UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **RELIABILITY STUDY OF DIESEL ENGINE OPERATING WITH BIODIESEL**

SESI PENGAJIAN: **2010/2011**

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RELIABILITY STUDY OF DIESEL ENGINE OPERATING WITH BIODIESEL

MUHAMAD HARIF BIN GHANI

BACHELOR OF ENGINEERING

UNIVERSITI MALAYSIA PAHANG

2010

RELIABILITY STUDY OF DIESEL ENGINE OPERATING WITH BIODIESEL

MUHAMAD HARIF BIN GHANI

Report submitted in partial of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Automotive Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2010

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

We certify that the project entitled "Reliability Study of Diesel Engine Operating with Biodiesel" is written by Muhamad Harif Bin Ghani. We 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. We 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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I hereby declare that I have checked this report and in my opinion this report is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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STUDENT'S DECLARATION

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

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ACKNOWLEDGEMENT

In the name of Allah, the Most Benevolent, the Most Merciful. Alhamdulillah, all praises to Allah, the Almighty, on whom ultimately we depend for sustenance and guidance. All praises to Allah for the strengths and His blessing in completing this report.

Special appreciation goes to my supervisor, Dr Rizalman Mamat, whose guidance, careful reading and constructive comments was valuable. His timely and efficient contribution helped me shape this into its final form and I express my sincerest appreciation for his assistance in any way that I may have asked. His invaluable help of constructive comments and suggestions throughout the report have contributed to the success of this project. My sincere thanks also go to Mr Amir Bin Abdul Razak, I owe special thanks for his consultations especially on this report. Certainly, not forgetting the UMP Faculty of Mechanical Engineering for providing the support and equipment required in order to completing this study.

Sincere thanks to all my friends especially and others for their kindness and moral support during my study. Thanks for the friendship and memories.

Last but not least, my deepest gratitude goes to my beloved parents; Mr. Ghani Bin Nasib and Mrs. Zaidah Bte Dahlan and to my brothers for their endless love, prayers and encouragement. To those who indirectly contributed in this research, your kindness means a lot to me. Thank you very much.

Dedicated to my parents

ABSTRACT

The use of alternative fuels issues: reducing the reliance on unstable supply of oil, reduce harmful emissions, and using renewable energy sources. This thesis focuses on the comparison of the four-engine reliability cylinder turbocharged diesel engine operating on diesel fuel and biodiesel. Steady-state tests conducted for the experiment to determine how the input energy adapted form of fuel down the machine. Over energy measured for the loss of engine coolant and exhaust, power output is used, as and light and untold losses. Results showed that the energy input of biodiesel distributed 37.4%, 31.1% and 29.6% into the main area air, exhaust, and power output, respectively. Similarly, to include energy distributed diesel 37.5%, 31.4% and 29.2% of the main areas of air, exhaust pipe, and output power, respectively. It is concluded from an uncertainty Analysis that there was no statistically significant difference in the results. Future improvements to obtain distinguished results are described.

ABSTRAK

Masalah penggunaan bahan bakar alternatif mengurangkan pergantungan pada bekalan minyak tidak stabil, mengurangkan pembebasan berbahaya dan menggunakan sumber tenaga yang boleh diperbaharui. Tesis ini tertumpu pada perbandingan kebolehpercayaan enjin diesel beroperasi pada minyak diesel dan biodiesel.

Steady-state ujian yang dilakukan untuk percubaan juga menentukan bagaimana bentuk tenaga masuk yang disesuaikan pada bahan bakar kepada enjin diesel. Lebih daripada tenaga yang diukur atas kehilangan pendingin enjin dan output kuasa knalpot, digunakan, dan kerugian sebagai cahaya dan tak terhitung. Keputusan kajian menunjukkan bahawa input tenaga biodiesel diedarkan 37,4%, 31,1% dan 29,6% ke udara pada kawasan utama, knalpot, dan daya keluaran, masing-masing. Demikian pula, untuk memasukkan tenaga diedarkan diesel 37,5%, 31,4% dan 29,2% dari kawasan utama hawa, paip ekzos, dan daya keluaran, masing-masing. Hal ini disimpulkan daripada analisis ketidakpastian yang tidak ada perbezaan yang signifikan secara statistik dalam keputusan.Pembaikan masa depan untuk mendapatkan hasil yang dijelaskan.

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Exh	Exhaust Gas Temperature

CHAPTER 1

INTRODUCTION

1.1 PURPOSE

Diesel engines are broadly used in medium and heavy duty applications because of their lower fuel consumption, higher brake thermal efficiency and lower emissions (such as CO and HC) compared with gasoline engines. Depletion of petroleum derivates increases the research interest in the area of alternative fuels. The high viscosity and low volatility raw vegetables oils are generally considered to be the major drawbacks for their utilization as fuels in diesel engines. The usage of raw vegetables oils in diesel engines leads to injector coking, severe engine deposits, filter gumming problems, piston ring sticking and thickening of the lubricating oil. However, these effects can be reduced through the esterification of the vegetables oil to form monoesters called as biodiesels. Biodiesel produced from the non- edible Jatropha oil decrease viscosity and improves the cetana number and heating value. (Abdelghaffar, 2002)

The development of computer technology narrows down the time consumptions for the sophisticated engine test through the simulation techniques. The insight of the combustion process is to be analyzed thoroughly, which enhance the power output of the engine and consider as the heart of the engine process. Thermodynamic models are mainly based on the first law of thermodynamics and are used to analyze the combustion and performance characteristics of engines. The purpose of writing this thesis is to study the reliability of diesel engines using biodiesel and diesel operations. Understand the performance characteristics diesel engine operating diesel fuel and biodiesel fuel (Mohamed N. Saeed, 2002).

1.2 GOAL

Engine reliability study is the first step to study the alternative fuel sources in the near future. This is the main reason for reaching the final goal of this thesis. The aim is to determine the amount of energy received by the diesel engine through fuel source and then measuring the output energy and losses throughout the system.

1.3 OBJECTIVE

The objective of this project is to study the reliability of diesel engine operating with diesel fuel and biodiesel fuel.

1.4 SCOPE

i. Study of effect performance characteristics diesel engine operating with biodiesel fuel and diesel fuel.
ii. Collect data temperature and pressure with DEWE software.
iii. Compare data from diesel fuel and biodiesel fuel operating with diesel engine.

1.5 PROBLEM STATEMENT

There has been plenty of research done so far on emissions testing both diesel and biodiesel. Research in the area of biodiesel has shifted towards making it more economically feasible by lowering production costs and increasing the energetic yields from various feedstocks. Where the research has been lacking is in relation to the better characterization of the performance of these fuels in all possible diesel applications.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

To get the right content in this thesis, it is important to analyze the development of diesel engines up to date, background information on biodiesel and the need for alternative fuels, and some background information on these programs.

2.2 DIESEL ENGINE DEVELOPMENT

The compression ignition engine was developed in 1892 by the German engineer, Dr.Rudolf Diesel (Leduc, 2007). It was developed for using a variety of fuel sources such as coal dust or peanut oil and it was shown at the 1900 World Exhibition in Paris, France (Leduc, 2007). Here peanut oil was the chosen fuel for the demonstration. In the early 1900's, Dr. Diesel was making statements implying that the use of the diesel engine with renewable fuels would help stimulate agricultural markets and that the renewable oils may someday be as valuable as petroleum and coal products (Leduc, 2007). It seems that day is fast approaching. The standard diesel engine operates on the principal that air in the engine cylinder is compressed to an extremely high pressure and temperature at which time the fuel is injected into the combustion chamber causing ignition. This is different from a gasoline engine which compresses both the air and fuel at the same time. Once the air and fuel is compressed, the gasoline engine relies on a spark to ignite the mixture causing combustion. The spark ignition or gasoline engine's need for electrical ignition requires the use of many components such as spark plugs, ignition coil, distributor, and a carburetor. The mechanical nature of the diesel engine's design makes it simpler, more rugged, more versatile, and its higher compression ratio makes it more efficient than the gasoline engine. It is because of these basic principles of the diesel engine's design that make it such a good candidate for a near term solution to our renewable energy needs (Engine Manufacturers Association, 2002).

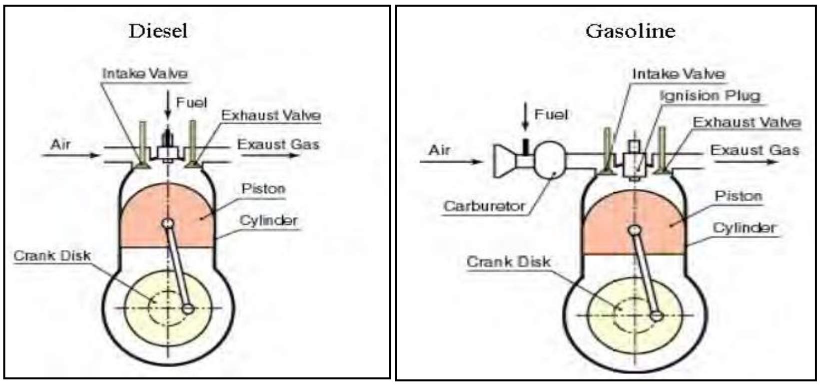

Figure 2.1: shows a basic schematic of a diesel and gasoline engine, respectively

Source: Engine Manufacturers Association 2002

Figure 2.1 shows the schematic layout of diesel and gasoline engines. The traditional drawbacks of the diesel engine are their cold weather operation, noisiness, pollution, and lack of power. However, with advancements in technology, almost all of these issues have been resolved. The most significant improvements were due to improvements to the fuel injection and air induction systems. Traditional diesel engines used indirect injection (IDI) systems where the fuel would enter a prechamber and partially combust there. Currently most diesel engines use direct injection (DI) systems where the injector tip is directed straight into the cylinder's combustion chamber.

The result of this improved design is a quieter, cleaner, and more powerful engine. Improvements to injection pumps and fuel injectors including higher pressures, multiple injections per stroke, and optimized spray patterns have improved combustion efficiencies resulting in more power, quieter delivery, and lower emissions from more complete combustion. Advancements in diesel engine air induction systems have really propelled their use into a variety of applications. The use of turbo chargers takes advantage of otherwise wasted exhaust gases to help deliver more intake air to the engine's combustion chambers. The force from hot exhaust gases entering the turbocharger spins a turbine connected to a compressor. The compressed air is then supplied to the engine increasing power and lowering emissions. Figure 2.2 shows the 2003 Cummins 5.9 L diesel engines and its common rail fuel system (Memmolo and Sam, 2008).

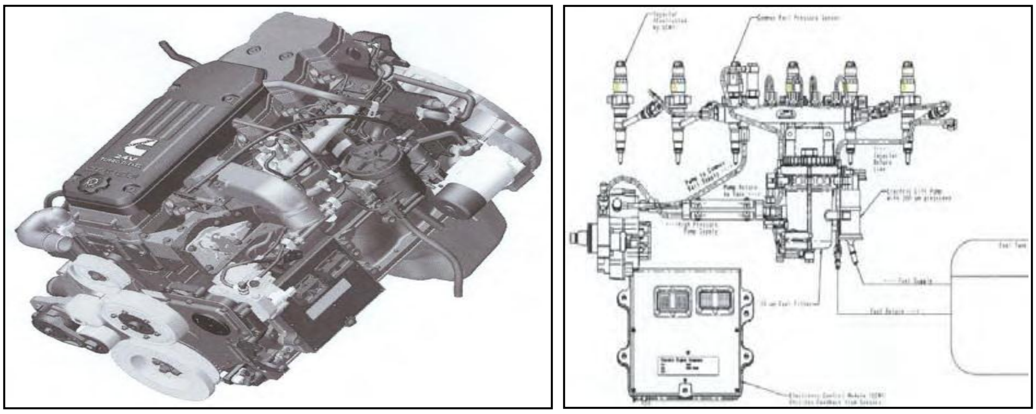

Figure 2.2: Cummins 5.9L diesel engine and common rail fuel system

Source: Memmolo 2008

With the addition of the common rail fuel system in 2003, Cummins was able to achieve 24% more power, 10% more torque, and a wider power band over its 2002 engine series (Memmolo 2008). Utilizing the common rail fuel system’s high pressures and multiple injections per combustion cycle, increased throttle response, reduced noise, and improved cold-start times were all achieved, as well as NOx and hydrocarbon emissions reductions of 25% over the 2002 series (Memmolo 2008). In 2007, Cummins was able to make this engine series almost 50% quieter with 10% higher common rail fuel pressures as well as other improvements (Cummins, Inc.).

