °C	-15 to 5	-3 to 12
Pour point, °C	-35 to -15	-15 to 10
Cetane Number	40 to 55	48-65

Neat biodiesel has good lubricity properties and contains essentially no sulfur or aromatics in comparison to petroleum diesel. Some proponents for biodiesel claim that the addition of just 1% biodiesel to conventional diesel fuel can improve lubricity by up to 65% [10].

Neat biodiesel has a relatively high pour point so it will tend to gel and/or form crystals more quickly than petroleum diesel in cold weather conditions. Biodiesel has poor cold flow properties due to the presence of saturated fatty acids. A recent study evaluated the operating parameters associated with blending biodiesel into petroleum based diesel at 2 percent by volume under wintertime temperature conditions typical of Minnesota. The study concluded that biodiesel must be kept at least 10° F above its cloud point for the blending to successfully avoid forming crystals or gel in the mixture [11].

Biodiesel is biodegradable, but this property could lead to increased biological growth during storage unless appropriate precautions are taken [12]. Biodiesel will generally soften and degrade certain types of elastomers and natural rubber compounds over time. Using high percent biodiesel blends can impact fuel system components that contain elastomers that are incompatible with biodiesel.

Biodiesel also is more susceptible than petroleum diesel to oxidative degradation. Factors effecting stability include the degree of natural antioxidant content, carbon chain length and degree of saturation of the biodiesel feedstock, and the presence of glycerides.

2.3.3 Sources of biodiesel

Soybean, palm, sunflower, safflower, cottonseed, rapeseed and peanut oils are considered as potential alternative fuels for diesel engines. Worldwide consumption of soybean oils is the highest in 2003 (27.9 million metric tons). Table 2.2 shows the world vegetable and marine oil consumption between 1998 and 2003.

Table 2.2: World vegetable and marine oil consumption (million metric ton)

Oil	1998	1999	2000	2001	2002	2003
SOybean	23.5	24.5	26.0	26.6	27.2	27.9
Palm	18.5	21.2	23.5	24.8	26.3	27.8
Rapessed	12.5	13.3	13.1	12.8	12.5	12.1
Sunflower seed	9.2	9.5	8.6	8.4	8.2	8.0
Peanut	4.5	4.3	4.2	4.7	5.3	5.8
Cottonseed	3.7	3.7	3.6	4.0	4.4	4.9
Coconut	3.2	3.2	3.3	3.5	3.7	3.9
Palm kernel	2.3	2.6	2.7	3.1	3.5	3.7
Olive	2.2	2.4	2.5	2.6	2.7	2.8
Fish	1.2	1.2	1.2	1.3	1.3	1.4
Total	80.7	85.7	88.4	91.8	95.1	98.3

Source: Demirbas

One of the renewable fuels is vegetable oil. Vegetables oils have become more attractive recently due to their environmental benefits and the fact that these are made from renewable resources. On the other hand, other significant problems such as starvation may caused by extensive use of vegetables oils. The vegetable oils fuels were not acceptable because they were more expensive than petroleum fuels.

A variety of biolipids can be used to produce biodiesel. These are (a) virgin vegetable oil feedstock, rapeseed and soybean oils are most commonly used, (b) waste vegetable oil, (c) animal fats including tallow, lard and yellow grease and (d) non-edible oils such as Jatropha, neem oil, castor oil, and tall oil.

In the United States, soybeans are commonly used for food products which why soybean biodiesel becoming the primary source for biodiesel in this country. Palm oil is used as a significant biodiesel source in Malaysia and Indonesia. In Europe, rapeseed is the most common base oil used in biodiesel production. On the other hand, the Jatropa tree is used as significant fuel source in India and southeast Asia.

2.3.4 Advantages of biodiesel as diesel fuel

There are many advantages of biodiesel as diesel fuel. Liquid nature portability, ready availability, and renewability are some of their advantages. Besides that, it also higher combustion efficiency, lower sulfur and aromatic content, higher cetane number and higher biodegradability. Main advantages of biodiesel include domestic origin, reducing the dependency on imported petroleum, biodegradability, high flash point and inherent lubricity in the neat form.

Availability and renewability of biodiesel

Biodiesel is the only alternative fuel so that low concentration biodiesel-diesel blends run on conventional unmodified engines. In can be stored anywhere petroleum diesel fuel is stored. Biodiesel can be made from renewable oilseed crops such as soybean, rapeseed and sunflower. Besides that, the risk of handling, transporting and storing biodiesel is much lower than petrodiesel. Biodiesel is safe to transport and handle because it has a high flash point compared to petroleum diesel fuel and it is also biodegradable. Biodiesel can be used alone or mixed in any ratio with petroleum diesel fuel. The most common blend is a mix of 20% biodiesel with 80% petroleum diesel, or called as B20.

.

Higher combustion efficiency of biodiesel

Oxygen content of biodiesel decreases its oxidation potential and improves the combustion process. Structural oxygen content of a fuel improves combustion efficiency because of the increase of the homogeneity of oxygen with the fuel during combustion. Biodiesel contains 11% oxygen by weight and contains no sulfur. Biodiesel is more lubricating than petroleum diesel fuel so their use can extend the life of diesel engines. Biodiesel has got better lubricant properties than petrodiesel.

The higher heating values (HHVs) of biodiesel are relatively high. The HHVs of biodiesels are slightly lower than that of gasoline, petrodiesel or petroleum, but higher than coal. Table 2.3 shows the comparison of chemical properties and HHVs between biodiesel and petrodiesel.

Table 2.3: Comparison of chemical properties and higher heating values (HHVs) between biodiesel and petrodiesel fuels

Chemical property	Biodiesel (methyl ester)	Diesel
Ash (wt%)	0.002-0.036	0.006-0.010
Sulfur (wt%)	0.006-0.020	0.020-0.050
Nitrogen (wt%)	0.002-0.007	0.0001-0.003
Aromatics (vol%)	0	28-38
Iodine number	65-156	0
HHV (MJ/kg)	39.2-40.6	45.1-45.6

Lower emissions by using biodiesel

Combustion of biodiesel provides over a 90% reduction in total unburned hydrocarbons (HC). Besides that, the combustion of biodiesel also provides 75-90% reduction in polycyclic aromatic hydrocarbons. Biodiesel provides significant reductions in particulates and carbon monoxide. A slight increase or decrease in nitrogen oxides are also provided by biodiesel depending on engine family and testing procedures.

Biodiesel contains little nitrogen as compared to with petrodiesel which is also used as reburning fuel. The N_2O reduction was strongly dependent on initial N_2O concentration and slightly dependent upon temperature, where increased temperature increased N_2O reduction.

In order to avoid some problems related to the decrease of power and torque and to the increase of NO_x emissions, the use of blends of biodiesel and diesel oil is preferred in engines. Emissions of all pollutants appear to decrease when using biodiesel except for NO_x. Table 2.4 shows that the average changes in mass emissions from diesel engines using the biodiesel mixtures relative to the standard diesel fuel.

