DESIGN AND DEVELOPMENT OF AUTOMATED ENGINE TEST CELL SYSTEM FOR SINGLE CYLINDER DIESEL ENGINE

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Declaration

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated.
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Abstract

Engine is getting more advanced which provided higher energy conversion as compared to when it first invented. Besides, the development of alternative fuels such as biodiesel caused more and more research and studies in the performance of engine. Due to large amount of data that must be collected in conventional engines, engineers are looking toward new methods of accelerating aside from manually setting the parameters. One of the solution is to make it automated and designing the software for engine test cell system by using processing device and measuring sensor with a reduced cost without compromising the performance and capabilities of an engine test cell. Automating engine test can greatly reduce the amount of testing time as well as provide robustness that manually changing setpoints cannot offer. In this research, in order to investigate the performance, emission and combustion of the engine effectively, an automated test cell has been developed. It provided automated recording of the quantifiable data including the torque measurement, speed measurement, fuel flow measurement, combustion data acquisition and emission data acquisition. It is also designed to provide real-time control on the dynamometer which make us easier to control the engine. A study of performance, emission and combustion characteristic of Palm Methyl Ester biodiesel and diesel, the B100 generally shows lower torque. Power and brake thermal efficiency. However, it have a higher specific fuel consumption. The difference in emission and combustion for B100 are lower CO and CO2 emission by 17-45% and 25-43% and also maximum 52% lower NOx emission.

Abstrak

Enjin semakin maju menyediakan penukaran tenaga yang lebih tinggi berbanding penukaran tenaga engin semasa dicipta. Selain itu, pembangunan bahan api alternatif seperti biodiesel mengakibatkan semakin banyak kajian dan kajian dalam performasi enjin. Jumlah data yang banyak perlu dikumpulkan dalam engine konvensional telah menyebabkan pembangunan kaedah baru yang mempercepatkan kajian selain menetapkan parameter secara manual. Pengumpulan data secara automatik dalam kajian engin dengan menggunakan sensor dengan kos yang dikurangkan tanpa menjejaskan prestasi sel ujian engin merupakan salah satu cara pengelesaian isu. Jumlah masa ujian boleh dikurangkan dengan mengautomasikan ujian enjin. Untuk mengkaji prestasi, pelepasan gas pollutan dan pembakaran enjin dengan berkesan, sel ujian enjin automatik telah dibangunkan. Sel ujian enjin menyekod automatik data yang boleh diukur termasuk ukuran tork, pengukuran kelajuan, pengukuran aliran bahan api, pemerolehan data pembakaran dan gas pelepasan pemerolehan data. Ia juga direka untuk menyediakan kawalan masa nyata pada dinamometer yang menjadikan kita lebih mudah untuk mengawal enjin. Kajian prestasi, pelepasan dan pembakaran ciri Palm Methyl Ester biodiesel dan diesel telah dikaji dalam kertas ini. B100 umumnya menunjukkan tork lebih rendah, kuasa dan brek kecekapan haba. Walau bagaimanapun, ia mempunyai penggunaan bahan api yang lebih tinggi tertentu. Perbezaan dalam pelepasan dan pembakaran untuk B100 adalah CO yang lebih rendah dan pelepasan CO2 sebanyak 17-45% dan 25-43% dan juga maksimum pelepasan NOx 52% lebih rendah.

Chapter 1 INTRODUCTION

1.1 Project Overview

Ever since engine have been invented in 18^{th} centuries, engine design has been improved drastically within this few decades. The race for engine consumption and pollutant emission reduction requires engines development time reduction and optimization. Besides, considering the issues of depletion of fossil fuel, alternative fuels such as biodiesel and ethanol are used as alternative for the fossil fuel. Research and studies on the alternative fuels is therefore in need for the development of the technologies. These emphasize a lot on the studies on the performance, emission and combustion characteristic of the fuel on engine in order to solve the problem faced in improving the engines and reduced pollutant emission. All the studies and researches requires a testing and characterizing on the engine with an engine test cell which mainly comprised of dynamometer as measuring instrument.