Additionally, this engine utilizes cooled exhaust gas recirculation (EGR) and other air-handling concepts, including Cummins own proprietary sliding-nozzle Variable Geometry Turbocharger to give optimum boost level as a function of engine rpm and load. The multi-injection-capable fuel system is then used to manage in-cylinder conditions to limit emissions. The particulate filter reduces Particulate Matter (PM) levels by 90% of pre-2007 levels” (Cummins, 2008.). These are all real-world examples of advanced diesel technology and their resulting improvements. Diesel engine technology is a significant industry today. There is a lot of research being done to maximize efficiencies, power, durability, and meet stringent emissions standards. The basics of the diesel engine have been explained but there are many specifics that have not been covered. To learn more about the current technologies including the designs of injectors, pumps, heads, valves, turbochargers, intercoolers, and much more see some of the manufacturer's websites including Cummins, Caterpillar, Detroit, John Deere, Kubota, or others. Another very good source is the Engine Manufacturer's (Memmolo, 2008).

Association (EMA, 2002), they are an association committed to improving engine technology as well as emissions controls both domestically and internationally. They provide the latest publications, legislations, position statements and news reports about issues in engine development.

2.3 BIODIESEL BACKGROUND

Since the use of biodiesel have been widespread and important, aspect is important to know about background information on biodiesel itself. Biodiesel is a fuel source derived from the latest fuel through a chemical process to meet the specifications prescribed by ASTM D6751 (ASTM Standard, 2004).

2.4 BIODIESEL BENEFITS

There is several reasons increased interest in bio-diesel as a positive environmental impact, safety, and security of energy, the effect of economic and financial incentives. Global warming environmental issues create more central to the prospects for the future. Biodiesel has been proven to be a good option to help address the problem of global warming. The use of biodiesel as a substitute for diesel fuel will significantly reduce emissions hydrocarbon, carbon monoxide, sulfur dioxide, and particles. Nitrogen oxides release that are not fully understood but many studies have shown that they increase the as of 10-15% of the increase and this is only the release of the intensive study for potential improvement. Biodiesel also reduce health risks from transport, storage and handling of fuel. Biodiesel is classified as biodegradable, nontoxic, and is not flammable.

The hotel makes accidental pollution of the environment. Because biodegradable, spills will require attention by making it easier transport. For non-toxic, water pollution or impact on the skin. Quality flash point of biodiesel made more secure storage for not capturing fire easily as gasoline diesel fuel. With fuel prices reaching record high and unstable oil import increased each year, it is clear that there is a need to use resources more fuel. Biodiesel can help maintain the economy while providing a higher level of energy. Since biodiesel to take advantage of animal fats and vegetable oils, increased use of has helped stimulate the marketing of agricultural and created many jobs in the production of biodiesel.

In addition to stimulating the economy of resources it provides to our own fuel, thus reducing the need military protection of foreign oil supplies that have become major issues in politics today. Biodiesel helps preserve natural resources and create jobs that motivate our government to offer financial incentives for them to produce fuel. Government subsidizes fuel based on the number and types of biodiesel blended into gasoline diesel fuel. This helps create a competitive price in the market aggressively. (Cheng, Upanieks and Mueller, 2006).

2.5 BIODIESEL PRODUCTION

Biodiesel can be produced in various processes. The most common aspect is extracting, hydrolysis, and micro emulsions. Most of the production process using a catalyst base extracting using virgin oil from raw materials like soy, carrots, mustard bean, peanut, sunflower or other oil producing crops. Biodiesel can also be made from waste vegetable oil or animal fat, but biodiesel from algae oil has the potential to become dominant in the near future. Algae are also used as raw materials of interest for ability to quickly and immediately copied the high oil content. Goal of this research is to produce algae-based bio-diesel by a extraction process and tested for performance and emission characteristics. In extraction process, a triglyceride (oil or fat) with alcohol reaction (Usually ethanol or methanol) to form a three and a glycerol ester. To speed up reaction produces an increase, a catalyst (usually NaOH or KOH) is used.

During reaction, triglycerides are broken and combined with alcohol and ester catalysts combine the glycerin. When the reaction is complete the results are complete separation of methyl or ethyl esters (biodiesel) and glycerin soap. That glycerin soap settles down and perverted to the increase.

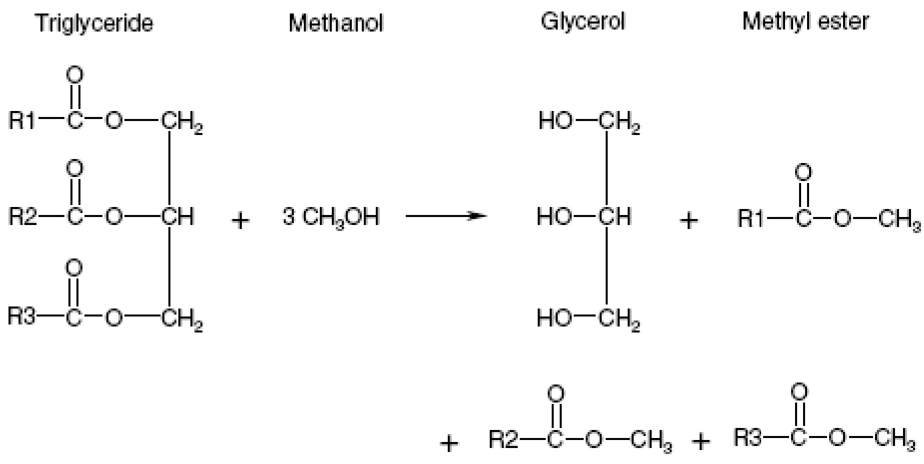

Figure 2.3: Chemical Reaction of triglyceride and methanol to produce biodiesel

Source: Goswani and Kreith 2007

Biodiesel is processed further to ensure that no reactant used UN-waste. This is usually done through the process of washing and drying process is not guaranteed water pollution. This is the basis extraction biodiesel production. This process is sensitive to the catalyst, water pollution, alcohol to triglyceride molar comparison, time, temperature, and other factors. This is very important to know that high biodiesel used will affect all aspects of systems used in the performance the release of machine wear. Purchase fuel from the retailer in this program is encouraged to review any the application (Cheng, Upanieks and Mueller, 2006).

2.6 PREPARATION OF LABORATORY AND BASE TEST APPARATUS

The main deliverables for this project were in the basic layout of the engine diagnostic testing system. These deliverables were performed in collaboration with instructor engineer and occasionally other students or faculty. The first thing we did was make room in lab for our testing equipment. This involved removing aspects of the previous electric vehicle testing equipment such as part of the chassis dynamometer, scraping the old electric test vehicle, and removing the external battery supplies. Next we acquired an engine which was specked out for our particular needs and supplied by Proton Company Sdn Bhd. This engine was part of a complete power unit included all electrical and cooling systems. It was mounted on a stand and needed a battery and fuel tank to be operational. To couple the engine to our dynamometer we used the services of a driveline shop to make a short driveshaft which connected the flywheel of the power unit to the input shaft on the dynamometer.

In order to insure that the exhaust properly exited the lab, 3” exhaust tubing was run approximately 50’ into lower temperature flexible tubing which reached the exterior of the building. An exhaust back pressure gauge was implemented and compared with factory specifications to insure that high exhaust pressures did not affect the diesel engine. After everything was set up, the system was calibrated and run so that we could begin to focus on our respective research areas. To make sure the existing dynamometer was operating properly, the engine’s power curve was compared to the manufacturer’s supplied data. The data collected for our engine compared very well throughout the operating range showing only slightly less torque at high speeds, likely due to the fact that the manufacturer's data was for the engine operating without a mechanical cooling fan and alternator. In all it took about 12 weeks to complete the basic engine diagnostic testing system.

With all of the purchases we had to make for equipment and miscellaneous items, the total cost of the basic system was around $2000 which included the engine power unit, the fuel and exhaust systems, the mounting and coupling equipment, and other miscellaneous parts. My personal research area involved the development of the thermal measuring and control systems for the engine’s lubrication, coolant and exhaust systems. In addition to this, I set up the system to control and monitor the air and fuel going into the engine. This involved monitoring the air and fuel’s temperatures and flow rates. Finally I had to monitor the environmental and atmospheric conditions to insure accuracy and repeatability of the experiments.

2.7 ENGINE PERFOMANCE OPERATING WITH BIODIESEL FUEL

For future generations of diesel engines also must be able to work with the use of alternative fuels such as biodiesel and alcohol mix because of the lack of fossil diesel and environmental concerns. The performance of biodiesel is slightly lower than that of diesel fuel, while the same amount of air and fuel is introduced into the cylinder (Senatore, Cardone et al 2000.). Almost no difference between performance of RME and ULSD when comparison is made at the same relative similarity ratio (Senatore, Cardone et al 2000.). Many studies have performed on diesel engines operating with biodiesel as an alternative to diesel fuel (Tsolakis et al, 2007). Most of the researchers have agreed biodiesel fuel that can be used alone or blended with conventional fossil fuel without having to make modifications to the standard diesel engine because biodiesel has properties similar to mineral diesel (Agarwal, 2007; Tsolakis, Megaritis et al. 2007). Although the energy density of biodiesel is lower than diesel fuel, there is almost no difference between the performance of the FMP and ULSD fueled engine when the comparison is made relative to the same air / fuel ratio (Lambda) is used in the machine (Senatore, Cardone et al 2000.).

A study conducted by Labeckas and Slavinskas the four-cylinder diesel machines are controlled by RME and fuel blends with mineral diesel. Machines are inhaled environmental, water cooled compression ignition combustion toroidal space in the piston head. Tests conducted on five different engine speeds of 1400rpm, 1600rpm, 1800rpm, 2000rpm and 2200rpm. They conclude that the operation of diesel engines with RME consumed more fuel and the low thermal relative to diesel fuel (Labeckas and Slavinskas 2006). Efficiency of diesel machines are usually equipped with a turbocharger to upgrade the capability to allow more air cylinder engine train ride. Turbochargers are generally driven pump the energy from the exhaust gas flow. Exhaust gas flows through the turbine, which in turn is used to drive the compressor. The pressure in waste gate is controlled by the compressor to ensure that the pressure in the cylinder is not too high. Alton et al. (2001) has been conducting research on single cylinder diesel engine operating with different types of vegetable oils and their methyl ester. They work with biodiesel fuels from different sources such as raw sunflower oil, crude cotton seed oil, crude soybean oil and their methyl esters, refined corn oil, the world of opium poppies and refined rapeseed oil. Results show that all the fuel on one cylinder diesel engine with only 18% variation in maximum engine power and maximum variation of 10% of engine torque.

Experimental research conducted on diesel engine has shown that burning biodiesel affect the volumetric efficiency of the SIA. This is due the temperature of the exhaust from diesel engines are associated with the combustion event in-cylinder engine and fuel type used in the machine. On the other hand, volumetric efficiency is affected by the discharge temperature (Balusamy and Marappan, 2007). Hasimoglu been doing experiments on four-cylinder turbo charged diesel engines operating with biodiesel and mineral diesel. It concludes that engine volumetric efficiency increased when the machine operates with biodiesel. The combustions biodiesel emitted less heat because of the lower and LCV. Since the exhaust gas temperature is lower than with mineral diesel. Therefore less heat is transferred to the machine, such as intake manifold (Hasimoglu, Ciniviz et al. 2008). This results increased the volumetric efficiency of air intake systems. Kandasamy et al. (2008) has been doing research on single cylinder diesel engine operating with biodiesel and mineral diesel (Kandasamy, Jeganathan et al. 2008). They concluded that the variation of volumetric efficiency is related to exhaust temperature. Volumetric efficiency of engine operation biodiesel is lower due to lower than the temperature of exhaust gas. The low-arrested exhaust air inlet temperature decreased and vice versa.

CHAPTER 3

METHODOLOGY

3.1 PREPARATION OF THE TEST FUEL

In the experiment study diesel and biodiesel was used as a fuel for engine. 5% volume of biodiesel was taken in a cleaned vessel, which is mixed with 95% by volume diesel, and thus a stable mixture was prepared to use in the test engine.

