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JUDUL: **ONE-DIMENSIONAL SIMULATION OF A DIESEL ENGINE OPERATING WITH BIODIESEL**

SESI PENGAJIAN: **2010/2011**

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ONE-DIMENSIONAL SIMULATION OF A DIESEL ENGINE OPERATING WITH BIODIESEL

MOHD RIZAL BIN SHAFIE

Thesis submitted in partial fulfillment of the requirements
for the award of the degree of
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UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled *"One-dimensional Simulation of a Diesel Engine Operating with Biodiesel"* is written by *Mohd Rizal Bin Shafie*. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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AWARD FOR DEGREE

Bachelor Final Year Project Report

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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.

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DEDICATION

Specially dedicated to my beloved family:

Allahyarham Shafie Bin Hj. Mamat

Naimah Binti Ibrahim

Muhammad Aliff Haiqal

Nursyakilla

Muhammad Yazid

and my supervisor Dr. Rizalman Mamat

for their greatest support and care

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ABSTRACT

This study is to explore one-dimensional simulation for four cylinders diesel engine. The simulation and computational development of modelling for the research is used the commercial Computational Fluid Dynamics (CFD) of GT-SUITE 6.1 software. The engine model was developed corresponding to a 2.0 litre Mitsubishi 4D68 four-cylinder diesel engine. The diesel engine is simulated to study the characteristic of engine performance when the engine is operating with biodiesel as an alternative fuel. The development of one-dimensional simulation modelling covers full engine cycle consisting of intake, compression, power and exhaust system. For the fuel used which is biodiesel, the database of biodiesel need to be determined because there is no available database for one-dimensional simulation. The results obtained from simulation were compared with the data from the diesel engine operating with conventional diesel. Then, the results gained for biodiesel simulation is compared to experiment to gain more information about its trend. The simulation results showed that the brake power and brake torque were reduced if the diesel engine was being fuelled with biodiesel. Using biodiesel also decrease brake thermal efficiency. The decrease of low heating value resulted to increase brake specific fuel consumption.

ABSTRAK

Kajian ini bertujuan untuk mengkaji simulasi satu dimensi bagi enjin diesel empat silinder. Simulasi dan pembangunan pengkomputeran model untuk kajian adalah menggunakan perisian komputasi bendalir dinamik (CFD) GT-SUITE 6.1. Model enjin dibangunkan berdasarkan enjin empat silinder Mitsubishi 4D68, 2.0 liter. Enjin diesel ini disimulasikan untuk mengkaji corak prestasi enjin apabila ianya menggunakan biodiesel sebagai bahan bakar alternatifnya. Pembangunan permodelan satu dimensi merangkumi sistem penyedupan, pemampatan, pembakaran dan sistem ekzos. Bahan bakar yang digunakan adalah biodiesel, justeru itu pangkalan data biodiesel perlu dikenalpasti kerana ianya belum ada bagi simulasi satu dimensi. Keputusan simulasi yang diperolehi dibandingkan dengan data dari enjin diesel yang beroperasi menggunakan minyak diesel biasa. Seterusnya, keputusan bagi simulasi biodiesel dibandingkan dengan eksperimen untuk memperolehi lebih maklumat mengenai coraknya. Keputusan simulasi menunjukan kuasa dan daya kilas merosot apabila enjin diesel menggunakan biodiesel sebagai bahan bakarnya. Penggunaan biodiesel juga menurunkan keberkesanan terma. Penurunan nilai pemanasan rendah mengakibatkan penggunaan bahan bakar khusus meningkat.

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LIST OF SYMBOLS

W	Work per cycle
A_p	Piston face area of all pistons
$\overline{U}_p$	Average piston speed
T	Torque
W_b	Brake work of one revolution
V_d	Displacement volume
n	Number of revolutions per cycle
η_{bth}	Brake thermal efficiency
$\dot{m}_f$	Rate of fuel flow into engine
$\dot{W}_b$	Brake power
η_{υ}	Volumetric efficiency

LIST OF ABBREVIATIONS

AFR	Air-fuel ratio
BDC	Bottom dead center
BP	Brake power
BSFC	Brake specific fuel consumption
BT	Brake torque
B5	Biodiesel blend (5 % biodiesel, 95 % petroleum)
B100	Biodiesel blend (100 % biodiesel)
CFD	Computational Fluid Dynamics
CI	Compression ignition
CO	Carbon monoxide
DI	Direct injection
FAEE	Fatty Acid Ethyl Ester
FAME	Fatty-Acid Methyl Ester
HC	Hydrocarbon
MEP	Mean effective pressure
NMHC	Non-Methane Hydrocarbon Compounds
NO_x	Nitrogen Oxide
PM	Particulate matter
POME	Palm Oil Methyl Ester
REE	Rapeseed Ethyl Ester
RME	Rapeseed Methyl Ester
SI	Spark-ignition
SOF	Soluble organic fraction

SO_2	Sulfur
TDC	Top dead center

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

For over centuries, machines are very common in term of helping human kind. For the main observation, transportation is very needed by all human to easier their task, easier their work. As the population grows, vehicles have become the number one in the chart of very important asset compared to other valuable asset. And the heart of this vehicle is engine.

Diesel engines which are direct injection (DI) and compression ignition (CI) engines have dominated the field of heavy-duty vehicles and marine transportations. Diesels are workhorse engines. That is why the diesel engines powering heavy-duty trucks, tractors, ships and other construction equipment. But the diesel engines are very dirty, loud and produce more emission. These superb diesel engines are increasingly being applied to light-duty vehicle in the past 30 years (Zheng, 2009).

Latest and modern diesel engines require more clean burning, stable fuel that will perform well in a numerous of operation varieties (Tsolakis et al., 2007). Therefore with the latest technology, there have been greater improvements toward these engines. However, the increase in price of diesel fuel, the rapid depletion of petroleum fuel and also higher stringent emission regulation force us to search for alternative fuel which can reduce emissions (Chen et al., 2008, Zheng, 2009).

In order to create alternative oxygenated fuels, the vegetable oils or their derived biodiesels (methyl or ethyl esters) are recently considered as promising fuels to supplant the fraction of petroleum distillates. The benefit of biofuel now has become valuable asset for reduction of greenhouse gas emissions (Luján et al., 2009b, Wheals et al., 1999). For diesel engines, biodiesel is under study as a viable alternative fuel for those engines (Luján et al., 2009b). Fuel derived from biological sources showing important advantages in emitted CO_2 reduction (Rickeard and Thompson, 1993, Graboski and McCormick, 1998, Demirbas, 2003). Although CO_2 is a kind of greenhouse gas, the CO_2 released by biofuel combustion can be fixed by growing more plants thus makes no net contribution to global warming (Wheals et al., 1999).

The previous study of diesel engine with biofuels such as biodiesel has promising the bright future especially in automotive industry; as replacement of diesel fuel and environment ecosystem.

1.2 OBJECTIVES

The objectives of this study are to:

i. Perform one-dimensional simulation of a diesel engine operating with biodiesel.
ii. Establish the database of biodiesel in GT-Suite.

1.3 SCOPE OF THE PROJECT

i. Perform one-dimensional engine modeling.
ii. Determine the characteristic of biodiesel (calculation based).
iii. Construct the database of biodiesel in simulation software.

1.4 PROBLEM STATEMENT

1.4.1 Problem

In the simulation software, there is no database of biodiesel available for one-dimensional simulation. It is very important to know the trend for the diesel engine which is being operated with biodiesel fuel.

1.4.2 Solution of The Problem

GT-POWER is a user friendly and very suitable for every engine simulation and being used by most car manufacturers. Therefore there is an alternative for the problem in defining fuel for the simulation. GT-POWER allows the users to create their own fuel files on the specific button to use the pre-processor. Referring to the biodiesel properties table, the biodiesel fuel can be created. The results gain by the simulation can give overview on how the biodiesel affect the diesel engine.

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 BASIC INTERNAL COMBUSTION ENGINES

2.2.1 Reciprocating Engines

The reciprocating engine, basically a piston-cylinder device, is one of the rare and creative inventions that have proved to be very versatile. They and have been used in many range of applications. It is the powerhouse of the vast majority trucks, automobiles, ships and electric power generators. (Yunus and Michael, 2007)

Figure 2.1 shows the basic components of a reciprocating engine. The piston reciprocates in the cylinder between two fixed positions called the top dead center (TDC). TDC is the position of the piston when it forms the smallest volume in the cylinder. Besides TDC, the latter position known as bottom dead center (BDC) indicates the position of the piston when it forms the largest volume in the cylinder (Figure 2.2). The stroke of the engine is the distance between the TDC and BDC which it has the largest distance that the piston can travel in one direction. Bore is the diameter of the piston. Intake valve allows the air or air-fuel mixture to be drawn into the cylinder. While the exhaust valve function is to expel the combustion products.

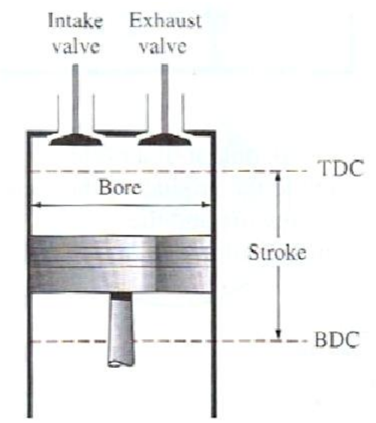

Figure 2.1: Nomenclature of reciprocating engines

Source: Yunus and Michael, 2007

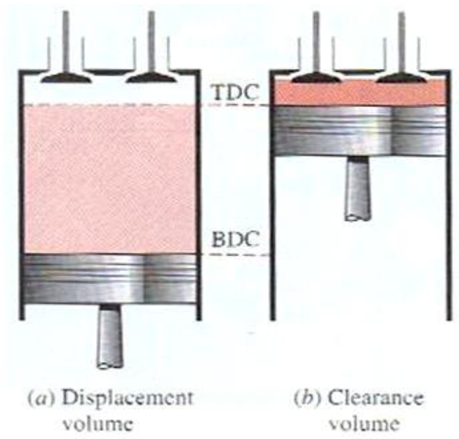

Figure 2.2: Displacement volume and clearance volume of reciprocating engine

Source: Yunus and Michael, 2007

The displacement volume is the term to indicate the volume displaced by the piston as it moves between TDC and BDC. The frequently used term in conjunction with reciprocating engines is the mean effective pressure (MEP). MEP is the fictitious pressure that, if it acted on the piston during the entire power stroke, which can produce the same amount of net work as the produced during the actual cycle. It also can be used as a parameter to compare the performance of reciprocating engine of equal size. The larger of MEP on the engine will deliver more net work per cycle and give better performance (Yunus and Michael, 2007).

The concept of compression ratio is really simple. During the compression process, the collisions between molecules will initiate heat that ignites the diesel fuel (Dempsey, 2008). In Figure 2.3, simple expression on mathematical forms and pictures will explain details.

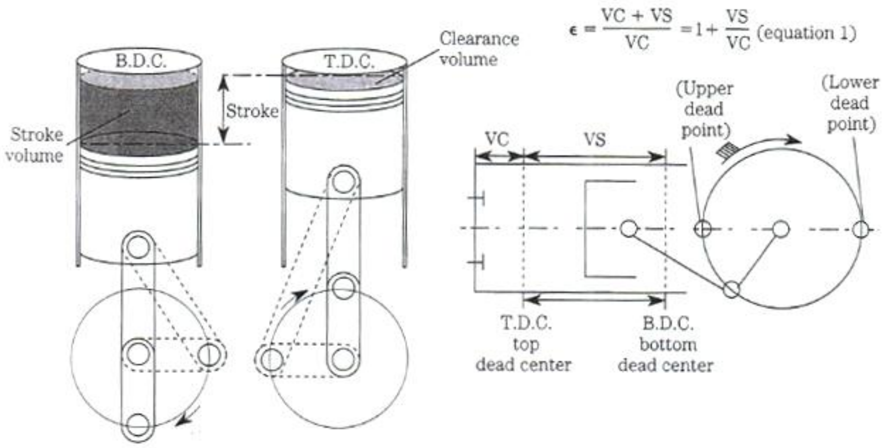

Figure 2.3: Concept of compression ratio

Source: Dempsey, 2008

The reciprocating engines are classified as compression-ignition (CI) engines or spark-ignition (SI) engine. Both of them are depending on how the combustion process in the cylinder is initiated. In CI engines, the air-fuel mixture is self-ignited because of the compressing the mixture above its self-ignition temperature. While in SI engines, the spark plug will initiate the combustion of the air-fuel mixture (Yunus and Michael, 2007).

2.3 DIESEL ENGINES

The history of biodiesel was started by Dr. Rudolf Diesel (1858 to 1913). In 1892, he embarked on research at MAN in Augsburg on his totally new engine which the ignition of fuel by compression process (GmbH, 2004). After many years of exploration and research, he introduced world's first diesel engine. Compared to gasoline engines and steam engines, this engine had number of advantages. It is less fuel consumptions and could be dimensioned for higher power outputs.

In 1922, Robert Bosch decided to develop a fuel-injection system for diesel engines. Those Bosch fuel-injection pumps were a stepping stone in achieving higher running speeds in diesel engine. In 1936, Mercedes-Benz 260D (2580 cc, 50 hp) was the first volume-production car to be fitted with a diesel engine. The vision of Rudolf Diesel had become reality. (GmbH, 2004)

The diesel engines are compression-ignition (CI) engines. In diesel engines, the spark plug and carburetor are replaced by a fuel injector. This due to the air when being compressed to a temperature that is above the auto-ignition temperature of the fuel, and combustion creates on contact as the fuel is injected into this hot air. In spark-ignition (SI) engines, also known as gasoline engines, air-fuel mixture is compressed during the compression stroke and the compression ratios are limited by the onset of auto-ignition or engine knock. But in diesel engines, only air is compressed during the compression stroke, which can eliminate the possibility of auto-ignition. (Yunus and Michael, 2007)

Therefore the diesel engines can operate on much higher compression ratios, between 12 and 24. Besides that, many of the stringent requirements placed on the gasoline engine can be removed from diesel engine. Thus less refined fuels (less expensive fuel) can be used in diesel engine. The diesel engines also burn fuel more completely compared to gasoline engines since they work on lower revolutions per minute (rpm) and having higher air-fuel mass ratio. It is more efficient than spark-ignition engine (gasoline) because they operate at much higher compression ratios (Yunus and Michael, 2007). Lower fuel cost and higher efficiency become the reason why they have been used in large ships and emergency power generation units. Figure

2.4 showed relationship between diesel compression ratio (c/r) and thermal efficiency (η_t). Modern diesel engines completed certain requirement such as clean burning; stable fuel that performs well under some variety of operating conditions (Tsolakis et al., 2007).