Quantifiable data can be acquired from the engine once it is mounted onto the engine test cell. Data acquired from the engine are quantities pertaining to linear or rotational movements for mechanical parts such as the crankshaft or piston, electrical voltages and current from sensors such as load cell, rotary encoder, pressure sensor or thermal sensor at different points on the engine. Once all the data acquired, performance and emission of an engine can be calculated and determined.

In a low budget test cell, engine testing typically needed operator to manually set parameters such as engine throttle, torque and speed. Manually setting parameters work well only when small amounts of data is needed. If large amount of testing is needed or even more parameters like throttle position, emission, fuel consumption is needed, the time taken to collect all the data for each data point will no doubt increase significantly. Besides, manually recording data are also prone to human error when such a large amount of parameters needed to be changed.

Large portion of data acquisition during the testing will be a lengthy process. Manually testing every aspect of the engine across difference parameters would take up days or even weeks to complete. This would then have followed by a period of time spent on processing and compiling all the logged data. So one of the problem existing in manually testing the engine would be time consuming. Not to mention the manual testing might require multiple labor. Few parameters set up and data acquisition have to work simultaneously which make the testing longer.

External test facility or third party test cell system would be an option for most of the parties. External test facility might deliver a quality test equipment and software or even with excellent testing services. On the other hand, test cell system purchased off the shelf might build in control system with excellent hardware and software. However, both of the option can cost a bomb. External test facility typically provides services with very high costs while test cell system in the market not only expensive but also have high maintenance cost.

Due to large amount of data that must be collected in conventional engines, engineers are looking toward new methods of accelerating. One of the solution is to make it automated and designing the software for engine test cell system by using processing device and measuring sensor with a reduced cost without compromising the performance and capabilities of an engine test cell. Automating engine test can greatly reduce the amount of testing time as well as provide robustness that manually changing setpoints cannot offer.

To evaluate the performance, emissions and combustion characteristics of the single cylinder diesel engine, a new engine test cell system is needed for single cylinder diesel engine. The setup of new engine test cell system consists of a single cylinder, four strokes diesel engine coupler to eddy current dynamometer which mounted on a test bed. The new engine test cell system will be focus on making it fully automated in order to be time efficient during the testing of single cylinder diesel engine.

The autonomous test cell has been developed which completed in three phases: hardware (dynamometer and test bed); electronics (sensors, data analyzer and controller) and software to control the test cell with the constraints of quality, time and cost.

This project deals with the design and development of automated engine test cell system for single cylinder diesel engine. A test bed design is constructed using CAD software and a program will be written to real-time control the engine and dynamometer, as well as automated measurement of all devices. Additionally, the performance, emissions and combustion characteristics of the diesel engine is tested under stationary engine operating cycle.

1.2 Problem Statement

Testing for the performance, emissions and combustion characteristics of the diesel engine has been a critical task in order to have better understanding and studies on the single cylinder diesel engine. Performing test manually on the single cylinder diesel engine with existing dynamometer is time consuming and inefficient while purchasing a new engine test cell with high purchase cost can cause the over budget of research. The manual testing of performance of single cylinder diesel engine is time consuming in the sense that operators is required to controlled the setting of dynamometer and the engine throughout the time to obtain the desired reading. In order to perform testing efficiently and lower cost, an automated diesel engine test cell system is required to be designed and developed. The measurement of the performance diesel engine test cell system is fully automated and the performance, emissions and combustion characteristics of the diesel engine can be determined with ease.

The depletion of fossil fuel and environment pollution issues have revitalized the need of alternative fuel and especially urged the development of biodiesel as one of renewable resources. The research on neat biodiesel as fuel for engine is currently insufficient and the performance for each of the biodiesel fuel type is solely base on the chemical process, heating value and viscosity of the fuel. Hence, more research on neat biodiesel is in need to determine the suitability of neat biodiesel to replace diesel fuel.