Table 3.1: Properties of fuels

Properties	Diesel	B5
Density @ 15°C(kg/m^3)	830	845.9
Viscosity @ 40°C(cSt)	2.8	4.6
Flash point (°C)	55	81
Cetane number	45	61.5

3.2 TEST ENGINE AND EXPERIMENTAL PROCEDURE

The experiment was conducted on the four cylinders, four stroke and water cooled engine with specifications shown in Table 2. The engine test bed consists of a test engine, dynamometer, measurement instruments and control panel. The eddy current dynamometerrated for 150kW maximum operating speed. The load on the dynamometer was measured by using a mechanical dial gauge that was calibrated by using standard weights just before the experiments.

Table 3.2: Specification of the test engine

Type	Diesel engine
Number of cylinders	4 in-line
Combustion chamber	Swirl chamber
Total displacement, dm^3	1.998
Cylinder bore, mm	82.7
Piston stroke, mm	93
Compression ratio	22.4
Inlet valve open (IVO)	20°
Inlet valve closing (IVC)	48°
Exhaust valve open (EVO)	54°
Exhaust valve closing (EVC)	22°
Cooling system	Water-cooled

Both the diesel and biodiesel (5% biodiesel and 95% diesel) fuels are used in the standard engine with different speed such as 1500, 1500, 200, 2500 and 3000 rpm. The experimental studies were made for the following 2 combinations.

i. Naturally Aspiratedconventional engine operated with diesel fuel.
ii. Naturally Aspirated conventional engine operated with biodiesel fuel.

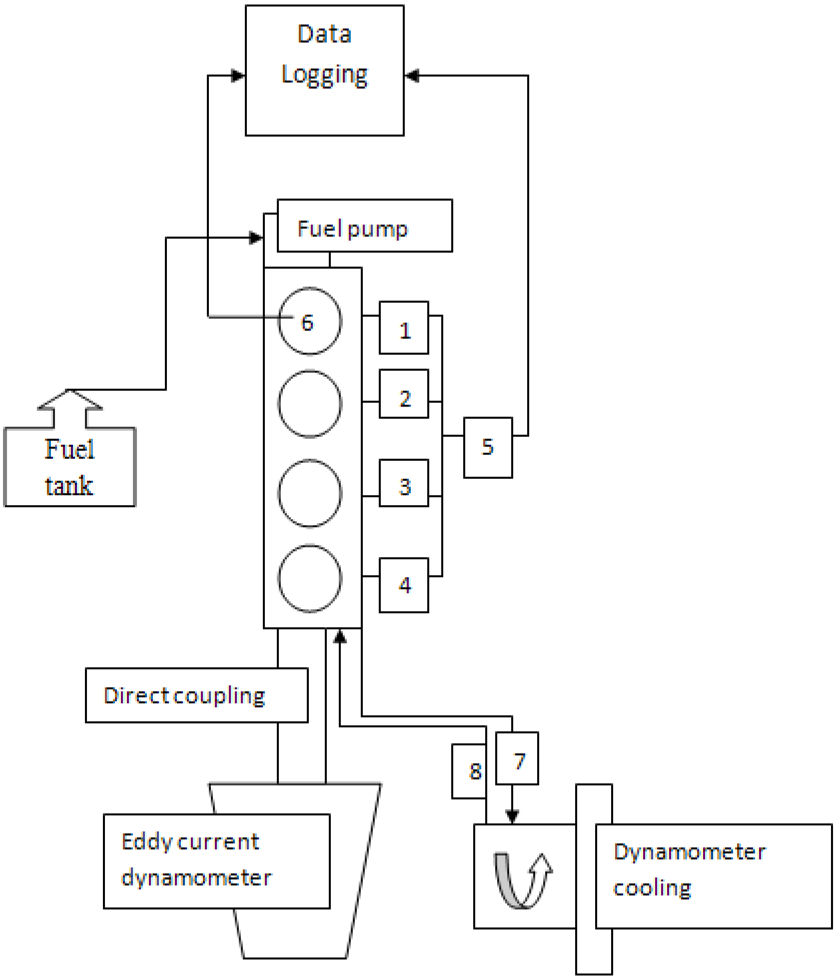

Figure 3.1: Schematic of experimental set up

where,

1. Thermo Couple (Exhaust Temperature 1)
2. Thermo Couple (Exhaust Temperature 2)
3. Thermo Couple (Exhaust Temperature 3)
4. Thermo Couple (Exhaust Temperature 4)
5. Thermo Couple (Exhaust Temperature 5)
6. Pressure Sensor (In-pressure Cylinder)
7. Cooling Out
8. Cooling In

Figure 3.2 shows the instrumented engine testing apparatus. Theconsiderations and details of this will be discussed in this chapter.

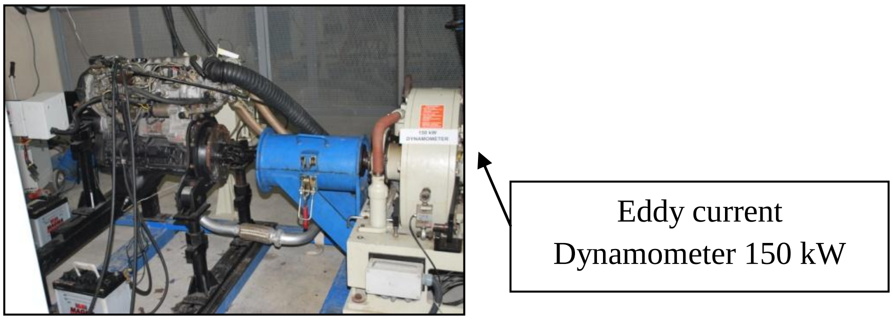

Figure 3.2: Testing apparatus

The testing apparatus for the work involved in this thesis was all located in Lab Automotive, FKMUMP Pekan, which had previously been used for electric vehicle testing. Theonly existing equipment in the lab that was used for this thesis was eddy-current dynamometer 150 kW and its control system. This liquid-cooled dynamometer wasset up and operational at the time the lab space was acquired. This unit had previouslybeen integrated into a roller carriage for chassis dynamometer testing which needed to bedisconnected and partially removed to make room for coupling the diesel engine directlyto the dynamometer.

3.3 ENGINE SELECTION

The diesel engine selection was based on the available lab space, the compatibility withthe existing engine dynamometer system, fuel consumption rate, and budget. Due to thedynamometer’s location in the room and utilized space of other lab projects, the wholediesel power unit including mounting and coupling systems had to fit within a tightfootprint of putting a significant restriction on the size of the engine. The dieselengine also had to fall within an acceptable power range for the dynamometer. Theconcern was that the dynamometer system would not be able to accurately read andcontrol the torque applied to the engine at low levels. It was determined from themanufacturer’s data that the load cell in dynamometer was very precise and accurate butthat the controller for the dynamometer was the limiting factor. There was insignificantinformation on the controller so it was determined experimentally from the previouselectric vehicle tests that the engine would have to be over 10 bhp to get into thecontroller's accuracy range. Fuel consumption rate was a factor in the engine selectionbecause the availability of algal based biodiesel is extremely limited. Since the otherstudent working on this project was using an algal biodiesel blend, hedetermined an acceptable fuel consumption rate which for most engines limited thepower output to less than 100 bhp.

The final engine selection was a 3000rpm, four cylindersand naturally aspirated. It was chosen because it met all of the criteria mentioned.Figure 3.2 shows a rear and side view of the engine and stand

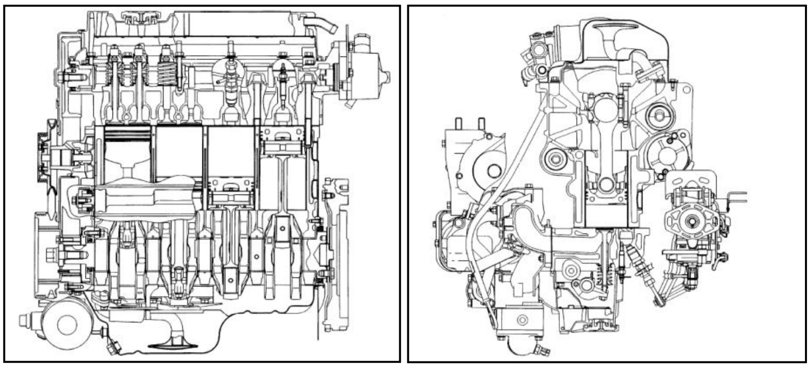

Figure 3.3: Drawing of the engine

It came as a complete power unit so it was already mounted on a stand, it was complete from the radiator to the flywheel, and it came with everything to be operational besides abattery and fuel tank. The power unit's footprint was which allowed foradditional mounting equipment and a coupling system. The compact unit fell in themiddle of the power range desired due to the turbo charger which also increasedefficiency helping meet the fuel consumption requirements. Best of all, the engine wasbroken and they gave us a significant discount. All of themanufacturer's data was supplied with the power unit and is located in Appendix B. Thisinformation was used with the permission of the distributor that supplied the engine andis only intended for use within this project at University Malaysia Pahang.

3.4 COUPLING THE ENGINE TO THE DYNAMOMETER

In order to couple the engine to the dynamometer, supplier a short shaft with universal joints at each end. They were bolted to the floor with concreteanchors. Between the I-beams and the power unit framework, additional spacers wereplaced to get the final desired height. Figure 3.4 show the I-beams, concrete anchors, andadditional spacers.

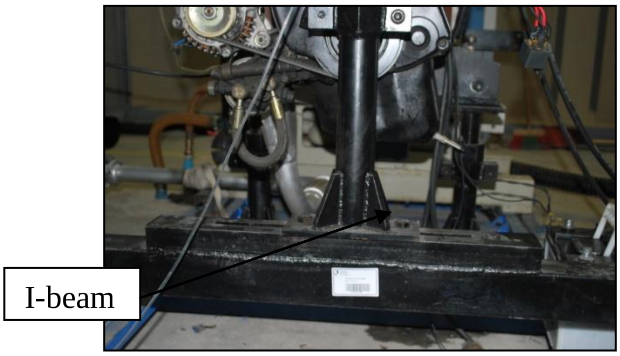

Figure 3.4: Mounting system

Connecting the driveshaft to the engine’s flywheel involved machining the surface flatand tapping mounting holes for the driveshaft flange. Figure 3.5 shows the flywheel andthe driveshaft flange bolted on via the tapped mounting holes.

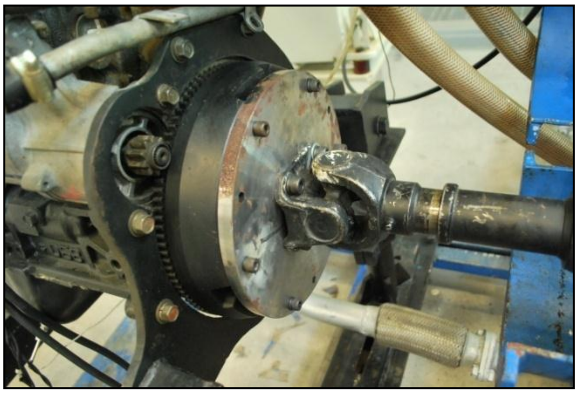

Figure 3.5: Machined flywheel with mounted driveshaft flange

On the dynamometer end, an 8” long 1 ¾” diameter solid 1040 steel shaft with 3/8” cutkeyways connected the driveshaft and dynamometer couplings. This shaft also had snappinggroves added to it and caps which constrained the shaft from moving verticallyinside the couplings. Figure 3.6 shows this arrangement.

Figure 3.6: Keyed and grooved shaft between couplings with caps

This completed the mounting and coupling of the diesel power unit to the dynamometerwhich was an essential deliverable that needed to be completed before the remainder ofthe energy balance measurement equipment could be implemented.

3.5 MEASUREMENT EQUIPMENT

Table 3.3 contains the specific measurements, the type of measuring equipment,equipment locations on the test apparatus, and the equipment resolution or accuracy needto perform the energy balance on the system.

Table 3.3: Measurements, equipment, locations, and symbols

Measurement	Symbol	Equipment	Location	Units
Torque	τ	Dynamometer	Driveshaft	N-m
Engine speed	N	Dynamometer	Driveshaft	rpm
Brake power	$\dot{W}_b$	Dynamometer	Driveshaft	kW
Ambient temperature	T_{amb}	Thermocouple	Air cleaner outlet	°C
Exhaust temperature	T_{exh}	Thermocouple	Exhaust manifold	°C
EGR temperature	T_{EGR}	Thermocouple	EGR manifold	°C
Fuel flow rate	$\dot{m}_f$	Scale and stopwatch	Fuel tank	L/s

The laboratory as shown in Figure 3.7 involves data logging station and testing engine area. The data logging station include Dewetron port and computer with Dewetron software. Testing engine area at outside room include dynamometer cooling, engine Mitsubishi 4D68, fuel tank and eddy current dynamometer 150kW.