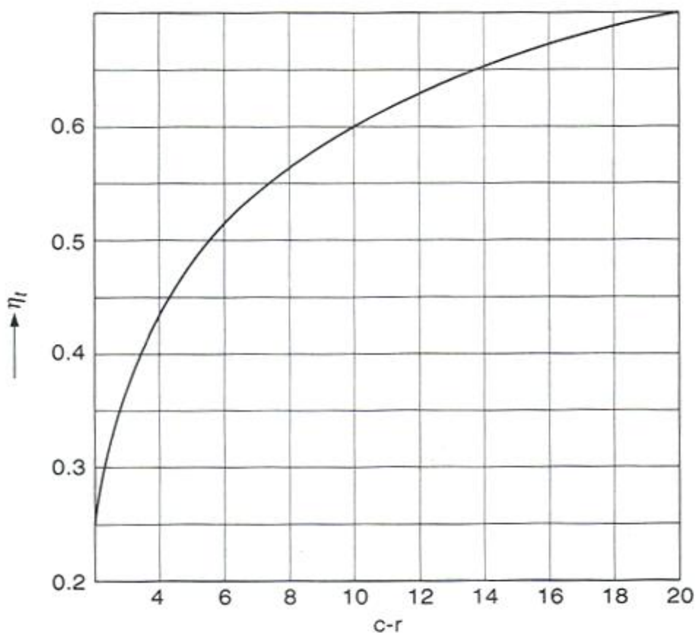

Figure 2.4: Relationship between diesel compression ratio (c/r) and thermal efficiency (η_t)

Source: Dempsey, 2008

2.4 FOUR-STROKE DIESEL ENGINES

Both SI and CI engines operate in the simple and same cycles, consisting of intake, compression, expansion, and exhaust event. There are two-stroke cycle and four-stroke engines. Telescoping the events into two stroke of the piston or one per crankshaft revolution is called two-stroke engines (Dempsey, 2008). Four-stroke engines happen when the piston executes four complete strokes (two mechanical cycles) within the cylinder or one per crankshaft revolution (Yunus and Michael, 2007, Dempsey, 2008). Figure 2.5 shows the four-stroke diesel engines operation and details information.

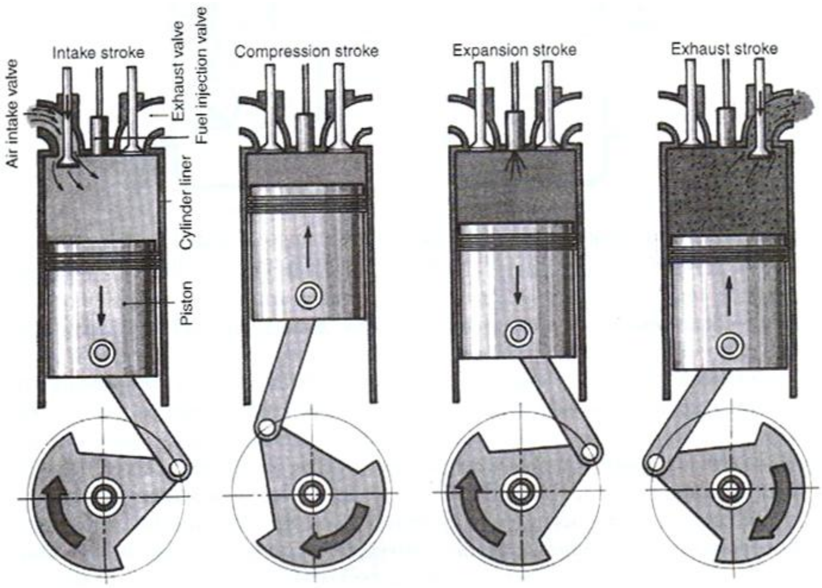

Figure 2.5: Four-stroke diesel engine operations

Source: Dempsey, 2008

2.4.1 Intake Stroke

At the open intake valve, air will be entering the cylinder, as the piston falls on the intake stroke (Dempsey, 2008). Sometime, some engines have one or two valves for each inlet and exhaust port (GmbH, 2004).

2.4.2 Compression Stroke

During the compression stroke, as the piston rounds BDC, the intake valve closes. The piston moves upwards which is compressing and heating air to ignition temperature. Near TDC on expansion stroke, fuel-injection begins. Fuel-injection system can inject fuel at high pressure (up to 2000 bar in modern engines) into the hot, compressed air (GmbH, 2004). This will continue for about 40° of crankshaft rotation (Dempsey, 2008).

2.4.3 Ignition Stroke

Then the fuel ignites and burns due to the heat of high compressed air in the cylinder (combustion chamber). The pressure forces the piston down in the bore on expansion or power stroke (Dempsey, 2008). The energy released during the combustion is depend on quantity of mass of fuel injected (GmbH, 2004).

2.4.4 Exhaust Stroke

The piston rises on the exhaust stroke, purging the exhaust gases through an open exhaust valve. The four-stroke cycle is complete, performing two crankshaft revolutions from its beginning after the piston move upward again, reaches TDC position (Dempsey, 2008, Yunus and Michael, 2007) and four-stroke operating cycle begins again with the intake stroke (GmbH, 2004).

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2.5 DIESEL FUELS

Distillation of crude oil has produces useful fuel called diesel. They consist of large different hydrocarbon compounds such as olefin, n-paraffins, naphthenes, i-paraffins and aromatic compounds. All of them have same range of boiling point of 160-380 °C (middle distillates). Diesel fuel ignites early compared to gasoline which is on approximately 350 °C and 500 °C respectively. (GmbH, 2004)

2.5.1 Quality Criteria

The high quality diesel fuels can be characterized by various factors (GmbH, 2004) such as high cetane number, narrow density and viscosity spread, low sulfur content and relatively low upper boiling point limit

2.6 RENEWABLE ENERGY SOURCES

For the last few decades, it is proved that the consumption of non-renewable source of energy caused too much environmental damage than any other human activities (Vijayalakshmi et al., 2007). For example is petroleum oil, which leads too much of vehicular pollution. The chemical gas produced by this oil has led to high concentrations of harmful gases in the atmosphere. This leads to global warming and ozone depletion. Because of these problems, alternative source has become number one of interesting topic nowadays (Vijayalakshmi et al., 2007).

The source that will never be exhausted such as wind and sun, are called renewable energy. They produce low emissions and available locally. Most of renewable source of energy are considered as non-polluting and clean. The renewable sources of energy are as below solar energy, wind energy, biomass energy and geothermal energy.

In this thesis, an alternative fuel used is biodiesel. Biodiesel is categorized under biomass energy. For definition, biomass is organic material made and produced from animals and plants. Biomass is derived from natural activities of human which produce lots of carbonaceous waste. From other numerous source such as agricultural crops, by-products from timber industry and wood, could also lead to biomass derivatives (Vijayalakshmi et al., 2007). The application of biomass energy is to generate electricity, heat, motion and fuel.

2.6.1 Biofuels

Biofuels are transportation fuel such as ethanol and biodiesel that are produced from biomass materials. Usually this fuel will be blended with the petroleum fuels namely with diesel and gasoline fuel. However, they also can be used on their own. Ethanol and biodiesel can be described as cleaner burning fuels because of fewer air pollutants (Vijayalakshmi et al., 2007).

Biofuels has already taken place in today markets such as PPO, biodiesel and bioethanol. They are denoted as first generation biofuels and usually produced from food crops (Rutz and Janssen, 2008). Second generation biofuels are not yet commercial on large scale because the conversion technology for them are still in the developmental stage. Second generation biofuels are bioethanol from cellulosic material and Biomass-to-Liquid (BtL-fuels) (Rutz and Janssen, 2008).

Both of the generation of biofuels has advantages and disadvantages. The main advantage of first generation biofuels is that they are available with today's technologies. Vice-versa, the main disadvantage of first generation biofuels is that only specific crops can be used for the biofuels production. (Rutz and Janssen, 2008)

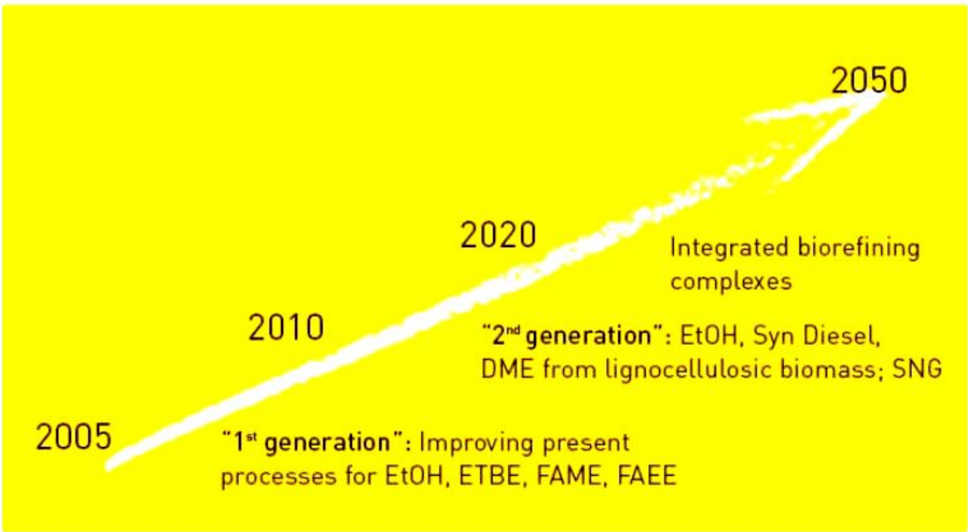


Figure 2.6: Future European Roadmap for Biofuels

Source: COMMUNITIES, 2003

2.7 BIODIESEL

Biodiesel is an alternative fuel formulated exclusively for diesel engines. The term of biodiesel is commonly referred to methyl ester (Carraretto et al., 2004). It is consists of alkyl esters of long chain fatty acids made from renewable biological materials such as vegetable oils or animal fats. Biodiesel can be used in usual diesel engines and presents some advantages compared to traditional petroleum-based diesel.

The appearance of biodiesel is light to dark yellow liquid. It has higher boiling point, practically immiscible with water and low of vapor pressure. Biodiesel has less density compared to water which is around 0.86 g/cm^3. Typical methyl ester is rather non-flammable due to higher flash point around 150 °C (Vijayalakshmi et al., 2007).

Biodiesel now can compete with other alternative fuels and clean-air options for urban transit fleets and government vehicles across the country. In addition to this, application of bio-fuel on diesel engines can reduce environmental pollution, strengthen agricultural economy, create job opportunities and reduce diesel fuel requirements (Chen et al., 2008).

2.7.1 History of Biodiesel

The history of biodiesel was started on 1900. This is when Dr. Rudolf Diesel, the German inventor of the diesel engine used peanut oil as fuel in his first original compression-ignition engine (Vijayalakshmi et al., 2007). In the early 20th century was that vegetable fuels (biodiesel) will be the primary fuel for diesel engines, and were used until the 1920’s, when petro-diesel made its entry. During the 1920's, diesel engine manufacturers decided to alter their engines utilizing the lower viscosity of the fossil fuel, best known as petro-diesel, rather than such biomass vegetable oil fuel. Crude oil began being cheaply extracted from deeper in the soil, so most of cars began using fuel from oil (petro-diesel) (Vijayalakshmi et al., 2007).

At that time all petroleum industries were able to make inroads in fuel markets because their fuel was much cheaper to produce compared to the biomass alternatives without realize that years ahead it would bring high pollution costs.

Therefore there was a near elimination of the biomass fuel production infrastructure was for many years because of the result of petro-diesel commercialization. Now that we have just begun to run out of petro-fuels, therefore we need an alternative fuel such as biodiesel. In the 2000's when crude prices started rising again and with a new world awareness on pollution and global warming, bio-fuel again become popular. Government subsidy of bio-fuel industries became common, especially in the first world. During U. S President George' speech, he wants upcoming 2025 of the United States to replace 75% of the oil coming from the Middle East (Vijayalakshmi et al., 2007).

After the oil shock in 1973 and 1979, governments and academics show interest in biofuels (Vijayalakshmi et al., 2007). Today, increasing concerns about the potential of global climate change, serious human health concerns and declining air and water quality, are inspiring the development of biodiesel, as a renewable, cleaner burning diesel alternative. Therefore environmental impact concerns and a decreasing cost differential made biomass fuels such as biodiesel a growing alternative. Besides, in remembrance of Dr. Rudolf Diesel first German run, August 10 has been declared as an International Biodiesel Day.

2.7.2 Biodiesel Types

Biodiesel have several of type, such as Rapeseed Methyl Ester (RME), Palm Oil Methyl Ester (POME), Rapeseed Ethyl Ester (REE) and Fatty-Acid Methyl Ester (FAME). Biodiesel also can be mixed with petroleum diesel in any percent represent by a number according to the "B" factor. For example, B20 represents 20 percent biodiesel with 80 percent petroleum (Vijayalakshmi et al., 2007). The term biodiesel usually refers to an ester, or an oxygenated, made from the oil and methanol. In other words, the name ''biodiesel'' can be applied to any transesterified vegetable oil that makes it suitable for use as a diesel fuel. Table 2.1 is a sample of biodiesel and diesel properties.

2.7.3 Biodiesel Production

Biodiesel fuel production and its applications extend all around the world, since it is originating in non-fossil fuel in CO_2 neutral principle (Daisuke et al., 2007). The term of transesterification is used to describe the important class of organic reactions where an ester is transformed into another through interchange of the alkoxy moiety. During biodiesel production, the molecular structure of lipid molecules is changed due to chemical transesterification process (Rutz and Janssen, 2008). Mainly the alcohols methanol and ethanol are being used during the transesterification process (Rutz and Janssen, 2008)

Table 2.1: Chemical and physical properties of commercial biodiesel and diesel oil

	Unit	Biodiesel sample 1	Biodiesel sample 2	Diesel D2
Density at 15 C	Kg/m^3	886.1	882.4	829.0
Viscosity at 40 C	Mm^2/s	4.3	4.66	2.40
Carbonious residue according to Conrason	%m/m	0.18	0.75	0.01
Ester content	%m/m	98.9	98.7	-
Free glycerol	%m/m	0.2	< 0.1	-
CFPP	°C	-4	-4	-4
LHV	MJ/kg	37.54	36.97	42.99
Ashes	%m/m	< 0.01	< 0.01	< 0.01
Phosphorous	mg/kg	274	37.6	-
Sulphur	%m/m	0.007	0.018	0.001
Iodine number	$g\ l_2/100g$	46	100.5	-
Oxidation stability	G/m^3	26.4	35.7	-
Distillation fractions				
250 °C	% v	0	0	42
320 °C		0	5	75
350 °C		87	81	87
370 °C		100	100	92

Source: Carraretto et al., 2004

Transesterification process is called alcoholysis when the original ester is reacted with an alcohol (Rutz and Janssen, 2008, Otera, 1993). During this process by which refined oil molecule is “cracked” and the glycerin is removed, thus resulting in production of glycerin soap and methyl-or ethyl esters (biodiesel) (Rutz and Janssen, 2008). If the transesterification process is involved methanol, it is called methanolysis which is the most commonly method to produce biodiesel (Rutz and Janssen, 2008). After methanolysis, the received biodiesel is Fatty Acid Methyl Ester (FAME). The utilization of bioethanol in an ethanolysis reaction produces biodiesel called Fatty Acid Ethyl Ester (FAEE). Ethanolysis is more environmentally friendly alternative, since it allows the production of an entirely renewable fuel. Besides, ethanol is much less toxic and resulting in increasing of the heat contents and cetane numbers of the resulting fuel (Rutz and Janssen, 2008).

Transesterification of alkyl esters is an important role in the industry with numerous applications from small volume production until large volume production. Examples for large-scale applications are the production of biodiesel (Ma and Hanna, 1999), polyethylene terephthalate (PET) in the polymer industry (Otera, 1993, Meyer and Hoelderich, 1999).

Vice-versa, small-scale fine-chemical production includes synthesis of intermediates for the pharmaceutical industry, the curing of resins in the paint industry and the production of food additives or surfactants (Otera, 1993, Corma et al., 1998).