Table 2.4: Average change in mass emissions from diesel engines using the biodiesel mixtures relative to the standard diesel fuel (%)

mixture	CO	NO_x	SO_2	Particulate matter	Volatile organic compounds
B20	-13.1	+2.4	-20	-8.9	-17.9
B100	-42.7	+13.2	-100	-55.3	-63.2

Source: Morris (2003)

2.4 CONCLUSION

This chapter gives much important knowledge regarding the project. It is clear that there are more sources of biodiesel and its properties give more advantages for combustion engine. This chapter also conclude advantages of biodiesel as alternative fuel**.**

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This section is mainly concerned with the engine testing on performance and emission characteristic of a diesel engine operating with biodiesel. The chapter 3 covers the apparatus and measuring devices, e.g. exhaust gas monitoring and analysis, fuel, and exhaust gas reforming system.

3.2 FLOW CHART

Figure 3.1 shows flow chart for this project. The project begins with literature review from journals. Then, after doing some reading and understanding, the project continue with engine testing. From engine testing, all the data's performance and emission was collected. These data's then was analyzed and transferred to graph. Lastly, the project ends with final report preparation.

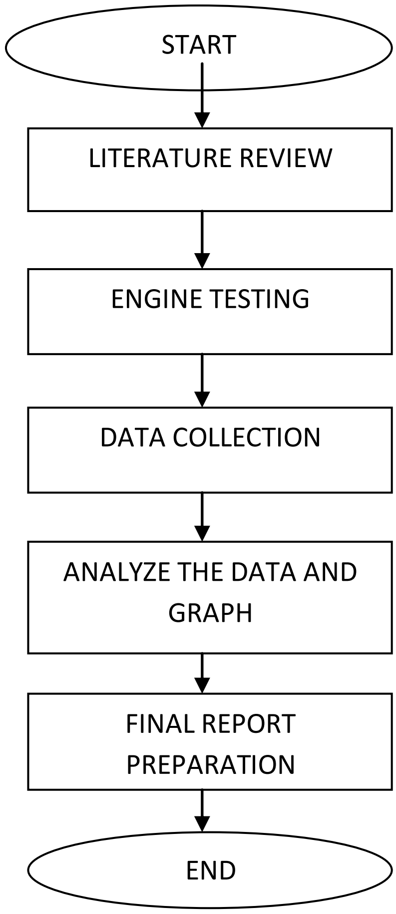

Figure 3.1: Project flow chart

3.3 ENGINE AND INSTRUMENTATION

3.3.1 Engine

The experiments of performance and emission characteristics were conducted on a typical four-stroke, four cylinder, water-cooled, direct-injection diesel engine (figure 3.2). The engine has 82.7 mm bore, 93 mm stroke, compression ratio of 22.4. The detailed specifications of the engine are given in Table 3.1.

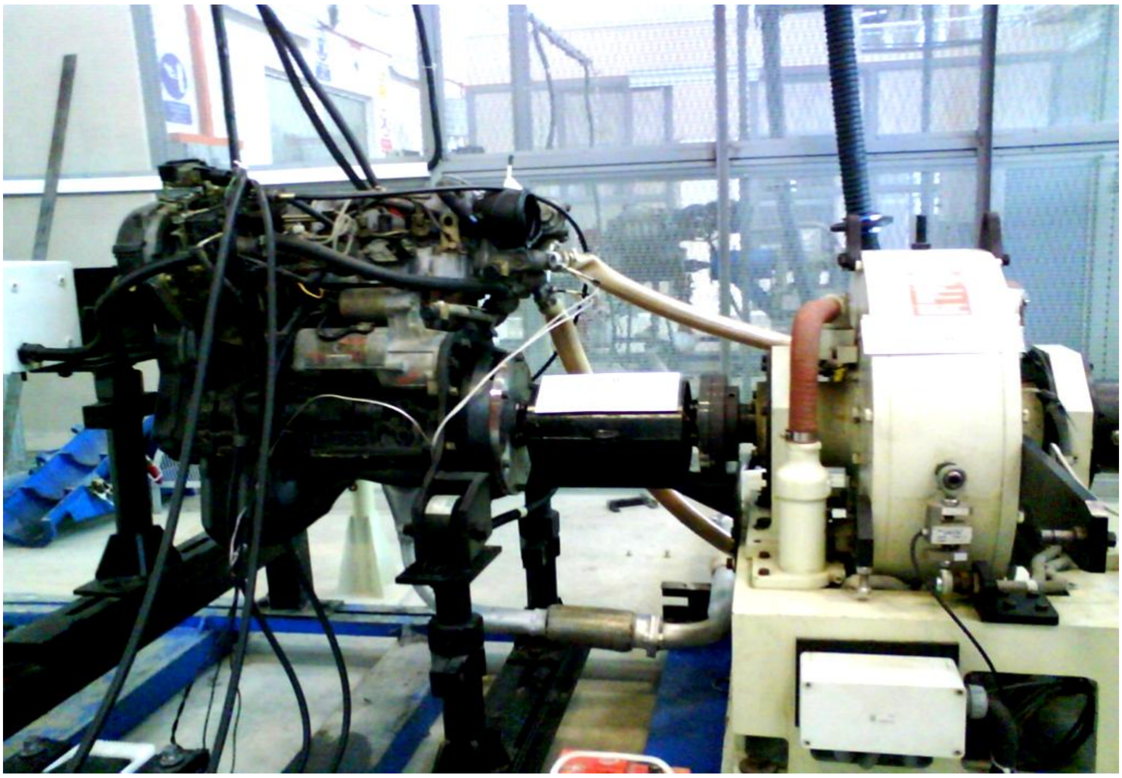

Figure 3.2: Photograph of test engine

Table 3.1: Technical specification of the engine

Description	Specifications
Type	Diesel engine
Number of cylinders	4
Combustion Chamber	Swirl chamber
Total displacement (dm^3)	1.998
Cylinder bore (mm)	82.7
Piston stroke (mm)	93
Compression ratio	22.4
Lubrication system	Pressure feed, full-flow filtration
Oil pump type	External gear type
Cooling system	Water-cooled
Water pump type	Centrifugal impeller type
EGR type	Single type
Fuel system	Electronic control distributor-type injection pump

3.3.2 Dynamometer

An eddy-current type water-cooled dynamometer model ECB-200F was used to load the engine. The dynamometer sizing was chosen to cover the full-load engine operation for the whole range of engine speeds. (Before performing experimentation, the dynamometer was calibrated in March 2010 using levers and weights that allow simple and precise adjustment and checking of the torque measuring chain, regardless of whether the brake is at standstill or rotating.