Figure 3.7: Laboratory environment

Figure 3.8 shows the computer used to log the data during testing, the 12 volt powersupply for the mass air flow sensor, the data logger, and the dynamometer controls andreadout.

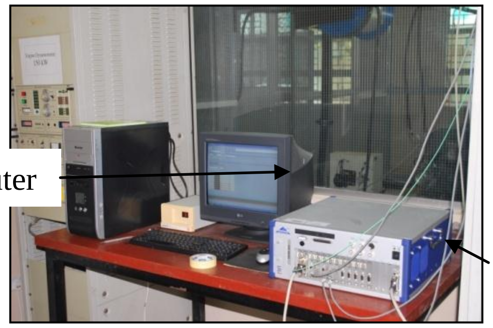

Figure 3.8: Data logging station

Figure 3.9 shows a closer look at the experimental set up.The eddy current dynamometer 150kW connects to engine testing with direct coupling. Thermocouple and pressure sensor collect data from engine testing to convert the data with Dewetron Supplier.

Figure 3.9: Test apparatus accessories

Figure 3.10 shows the test apparatus from a different angle.Engine dynamometer will give a signal to the eddy current dynamometer for setup load and speed at engine testing. Engine is cooled by cooling dynamometer.

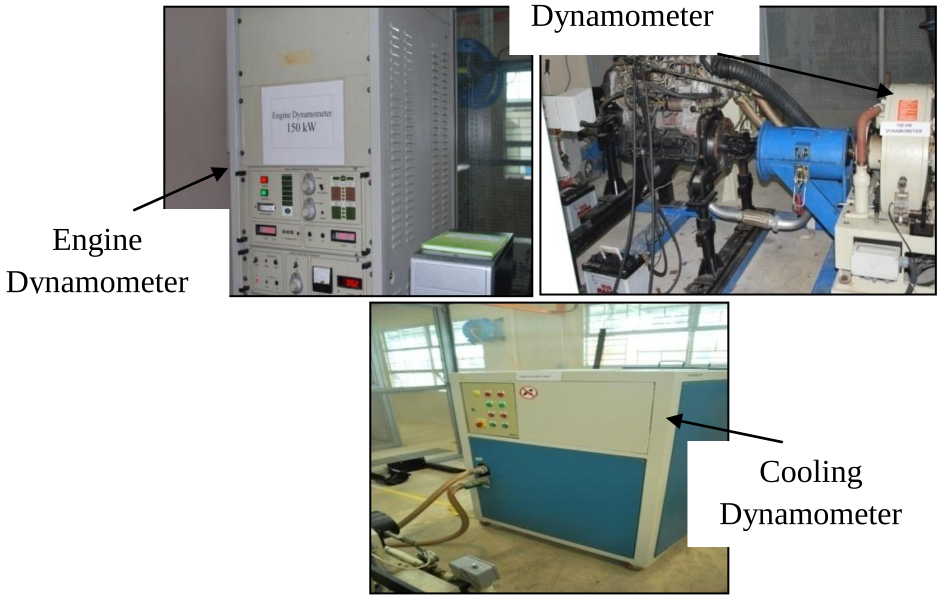

Figure 3.10: Test apparatus

The following series of pictures shows the actual placement of the measurementequipment on the engine. Figure 3.11 shows the exhaust, coolant out, and ambient airthermocouple locations. Exhaust gas temperature after the turbine and after compressor (before inlet valve) was measure using thermocouple.

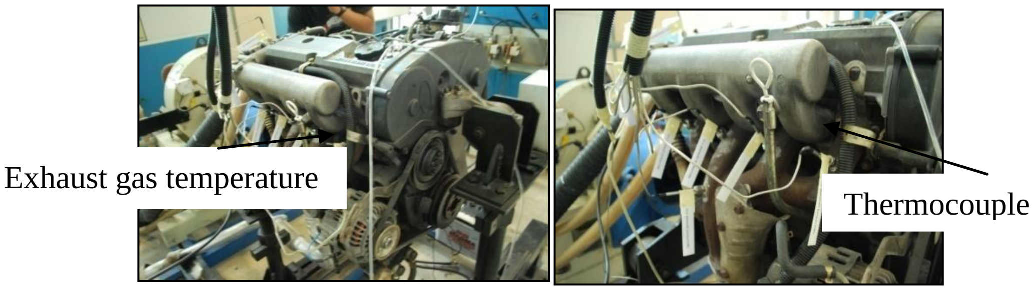

Figure 3.11: Measurement equipment placement

Figure 3.12 shows the other side of the engine. Pictured are the coolant in, fuel supply,and oil thermocouple locations. It also shows the fuel tank on top of its scale, the fuel flow meter and the outside temperature location.

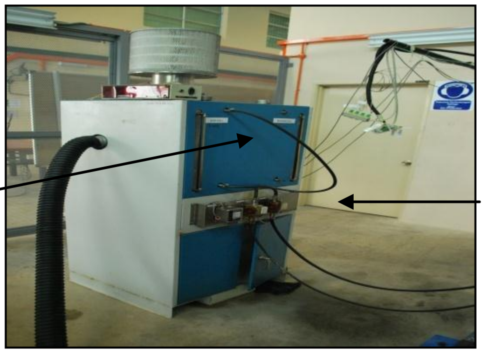

Figure 3.12: Measurement equipment placements (other side of engine)

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 EXHAUST GAS TEMPERATURES

Data were collected for analysis in this study judged by some experimental methods. Data from alleach trial the fuel is filtered and combined to plot the results for individual measurements. An example of this is a diagram that shows all the temperature measurements for a number of attempts of B5 are plotted on the 1000-3000rpm.

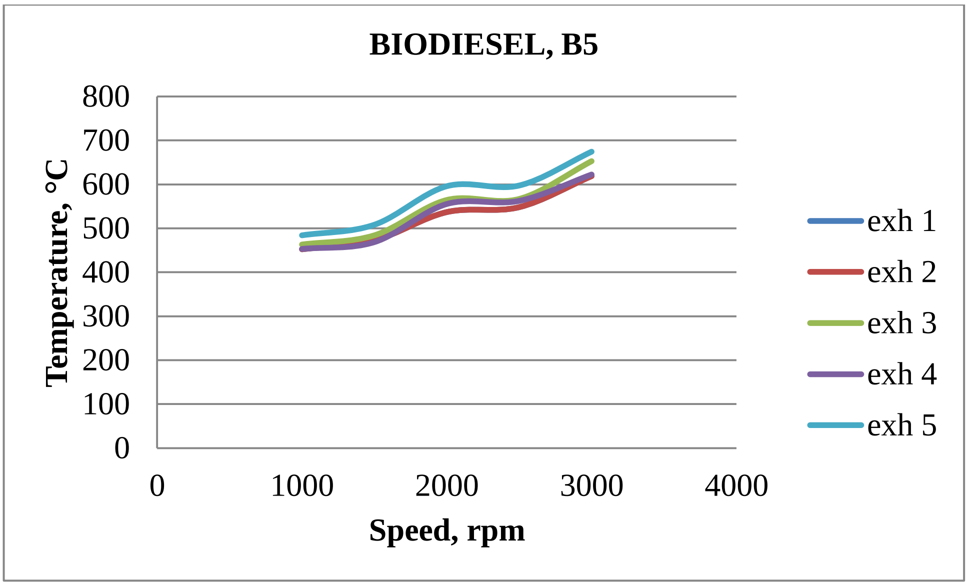

Figure 4.1: Exhaust temperatures with speed for biodiesel at 50% load

The goal of the test plan was to achieve steady-state test conditions during most of thetrial. The temperatures shown in Figure 4.1 suggest that most of the measurements takenbegan to stabilize around the 2000rpm. It is also shown that the measurementsfollow the same trends which were determined to be the result of the ambient airtemperature controlled by the environmental conditions outside thetesting laboratory. The dependence the measurements had on the ambient air temperaturewill be shown in greater detail later in this section. The trends and measured values forthe diesel fuel trials were very similar to the biodiesel trials. Therefore, the diesel fuelplots are only shown in comparisons with biodiesel when needed.

A closer examination of the individual measurements revealed that the values did notreach a true steady state condition and that the values were not consistent from trial totrial. Figure 4.2 shows a diesel fuel running at 1000-3000rpm.

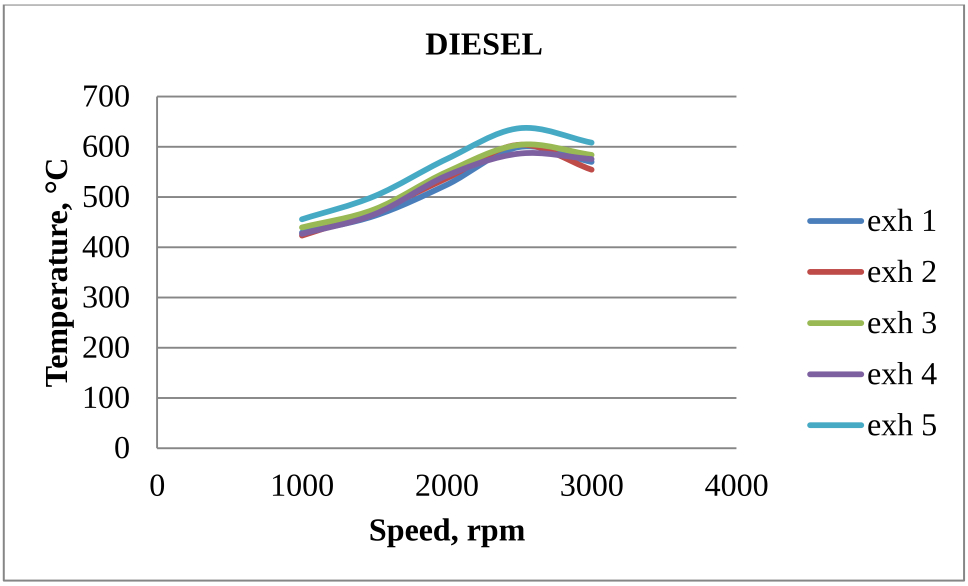

Figure 4.2: Exhaust temperatures with speed for diesel at 50% load

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Figure 4.2 shows that the temperature readings in most trials increased throughout butapproached steady-state conditions in the later half of the trials. Additionally, the overalltemperatures decreased in most cases as the number of trials progressed. Data in the trial of four different type’s rpm and it showed the usual decline in the last two rpm test.

4.2 DATA ANALYSIS

Upon inspection of all the measurement trials for both fuel sources, it was determinedthat analyzing the data between 1000 to 3000 rpm for each trial would give consistenttemperatures, small fluctuations, and an acceptable number of data points for each trialFigure 4.3 shows the 1000 to 2500 rpm selected to analyze for the samedata shown in Figure 4.2.