1.3 Objectives

The objectives of the project are:

1. To design and develop an automated test cell system for single cylinder diesel engine.
2. To provide real time control on the engine and dynamometer with simple GUI.
3. To evaluate the performance, emissions and combustion characteristic of the single cylinder diesel engine by comparing diesel and neat biodiesel.

1.4 Scope of Work

In this research, the automated test cell system for single cylinder diesel engine is separated into 3 phase included the design and construction of test bed, real time control and programing for automation and diesel and beat biodiesel performance evaluation. In phase one, test bed is designed and constructed to fit the Yanmar Engine L48N6 to the eddy current dynamometer. After the engine mounted on the test bed. Sensors and data acquisition system have been installed on the engine and eddy current dynamometer and connected to the computer. In the second phase, programming using software like LabVIEW, Arduino and DeweSoft have been done to realize the real-time control and automated data acquisition function on the test cell system. The research is then cover the performance, emission and combustion characteristic of the neat palm methyl ester biodiesel are analyzed and compared with diesel.

1.5 Gantt Chart

Gantt Chart Planning for the Project	Sem 1(weeks)								Sem 2(weeks)														
Project Activities	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Literature review and gather information																							
Moving Eddy current dynamometer and test cell base to engine lab																							
Assembly and connect all the component																							
Mounting of dynamometer and engine on test bed																							
Installation of sensors, data acquisition system and other measuring device.																							
Programming in Arduino, LabVIEW and DeweSOFT																							
Program testing																							
Measurement of performance, emission and combustion characteristic of Palm Methyl Biodiesel and diesel.																							
Thesis Writing																							

Chapter 2 LITERATURE REVIEW

2.1 Literature Review

2.1.1Engine Test Cell Overview

Two main components of an engine test cell are the engine and the dynamometers. The inputs of test cell include physical matter such as fluids and air, energy sources such as fuel and electricity, and load applied and the outputs will be visualization of data of torque, speed and power, exhaust emission and heat.

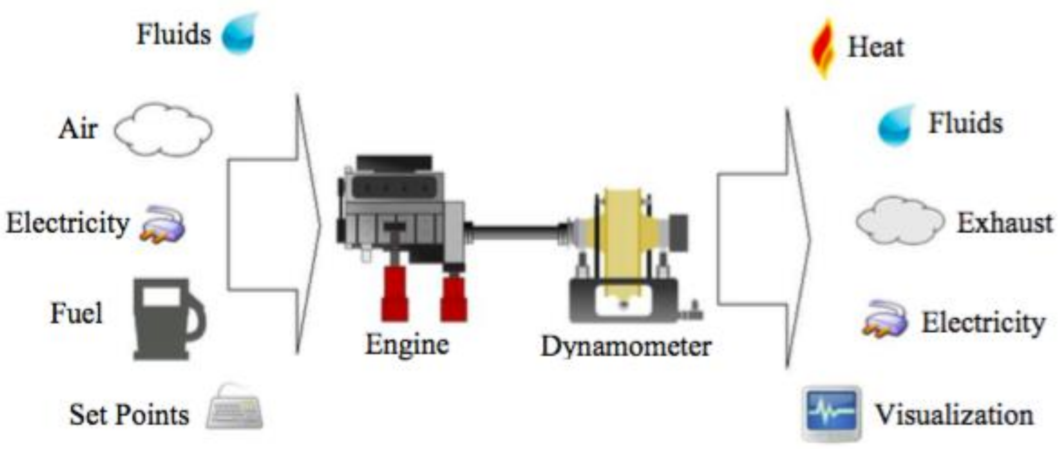


Figure 2.2.1:Test Cell Inputs and Output(Fountaine, 2012)

2.1.2 Diesel engine

Diesel engine was invented by Dr. Rudolf Diesel in 1892 which uses compression ignition. His invention bring a revolutionary change to the industrial. In 1885, Diesel begin the development of a compression ignition engine and the process last for 13 years. At 1893, prototype began with a 150mm bore/400mm stroke design which the first engine test was unsuccessful. At 1897, Diesel successfully demonstrated a diesel engine with 26.2% efficiency after series of improvement and testing prior to the first engine test.