Petroleum fuels have already created heavy environmental toll on the earth. Biofuels are promising as an alternative way to reduce the emissions of both greenhouse gases and urban air pollutants. Cultivation from them could cause huge disruptions in land use but if they are being managed properly, the cultivation of energy crops will facilitate the sequestration of carbon in the soil and restoring the ecosystem. (INSTITUTE(WWI), 2006)

2.8 ADVANTAGES OF BIODIESEL

2.8.1 Biodiesel Prolongs Engine Life

Biodiesel is much better for engine than conventional petro-diesel and can actually prolong the life of the engine. Also an engine that runs on biodiesel is much cleaner because of the solvent effect of biodiesel and this as well reduces engine wear and increases engine life. A minor number of experiments have also been reported some improvement or some decrease in thermal efficiency when using biodiesel fuels. Researchers explained their observed increase in efficiency by means of an improved combustion, giving no further reasoning (Kaplan et al., 2006). It is asserted that an improvement in thermal efficiency occurs when 20% blends are used, thereby compensating for the loss of heating value.

2.8.2 Biodiesel Is Environmentally Friendly

Biodiesel is less toxic than salt and biodegrades quicker than sugar. Overall, biodiesel fuel presents lower Sulfur Dioxide content, higher flash point and lower total contamination values compared to diesel fuel (Lapuerta and Agudelo, 2004). For biodiesel emissions, the present of zero or low content of sulfur lead to sulfur pollutants (SO_2) and even much lower compared to emissions of conventional fuels (Bozbas et al., 2008). Using biodiesel in any conventional compression ignition diesel engine will result in an effective reduction of CO_2 emissions because biodiesel is carbon neutral in principle (Daisuke et al., 2007).

2.8.3 Biodiesel Has Economic Advantages

The price of biodiesel is cheaper than regular diesel fuel. There is an excess production of soybeans; therefore biodiesel is an economic way to utilize this surplus. Actually the cost of biodiesel depends on the places where the soy beans grow, the agriculture techniques that are used, and basically the process technology to get the biodiesel as well as the intermediate processes that are required (Carraretto et al., 2004). Besides biodiesel can be produced locally from locally sourced feedstock or waste products like used cooking oil.

2.8.4 Higher Density

Biodiesel has higher density compared to the commercial diesel oil D2, biodiesel has a higher density and a greater cetane number (usually above 50, due to the long linear acid chains that reduce the ignition delay of the air–fuel mixture). In addition, the high flash point which is more than 100°C makes the storage and transportation issues become less important (Carraretto et al., 2004). Because of biodiesel has higher density than diesel, more mass is introduced for an equal volume. The blends also were made volumetrically (Luján et al., 2009b).

2.8.5 No Engine Modifications Necessary

Pure unblended biodiesel fuel can generally be used directly in existing oil heating systems and diesel engines without any mechanical modification, as pure or blended with diesel (Tsolakis et al., 2007, Vijayalakshmi et al., 2007). This is an advantage over other alternative fuels, which can be expensive to use initially due to high cost of equipment modifications or new purchases. Almost the same energy per gallon as petroleum diesel will be produced by diesel.

2.9 ENGINE PERFORMANCE PARAMETERS

2.9.1 Brake Power

Power is defined as the rate of work of the engine. If n = number of revolutions per cycle and N = engine speed, the brake power can be expressed as Eq. (2.1) (Pulkrabek, 2004):

$$\dot{W} = WN/n$$

$$\dot{W} = 2\pi N\tau$$

$$\dot{W} = \left(\frac{1}{2n}\right)(mep)A_p\bar{U}_p$$

$$\dot{W} = (mep)A_p\bar{U}_p/4 \tag{2.1}$$

where W = work per cycle

A_p = piston face area of all pistons

$\bar{U}_p$ = average piston speed

2.9.2 Brake Torque

Torque is an indicator of an engine's ability to do work. It is defined as force acting at a moment distance and has units of N-m or lbf-ft. Torque (τ) is related to work by (Pulkrabek, 2004):

$$2\pi\tau = W_b = (bmep)V_d/n \tag{2.2}$$

where W_b = brake work of one revolution

V_d = displacement volume

n = number of revolutions per cycle

For a four-stroke cycle engine that takes two revolutions per cycle,

$$\tau = (bmep)V_d/4\pi \tag{2.3}$$

2.9.3 Brake Thermal Efficiency

Brake thermal efficiency (η_{bth}) is the ratio of energy in the brake power (BP), to the input fuel energy in appropriate units (Ganesan, 2003). Solving for thermal efficiency as per below:

$$n_{bth} = \frac{BP}{Mass\ of\ fuel\ x\ calorific\ \ value\ of\ fuel} \tag{2.4}$$

2.9.4 Brake Specific Fuel Consumption

In the engine testing, fuel consumption is measured as mass flow per unit time (Heywood, 1988). It is denoted as $\dot{m}_f$. For previous studies, many researchers are interested on specific fuel consumption (sfc) parameter. It is defined as the fuel flow rate, $\dot{m}_f$ per unit power output, P (Heywood, 1988). This parameter measures how efficiently an engine is using the fuel supplied to produce work. For CI engines, best values of brake specific fuel consumption (BSFC) are lower and in large engines can go below 200 g/kW·h. Brake specific fuel consumption as:

$$BSFC = \dot{m}_f / \dot{W}_b \tag{2.5}$$

where $\dot{m}_f$ = rate of fuel flow into engine
$\dot{W}_b$ = Brake power

2.10 BIODIESEL EFFECTS ON ENGINE EMISSIONS

Many researchers had doing some experiments on diesel engine, by fuelled the engine with vegetable oils or biodiesels, to investigate the performance emissions characteristics produced from this renewable source. Previous studies show that by using biodiesel, it will lead to the increasing amount NOx emissions (Luján et al., 2009a, Daisuke et al., 2007, Rakopoulos et al., 2006, Carraretto et al., 2004). In general, previous analyses show that by fuelling diesel engine with biodiesel also emit lower amount of particulate matter (PM) emissions (Chen et al., 2008, Rakopoulos et al., 2006). Unburned hydrocarbon (HC) and carbon monoxide (CO) emissions are reduced with the addition of biodiesel as a fuel for diesel engine testing (Luján et al., 2009a). The performance of diesel engine fuelled with biodiesel or the vegetable oil blends showing higher specific fuel consumption with extensions of brake thermal efficiency (Rakopoulos et al., 2006). Besides, the smoke (soot) emitted by all biodiesel fuel is significantly lower compared to the diesel fuel (Rakopoulos et al., 2006, Daisuke et al., 2007).

2.10.1 Nitrogen Oxide

Conventional diesel engine without any modification for biodiesel, which operating with biodiesel, will increase Nitrogen Oxide (NO_x) emissions with the biodiesel content (Luján et al., 2009a). The reason is due to the change in fuel characteristics (Daisuke et al., 2007). The fuel which contains organo-nitrogen compounds combust thus will result in performing of NO_x. During the combustion process, the nitrogen bound in the fuel will release as a free radical and form free NO or

N_2 (Mamat, 2009). Through this process, there is no organic bound of nitrogen in high quality gaseous fuel, which yields to ignorable amount of NO_x (Mamat, 2009). Therefore it is necessary to introduce new strategies into diesel engines fuelled with biodiesel for lower NO_x emissions than conventional diesel fuel case (Daisuke et al., 2007) and needs to be examined with more caution (Hamdan and Khalil, 2009). Previously, D. Kawano (Daisuke et al., 2007) proved in the research that CO, Non-Methane Hydrocarbon Compounds (NMHC) and NO_x emissions can be reduced by increasing Exhaust Gas Recirculation (EGR) rate.

2.10.2 Carbon Monoxide

Mostly, Carbon Monoxide (CO) emissions are closely related to fuel rich combustion. Therefore, spark ignition (SI) engines significantly produce more amount of CO emission compared to diesel engine (Mamat, 2009). During combustion process, not all hydrocarbons are oxidized to CO_2 due to non-complete combustion (Luján et al., 2009a). This phenomena lead to CO emissions. By adding small amounts of biodiesel in pure diesel fuel leads to decreasing of CO emissions (Luján et al., 2009a). However, researchers (Mamat et al., 2009a) found that that the combustion of Rapeseed Ethyl Ester (RME) in a diesel engine produces more CO as compared to B50 and ultra low sulfur diesel (ULSD). And J. M Luján (Luján et al., 2009a) also shows an increase on CO emission after using B50 and B100, which is 5.2 % and 9 % respectively.

2.10.3 Unburned Hydrocarbons

Hydrocarbons (HC) can be defined as a compound composed of hydrogen and carbon (Energy, 2006). The combustion of diesel fuel engines involved complex heterogeneous processes. Incomplete combustion still occurred even though diesel fuel takes place in fuel-lean conditions (Mamat, 2009). Biofuels, such as biodiesel and ethanol contain more oxygen in the fuel. Thus it is helpful for the HC oxidation and lead to the reducing of HC emissions (Chen et al., 2008). Higher cetane number of biodiesel also contributes to the reduction of the ignition delay. This will also reduce HC emissions.

2.10.4 Particulate Matter

Particulate emission (PM) reduction has become one of the most important advantages of biodiesel (Luján et al., 2009a). Particulate matter (PM) is defined as a generic term for a broad class of chemically and physically diverse substances that exist as discrete particles (liquid droplets or solids) over a wide range of sizes (Rutz and Janssen, 2008). Generally PM has three components which is dry soot (DS), soluble organic fraction (SOF) and sulfate (Chen et al., 2008). At low and high loads, the engine emitted higher PM emissions. But for the medium loads, PM emissions are low (Chen et al., 2008). The oxygenated compound contained in the biodiesel produce lower amount of PM emissions (Luján et al., 2009a). During the combustion, oxygen contained in biodiesel contributes to the increasing of the local oxygen-fuel ratio (Luján et al., 2009a).

2.11 SUMMARY

In the presented paper, main concern about the new fuel is on environment and economic aspect. There are lots of researches based on experimental diesel test engine operating with biodiesel. Within the studies, there is a little number of researchers work on engine simulation of diesel engine fuelled with biodiesel. The simulation is very interesting and all data collected can be compared with the experimental data to achieve more knowledge and seek for better solutions for fuel exhaustion.

CHAPTER 3

ENGINE SIMULATION

3.1 INTRODUCTION

This section is mainly concerned with the development of the four cylinders modeling and simulation for four-stroke direct-injection (DI) diesel engine. All the data are selected corresponding to the real engine (Figure 3.1). The Chapter 3 covers the development of the four cylinders modeling in one-dimensional simulation for four-stroke direct-injection (DI) diesel.

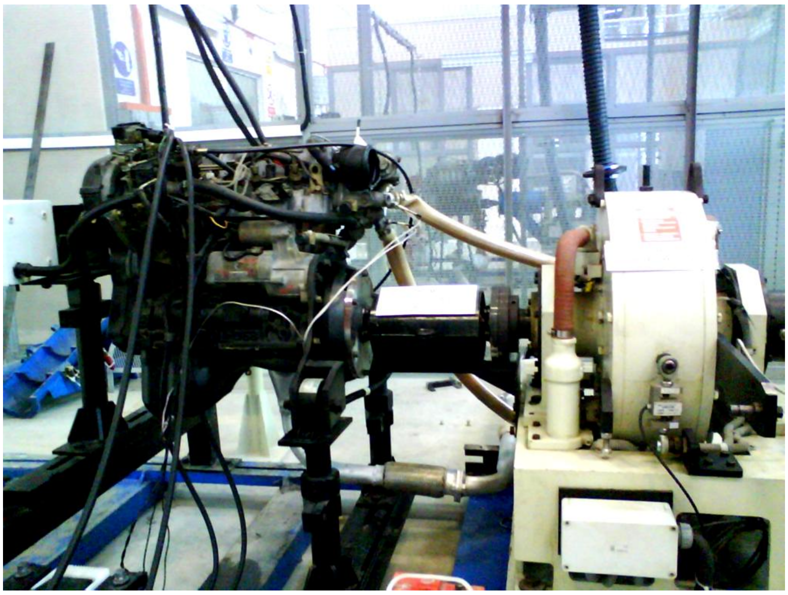
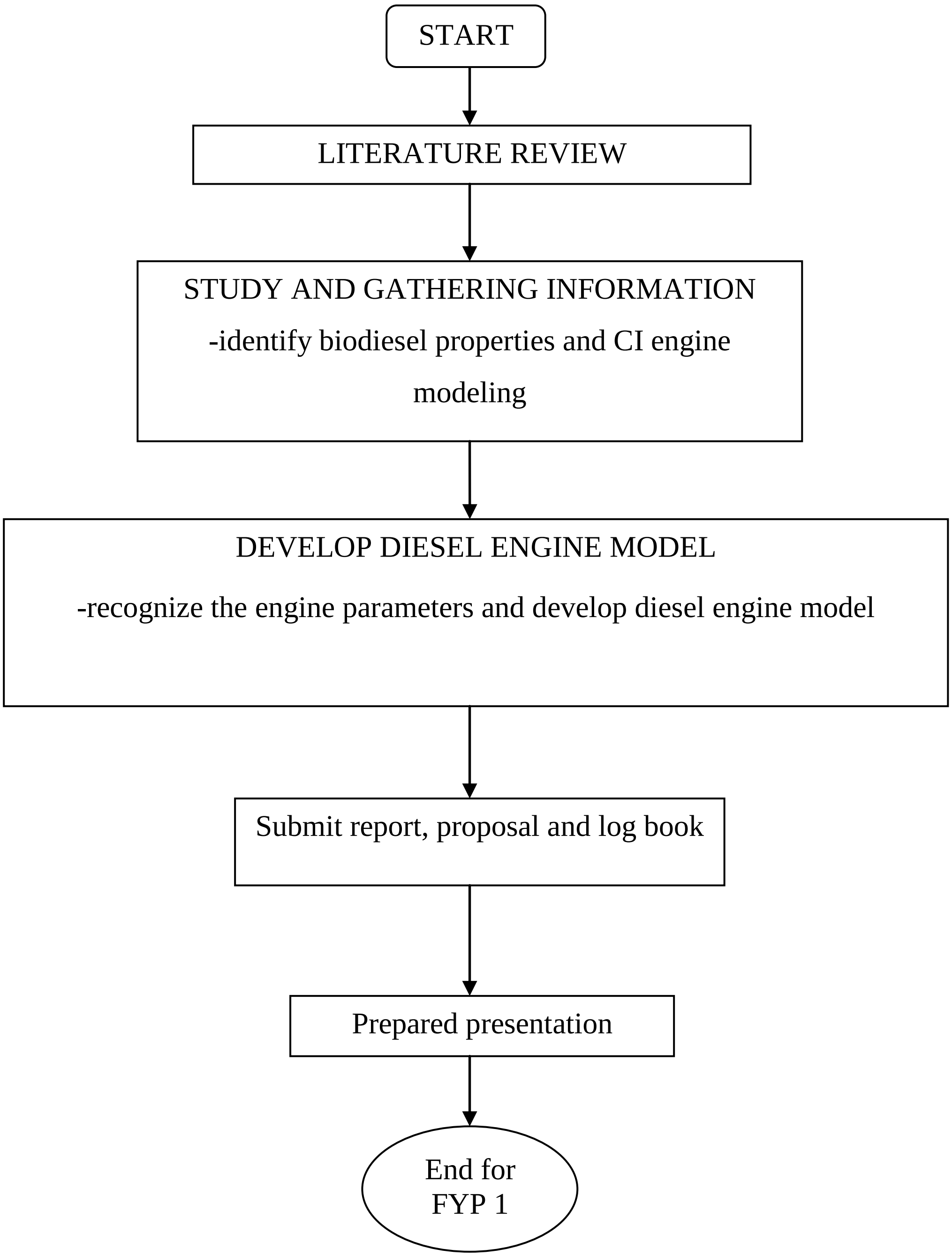