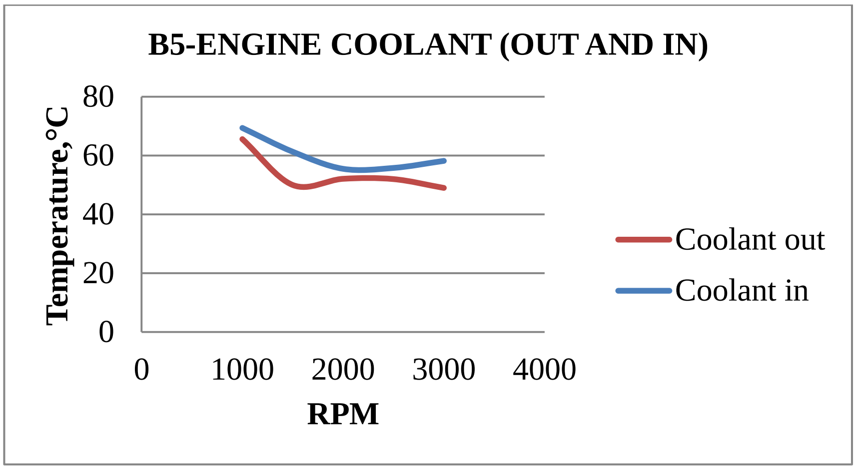

Figure 4.3: Engine coolants with rpm for biodiesel at 50% load

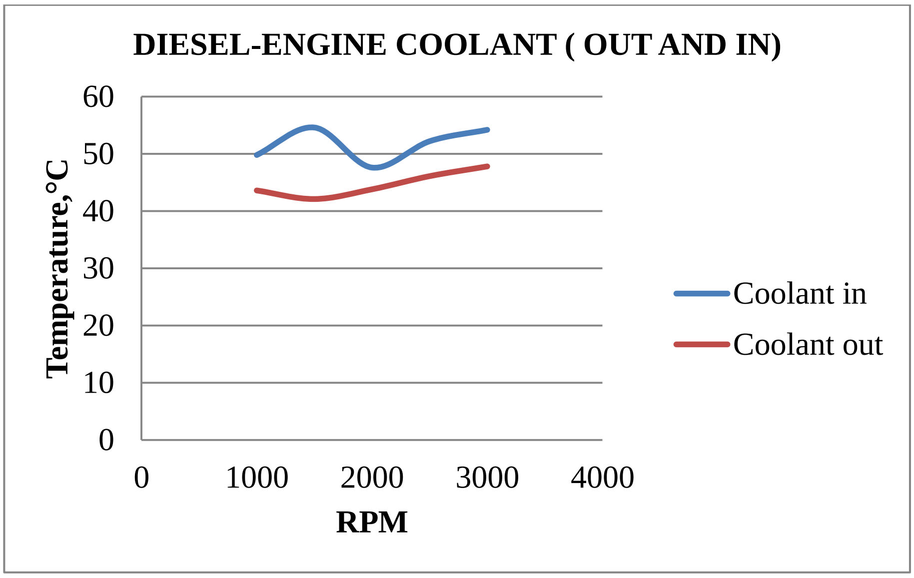

Figure 4.4: Engine coolants with rpm for diesel at 50% load

Due to the slightly increasing trend of the data evident in Figure 5.3, linear trend lineswith their respective equations were applied. The slopes and y-intercepts were averagedto come up with a single equation for temperature as a function of time used to model thetrials as a single average. The individual trend line equations also provided approximatedvalues for the coolant temperatures as a function of rpm for the 4 individual trials.Linear trend lines were chosen to model the data collected for each trial because this gavemore conservative estimates than a polynomial fit trend line. In order to approximate themeasurement uncertainty independent of the variability in the data due to ambienttemperature, the difference between the approximated and measured values for each trialwere determined and the standard deviation of this difference was calculated. Then tocompute the uncertainty based on a 95% confidence interval, the average of the 4 standard deviations (σ *a)* was divided by *n* where *n* = 360, and multiplied by the tablevalue from the Student's T-distribution for 95% confidence with 6 trials. Equation 10 shows the standard equation just described.

(2.571)*nMean a* σ

All of the graphed data with trendiness, raw data and calculations for Eq. 10 can befound in B51000-3000rpm and Diesel 1000-3000rpmfor biodiesel anddiesel respectively. These are included as a supplement to the thesis along with Biodiesel and Diesel.

4.3 ENGINE TORQUE

The B5 torque values, used for determining power output, for 4 variable rpm testing are shown inFigure 4.6. Here it is clear that the torque values steadily decreased over rpm. Thetorque values were all manually recorded off of the dynamometer readout during thetesting.

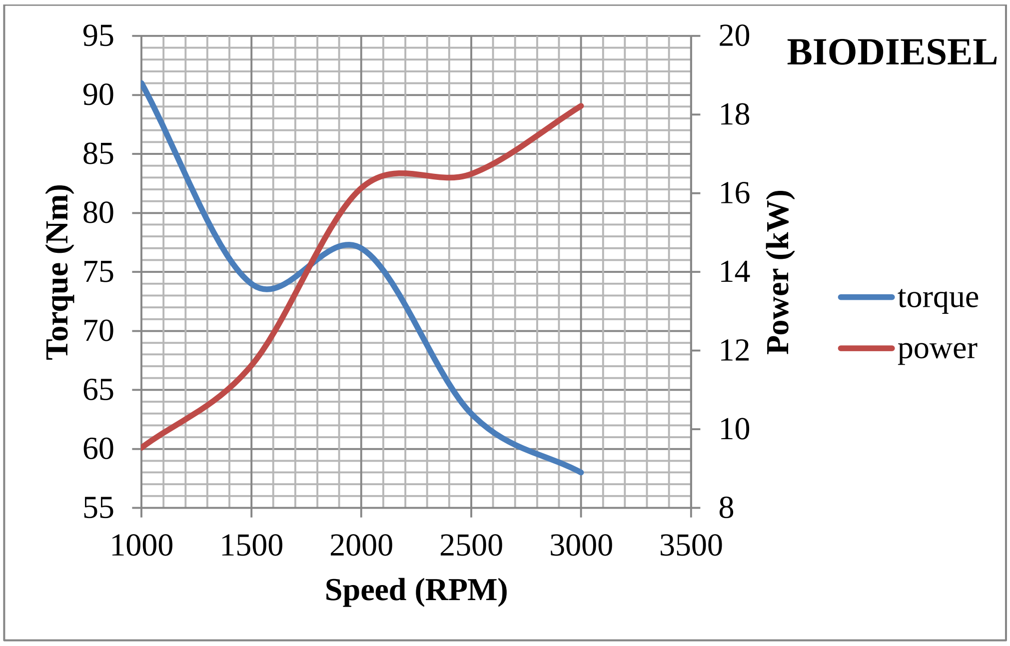

Figure 4.5: Torque and Power with rpm for biodiesel at 50% load

In a similar fashion to the temperature values the torque data in the 1000-3000rpm was selected, and the same analysis was performed using Equation 10. Figure 4.5 and Figure 4.6shows these torque values for B5 and Diesel with their linear trendiness.The raw data, calculations, and graphs for the torque and power can be seen inthe “Torques and Power” tab with Biodiesel and Diesel.

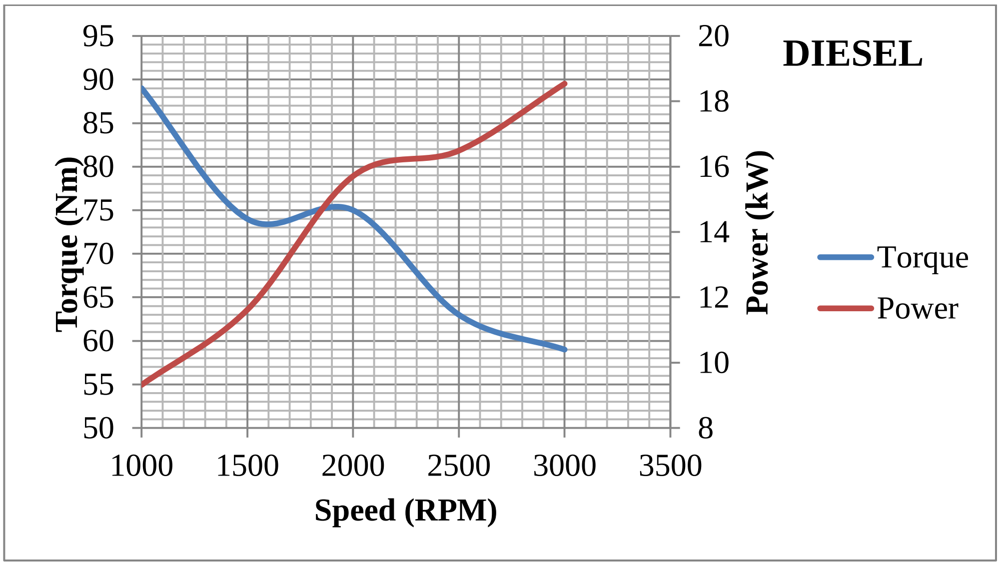

Figure 4.6: Torque and Power with rpm for diesel at 50% load

In Figure 4.6 shows high torque at low speed and high power at high speed. Indicated power increases with speed while brake power increases to a maximum. This is because friction increases with engine speed to a higher power and becomes dominant at higher speeds.

4.3.1 DATA TORQUE AND POWER

Table 4.1: Torque and Power with rpm for biodiesel at 50% load

Speed, rpm	**Torque, τ**	**Power, $\dot{W}_b$**
1000	91 N-m	9.53 kW
1500	74 N-m	11.62 kW
2000	77 N-m	16.13 kW
2500	63 N-m	16.49 kW
3000	58 N-m	18.22 kW

Table 4.2: Torque and Power with rpm for diesel at 50% load

Speed, rpm	**Torque, τ**	**Power, $\dot{W}_b$**
1000	89 N-m	9.32 kW
1500	74 N-m	11.62 kW
2000	76 N-m	15.92 kW
2500	63 N-m	16.49 kW
3000	59 N-m	18.54 kW

4.3.2 SAMPLE CALCULATION

Power with 1000rpm for biodiesel at 50% load

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

$\dot{W}_b$ =(2π radian/rev)(1000/60rev)/sec)(91 N-m)

$\dot{W}_b$ =9530 N-m/sec= 9.53 kW

Power with 1000rpm for diesel at 50% load

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

$\dot{W}_b$ =(2π radian/rev)(1000/60rev)/sec)(89 N-m)

$\dot{W}_b$ =9320 N-m/sec= 9.32 kW

4.4 IN-CYLINDER PRESSURE

Figure 4.7, Figure 4.8, Figure 4.9, Figure 4.10 and Figure 4.11 shows the pressure in cylinder operating with biodiesel fuel as function 1000-3000rpm.