To control the dynamometer, a dynamometer control system was used; it was positioned in the control room and was wired by an interconnection loom to the dynamometer. In addition, since the dynamometer is water-cooled type, a flow switch was installed in a cooling water feed line to detect the movement of water and was wired to the controller for safety.

Generally, at any revolution speed except idle speed the engine operates on torque-controlled mode by which the user must set the dynamometer controller to be speed-controlled mode. However, at the idle speed when the engine operates on speed-controlled mode, the user must set the dynamometer controller to the torque-controlled mode. This is extremely important because the wrong setting could destroy the engine transmission mechanism as well as the propshaft.

3.3.3. Fuelling system

The fuelling system is also illustrated in Figure 3.3. Diesel fuel from the fuel store/pump room was transported by a pneumatically operated feeding pump through the fuel supply system and was stored in a tank, on the left hand side in Figure 3.3. The other container, labeled ‘Biodiesel Fuel Tank’ was used to store biodiesel blended fuels.

Figure 3.3: Fuel tank

3.3.4 Temperature and pressure data acquisition

An additional data acquisition system for temperature and pressure is shown in Figure 3.4. The system comprised two 8-channel \ boxes for temperature measurement and an 8-channel box for pressure (analogue) measurement. Their specification and the channel designation are shown in Figure 3.4 and Table 3.2, respectively.

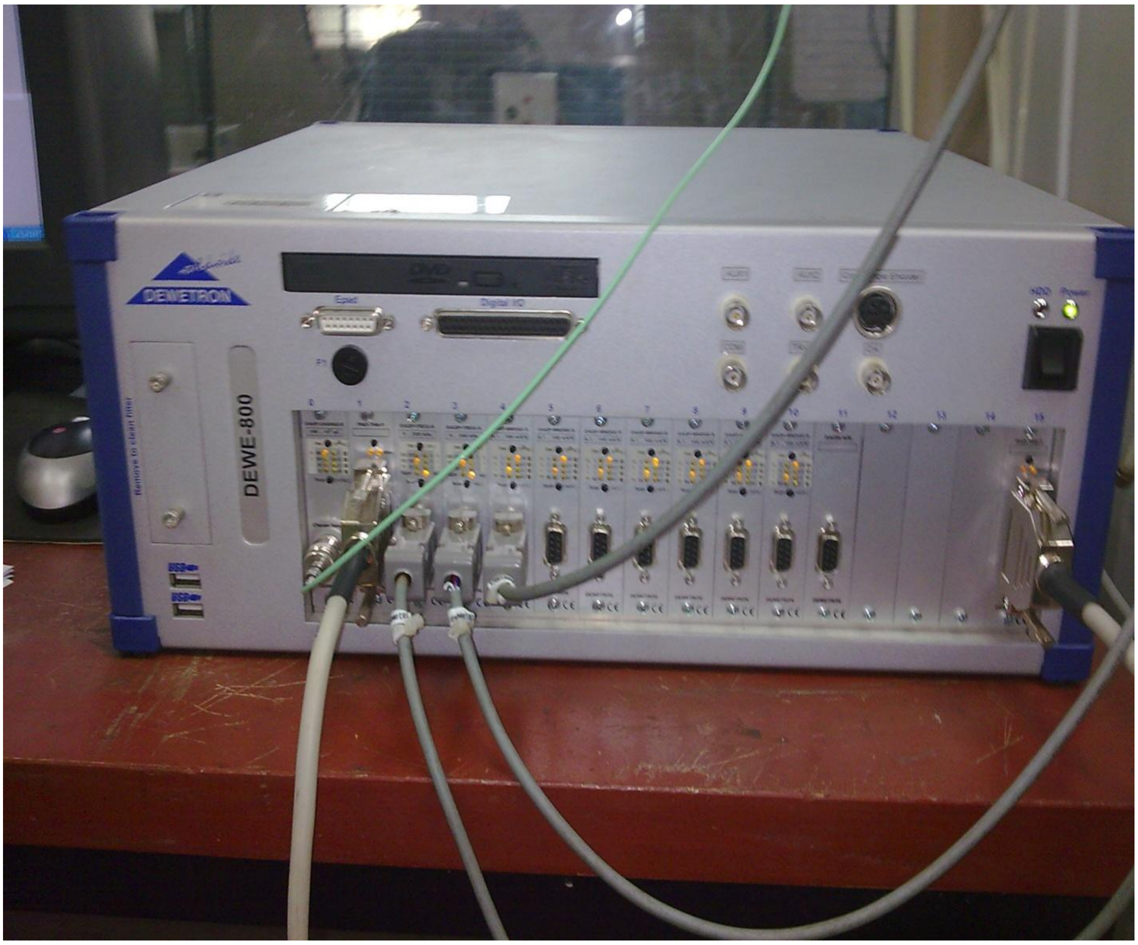

Figure 3.4: Data acquisition system

Table 3.2: Specification data acquisition system

DEWE-800	
Slots for DAQ or PAD modules	16
Total PCI-slots	2 full / 1 half length Opt. 2 full / 4 half length
Hard disk	250 GB
Data throughput	Typ. 70 MB/s
Power supply	95 to 260 V
RAM	2 GB
USB interface	4
Storage drive	Internal DVD +/-RW burner
Dimensions	437 x 443 x 181 mm (17.2 x 17.4 x 7.1 in.)
Weight	Typ. 12.5 kg
Operating temperature	0 to +40 °C
Storage temperature	-20 to +70 °C
Humidity	10 to 80 % non cond., 5 to 95 % rel. humidity

3.4 EXPERIMENT PROCEDURE

The samples diesel and biodiesels were then tested for their performance in a diesel engine and for their emission characteristics. A four-cylinder, four-stroke, naturally aspirated, direct-injection diesel engine was used as the test engine in this experiment. The displacement volume of this engine is 1.998 dm3. An eddy-current dynamometer in combination with the diesel engine was used to control the engine. A gas analyzer measured the emissions from the diesel engine, and the temperature of the exhaust gas was measured by a K-type thermocouple.

The experimental set-up and measuring instruments are shown in Fig.3. 4. The engine experiment was carried out under fixed 50% engine load and varied engine speeds from 1000 to 3000 rpm. The power, torque, fuel consumption and emissions were measured.