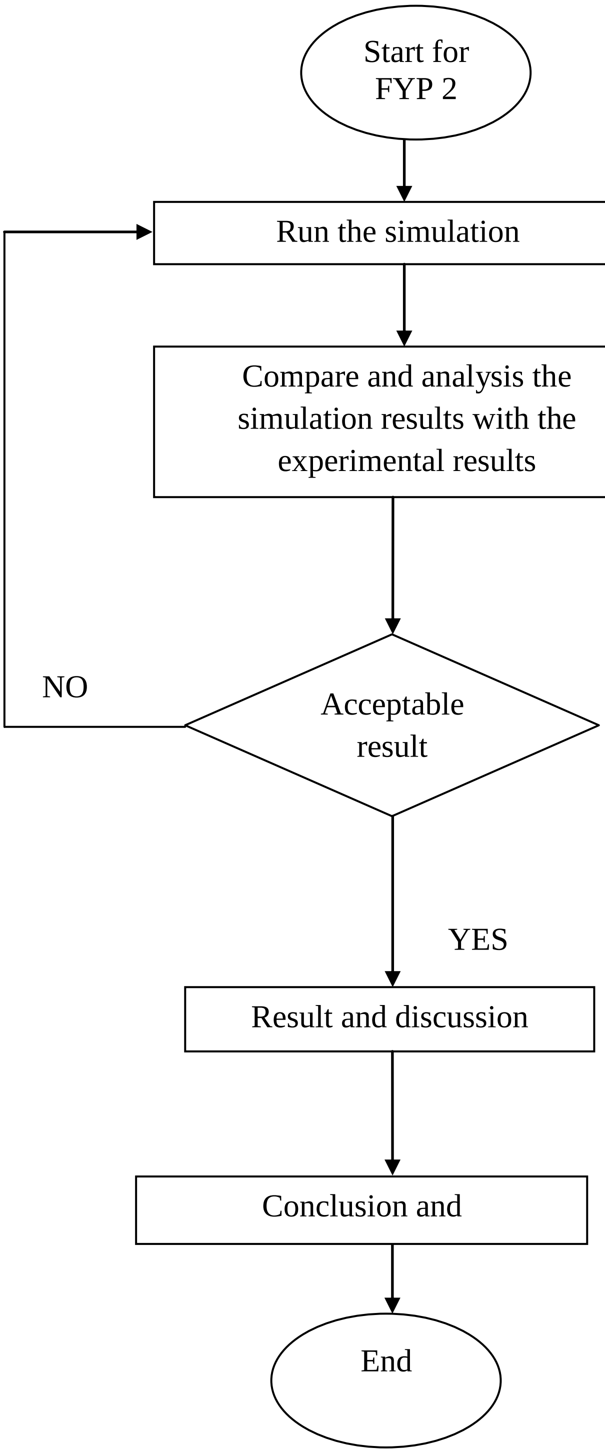
Figure 3.1: Photograph of test engine

3.2 FLOW CHART

3.2.1 Flow Chart/ Project Flow for Final Year Project I (FYP 1)



3.2.2 Flow Chart/ Project Flow for Final Year Project II (FYP II)



3.3 MODELING CI ENGINE IN GT-POWER

The purpose of this study is to perform analysis of one-dimensional simulation of diesel engine operating with biodiesel. Thus for the simulation, it is done by using GT-POWER software package tool. GT-POWER is one-dimensional computer-aided engineering code developed by Gamma Technology; uses for modeling engines.

GT-POWER is popular engine simulation software which is designed for steady-state and transient simulations. It is applicable to many types of the internal combustion engines and provides the user with many components to model any advanced concept. In the other hand, GT-POWER provides a completely coupled interface to many industry-standard CFD codes. This allows various system components with complex geometry or physical phenomena to be simulated as a full three-dimensional model.

In addition, GT-POWER provides a completely coupled interface to user-defined external models and numerous other commercial codes, which can establish controls for the GT-POWER system or employed to further describe the physics of a system component.

Besides, the simulation is advancing as quickly as computer will allow. The analysis becomes easier even though there is numerous configuration possibility and component option. The other competitor for GT-POWER is Ricardo WAVE.

3.4 MODELING ENGINE

The model has been developed using GT-POWER software. All parameters in the model were following the real engine specification as shown in Table 3.1. For model development in GT-POWER, first step is the measurement of the engine components size. Then, all the engine components parameter will be input to the GT-POWER library.

In GT-POWER's menu, Windows was selected and then Tile with Template Library. This will place the GT-POWER template library on the left hand side of the screen. In the engine template library, it contains all of the available templates that can be used in the GT-POWER. Some of these engine templates need to be copied into the project before they can be used to create objects and parts. For modeling engine simulation, the icons listed on the template library are dragged into the project library.

In the diesel engine modeling using GT-POWER computational model, it was divided into three main systems. They were intake system model, engine cylinder and fuel injection system model and lastly the exhaust system model.

Table 3.1: Specification of the engine

Engine parameters	**Value**
Model	Mitsubishi 4D68
Type	Air-cooled diesel engine
Bore (mm)	82.7
Stroke (mm)	93.0
Displacement (L)	1.998
Number of cylinders	4 in-line
Compression ratio	22.4
Connecting rod length (mm)	150.0
Piston pin offset (mm)	1.0
Intake valve open (BTDC)	20°
Intake valve close (ABDC)	48°
Exhaust valve open (BBDC)	54°
Exhaust valve close (ATDC)	22°
Ignition system	Direct injection

3.5 MODELING INTAKE SYSTEM

Optional of the first step of building engine model in GT-POWER is to modeling the intake system. For the selected diesel engine, the intake system has a few components, size and different data. The system was started from environment till the intake valve. The intake system components in the GT-POWER model were environment, intrunner, inport, intvalve.

Figure 3.2 showed the intake system components for one cylinder only. The other three cylinders had the same configurations of the intake system as for the one cylinder. The components in this system require a few data to complete the data form before running the model.

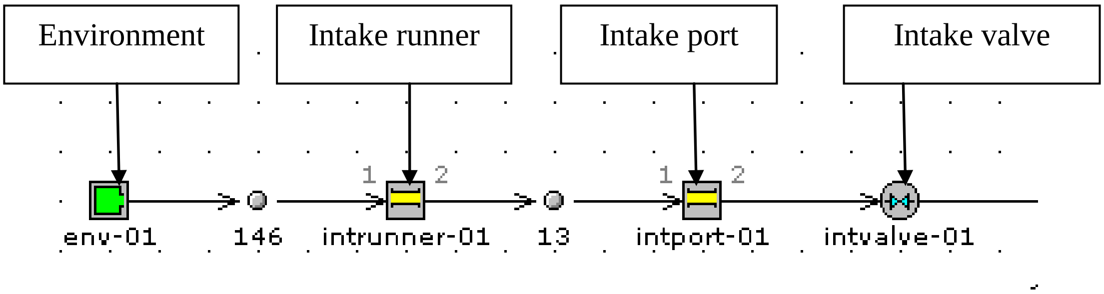


Figure 3.2: Intake system components

Data in environment panel are pressure, temperature, pressure flag and composition. Table 3.2 showed the intake system parameters for the model. For the study, 2.4 bar is set as the environment pressure. The same goes for environment temperature, which is assumed to be 300 K. Initial fluid compositions is assumed to be fresh air and by neglecting the existing of NO, NO_2 and CO concentration.

Table 3.2: Intake system parameters

Parameters	**Attributes**	**Value**
Environment	Pressure	2.4 bar
	Temperature	300 K
	Composition	Air

Intake runner	Length	250 mm
	Inlet diameter	35.33 mm
	Outlet diameter	40 mm
Intake port	Length	80 mm
	Inlet diameter	40 mm
	Outlet diameter	40 mm
Intake valve	Reference diameter	45.5 mm

3.6 MODELING ENGINE CYLINDER AND FUEL INJECTION

The engine cylinder and fuel injection system were focused in the engine cylinder performance supports diesel fuel from fuel injection system, fresh air intake system and exhaust gas to exhaust system. There were many components in the engine cylinder and fuel injection system of the diesel engine. However the basic for all diesel engines were the same components. Then the components, size and data must be recorded and inserted into the GT-POWER form.

The engine cylinder and fuel injection system component are injector, cylinder and engine. Every components in this system were needed any data to complete the data form and running the model. Figure 3.3 and Table 3.3 showed the engine cylinder and fuel injection system components and injector parameters respectively. It shown only for one cylinder and the rest three cylinders shared the same configuration instead of engine. Engine was only one, which representing overall of the cylinders.

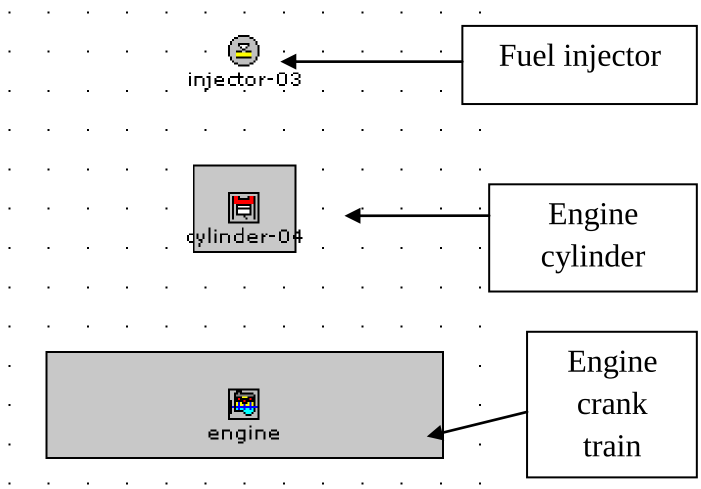


Figure 3.3: Engine cylinder and fuel injection system components

Table 3.3: Injector parameters

Parameters	**Value**
Injector type	InjProfileConn
Nozzle hole diameter	0.1 mm
Number of holes	2

3.6.1 Engine Cylinder

Engine cylinder input panel consist of various attributes such as the start of cycle, cylinder geometry object and initial state name. Figure 3.4 showed the input panel for it. The dimension of bore, stroke and connecting rod which are measured corresponding to the real engine were inputted in this general engine panel. Others components, size and data must be recorded and inserted to the GT-POWER template library input panels. Data in the engine cylinder geometry are bore, stroke, wrist pin to crank offset, compression ratio, TDC clearance height and connecting rod length as seen in Figure 3.5.

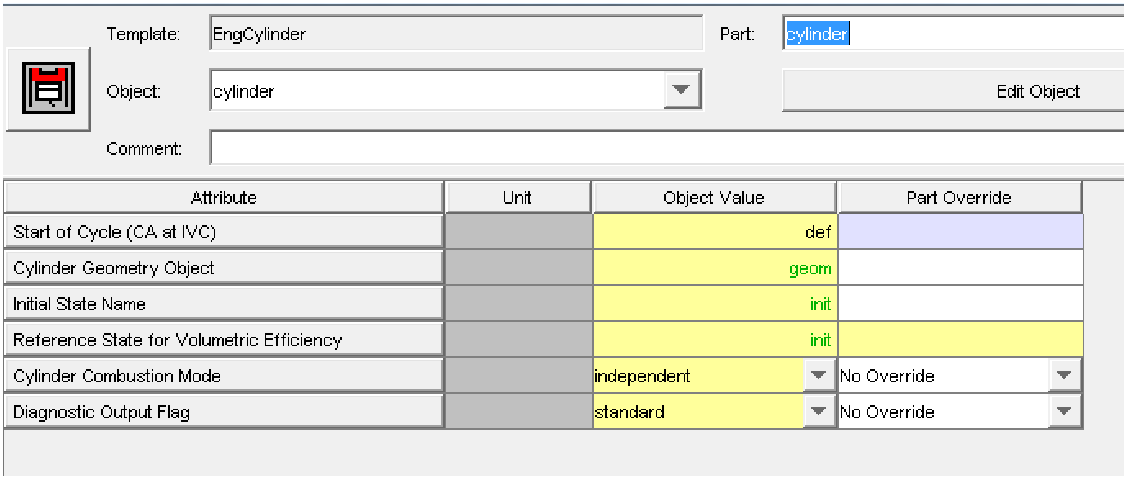


Figure 3.4: Engine cylinder input panel

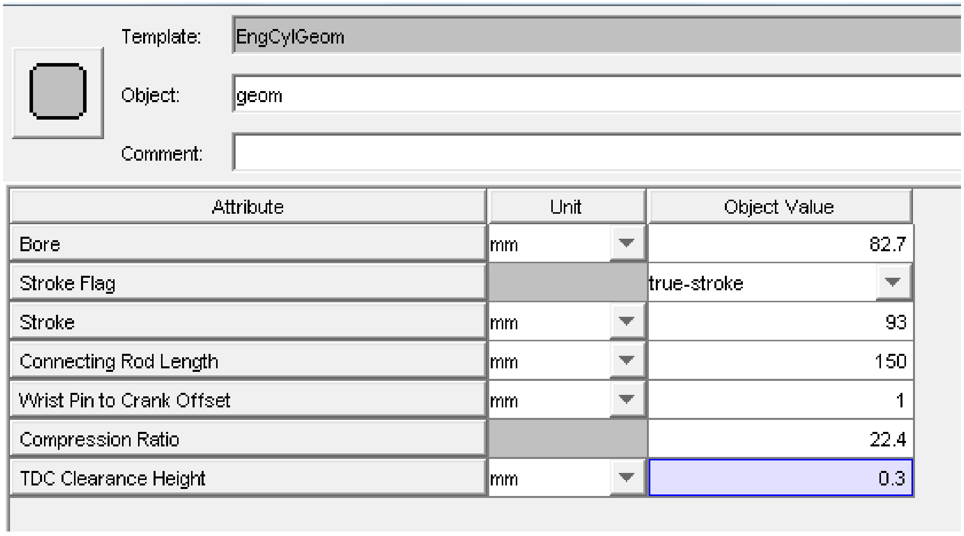


Figure 3.5: Engine cylinder geometry input panel

3.6.2 Engine Crank Train

The input panel for the template of engine crank train consists of number of cylinders, configuration of cylinder and engine type. Figure 3.6 showed the input panels for engine crank train of the simulation model.