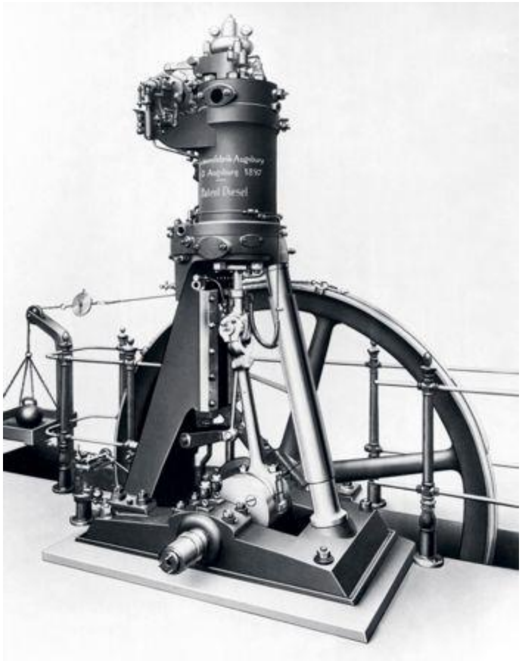


Figure 2.2 : Diesel's third test engine at 1897

Early diesel engine were large and operated at low speeds due to the limitations of their compressed air-assisted fuel injection systems. The diesel engine were also initially used primarily in stationary and ship propulsion applications in the form of relatively low speed four-stroke engine normally aspirated engines(Challen & Baranescu, 1999). As the years go by, diesel engine has become one of the main transportation fuel with high energy efficiency.

A diesel engine is an internal combustion engine that converts chemical energy in fuel to mechanical energy that moves pistons in the cylinders. The piston connects to the engine crankshaft which change their linear motion into the rotary motion hence run the engine. The combustion process is very similar to gasoline engine. Diesel engine is different from a gasoline engine in which gasoline use a spark plug to cause the explosions whereas in diesel engines, fuel ignites on its own. A mist of fuel is sprayed into the cylinder with high temperature compressed air with fuel injection system. The high temperature air cause instantly fuel ignition and an explosion without any need for a spark. The engine is developed by Rudolf Diesel in 1893(Challen & Baranescu, 1999).

Diesel can operate in a higher compression ratio as compared to gasoline engine hence produce higher efficiency. The advantage of diesel engine is that it can operate in a low rotational speed, high thermodynamic efficiency and small pumping loss.

A fundamental classification of diesel engines is two-stroke engine and four-stroke engine. The main difference between the two engines is that combustion in two-stroke engine occurs every revolution while combustion in four-stroke engine occurs once in every two revolutions. The vast majority of the diesel engine on the market operates on the four –stroke engine due to its advantages over two-stroke engine which is higher efficiency.

The four-stroke engine work based on four cycle which is intake, compression, combustion and exhaust. The cycle begins at Top Dead Centre when the piston is farthest away from the axis of the crankshaft. A cycle refers to the full travel of the piston from TDC to BDC which is half a revolution.