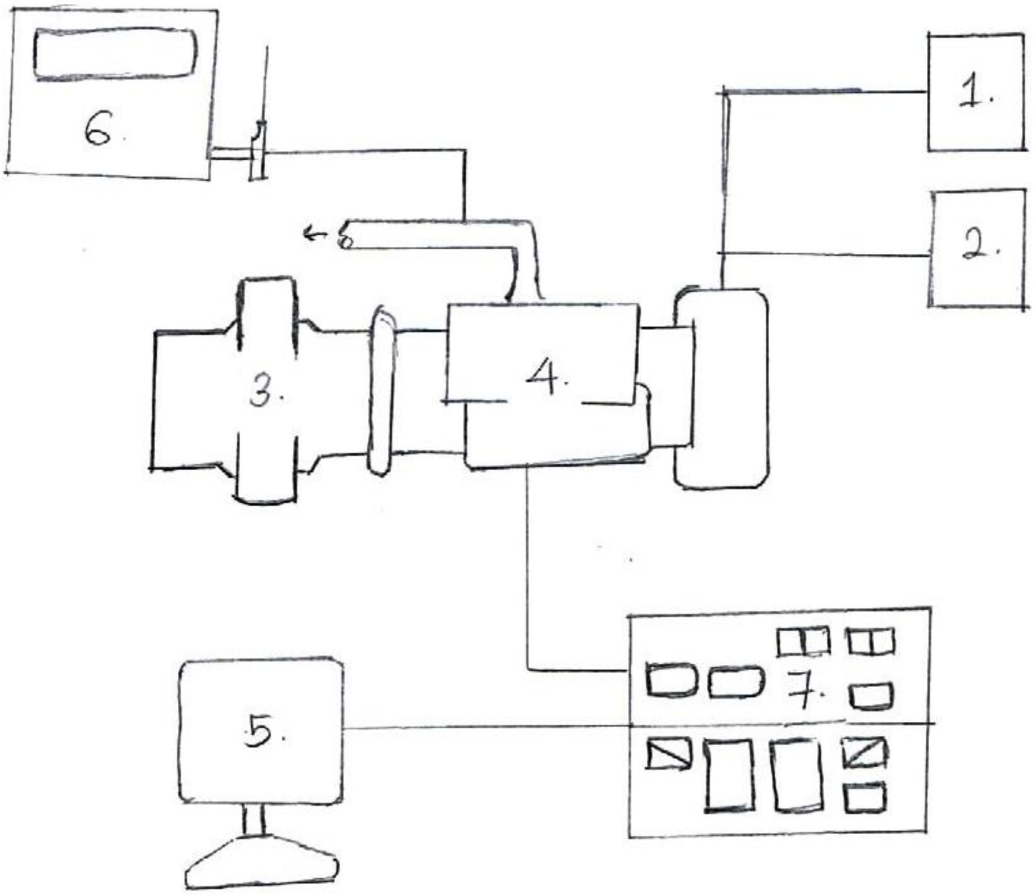

Figure 3.4: Experiment setup

Where:

1. Diesel fuel tank
2. Biodiesel fuel tank
3. Eddy current dynamometer
4. Diesel engine
5. PC for analyzing engine test data
6. Exhaust gas analyzer
7. Data acquisition system

3.5 CONCLUSION

This chapter gives much important knowledge regarding all the methods used in the project. Various methods have been used to get the information for the project such as using eddy current dynamometer controller to set engine speed and percentage of throttle, using DEWESoft software to get temperature and pressure reading, and using gas analyzer to get gases emission reading. By referring to the methodology flowchart in Figure 3.1, the flow of the project can be seen and understood easily.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter is mainly about the discussion of the experiment results of using biodiesel and diesel fuel. The results can be divide by two parts, which is explanation of the engine performance and emissions characteristic produced by fuelling diesel and biodiesel. All the data such as graphs and tables are all summarized.

4.2 ENGINE TORQUE AND POWER

The trend of performance curves (power and torque) are very likely those mentioned in valid concerned existing literature. Range of speed was selected between 1000 rpm and 3000 rpm.

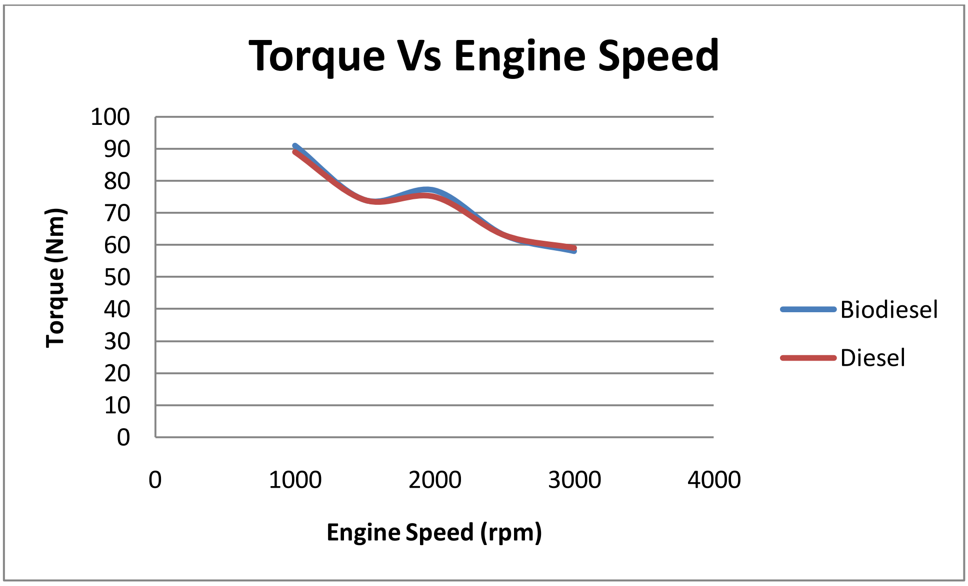

Figure 4.1: Engine torque vs Engine speed

Figure 4.1 shows the comparison of torque for diesel and biodiesel under speed characteristic at 50% load. Engine test results with diesel fuel showed that maximum torque was 89.0 Nm which occurred at 1000 rpm meanwhile for biodiesel fuel showed that maximum torque was 91.0 Nm which occurred at 1000 rpm. Table 4.1 below shows engine torque data.

Table 4.1: Engine torque data

Engine Speed (rpm)	Engine torque with Biodiesel (Nm)	Engine torque with Diesel (Nm)
1000	91	89
1500	74	74
2000	77	75
2500	63	63
3000	58	59