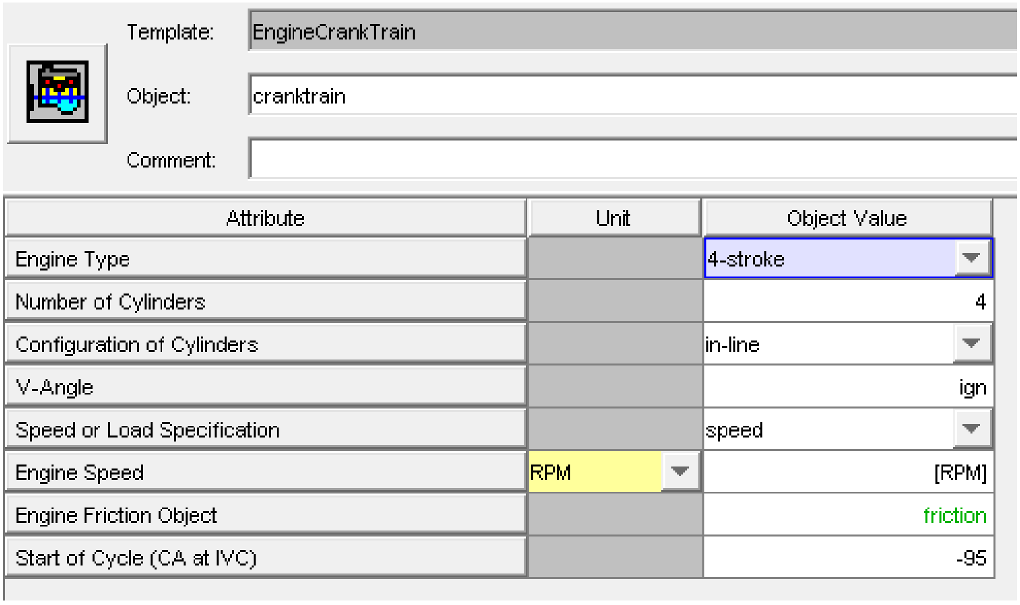


Figure 3.6: Engine crank train input panel

3.7 MODELING BIODIESEL PROPERTIES

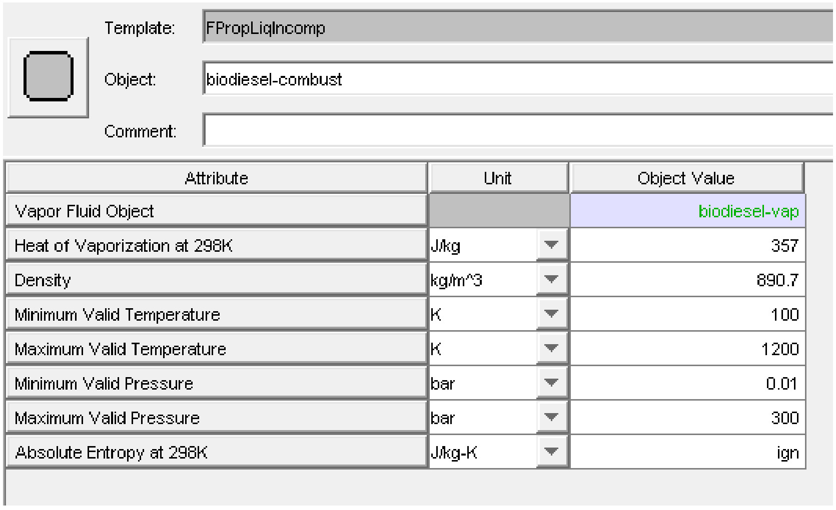
In GT-POWER, there is no biodiesel fuel in its Fuel Properties panel. In GT-POWER, a gas reference object is commonly described by its C:H:O:N compositions. For incompressible/combustible liquid properties, information about density, vapor fluid object and heat of vaporization are the necessary input to GT-POWER.

Typically every liquid reference object must be associated with a gas reference object so that the properties of the liquid will be known if the fluid evaporates. Then, for the gas/vapor properties of biodiesel need to be determined which it consists of molecular weight, lower heating value, and number of atoms per molecule which is carbon, hydrogen, nitrogen and oxygen.

The detailed properties of the biodiesel and reference diesel that are used in the simulation are listed in Table 3.4 and in Appendix A based on J. Zheng's paper (Zheng, 2009). Figure 3.7 and Figure 3.8 showed how the biodiesel data were being entered into the diesel engine model.

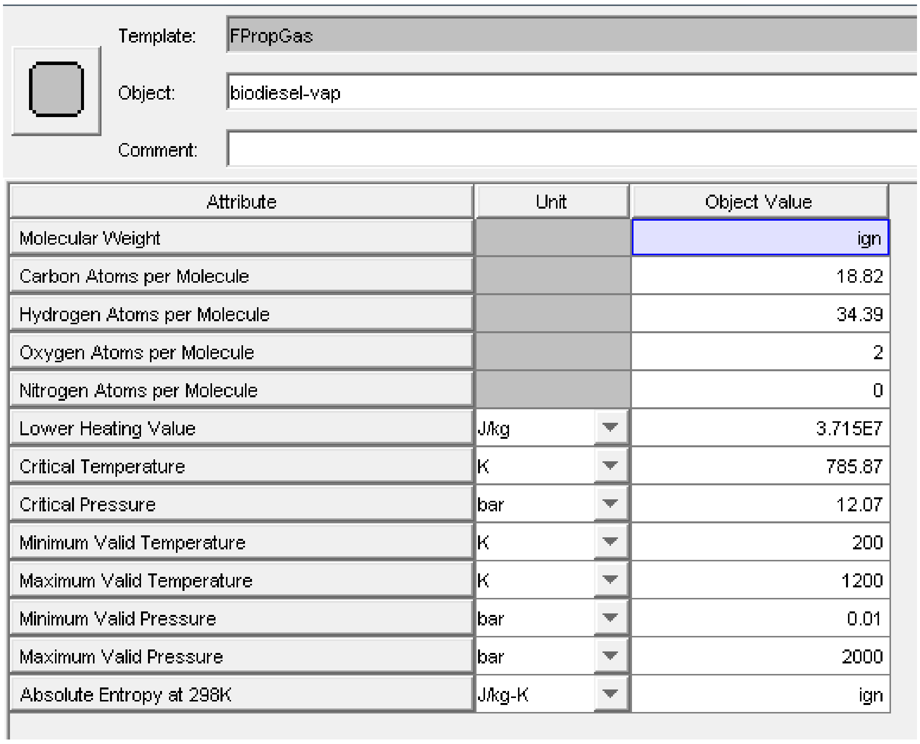
Table 3.4: Properties comparison between biodiesel and diesel 2

State	Item	Unit	Biodiesel	Diesel 2
Vapor	C Atoms per Molecule		18.82	13.5
	H Atoms per Molecule		34.39	23.6
	O Atoms per Molecule		2	0
	N Atoms per Molecule		0	0
	Lower Heating Value	kJ/kg	37150	43250
	Critical Temperature	K	785.87	569.4
	Critical Pressure	bar	12.07	24.6
Liquid	Heat of Vaporization	kJ/kg	357	250
	Density	kg/m^3	890.7	830


Template: FPropLiqIncomp
Object: biodiesel-combust
Comment:

Attribute	Unit	Object Value
Vapor Fluid Object		biodiesel-vap
Heat of Vaporization at 298K	J/kg	357
Density	kg/m^3	890.7
Minimum Valid Temperature	K	100
Maximum Valid Temperature	K	1200
Minimum Valid Pressure	bar	0.01
Maximum Valid Pressure	bar	300
Absolute Entropy at 298K	J/kg-K	ign

Figure 3.7: Liquid Properties Panel for biodiesel



Template: FPropGas
Object: biodiesel-vap
Comment:

Attribute	Unit	Object Value
Molecular Weight		ign
Carbon Atoms per Molecule		18.82
Hydrogen Atoms per Molecule		34.39
Oxygen Atoms per Molecule		2
Nitrogen Atoms per Molecule		0
Lower Heating Value	J/kg	3.715E7
Critical Temperature	K	785.87
Critical Pressure	bar	12.07
Minimum Valid Temperature	K	200
Maximum Valid Temperature	K	1200
Minimum Valid Pressure	bar	0.01
Maximum Valid Pressure	bar	2000
Absolute Entropy at 298K	J/kg-K	ign

Figure 3.8: Gas Properties Panel for biodiesel

3.8 MODELING EXHAUST SYSTEM

For the selected diesel engine, the exhaust system has a few components, size and different data. The system was started from the intake valve till environment. The exhaust system components in the GT-POWER model were environment, exhrunner, exhport, and exhvalve.

Figure 3.9 and Table 3.5 showed the exhaust system components configuration for the four cylinders and exhaust system parameters respectively. The components in this system require a few data to complete the data form before running the model.

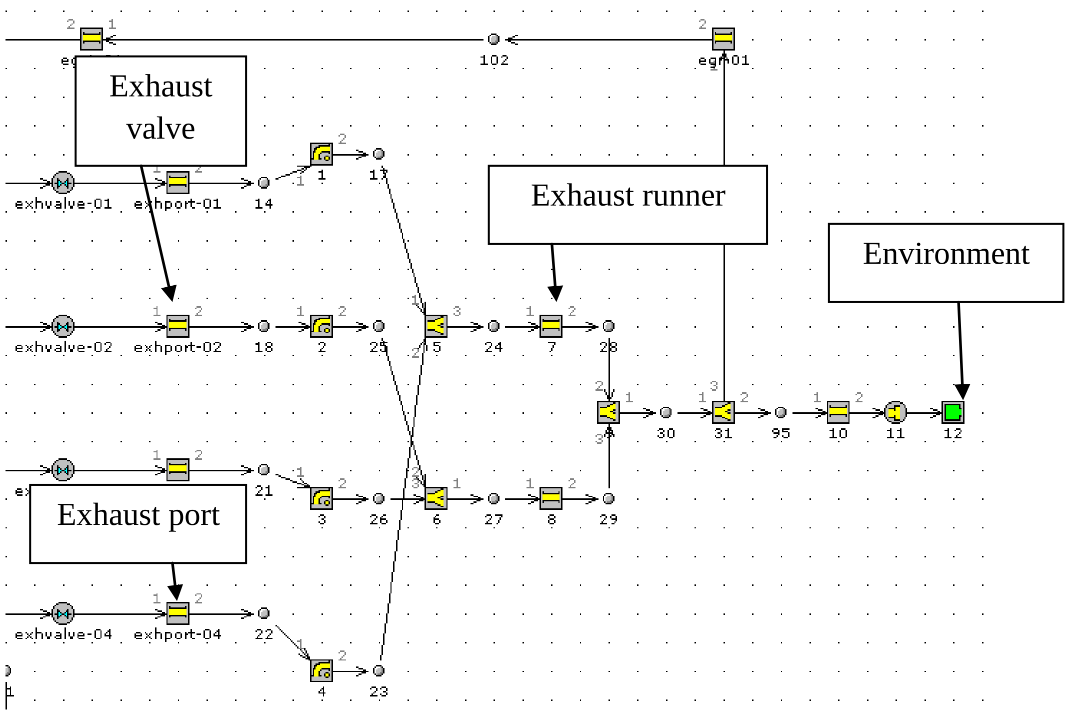


Figure 3.9: Exhaust system components

Table 3.5: Exhaust system parameters

Parameters	Attributes	Value
Environment	Pressure	2.4 bar
	Temperature	300 K
	Composition	Air
Exhaust runner	Length	100 mm
	Inlet diameter	50 mm
	Outlet diameter	50 mm
Exhaust port	Length	60 mm
	Inlet diameter	30 mm
	Outlet diameter	30 mm
Exhaust valve	Reference diameter	37.7 mm

After completing the simulation model (Figure 3.10), Plot Options requesting were made (Figure 3.11). Plot Options are plots of results over the course of a single engine cycle (the last engine cycle in multi-cycle simulations) which indicated what are the interested parameters of the study that are going to be observed. Plot Options may be requested by selecting the appropriate plot from the plot panel within each part.

After finished with the model development, simulation of GT-POWER is started. The model was set to run at various engine speeds from 1000 rpm to 4000 rpm. By running the solver, a shell will open, noting the version of the solver being used. The progress of simulation is showed by Windows in the form of scrolling text. Once the input has been read successfully, it is all set to create the requested data for post-processing in GT-POST. Most of the output is available in the post-processing application GT-POST. GT-POST is powerful tool that can enable users to view animation and order analysis output.

After the results of the simulation being gathered, they were compared to the experimental results. In the simulation, a model was operating with biodiesel B100 blend, while in experiment the engine was fueled with biodiesel B5 blend. Biodiesel B100 is compared to B5 because there is no available data for B5 for simulation.

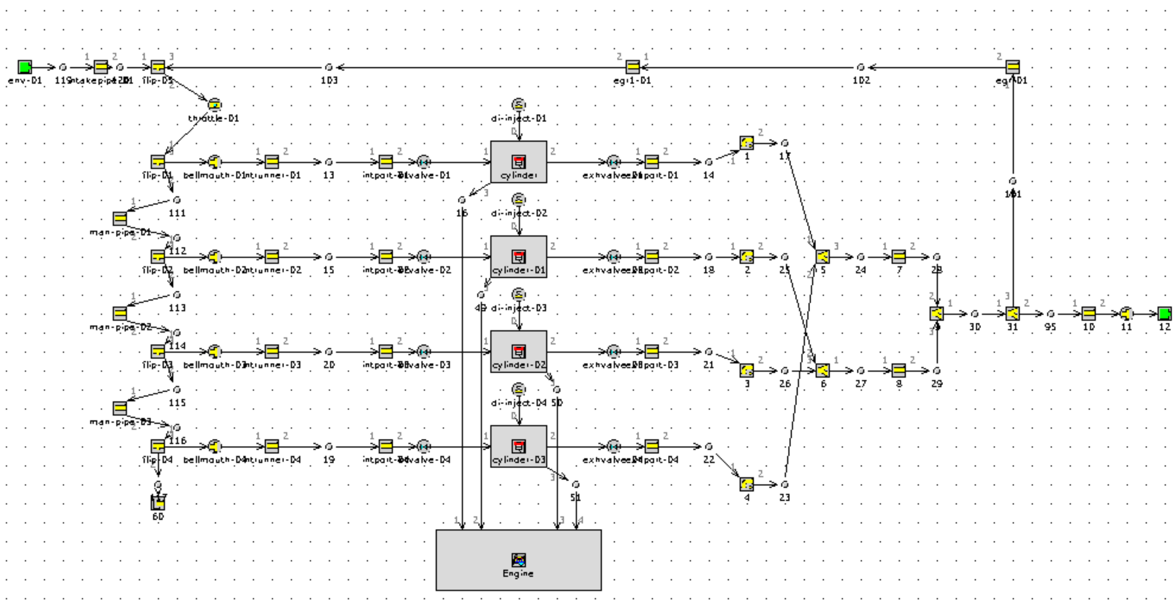


Figure 3.10: Four cylinders diesel engine modeling using GT-POWER

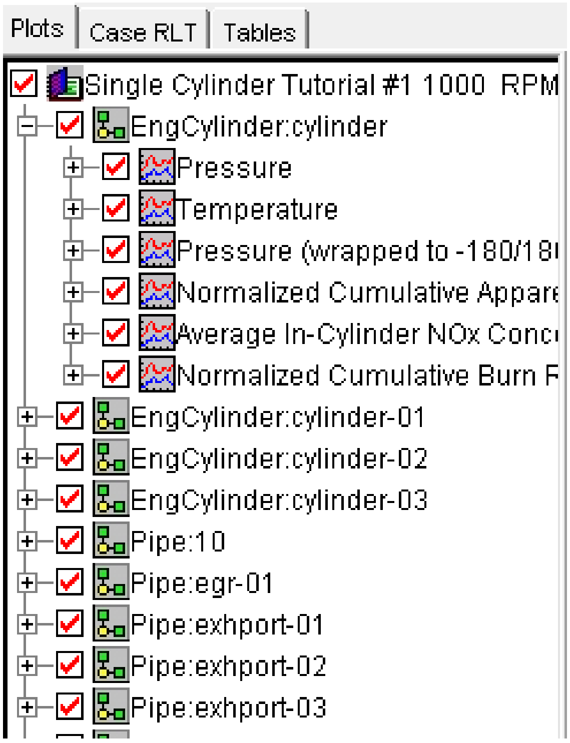


Figure 3.11: GT-POST windows component output menu

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter is mainly about the discussion of the simulation results of an engine model using biodiesel and diesel fuel and the validation with the experiment results. The results can be divided into two sections.

The first section is the explanation of the simulation model focusing on engine performance parameters and comparison between diesel fueled model and biodiesel fueled model. Second section is the evaluation of experimental and simulation results. All the data such as graphs all summarized.

4.2 ENGINE PERFORMANCE BY SIMULATION

The performance of the simulation model fueled with diesel and biodiesel were discussed. The variation of the engine performance that had been discussed are engine air flow, volumetric efficiency, brake power, brake torque, brake specific fuel consumption, brake thermal efficiency, and in-cylinder pressure. The results from the simulation model were compared the trends between the diesel and biodiesel fuel.