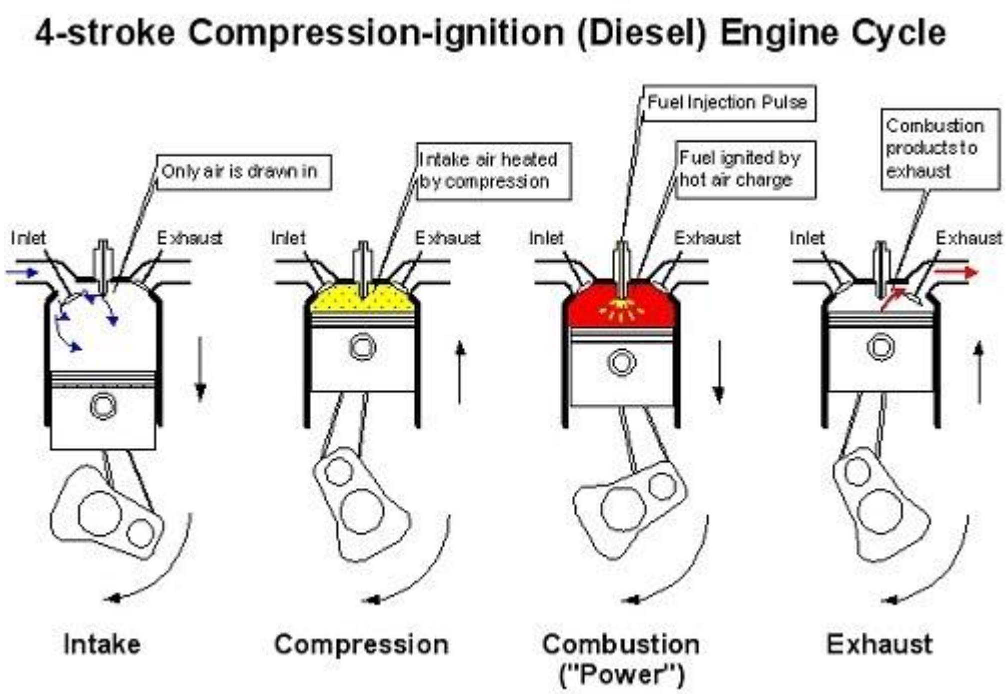


Figure 2.3:4-stroke Compression-ignition engine cyle

Intake stroke: inlet valve opens and air is forced by atmospheric pressure into the cylinder. Intake stroke take place when the piston moves from top dead center to bottom dead center. The volumetric efficiency of the engine would be defined as the volume of air relative to the volume of the cylinder.

Compression stroke: Both the inlet valve and exhaust valve are closed during the compression stroke. The piston moves towards Top dead center and compress the air.

Power Stroke: When the piston is moved to Top Dead Center, fuel is injected into the diesel engine. The compressed air with high temperature ignites the fuel and cause massive pressure from the combustion of fuel-air mixture produce a large pressure force the piston back to bottom dead center.

Exhaust stroke: The exhaust valve is open and the burnt product of the combustion is forced out through the exhaust valve by the piston. The whole process is completed.

2.1.3 Eddy Current Dynamometer

A dynamometer is a device used for measuring force, torque or power. For example, the power produced by an engine or motor can be calculated by simultaneously measuring torque and rotational speed. Dynamometer place a load on the engine or motor in order to measure the amount of power that can be produced against the load. Power is a product of the torque and angular speed. Dynamometers can be classified into two types which are power absorption dynamometers and power transmission dynamometers.

The dynamometer used in this research is eddy current dynamometer which is one of the power absorption dynamometers. The working principle of eddy current dynamometer is based on Eddy-Current (Fleming's law of right hand). It consists a stator fitted with a number of electromagnets and a rotor disc made of copper. The current runs through the copper coil and form a magnetic flux around the stator and rotor. When the rotor rotates, eddy current produced in the stator due to variation of magnetic flux. These eddy currents are dissipated in the form of heat energy hence the dynamometer requires external cooling system to remove the heat. The load in internal combustion engine testing is controlled by regulating the current in the electromagnets. Advantages of choosing Eddy-current dynamometer would be low inertia due to disk type air gap. It is mechanically simple and well adapted to computer control(Martyr & PLINT, 2011).