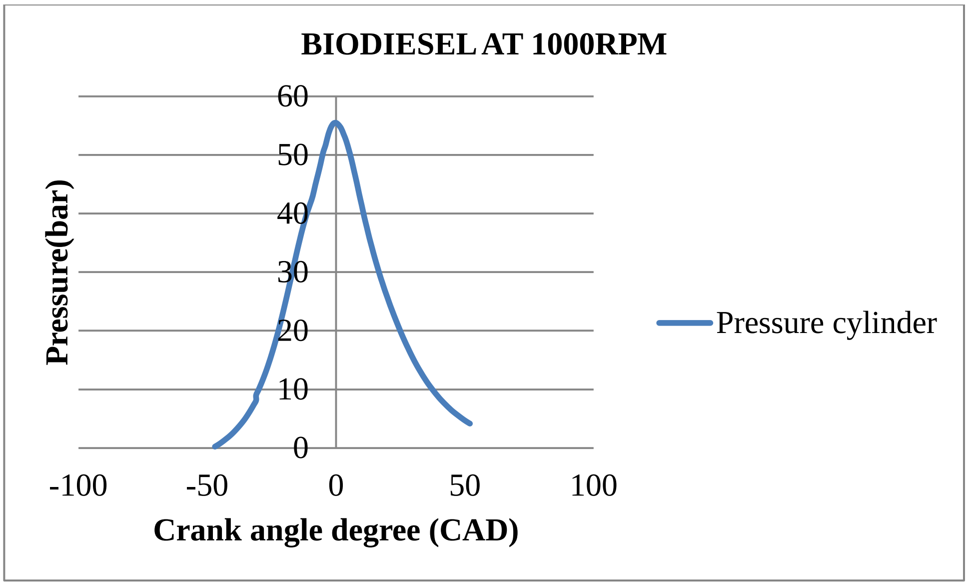

Figure 4.7: Pressure in cylinder by 1000rpm with CAD for biodiesel at 50% load

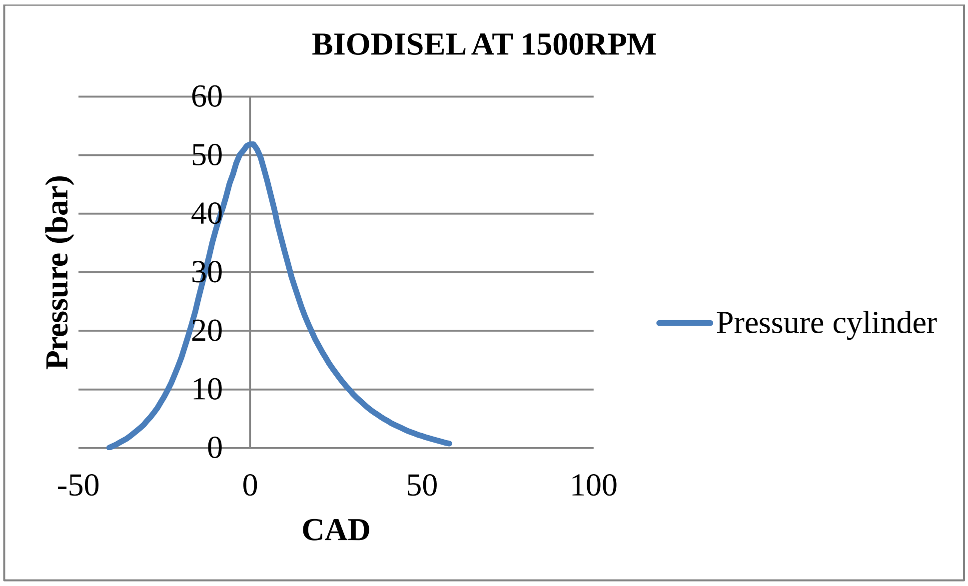

Figure 4.8: Pressure in cylinder by 1500rpm with CAD for biodiesel at 50% load

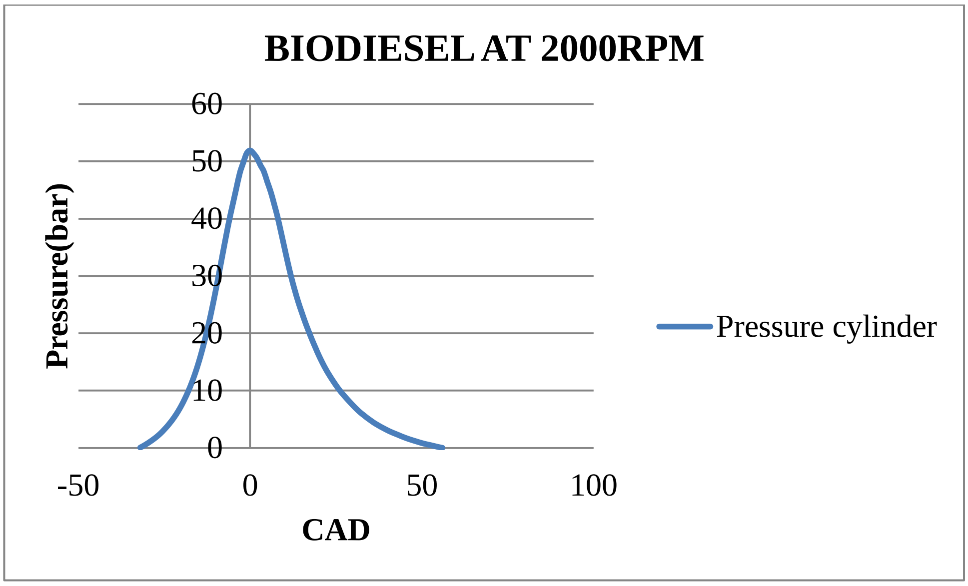

Figure 4.9: Pressure in cylinder by 2000rpm with CAD for biodiesel at 50% load

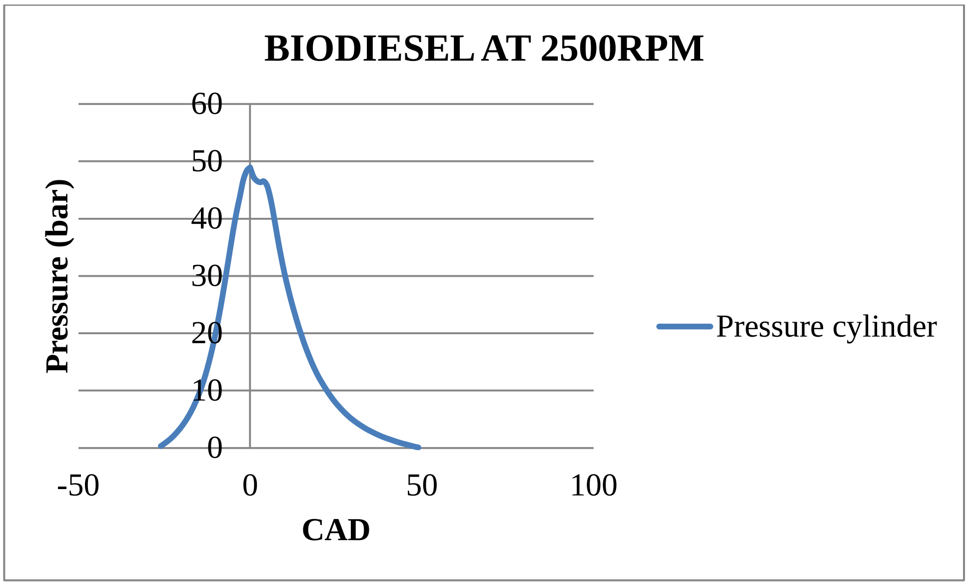

Figure 4.10: Pressure in cylinder by 2500rpm with CAD for biodiesel at 50% load

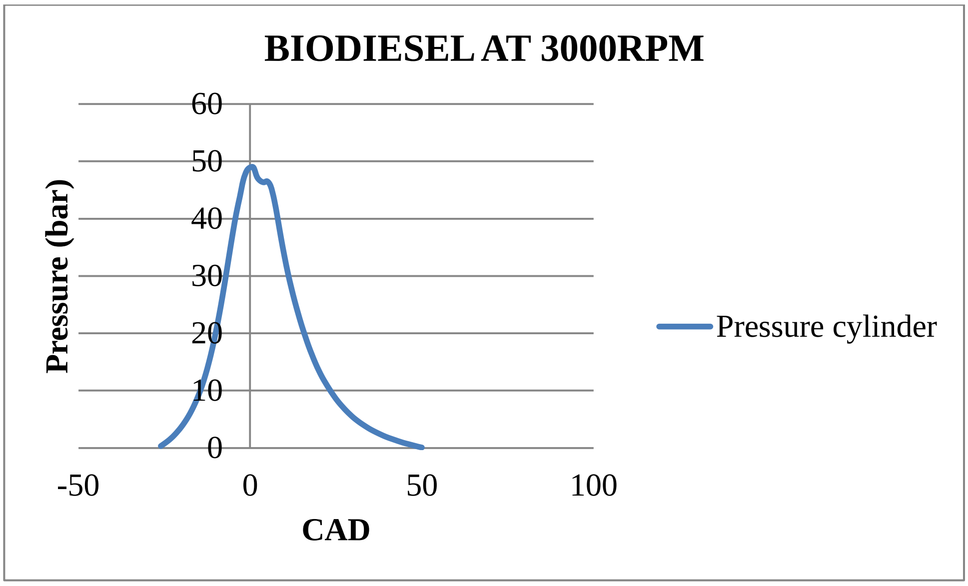

Figure 4.11: Pressure in cylinder by 2000rpm with CAD for biodiesel at 50% load

Figure 4.12, Figure 4.13, Figure 4.14, Figure 4.15 and Figure 4.16 shows that the pressure in cylinder at 1000-3000rpm operating with diesel fuel. In CI engine the cylinder pressure is depends upon the fuel-burning rate during the premixed burning phase. The high cylinder pressure ensures the better combustion and heat release. The Figure 4.7 and Figure 4.8show the typical pressure variation with respect to engine speed. The advantage of higher temperatures of diesel engine increases the cylinder pressure throughout the speed range. The cylinder pressure for biodiesel is higher than diesel about 1%(VanGerpen, 2001).