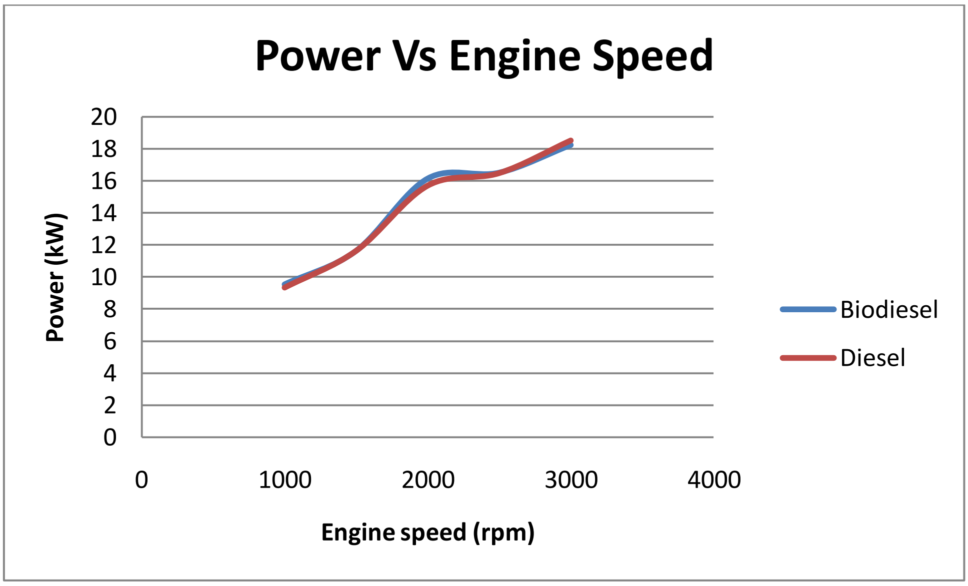

Figure 4.2: Engine power vs Engine speed

Figure 4.2 shows the comparison of power output for diesel and biodiesel under speed characteristic at 50% load. It can be seen that the power output of biodiesel engine is almost the same as that of diesel engine. The reason is that the engine delivers fuel on volumetric basis and the density are higher for biodiesel than for diesel, so the plunger in the fuel injection pump discharges more biodiesel compared to that of diesel. Table 4.2 below shows engine power data.

Table 4.2: Engine power data

Engine Speed (rpm)	**Engine power with Biodiesel (kW)**	**Engine power with Diesel (kW)**
1000	9.529498	9.320058
1500	11.62389	11.62389
2000	16.12684	15.70796
2500	16.49336	16.49336
3000	18.22124	18.5354

Engine power equation can be expressed as:

$$P = 2(\pi) \times (N) \times (T)$$

Where:

P = Engine power (W)

N = Engine speed

T = Engine torque (Nm)

Example calculation of engine power with Biodiesel:

$$P = 2(\pi) \times (N) \times (T)$$
$$= 2\pi \times (1000/60) \times (91)$$
$$= 9.529498 \text{ kW}$$

Example calculation of engine power with Diesel:

$$P = 2(\pi) \times (N) \times (T)$$
$$= 2\pi \times (1000/60) \times (89)$$
$$= 9.320058 \text{ W}$$

4.3 FUEL CONSUMPTION RATE

Figure 4.3 shows fuel consumption rate with biodiesel and diesel fuel vs. engine speed. The curves show that fuel consumption rate of biodiesel fuel is very high to diesel fuel.

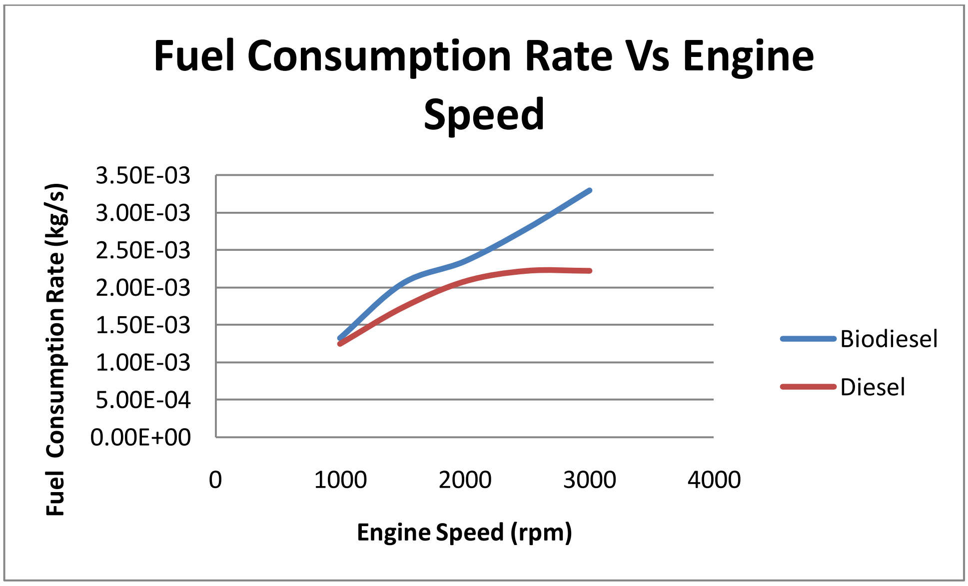

Figure 4.3: Fuel consumption rate vs. engine speed

Figure 4.3 shows that fuel consumption rate for biodiesel fuel is higher than diesel fuel because of biodiesel has higher density compared with diesel. Table 4.3 below shows fuel consumption rate data.

Table 4.3: Fuel consumption rate data

Engine Speed (rpm)	Biodiesel fuel consumption rate (kg/s)	Diesel fuel consumption rate (kg/s)
1000	1.32E-03	1.25E-03
1500	2.05E-03	1.73E-03
2000	2.35E-03	2.08E-03
2500	2.79E-03	2.22E-03
3000	3.30E-03	2.22E-03

Fuel consumption rate can be expressed as:

Fuel consumption rate = ρ x Q

Where:

ρ = Fuel density (kg/m^3)

Q = Fuel volume flow rate (m^3/s)

Example calculation of fuel consumption rate with Biodiesel:

Fuel consumption rate = ρ x Q

= (880) x (1.50x10^-6)

= 1.32x10^-3 kg/s

Example calculation of fuel consumption rate with Diesel:

Fuel consumption rate = ρ x Q

= (832) x (1.50x10^-6)

= 1.25x10^-3 kg/s

4.4 BRAKE SPECIFIC FUEL CONSUMPTION (BSFC)

The curves in Figure 4.4 show that the brake specific fuel consumption (BSFC) of diesel and biodiesel fuel vs. engine speed. Brake specific fuel consumption for biodiesel are higher than brake specific fuel consumption for diesel fuel. The BSFC is defined as the ratio of the fuel consumption rate to the engine brake horsepower output.