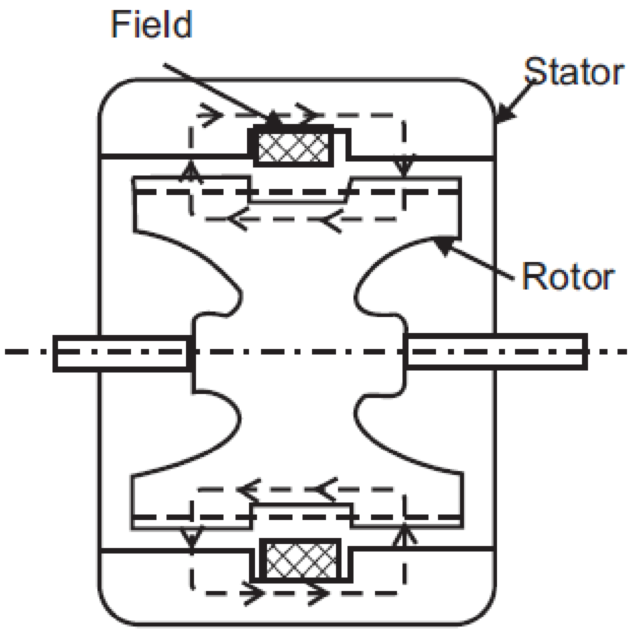


Figure 2.4 : Eddy Current Dynamometer

The eddy current dynamometer is mechanically anchored at a point where the dynamometer able to rotate freely. The rotation is resisted by the load cell which used to measure the magnitude of the force or torque applied to the shaft of the dynamometer. In order to measure the output power of the engine, dynamometer speed is measured by using additional speed sensor.

2.1.4 Engine Testing

Engine Performance is measured by power output, torque, economy, durability and emissions. It is important for an engine to develop, to run and to test at its best before mass production for its purpose. Basic Instrumentation for Engine Testing would be:

i) Power/torque measurement
ii) Engine Speed measurement
iii) Fuel Flow rate measurement
iv) Combustion analysis

In power and torque measurement, parameters of torque and speed of the engine is measured. For the measurement of torque, load cell is used while for the measurement of dyno speed, speed sensor is used. To determine the fuel economy, fuel flow rate measurement is important as it is used to calculate the fuel consumption. The brake specific fuel consumption that is used to determine the fuel efficiency of an engine respect to power is then determined. The combustion analysis of engine is important in giving information about the combustion happened in the cylinder. The most useful quantity to record is in-cylinder pressure which measured by pressure sensor integrated into the engine.