4.2.1 Engine Air Flow

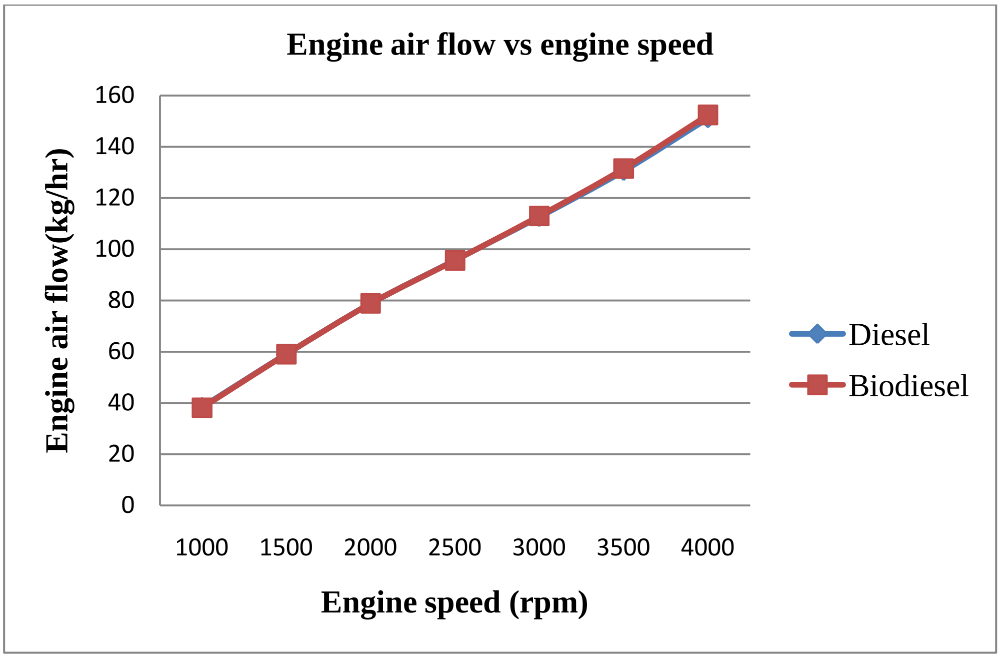


Figure 4.1: Effect of engine speed variation on engine air flow

Figure 4.1 shows the effect of engine air flow with respect to various engine speeds. It can be seen that the trend for engine air flow are similar for diesel and biodiesel. The engine air flow is increased as the increasing of the engine speed. The stoichiometric air-fuel ratio (AFR) for diesel is 14 % lower than biodiesel fuel. Therefore, the engine air flow operated with diesel is slightly lower due to inducted less air as compared to biodiesel fuel.

4.2.2 Volumetric Efficiency

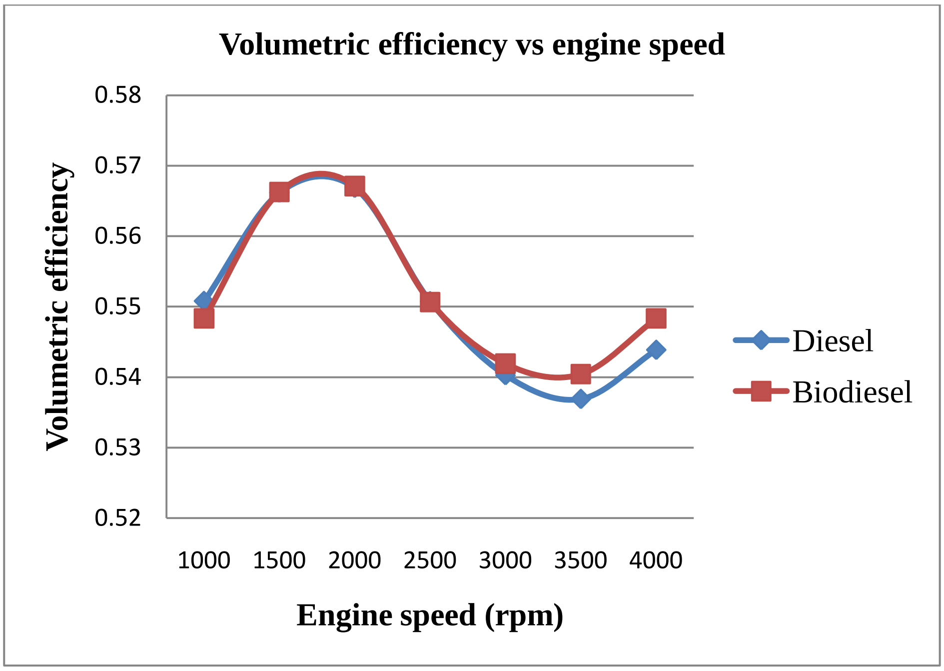


Figure 4.2: Variation of volumetric efficiency against engine speeds

Figure 4.2 shows the effect of volumetric efficiency, η_{υ} with respect to engine speed. It is observed that the maximum efficiency achieved at 2000 rpm of the engine speed. The maximum efficiency for diesel and biodiesel are 0.566832 and 0.567105 respectively. The engine with higher volumetric efficiency generally able to run at higher speeds and producing more overall power due to less parasitic power loss moving air in and out of the engine. However, at the engine speed of 2500 rpm there is a sudden decreasing of volumetric efficiency and started to increase at the beginning of 3000 rpm. After 3500 rpm, both fuel experienced of the increasing of volumetric efficiency.

The decreasing of volumetric efficiency due to higher speed is accompanied by some phenomenon that have negative influence on η_{υ}.The phenomenon included the charge heating in the manifold and higher friction flow losses which increased as the square of the engine speed (Rahman et al., 2009). In an engine cylinder operational, the increasing of engine speed will result the increasing mass flow rate of unburned nonfuel gases past all intake valves, therefore the volumetric efficiency will be decreased (Semin et al., 2009).

4.2.3 Brake Power

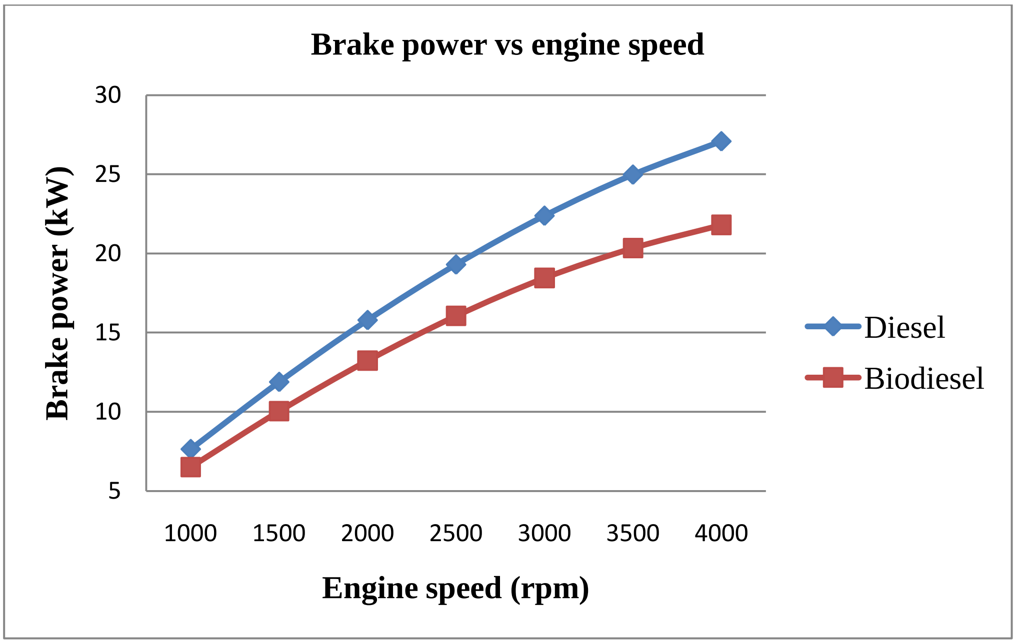


Figure 4.3: Brake power versus engine speed

Brake power is the useful energy experienced at the output shaft. Figure 4.3 shows the trend of engine brake power at certain engine speed. Normally, brake power for diesel fuel and biodiesel are increase with the engine speed. However, diesel fuel produces more brake power compared to biodiesel. It was observed that the injection delay of diesel fuel was longer than that of biodiesel. A close resemblance occurred at low speed representing small discrepancy in output between both fuels. At lower engine speed of 1000 rpm, the outputs produced by diesel are 7.64 kW and 6.51 kW respectively.

However, at higher speed, a clear gap appeared between the diesel fuel and biodiesel. The maximum brake power for diesel and biodiesel are 27.08 kW and 21.80 kW respectively. The maximum reduction brake power recorded was about 19.49 % at the highest speed. The reason for this phenomenon is because the heating value of the fuel affects the power of an engine. The lower energy level of the biodiesel fuel causes some reductions in the engine power when it is used in diesel engines without any modifications.

4.2.4 Brake Torque

The engine torque is a measurement of the engine's ability to do work while power is the rate at which work is done. Figure 4.4 shows the simulation model for the brake torque against various engine speeds.

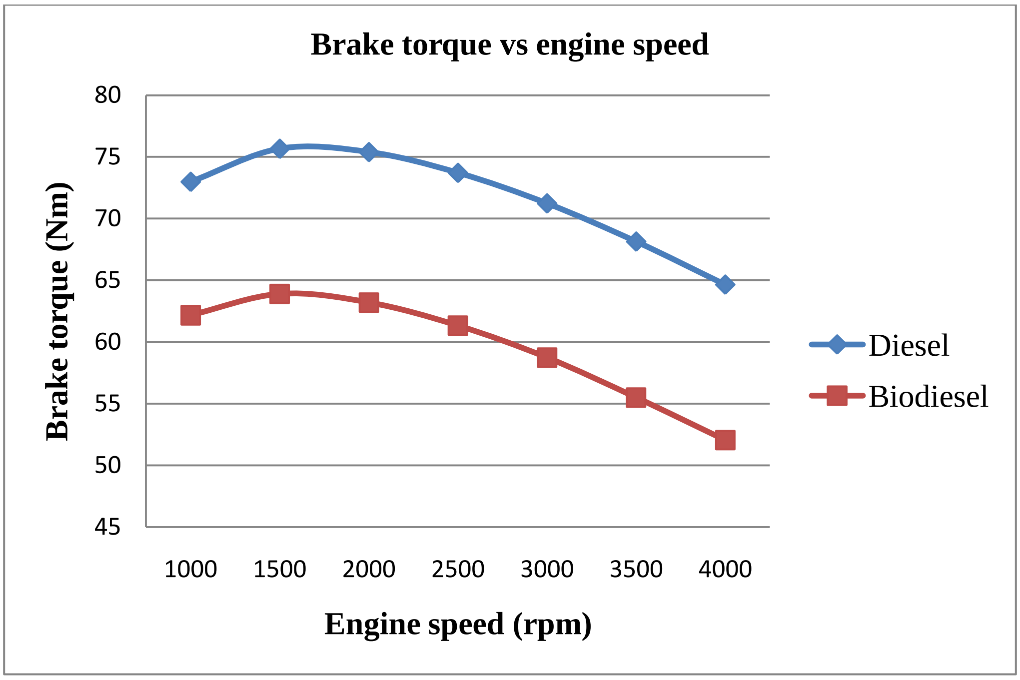


Figure 4.4: Variation of brake engine torque against engine speed

From figure, torque produced by diesel is higher compared to biodiesel. Normally, at low speed, torque increases as engine speed increase. As engine speed increase further, torque reaches a maximum and then, decreases as shown in Figure 4.4. From Figure 4.4, it is clearly shows the gap between diesel fuel and biodiesel. At low engine speed of 1000 rpm, torque produced by diesel and biodiesel are 72.99 Nm and 62.17 Nm respectively. The torque for both fuels increase to the maximum. The maximum brake torque recorded for diesel and biodiesel are 75.67 Nm and 63.89 Nm respectively. The maximum reduction brake engine torque recorded was about 19.49 % when engine speed achieved at 4000 rpm. The decreasing of torque is due to the engine condition which is unable to ingest a full charge of air at the higher speed (Pulkrabek, 2004)

4.2.5 Brake Specific Fuel Consumption

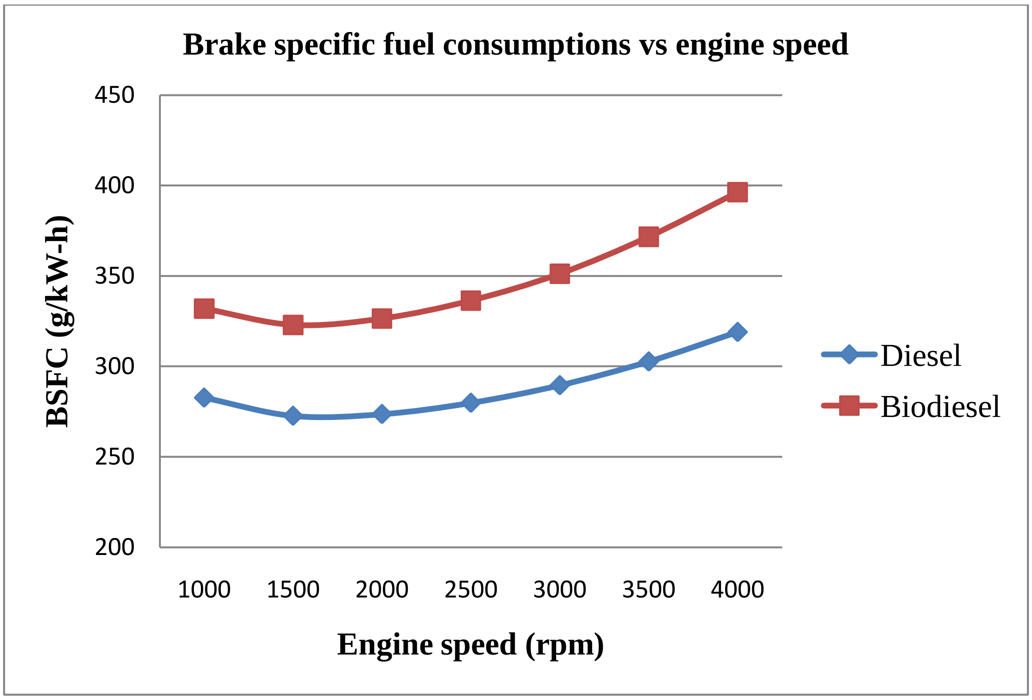


Figure 4.5: Effect of engine speed variation on brake specific fuel consumption

Figure 4.5 shows the variation of brake specific fuel consumption (BSFC) with speed for diesel and biodiesel. By fuelling the engine with biodiesel, BSFC is certainly increases compared to by fuelling with diesel. The model shows that for the engine operating with diesel, BSFC is high during at 4000 rpm of engine speed. While for biodiesel, it is also at the same speed which is at 4000 rpm. It is observed that for biodiesel, BSFC is a little higher than the corresponding diesel fuel case. The minimum BSFC obtained for diesel was 272.597 g/kW-h while for biodiesel was 322.842 g/kW-h. For both diesel and biodiesel, fuel consumption increases at high speed because of the greater friction losses (Pulkrabek, 2004). The increased of BSFC for biodiesel is mainly due to the lower calorific value of biodiesel (37.27 MJ/kg), compared to diesel fuel

(42.5 MJ/kg). A significant increase of BSFC over the entire speed range also due to greater density of biodiesel compared to diesel which are 890.7 kg/m^3 and 830 kg/m^3 respectively (Carraretto et al., 2004). Decreasing the biodiesel amount in the fuel blend will decrease the BSFC.