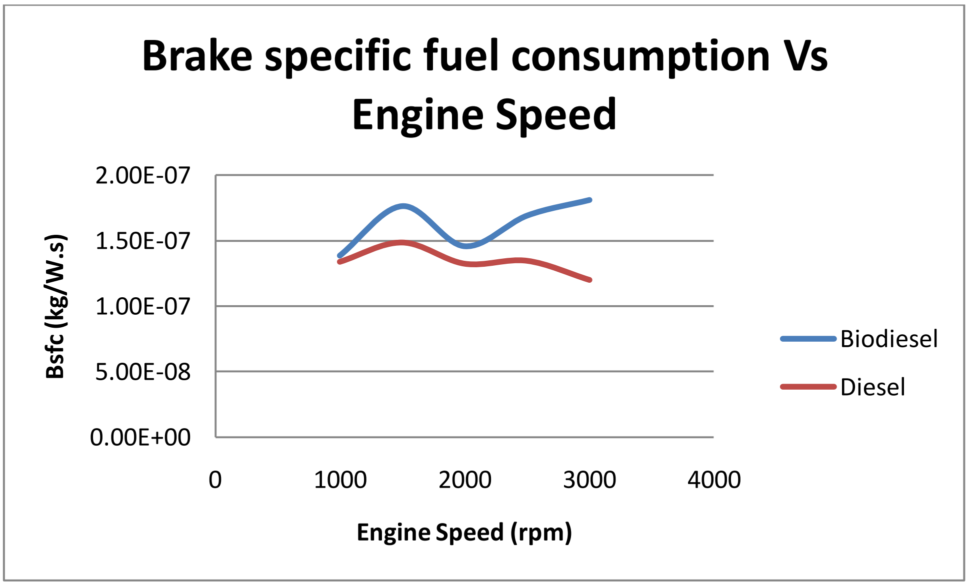

Figure 4.4: Brake specific fuel consumption vs. Engine Speed

Figure 4.4 shows that brake specific fuel consumption for biodiesel fuel is higher than diesel fuel. Diesel has the lower BSFC value because diesel has higher heating value compared to biodiesel, and needed the lowest fuel consumption rate for achieving the same engine brake horsepower output as the biodiesel fuels. Table 4.4 below shows brake specific fuel consumption data.

Table 4.4: brake specific fuel consumption data

Engine Speed (rpm)	**Biodiesel brake specific Fuel Consumption (kg/W.s)**	**Diesel brake specific Fuel Consumption (kg/W.s)**
1000	1.39E-07	1.34E-07
1500	1.76E-07	1.49E-07
2000	1.46E-07	1.32E-07
2500	1.69E-07	1.35E-07
3000	1.81E-07	1.20E-07

Brake specific fuel consumption can be expressed as:

BSFC = Fuel consumption rate / Power

Example calculation of brake specific fuel consumption with Biodiesel:

BSFC = Fuel consumption rate / Power

= (1.32x10^-3) / (9529.498)

= 1.39x10^-7 kg/W.s

Example calculation of brake specific fuel consumption with Diesel:

BSFC = Fuel consumption rate / Power

= (1.25x10^-3) / (9320.058)

= 1.34x10^-7 kg/W.s

4.5 BRAKE MEAN EFFECTIVE PRESSURE (BMEP)

Figure 4.5 show brake mean effective pressure vs. engine speed for diesel and biodiesel fuel. It can be seen that the BMEP of biodiesel is slightly higher than diesel fuel.

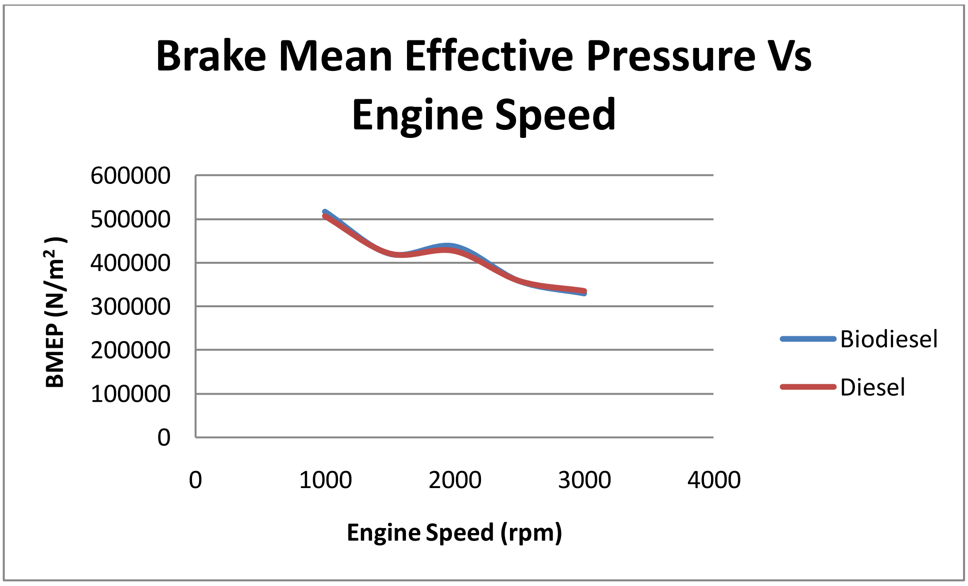

Figure 4.5: Brake mean effective pressure vs. engine speed

Figure 4.5 shows that brake mean effective pressure for biodiesel are slightly higher than diesel because biodiesel produce higher torque than diesel. Table 4.5 below shows brake mean effective pressure data.

Table 4.5: Brake mean effective pressure data

Engine Speed (rpm)	**BMEP with biodiesel (N/m^2)**	**BMEP with diesel (N/m^2)**
1000	517438.8	506066.5
1500	420774.4	420774.4
2000	437832.8	426460.5
2500	358226.9	358226.9
3000	329796.2	335482.3

Brake mean effective pressure can be expressed as:

$$BMEP = 4 (\pi) \times (T) / Vd$$

Where:

BMEP = Brake mean effective pressure (N/m^2)

T = Engine torque (Nm)

Vd = Engine displacement volume (m^3)

Example calculations of brake mean effective pressure with Biodiesel:

$$BMEP = 4 (\pi) \times (T) / Vd$$
$$= 4 \pi \times (91) / (0.00221)$$
$$= 517438.8 \ N/m^2$$

Example calculations of brake mean effective pressure with Diesel:

$$BMEP = 4 (\pi) \times (T) / Vd$$
$$= 4 \pi \times (89) / (0.00221)$$
$$= 506066.5 \ N/m^2$$

4.6 EQUIVALENCE RATIO (Φ)

Figure 4.6 shows the fuel/air equivalence ratio of the biodiesel and diesel fuels under varied engine speeds and constant engine load. The equivalence ratio is defined as the actual fuel to air ratio divided by the stoichiometric fuel to air ratio on a mass basis.