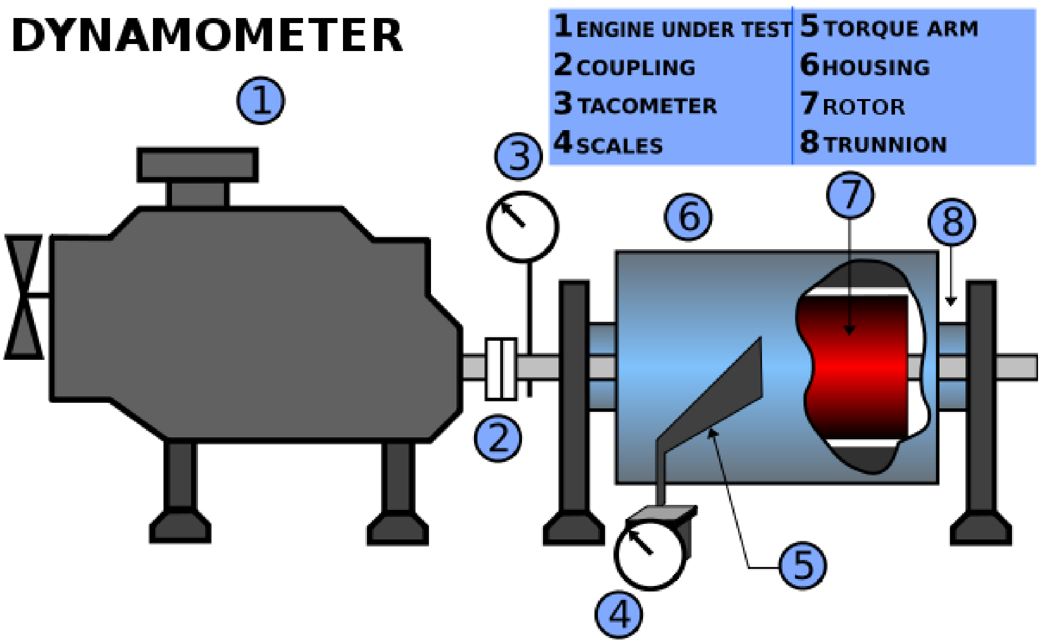


Figure 2.5: Schematic Overview of Engine Testing

2.1.5 Biodiesel

Biodiesel is a liquid biofuel made from vegetable oils or animal fats which can be used as an alternative fuel to replace petroleum diesel. It can be used alone or blended with diesel in almost all of the diesel engine with little or no modification on the engine.

ASTM international defines biodiesel as a mixture of long-chain monoaklylic esters from fatty acids obtained from renewable resources to be used in diesel engine. Blends with diesel fuel are indicated as "Bx" where "x" is the percentage of biodiesel in the blend(Pahl, 2005).

Using Biodiesel as a replacement for diesel fuel have few of the advantages are it is renewable fuel obtained from vegetable oils or animal fats and its waste is biodegradable and nontoxic. With the lower emissions of pollutants like carbon monocide, particulate matter, nitrogen oxide and cyanide. There are few drawback of using biodiesel which is higher fuel consumption due to lower calorific value, high freezing point which make it not suitable to operate at cold condition. For now, the price of biodiesel is much more expensive than pure diesel however there is no doubt that the price of diesel will rise once it depleted.

2.2 Journal Review

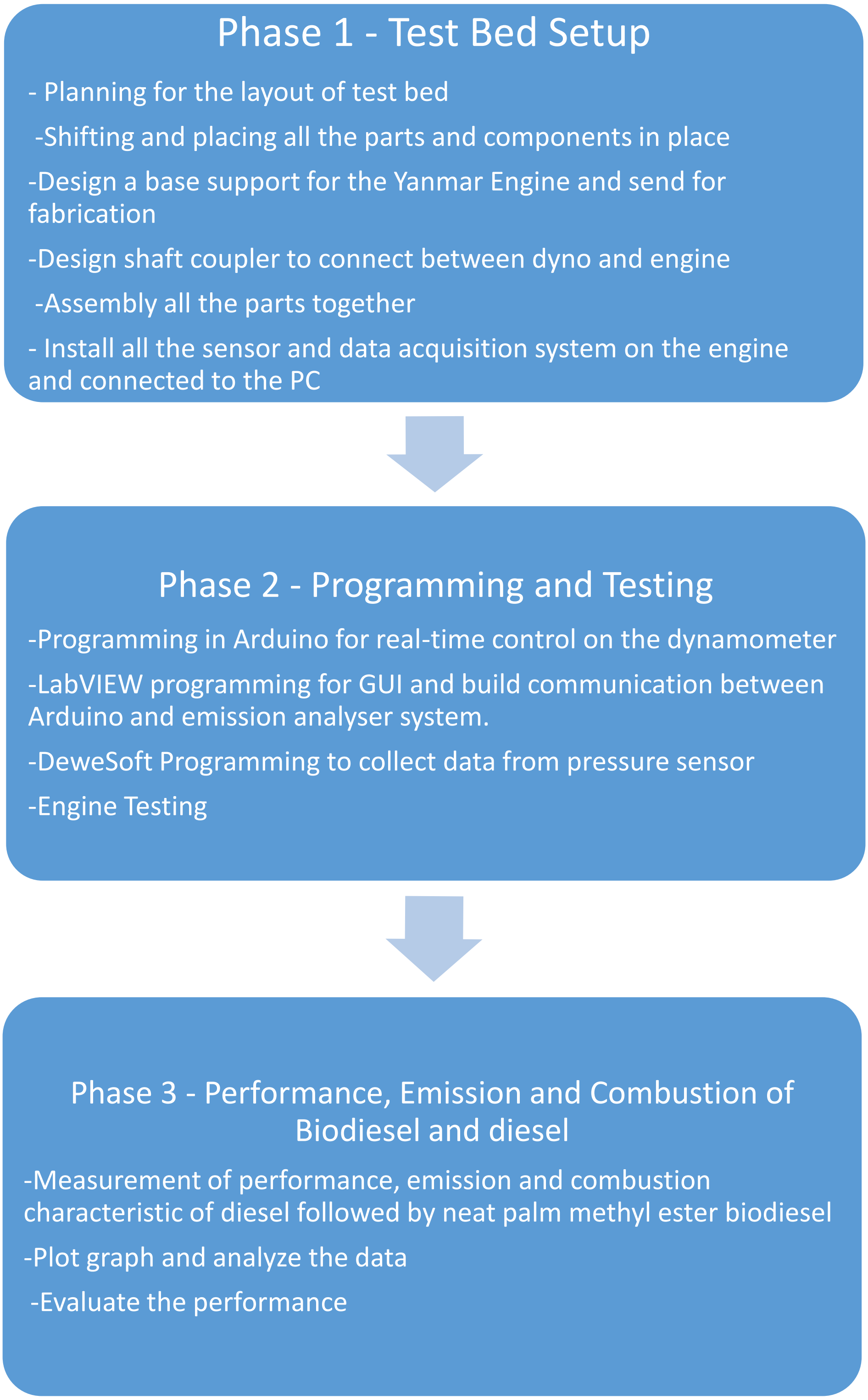
Tony Fountaine designed and developed a test cell control system through an approach to design a software and hardware with cost approximately ten times lower than the commercially available systems and the data output from the control system superior to the commercially available systems(Fountaine, 2012). The engine testing control system developed has the capability of running automatic test sequences in real time but on the contrary, the setup and developed control system is complicated and the development of the software from scratch is a lengthy process.