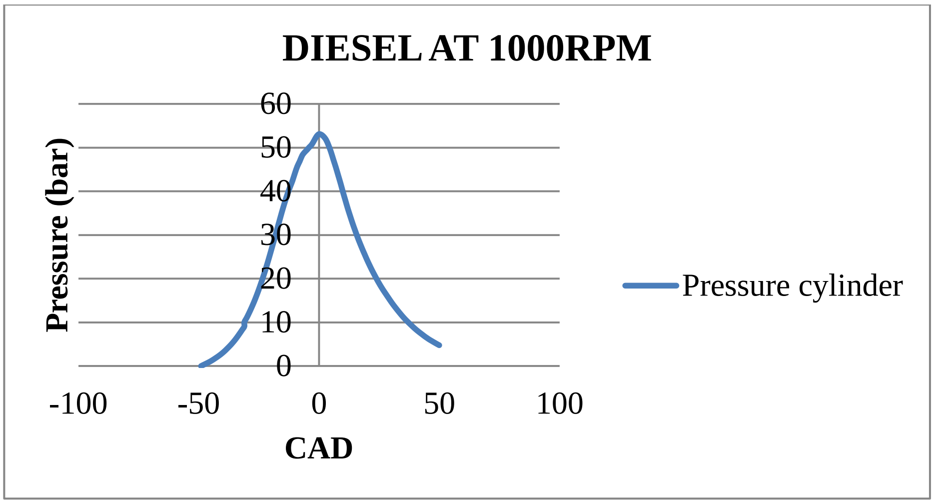

Figure 4.12: Pressure in cylinder by 1000rpm with CAD for diesel at 50% load

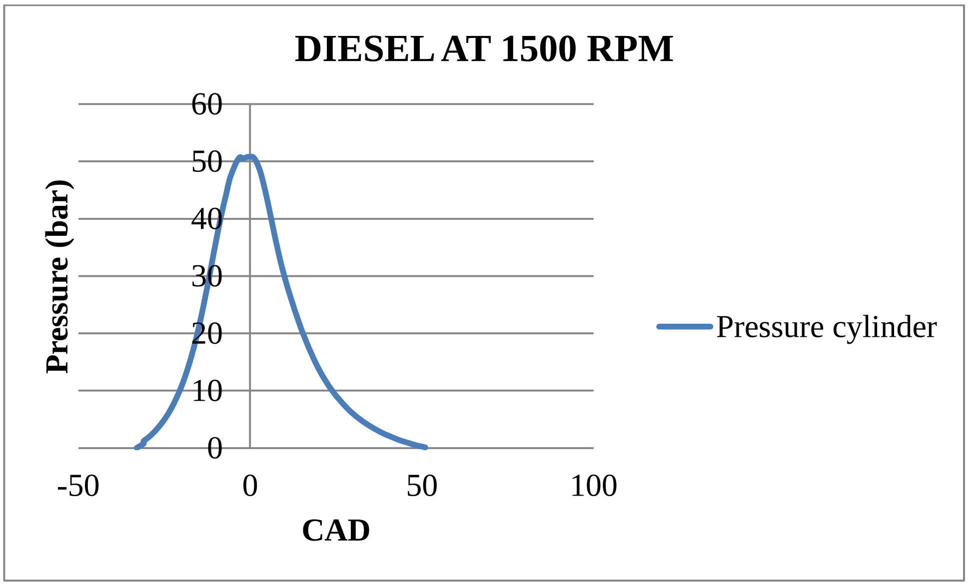

Figure 4.13: Pressure in cylinder by 1500rpm with CAD for diesel at 50% load

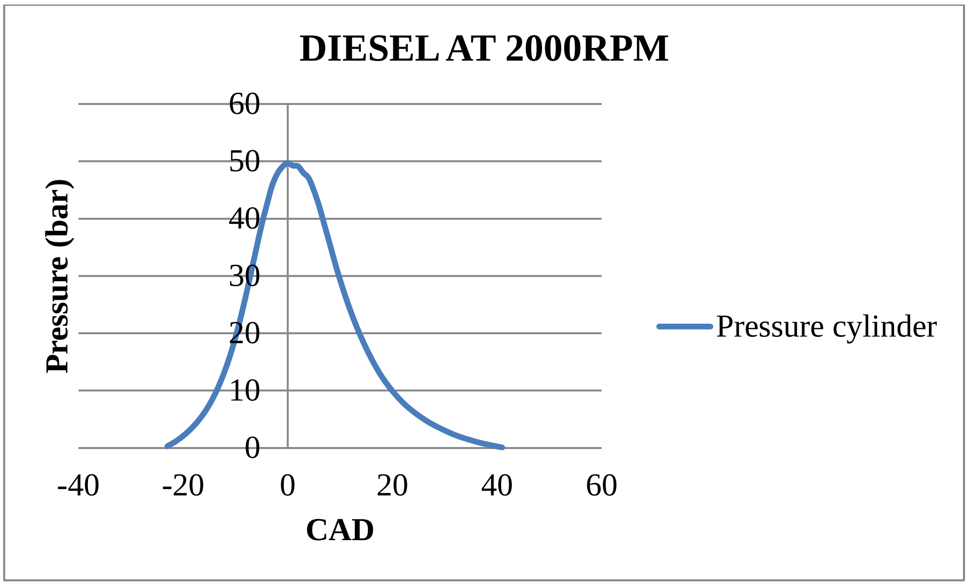

Figure 4.14: Pressure in cylinder by 2000rpm with CAD for diesel at 50% load

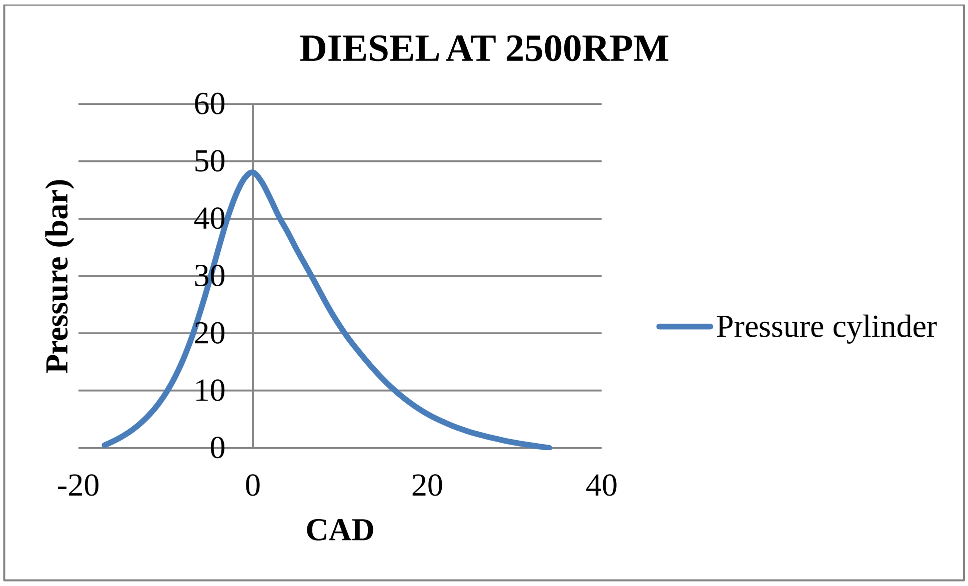

Figure 4.15: Pressure in cylinder by 2500rpm with CAD for diesel at 50% load

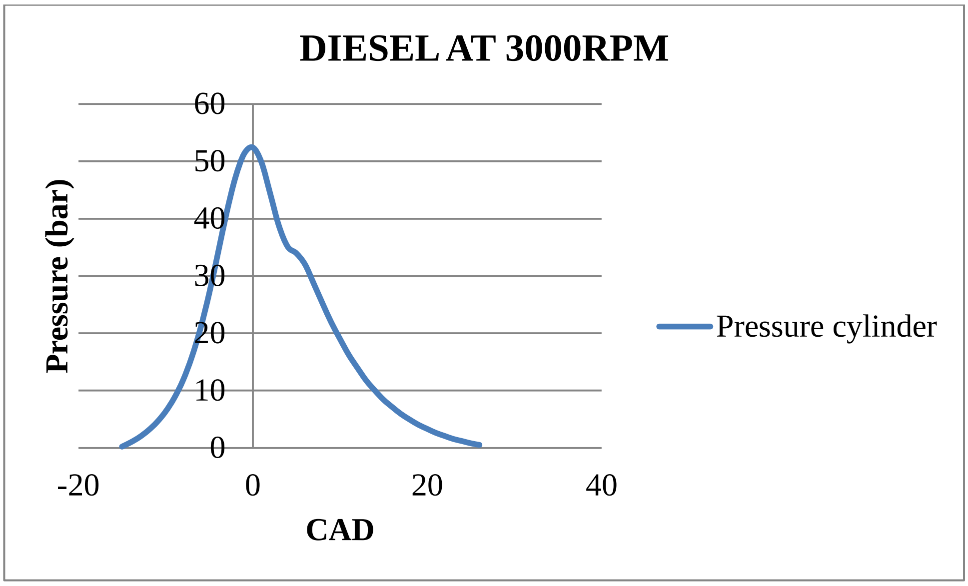

Figure 4.16: Pressure in cylinder by 3000rpm with CAD for diesel at 50% load

Though the lower calorific value of biodiesel and higher initial temperature due to the domination of residual gases decreases the volumetric efficiency in CI engines, thus reduces the peak pressure and work done. However the cylinder pressure for biodiesel and diesel due to the oxygenated nature of biodiesel improves the combustion process.

Noted, that the maximum pressure obtained for biodiesel is closer with TDC rather than diesel fuel. The fuel-burning rate in the early stage of combustion is more than the diesel fuel, which bring the peak pressure more close to TDC. During the expansion, the torque produced by the engine is kind enough to go for the next cycle with the consumption of more fuel(Hemmerlein, 1991).

The peak pressure of the engine is higher when using biodiesel then that of diesel. It may be due to lower quality of hydrocarbon in the biodiesel and lower pressure rise while burning. The oxygen atoms in the biodiesel molecule itself make the complete combustion of fuel and hence more energy is released. So that, biodiesel-fueled engine produces high peak temperatures than that of biodiesel-fueled engine (Hemmerlein, 1991).

4.4.1 Variation In-cylinder pressure

Figure 4.17 and Figure 4.18 shows the variation In-cylinder pressure of diesel engine operating with biodiesel fuel and diesel fuel as function 1000-3000rpm.

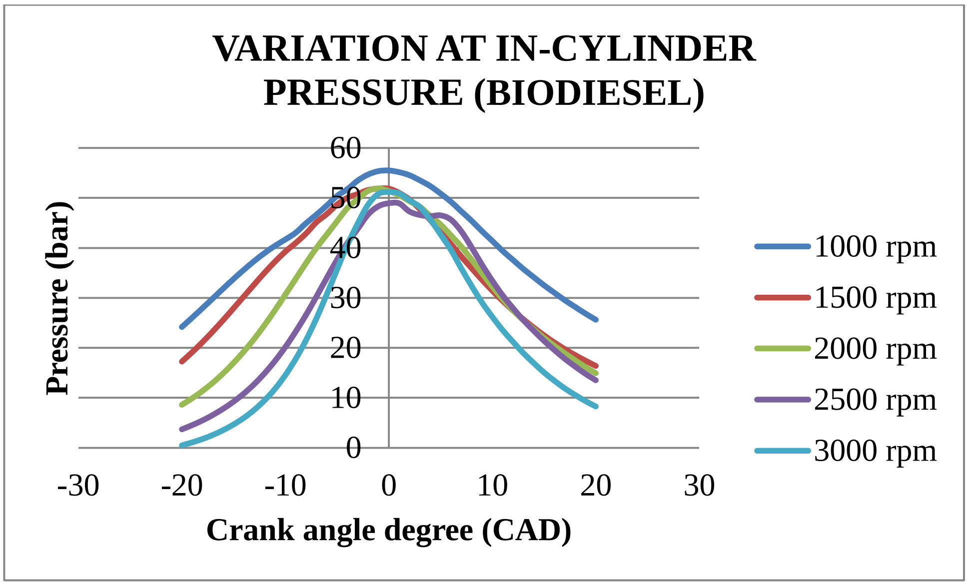

Figure 4.17: Variation at In-cylinder pressure of biodiesel fuel

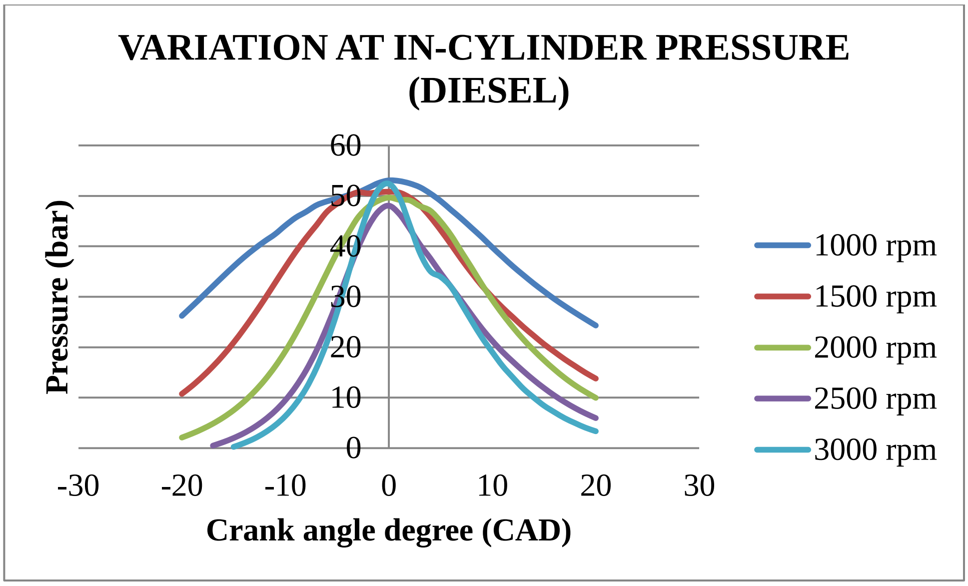

Figure 4.18: Variation at In-cylinder pressure of diesel fuel

Figure 4.17 shows the variation of the characteristics of diesel engines different oils. This variation is shown in a long time and the average value of properties divided by the respective standard deviation. From Figure 4.17 we know that all the different coefficients of variation decreased as expenses have risen. There is a clear difference. The combustion quantity, duration and amount of combustion coefficient of premixed burning biodiesel fuel higher than diesel. This explains diesel combustion is more stable than biodiesel in premixed combustion period. For the combustion of the quantity of diesel combustion decreased and the temperature inside the cylinder decreased. So the burning is stable.

4.4.2 Pressure Maximum in Cylinder

Figure 4.19 and Figure 4.20 shows the pressure maximum in-cylinder of diesel engine operating with biodiesel fuel and diesel fuel as function 1000-3000rpm.

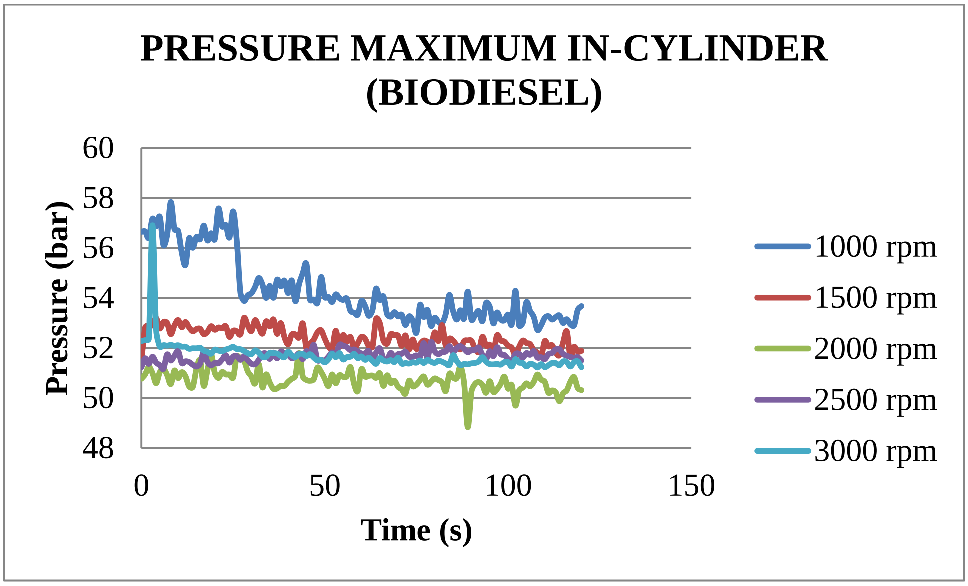

Figure 4.19: Pressure maximum in cylinder for biodiesel fuel

Variation of peak pressure and maximum pressure rise at the different speed engines are shown in the Figure 4.19. The peak pressure difference between the two fuels can be observed at 50% load condition, after it dropped to a mixture of biodiesel compared to the neat because the reasons discussed in the final section. The maximum peak pressure is obtained for the mixture at 50% load, at engine speed with 1000rpm.