4.2.6 Brake Thermal Efficiency

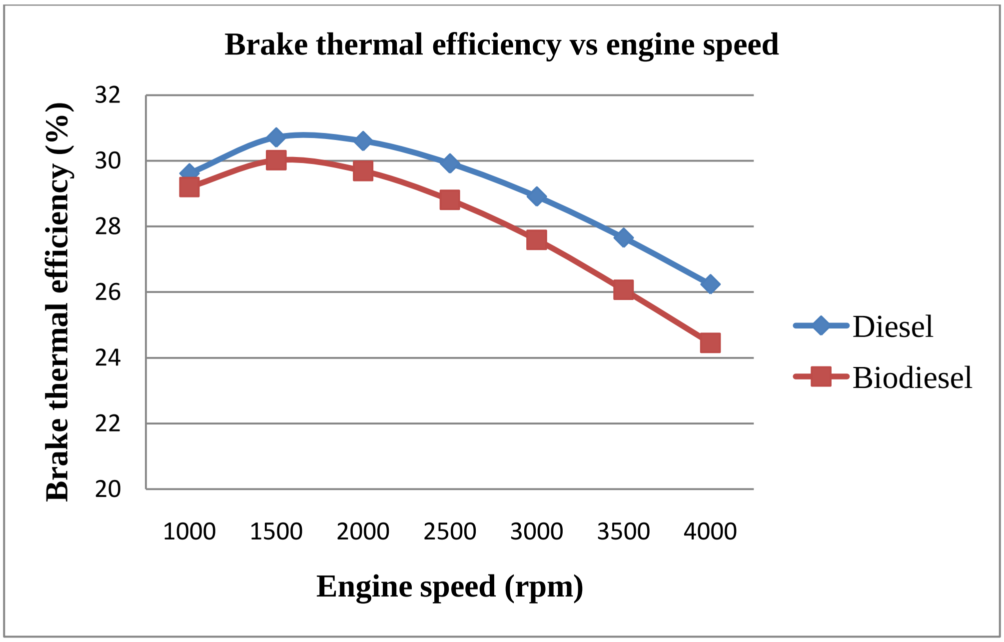


Figure 4.6: Effect of engine speed variation on brake thermal efficiency

Figure 4.6 shows the correlation between brake thermal efficiency of the engine with various engine speeds. Both of them generally show similar trends and closely resemble to one another. The brake thermal efficiencies for biodiesel were lower compared to diesel fuel. It is noting that the brake thermal efficiency is simply the inverse of the brake specific fuel consumptions (Hamdan and Khalil, 2009).

The maximum brake thermal efficiency for diesel is 30.71 % at 1500 rpm of engine speed. While for biodiesel, a recorded value is 30.07 %. At higher engine speed of 4000 rpm, both fuels have low brake thermal efficiencies which are 26.24 % and 24.45 % for diesel and biodiesel respectively. Brake thermal efficiency is lower for biodiesel due to its lower calorific value compared to diesel fuel. Increasing the biodiesel amount in the fuel blend decreased the brake thermal efficiency of the engine.

4.2.7 In-cylinder Pressure

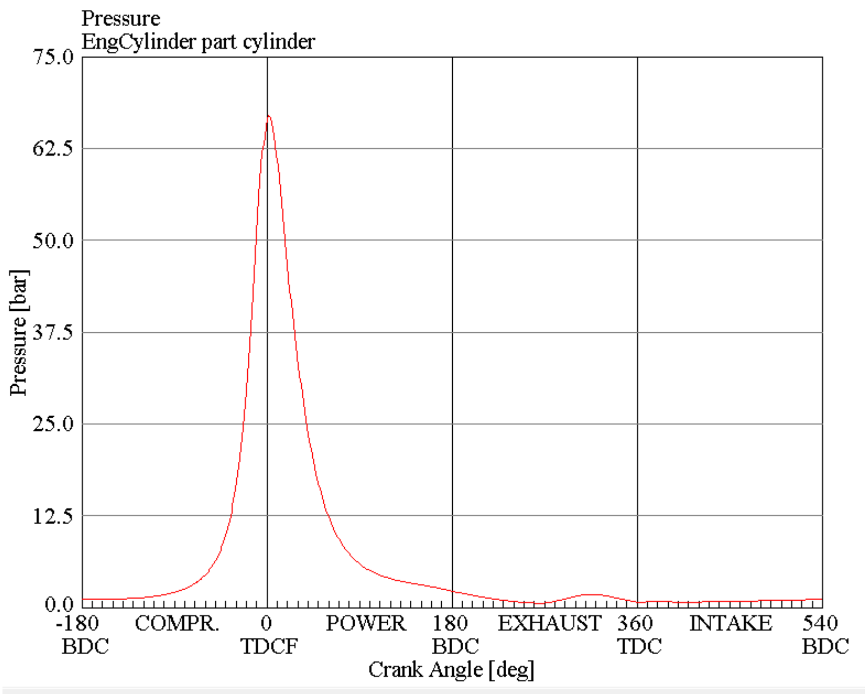


Figure 4.7: In-cylinder pressure for diesel model

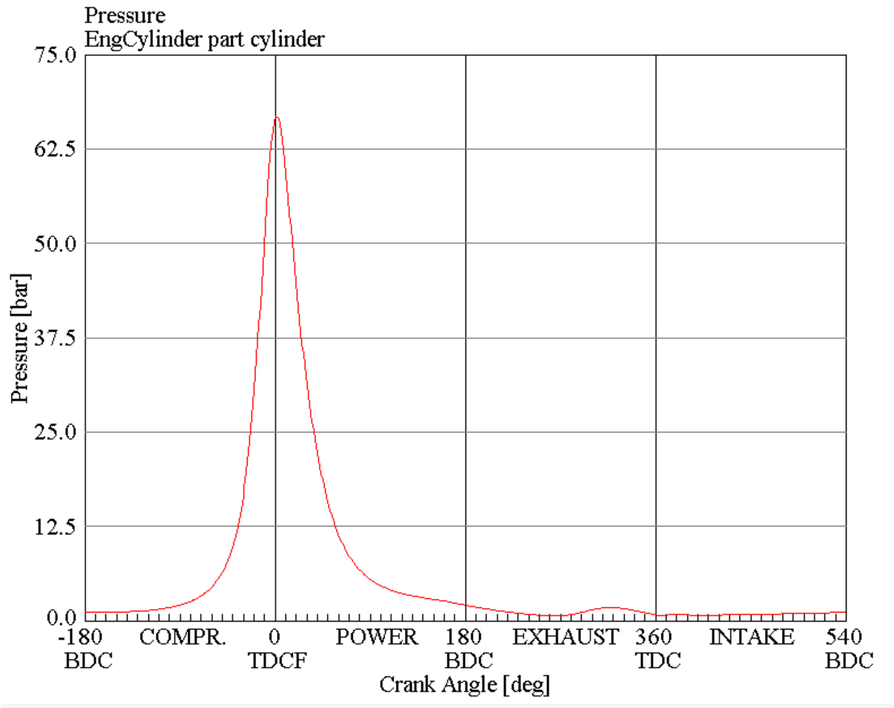


Figure 4.8: In-cylinder pressure for biodiesel model

The in-cylinder pressure for two different fuels was investigated in the diesel engine model operating with diesel and biodiesel. The in-cylinder pressure data was taken from cylinder number one of the engine operating at 4000 rpm. Figure 4.7 and Figure 4.8 are in-cylinder pressure recorded in GT-POST for diesel and biodiesel model respectively. Figure 4.9 shows comparison of cylinder pressure between diesel fuel and biodiesel. The blue line and red dash represent in-cylinder pressure for diesel and biodiesel respectively.

The results show that the peak pressure for diesel is higher compared with biodiesel. The highest pressure of the engine cylinder pressure is in TDCF, because this step is need the highest pressure to combustion. It can be seen that in-cylinder pressure for diesel is at peak (66.95 bar) after an ignition on 1.285 degree of crank angle (CAD). For biodiesel, in-cylinder pressure is at peak (66.80 bar) when on 0.136 CAD. The trend for cylinder pressure is similar for diesel and biodiesel starting from -20 CAD until they reach peak pressure value on 1.285 CAD and 0.136 CAD respectively.

The injection for biodiesel was advanced by certain crank angle degree compared with injection of diesel fuel. Early injection for biodiesel resulted in an early start of combustion which produced higher cylinder pressure (Mamat et al., 2009b).

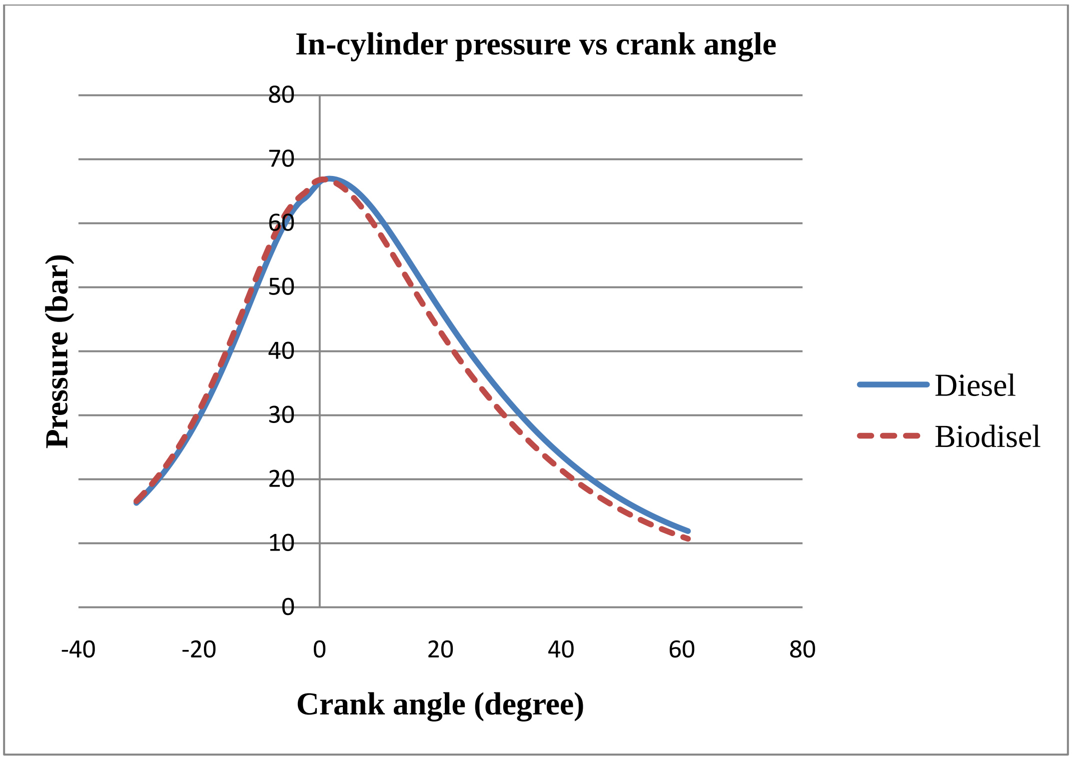


Figure 4.9: In-cylinder pressure at 4000 rpm

When combustion starts earlier in the cycle, the work transfer from the piston to the gases in the cylinder at the end of the compression is too large. However, if the combustion starts too late, the peak cylinder pressure will reduce, and the expansion stroke work transfer from the gas to the piston will decrease (Alla, 2002).

4.3 EVALUATION OF EXPERIMENTAL AND SIMULATION RESULTS

4.3.1 Evaluation of Experiment and Simulation Results of Diesel Fuel

The comparison between simulation and experimental results are consists of brake power and brake torque. Figure 4.10 shows the comparison of brake power between simulation and experiment results for diesel and biodiesel. For easier comparison, the results for simulation and experiment of engine fuelled with diesel are being compared in Figure 4.11 and Figure 4.12.

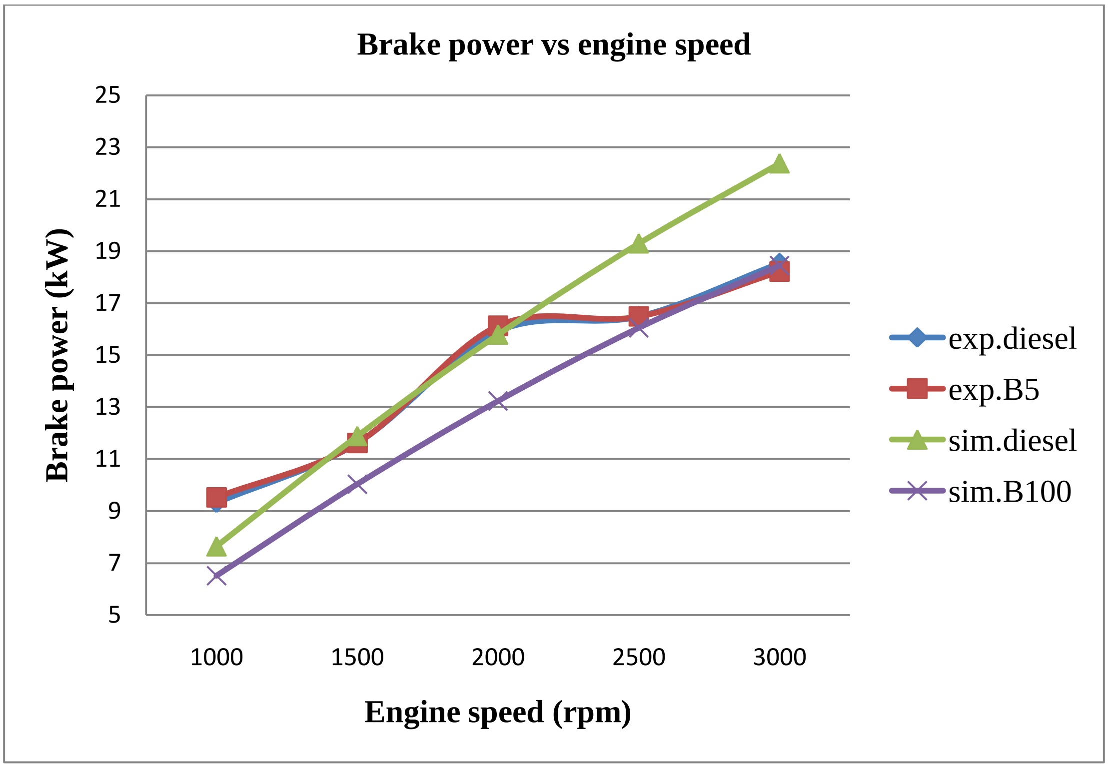


Figure 4.10: Comparison of brake power between experiment and simulation

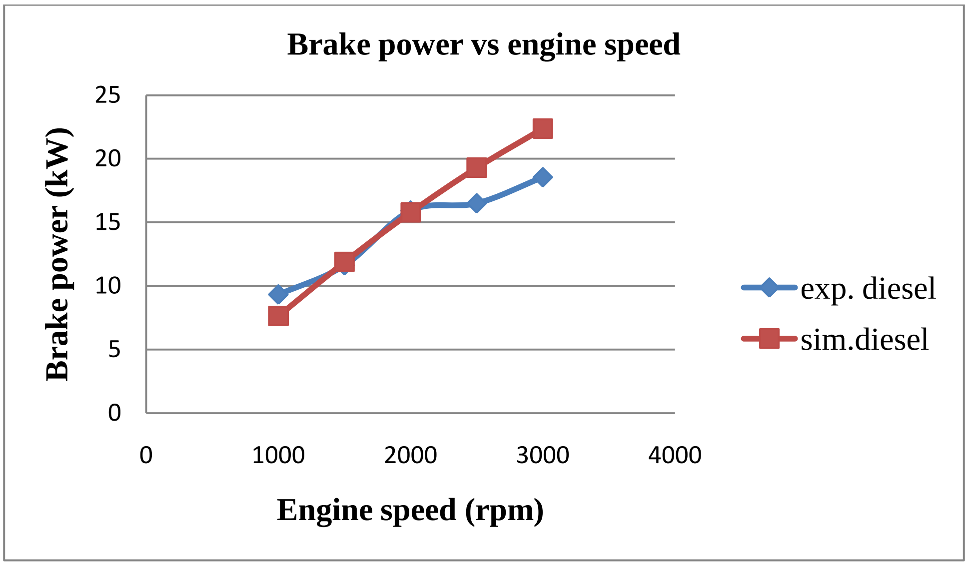


Figure 4.11: Brake power for experiment and simulation of diesel fuel

From Figure 4.11, a close resemblance occurred between experiment and simulation of diesel fuel. The graph of diesel simulation point is similar with the experiment result. At 1500 rpm, it was recorded for engine experiment fueled with diesel produced 11.62 kW of power while for simulation was 11.89 kW. At 2000 rpm, the results show that the value for both situation nearly the same. The value is 15.92 kW for experiment while for simulation is 15.79 kW, a little lower than of experiment. Both graphs show the increasing of brake power even though a small increment for experiment at 2500 rpm. The highest brake power recorded for experiment and simulation are 18.54 kW and 22.38 kW respectively.