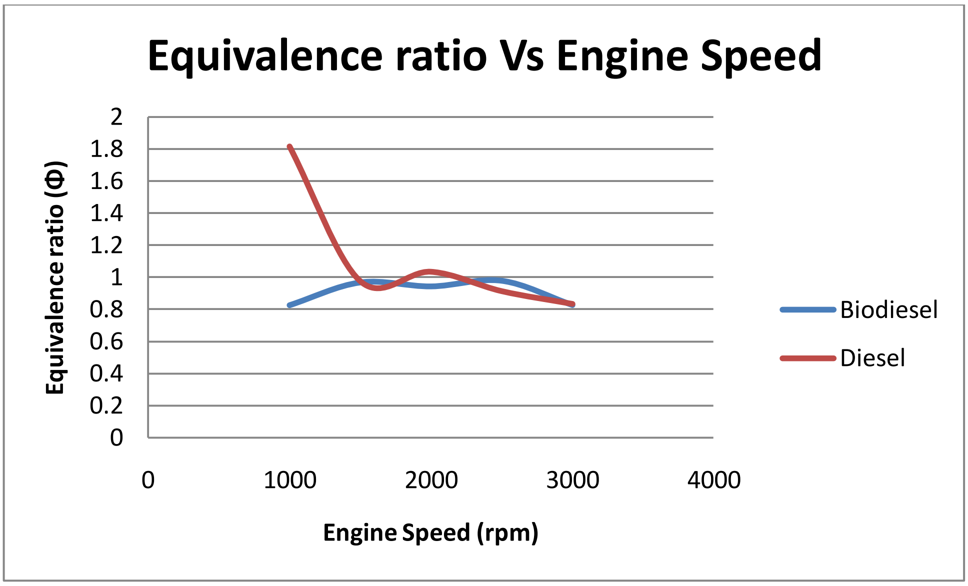

Figure 4.6: Equivalence ratio vs. Engine speed

Biodiesel has the lower fuel/air equivalence ratio in comparison with diesel fuel, as shown in figure 4.6. Biodiesel has lower carbon content indicates it has a lower rate of fuel consumption and a lower heating value. Table 4.6 below shows equivalence ratio data calculation.

Table 4.6: Equivalence ratio data

Engine Speed (rpm)	Equivalence ratio with Biodiesel	Equivalence ratio with Diesel
1000	0.823673	1.813665
1500	0.967049	0.973983
2000	0.94208	1.032532
2500	0.977552	0.911361
3000	0.824679	0.831909

Equivalence ratio can be expressed as:

Φ = Stoichiometric fuel to air ratio / actual fuel to air ratio

Example calculation of equivalence ratio with Biodiesel:

Φ = Stoichiometric fuel to air ratio / actual fuel to air ratio

= 13.5 / 16.39

= 0.823673

Example calculation of equivalence ratio with Diesel:

Φ = Stoichiometric fuel to air ratio / actual fuel to air ratio

= 14.6 / 8.05

= 1.813665

4.7 CARBON MONOXIDE EMISSION (CO)

The variation of CO emissions with engine speed for different fuels is compared in Figure 4.7. The minimum and maximum CO produced were 0.04–3.88%.

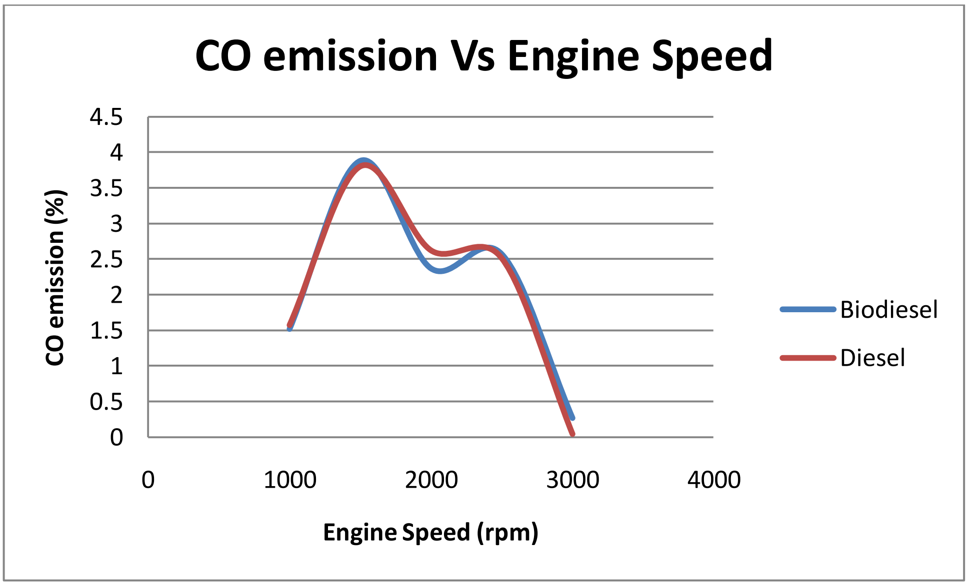

Figure 4.7: CO emission vs Engine Speed

Figure 4.7 shows that CO emissions of biodiesel are lower than diesel due to their more complete oxidation compared to diesel. Some of the CO produced during combustion of biodiesel have converted into CO_2 by taking up the extra oxygen molecule present in the biodiesel chain and thus reduced CO formation. Table 4.7 show CO emission data of diesel and biodiesel fuel.

Table 4.7: CO emission data

Engine Speed (rpm)	**CO emission of biodiesel (%)**	**CO emission of diesel (%)**
1000	1.52	1.57
1500	3.88	3.8
2000	2.37	2.62
2500	2.57	2.51
3000	0.27	0.04

4.8 CARBON DIOXIDE EMISSION (CO_2)

The carbon dioxide (CO_2) emission for using diesel and biodiesel as the engine test fuels under the condition of constant engine load and varied engine speeds are shown in Figure 4.8.

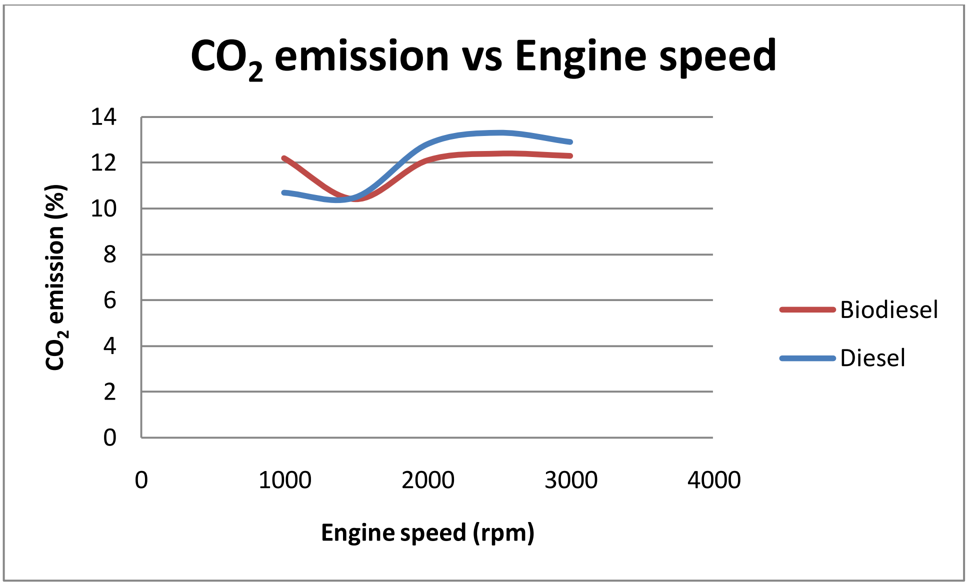

Figure 4.8: CO_2 emission vs. Engine speed

Figure 4.8 shows that biodiesel had lower CO_2 emission than diesel. This is attributed to the fact that biodiesel is a low carbon fuel and has a lower elemental carbon to hydrogen ratio than diesel fuel. The burning of biodiesel with air will therefore form lower CO2 emission than diesel. Table 4.8 below shows CO_2 emission data for using diesel and biodiesel fuel.