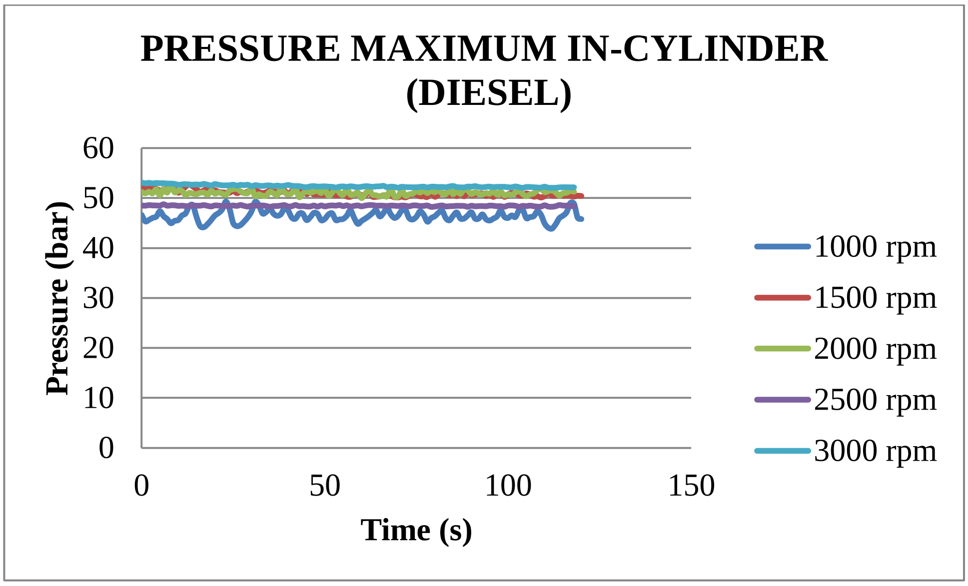

Figure 4.20: Pressure maximum in cylinder for diesel fuel

Pressure in Figure 4.20 increase rate is the first derivative of cylinder pressure related to the smooth operation of the engine. Maximum level increases with increasing pressure initially and then decreased as the load effect on the premixed phase protruding from the lower costs, while the role of diffusion combustion phase remains significant at higher loads. The maximum level of pressure rise is higher for biodiesel than diesel is relatively neat, especially for the higher ignition delay.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter will focus on conclusions that were able to be made based on the results and any future work that should be done in accordance with them. Also, the goals and objectives that were outlined in chapter 1 will be discussed to show how well the work in this thesis met the expectations.

5.2 CONCLUSION

The results in chapter 4 were determining the combustion and performance characteristics of the compression ignition engine. The experimental has been developed in such way that it can be used for characterizing any hydrocarbon fueled engines like diesel, biodiesel or their blends. The experiment results shows that, with increases in speed the pressure, exhaust temperature and in-cylinder pressure will be increase. CI engines operated with diesel shows better performance than biodiesel operation but not up to the extent of lower level. The predicted results are compared with the experimental results of the engine by diesel and B5 in CI engine. This experimental predicted the engine performance characteristics in closer approximation to that of experimental results.

The variation in experimental and theoretical results may be due to the fact that in theoretical model homogenous mixture with complete combustion is assumed. But in general, it is difficult to obtain complete combustion. Despite the simplification resulting from the assumed hypothesis and empirical relations, the developed simulation proved to be reliable and adequate for the purposed. Hence, it is believed that this experimental is suitable for prediction of the combustion and performance characteristics of the CI engines fueled with any hydrocarbon fuel in both conventional engines.

5.3 RECOMMENDATION

The ambient air temperature conclusions suggest future improvements to the laboratory and/or the test plan. To keep the temperatures more consistent throughout a single testing, a better source of outside air should be supplied. To keep the average temperatures of all the trials closer together they should be tested when the outside air temperature is not changing. One other consideration would be placing an in-line air heater with a feedback\ controller on the engine's air intake to keep those temperatures constant. Finally, if the air ventilation or heater addition can not be achieved, running tests with outside air temperatures below 53°C and lowering the energy inputs by reducing the engine speed or changing throttle positions should help. 32°C is about the temperature outside the lab by the end of the tests for this thesis when steady-state readings were shown to be achievable.

Figure in chapter 4 shows the steady decrease in torque as a function of time analyzed for the energy balance comparison. The average torque values for diesel and biodiesel decreased 2-3% over this rpm testing. If all other variables were kept constant during the test, one would expect the torque values to be consistent. Since the other variables did not stay constant during testing, a change in torque is not surprising. However, this percentage decrease in torque is on the order of about 5 types engine speed as large as the increases seen in the ambient air and its other dependent temperatures shown in Figure 5.1.

The torque output is the result of forces acting on the pistons producing crankshaft rotation which is measured by the dynamometer. These forces are caused by the combustion of fuel and intake air in each engine cylinder's combustion chamber. It seems possible that the torque output would decrease as intake air temperatures increased because warmer air is less dense and therefore contains less oxygen necessary for complete combustion of the fuel. Since diesel engines rely on compressing air to high pressures and temperatures to ignite injected fuel, higher intake air temperatures could also change the ignition delay times. Ignition delay is the amount of time between the injection of fuel and the start of combustion.

Changes in ignition delay will affect the time at which the fuel starts to burn and the rate that heat is released. This could change the efficiency of the combustion process causing changes in the torque output. The optimum injection timing is determined and set by the manufacturer to account for combustion characteristics, such as ignition delay, based on the fuels and operating conditions they predict the engine will be used in. It can be concluded that the intake air temperatures were too high for peak efficiency to be reached due to the magnitude of our ambient air temperatures.

Looking at the large 9-10% increase in fuel supply temperatures as well as the 5% increase in fuel return temperatures from Figure 5.4, it can be concluded that, like air, the fuel density is lower at increased temperatures. Temperature also affects fuel viscosity which can impact combustion processes due to injection characteristics like spray tip penetration and fuel atomization. It was determined that the refueling procedure partially affected the fuel temperatures because the amount of fuel remaining in each tank differed from trial to trial. Adding additional (cool) fuel to each (warm) tank instead of completely replacing the fuel from our main supplies did not produce consistent temperatures at the start of each trial. Additionally, the surface the fuel tanks were placed on between tests transferred different amounts of heat. Placing the tanks on the cool concrete floor removed more heat from the tanks than the wooden bench top. It is recommended to modify the refueling procedure for future testing based on these findings.

Looking at the correlation between the fuel and air properties on the torque output, it suggests trying to control and monitor the sensitivity these products have on the torque output in the future. There is much more room for improvement with the fuel based on the consistency issues as well as larger temperature changes during the trials as mentioned earlier. Estimations of the air to fuel ratio indicate values of about 20:1 for biodiesel and 23:1 for diesel fuel. This shows that the air is the dominant presence in the combustion process but the fuel contains much more energy so its variation may have the largest impact on the torque output. The air to fuel ratios had to be estimated by the mass air flow rate given by the engine manufacturer because the mass air flow sensor on the engine did not work properly during testing.

In the future, these mass air flow values need to be measured for the trials of each fuel source to be able to make stronger conclusions about the sensitivity of air properties on torque output. Also, the procedure for monitoring the fuel flow rate needs to be improved because the flow rate was based on the weight change of fuel in the tank over the 1000-3000rpm. The weight values were only recorded at the beginning and end of the trial which give a very accurate average fuel flow rate for the trial, but it does not show any variations in the flow rate throughout the trial which could have changed based on density and viscosity changes from the increasing fuel temperatures. Multiple scale readings recorded in the future will produce precise fuel consumption results at any point during a trial. This will aid in drawing more accurate conclusions about fuel injection and combustion characteristic that may vary between diesel and biodiesel fuels.

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APPENDIX A

Data Experiment

i. Data for fuel flow rate for diesel engine operating with biodiesel fuel

RPM	FLOWRATE (m3/s)
1000	0.0000015
1500	0.0000023
2000	0.0000027
2500	0.0000032
3000	0.0000038

ii. Data for fuel flow rate for diesel engine operating with diesel fuel

RPM	FLOWRATE (m3/s)
1000	0.0000015
1500	0.0000021
2000	0.0000025
2500	0.0000027
3000	0.0000027

iii. Data for AFR for diesel engine operating with biodiesel fuel

Rpm	AFR
1000	16.39
1500	13.96
2000	14.33
2500	13.81
3000	16.37

iv. Data for AFR for diesel engine operating with diesel fuel

Rpm	AFR
1000	8.05
1500	14.99
2000	14.14
2500	16.02
3000	17.55

v. Data exhaust temperature, cooling temperature, and ambient temperature for diesel engine operating with biodiesel fuel.

rpm	1000	1500	2000	2500	3000
exh 1,°C	452.4	472.8	537	548.2	618.9
exh 4,°C	453.2	468.7	555.4	562.5	622.5
exh 5,°C	484.1	508.2	595.9	597.5	674.4
exh 3,°C	463.2	484.1	564.5	566.9	652.9
exh 2,°C	447.2	478.3	550.9	560.4	620.8
Cool In,°C	69.4	61.3	55.5	55.8	58.2
Cool Out,°C	65.6	50	52.1	52	49
Ambient,°C	31.7	33	34.2	37.6	37.3

vi. Data exhaust temperature, cooling temperature, and ambient temperature for diesel engine operating with diesel fuel.

rpm	1000	1500	2000	2500	3000
exh 1,°C	429.2	462.4	524.3	599.5	569.9
exh 4,°C	426.5	465.6	542.6	586.4	575.5
exh 5,°C	455.6	501.6	575.7	636.9	608.2
exh 3,°C	439.4	475.4	549.9	603.8	583.8
exh 2,°C	423.2	470.9	537.5	604	554.4
Cool In,°C	49.8	54.6	47.6	52.2	54.2
Cool Out,°C	43.6	42.1	43.8	46.1	47.8
Ambient,°C	29.1	29.9	30.3	32.5	32.9

vii. Data torque and power for diesel engine operating with biodiesel fuel.

Speed (rpm)	TORQUE (Nm)	PERFORMANCE (kW)
1000	91	9.53
1500	74	11.62
2000	77	16.13
2500	63	16.49
3000	58	18.22

viii. Data torque and power for diesel engine operating with diesel fuel.

Speed (rpm)	TORQUE (Nm)	PERFORMANCE (kW)
1000	89	9.32
1500	74	11.62
2000	76	15.92
2500	63	16.49
3000	59	18.54

APPENDIX B

Instruments and Measurement Tools

i. Thermocouple k-type

Thermocouple Specification

Type	K
Wire Material	Chrome (+ve), Alumel (-ve)
Range	-328 to 2300 ^{o}F
ANSI Standard limits of Error	±4.0^{o}F or 0.75%

ii. Pressure sensor

Pressure sensor Specification

Range	0-250 bar
Overload	300 bar
Sensitivity	-20 pC/bar
Calibrated partial range	0-50 bar
Linearity	0,5 % FSO

iii. Gas analyzer

iv. Fuel flow meter

c) Cooling for Pressure dynamometer

APPENDIX C

Setup instrument before engine testing

a) Drilling process

b) Threading process

c) Placement for pressure sensor and thermocouple

EGR

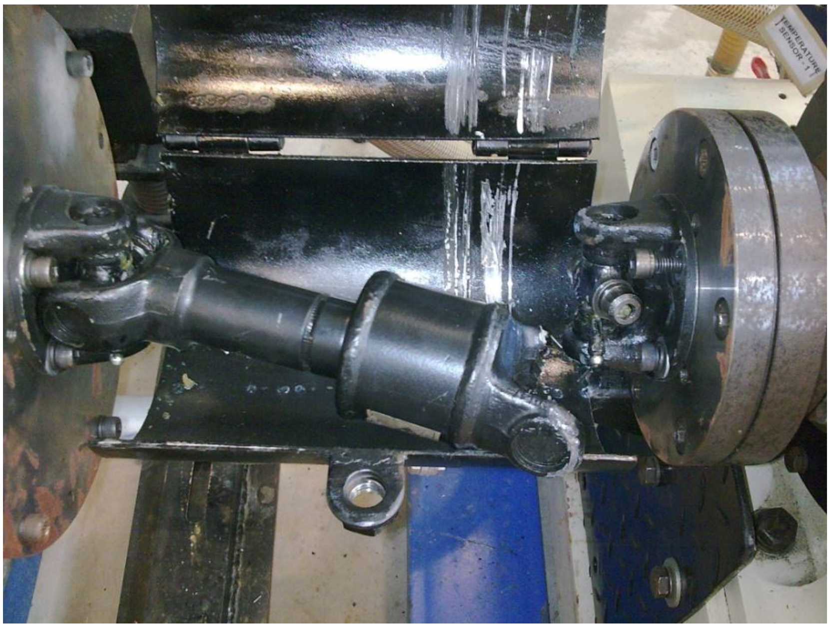
Cover for thermostat

Exhaust extractor

APPENDIX D

Problem in Experiment

a) Direct coupling not support load f engine (crash)



Direct coupling crash at test bed

Direct coupling crash

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