Figure 4.12 shows the comparison of brake torque between simulation and experiment results for diesel fuel. At 1500 rpm and 2000 rpm of engine speed, both results almost shared the same values. However, there are big difference values of brake torque between experiment and simulation occur at 1000 rpm, 2500 rpm and 3000 rpm. The highest torque for experiment is at 1000 rpm which is 89 Nm. While for simulation, highest torque is at 1500 rpm which is 75.67 Nm. The lowest brake torque for experiment and simulation are 59 Nm and 71.24 Nm respectively. Both results can be accepted since there is not much difference of value. At 1500 rpm, brake torque produce are 74 Nm and 75.67 Nm for experiment and simulation, respectively. This value of brake torque for simulation is 2.21 % higher than the experiment. Again, the value nearly the same at engine speeds of 2000 rpm which are 76 Nm and 75.40 Nm for experiment and simulation, respectively. The experiment result shows its value is higher than simulation with the increment of 1.26 % of brake torque.

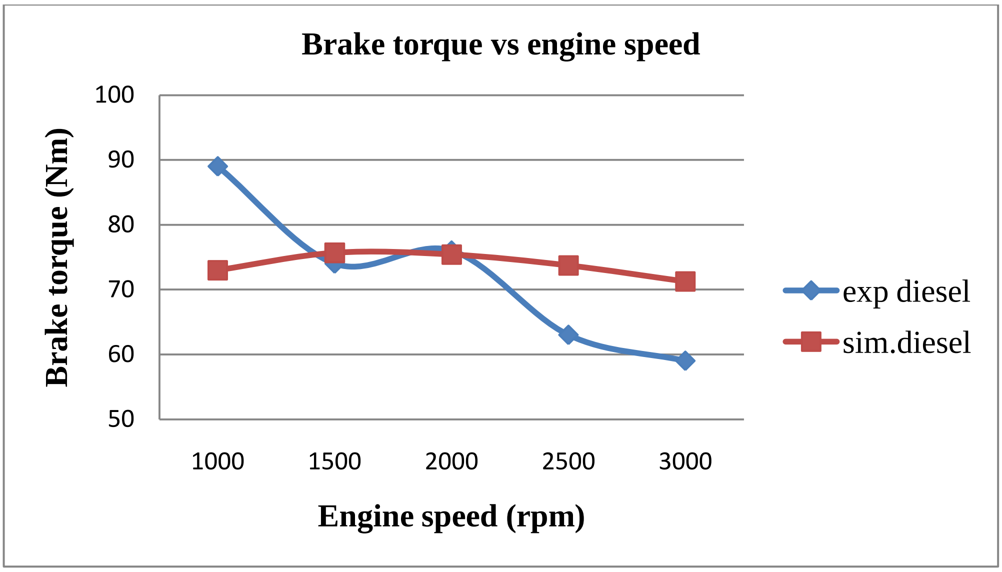


Figure 4.12: Brake torque for experiment and simulation of diesel fuel

4.3.2 Evaluation of Experiment and Simulation Results of Biodiesel Fuel

For the experiment, engine is fueled with biodiesel B5 blend while for simulation is using biodiesel B100. The purpose of this comparison is to observe the trend of the engine brake torque and power of a diesel engine when it is being fueled with biodiesel blends. Figure 4.13 and Figure 4.14 show the comparison of brake power and brake torque between simulation and experiment for biodiesel respectively. The trends for both situations are same which is the increasing of break power and reduction of brake torque against engine speeds.

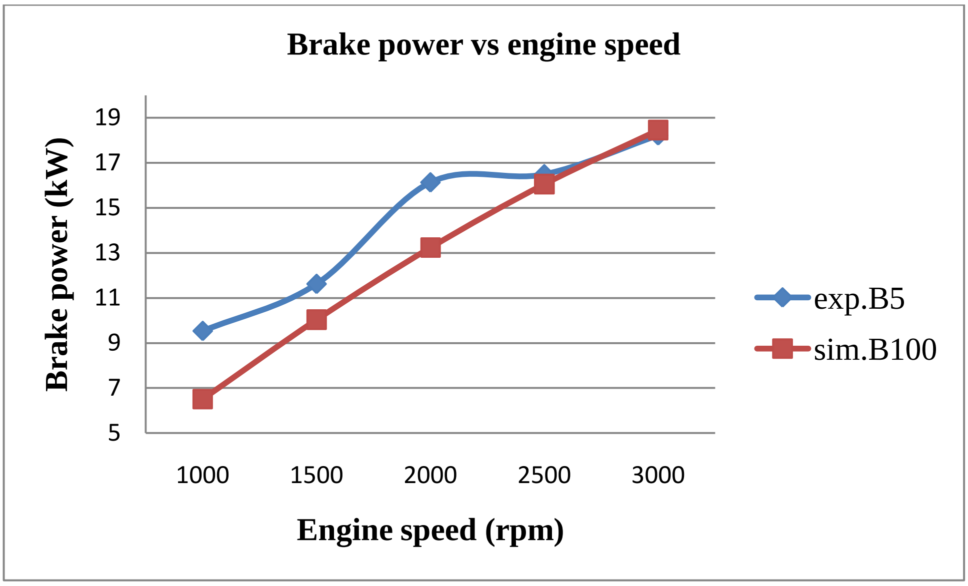


Figure 4.13: Brake power for experiment and simulation of biodiesel fuel

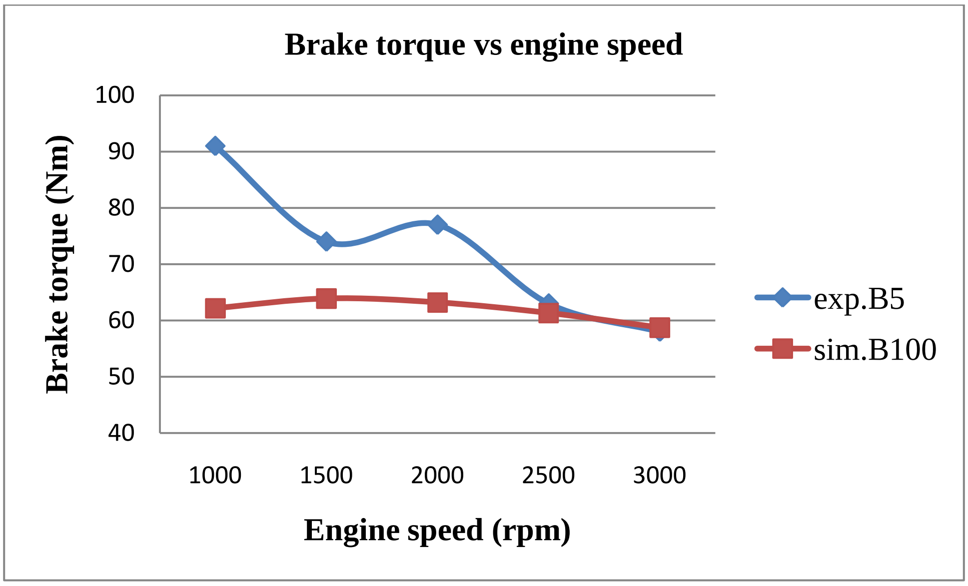


Figure 4.14: Brake torque for experiment and simulation of biodiesel fuel

From Figure 4.10, it can be seen that by using biodiesel, there is a reduction of brake power and brake torque compared to diesel fuel. For the experiment, there is a small reduction of diesel engine's brake power and brake torque after being fueled with biodiesel B5 blend. When B5 is used, 2.0 % of brake power and 2.6 % of brake torque are reduced.

From Figure 4.13, the brake power produced by B100 is lower than B5. From Figure 4.10, the gaps of brake power and torque between diesel and biodiesel cause by the difference of fuel blend properties. It is well known that by fueling diesel engine with lower blend of biodiesel will cause small reduction of brake power and torque as reported by Carraretto (Carraretto et al., 2004). That explains why B100 causes more reduction of break power and torque than B5 after being compared to diesel fuel.

Based on Figure 4.13 and Figure 4.14, the prediction can be made if the simulation if using B5 blend instead of B100 blend. If the simulation is using B5, the expected result for brake power and torque are upper than B100 result and located in the middle of both graphs. Thus, simulation result of B5 also will show a small reduction of brake power and torque compared to B100.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The effect of using the different fuels which is diesel and biodiesel, and their impact on the engine performance of a four cylinders diesel engine has been investigated and the conclusions can be summarized as follows:

1) From simulation, the brake specific fuel consumption (BSFC) increased mainly due to the lower low heating value. BSFC for biodiesel was higher than that of diesel fuel.

2) During the engine speed at 1500 rpm, the engine model showed the lowest of the brake specific fuel consumption for both fuels.

3) The lower energy content of biodiesel caused some increment in the brake specific fuel consumption of the engine depending on the percentage of biodiesel in blend.

4) The results gained from simulation were validated with the experimental to get more clear understanding to know how the percentage of correctness of the data and to predict the trends of diesel engine fueled with biodiesel.

5) Lower blend of biodiesel will cause small reduction of brake power, brake torque and brake thermal efficiency.

5.2 RECOMMENDATION

Due to the unknown characteristics of the biodiesel fuel, some observations from both the simulation and the experiment still cannot be well explained. With more accurate experimental data, recommendations for future work are,

1) It is better to use lower blend of biodiesel in the conventional diesel engine without any modification.

2) For more understanding of biodiesel combustion in the cylinder, it would be useful to use 3D computational fluid mechanics by and adding detailed chemical kinetics into the current one-dimensional engine model.

3) It is useful to model the diesel engine by adjusting certain parameters and variables for the engine performance improvement before the modification and testing are done to the real engine.

4) To get more understanding and useful information on the emission of the diesel engine by simulation, it is better to use other software that is able to predict and produce results on emission.

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APPENDIX A

PROPERTIES OF BIODIESEL AND DIESEL FUEL

Table 6.1: Properties comparison between biodiesel and diesel 2

State	Item	Unit	Biodiesel	Diesel 2
Vapor	C Atoms per Molecule		18.82	13.5
	H Atoms per Molecule		34.39	23.6
	O Atoms per Molecule		2	0
	N Atoms per Molecule		0	0
	Lower Heating Value	kJ/kg	37150	43250
	Critical Temperature	K	785.87	569.4
	Critical Pressure	bar	12.07	24.6
	Enthalpy	kJ/kg	See Appendix A1	See Appendix A1
	Viscosity	Pa-s	See Appendix A2	See Appendix A3
	Thermal Conductivity	W/m-K	See Appendix A2	See Appendix A3
Liquid	Heat of Vaporization	kJ/kg	357	250
	Density	kg/m^3	890.7	830
	Enthalpy	kJ/kg	See Appendix A4	See Appendix A4
	Viscosity	kg/m-s	See Appendix A5	See Appendix A6
	Thermal Conductivity	W/m-K	See Appendix A5	See Appendix A6

APPENDIX A1

Table 6.2: Enthalpy constants for vapor biodiesel and diesel

Enthalpy Constants	Biodiesel	Diesel 2
a1	1675	1634.3
a2	1	1.8191
a3	0	0
a4	0	0
a5	0	0

APPENDIX A2

Table 6.3: Viscosities and thermal conductivities of biodiesel vapor

Temperature (K)	Dynamic Viscosity (Pa-s)	Thermal Conductivity (W/m-K)
617	8.05715E-05	0.023996841
620	8.09543E-05	0.024174589
640	8.34962E-05	0.025364339
660	8.60214E-05	0.026562371
680	8.85297E-05	0.027768685
700	9.10212E-05	0.02898328
720	9.34959E-05	0.030206157
740	9.59537E-05	0.031437315
760	9.83948E-05	0.032676755
780	0.000100819	0.033924477
800	0.000103226	0.03518048
820	0.000105617	0.036444765
840	0.000107991	0.037717331
860	0.000110348	0.038998179
880	0.000112688	0.040287309
900	0.000115011	0.04158472
920	0.000117318	0.042890413
940	0.000119608	0.044204387
960	0.000121881	0.045526643
980	0.000124137	0.046857181
1000	0.000126376	0.048196

APPENDIX A3

Table 6.4: Viscosities and thermal conductivities for diesel vapor

Temperature (K)	Dynamic Viscosity (Pa-s)	Thermal Conductivity (W/m-K)
303.15	8.02E-06	0.00829904
373.55	6.75E-06	0.00829904
475.35	475.35	475.35

APPENDIX A4

Table 6.5: Enthalpy constants for liquid diesel and biodiesel

Enthalpy Constants	Biodiesel	Diesel 2
a1	2050	2050
a2	0	0
a3	0	0

APPENDIX A5

Table 6.6: Viscosities and thermal conductivities for liquid biodiesel

Temperature (K)	Dynamic Viscosity (Pa-s)	Thermal Conductivity (W/m-K)
300	4.60E-05	0.17887
310	3.66E-05	0.17719
320	2.99E-05	0.17549
330	2.50E-05	0.17377

APPENDIX A6

Table 6.7: Viscosities and thermal conductivities for liquid diesel

Temperature (K)	Dynamic Viscosity (Pa-s)	Thermal Conductivity (W/m-K)
300	0.000045993	0.17887
310	0.000036646	0.17719
320	0.00002994	0.17549
330	0.000024982	0.17377
340	0.000018309	0.17031
350	0.000018309	0.16855
360	0.000016007	0.16855
370	0.000014157	0.16678
380	0.000012649	0.165
390	0.000011402	0.1632
400	0.00001036	0.16139
410	0.00000948	0.15955
420	0.000008729	0.1577
430	0.000008083	0.15584
440	0.000007523	0.15395
450	0.000007034	0.15204
460	0.000006604	0.15011
470	0.000006224	0.14816
480	0.000005886	0.14618
490	0.000005584	0.14418
500	0.000005313	0.14216
510	0.000005069	0.14011
520	0.000004848	0.13803
530	0.000004647	0.13591

Table 6.7: Continued

Temperature (K)	**Dynamic Viscosity (Pa-s)**	**Thermal Conductivity (W/m-K)**
540	0.000004463	0.13377
550	0.000004296	0.13159
560	0.000004142	0.2937
570	0.000004	0.12711
580	0.000003869	0.12481
590	0.000003748	0.12247
600	0.000003636	0.12007
610	0.000003531	0.11762
620	0.000003434	0.11511
630	0.000003343	0.11253
640	0.000003259	0.10988