Table 4.8: CO_2 emission data

Engine Speed (rpm)	CO2 emission of biodiesel (%)	CO2 emission of diesel (%)
1000	12.2	10.7
1500	10.4	10.5
2000	12.1	12.8
2500	12.4	13.3
3000	12.3	12.9

4.9 HYDROCARBON EMISSION (HC)

Figure 4.9 show the hydrocarbon emission of the biodiesel and diesel fuels under varied engine speeds and constant engine load.

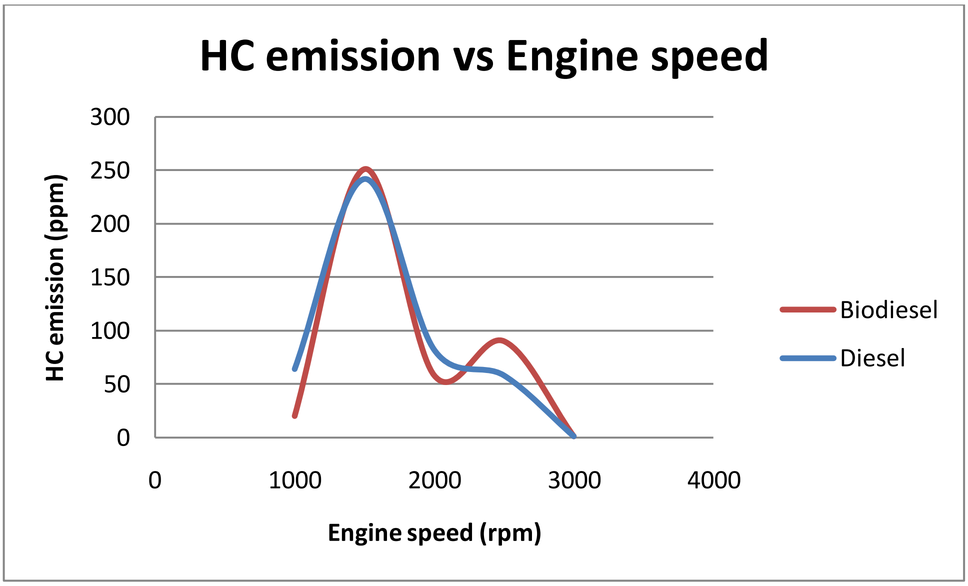

Figure 4.9: HC emission vs. Engine speed

The emissions of HC are found low for both diesel and biodiesel initially and they get increased with increasing engine speed as shown in figure 4.9. The HC emissions of biodiesel are less compared with diesel due to its efficient burning. Hydrocarbon emission data of diesel and biodiesel fuel was shown in table 4.9 below.

Table 4.9: HC emission data

Engine Speed (rpm)	HC emission of biodiesel (ppm)	HC emission of diesel (ppm)
1000	20	64
1500	251	242
2000	58	82
2500	90	58
3000	1	1

4.10 NITROGEN OXIDES EMISSION (NO_X)

The nitrogen oxides (NO_x) emission for using diesel and biodiesel as the engine test fuels under the condition of constant engine load and varied engine speeds are shown in Figure 4.10.

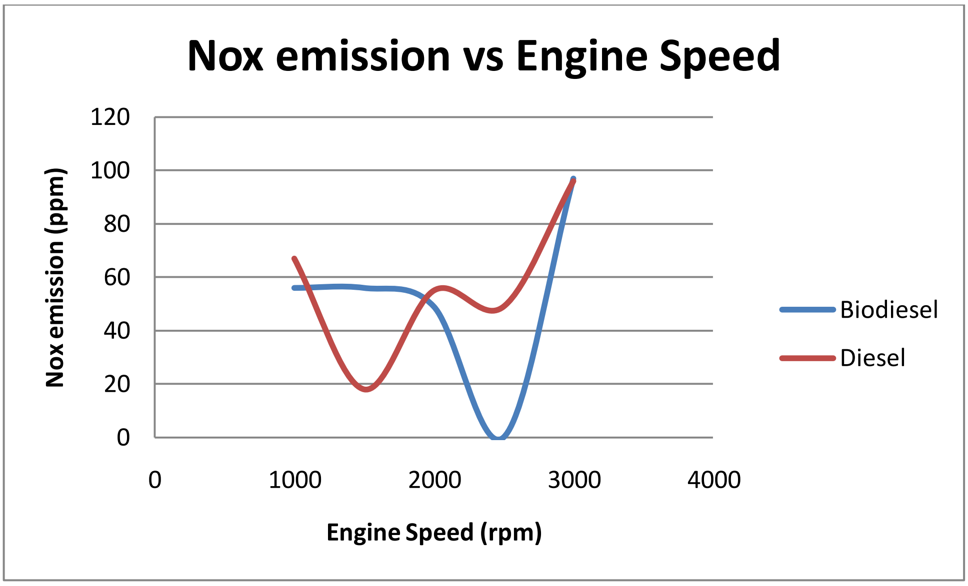

Figure 4.10: NO_x emission vs. Engine speed

In case of biodiesel burning continuously even during exhaust, due to its heavier molecules, exhaust temperature increases and this is the cause for higher content of NOx compared to diesel. Table 4.10 below shows NO_x emission data for using diesel and biodiesel fuel.

Table 4.10: NO_x emission data

Engine Speed (rpm)	**NO_x emission of biodiesel (ppm)**	**NO_x emission of diesel (ppm)**
1000	56	67
1500	56	18
2000	49	55
2500	0	49
3000	97	96

4.11 SUMMARY

From these results, it shows that biodiesel can give higher performance and lower emission gases of the engine. In terms of performance, biodiesel provide lower torque and power output engine compared with diesel. For biodiesel, BSFC is higher than diesel so it save energy and cost. In terms of emission, using biodiesel reduce gases emission like CO, HC, and CO_2.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

This chapter covers about the conclusion of the performance and gas emissions characteristics of a diesel engine operating with biodiesel. This conclusion was made based on the result and discussion earlier.

5.2 CONCLUSION

The main conclusion derived by this research is that using biodiesel as a engine fuel can increase performance of engine and decrease gas emissions.

5.3 RECOMMENDATIONS

For further research, performance and emission characteristics of a diesel engine operating with biodiesel can be analyzed with variable percentage of throttle. By this, accurate result can be determine.

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