A biofuels engine testing facility was developed by Duncan Palmer from Stellenbosch University(Palmer, 2008). The test cell developed was instrumented with sensors and controlled by programmable logic controller in order to control the test, monitor alarms and sample data. The engine test cell design is simple and fully operational but with drawback of manual setting of parameters and data collection.

Aaron Farley designed and implemented a small electric motor dynamometer used for the laboratory curriculum. The dynamometer developed using SolidWorks and data acquisition using LabVIEW and LabJack devices. The dynamometer can have less than 10% error compared to the manufacturer supplied data in measurement of speed and torque(Farley, 2012).

Chapter 3 METHODOLOGY

3.1 Flow Chart



3.2 Engine

A single cylinder Yanmar L48N6 diesel engine (Figure 3.1) is selected as the engine testing in this research. This is a 3.1 kW air cooled diesel engine that uses a mechanical injection pump without ECU.

Figure 3.1 : Specification of Yanmar L48N6

3.3 Test Cell Layout

It was decided that the test cell hardware to be placed in the engine lab with the controller beside. All the dynamometer component including the base have been moved to engine lab according to the layout shown in Figure 3.2. Dynamometer has been mount on the C-base structure while the C-base structure has been mount on the ground.

Figure 3.2 : Dynamometer mounted on the base structure.

Figure 3.3 shows the test cell layout planned. The test cell layout plan show that the dynamometer mounted on the base are placed in the middle of the space in the engine room mounted together with the Yanmar Diesel Engine with coupler. Controller equipment is placed on the right side of the engine test cell for the best view and control. Utilities tower is placed on the left side of the test cell which accommodate the fuel tank, battery and fuel consumption measuring instrument for easy accessibility. The dynamometer is connected to the cooling tower located outside of the engine lab for the cooling purpose.

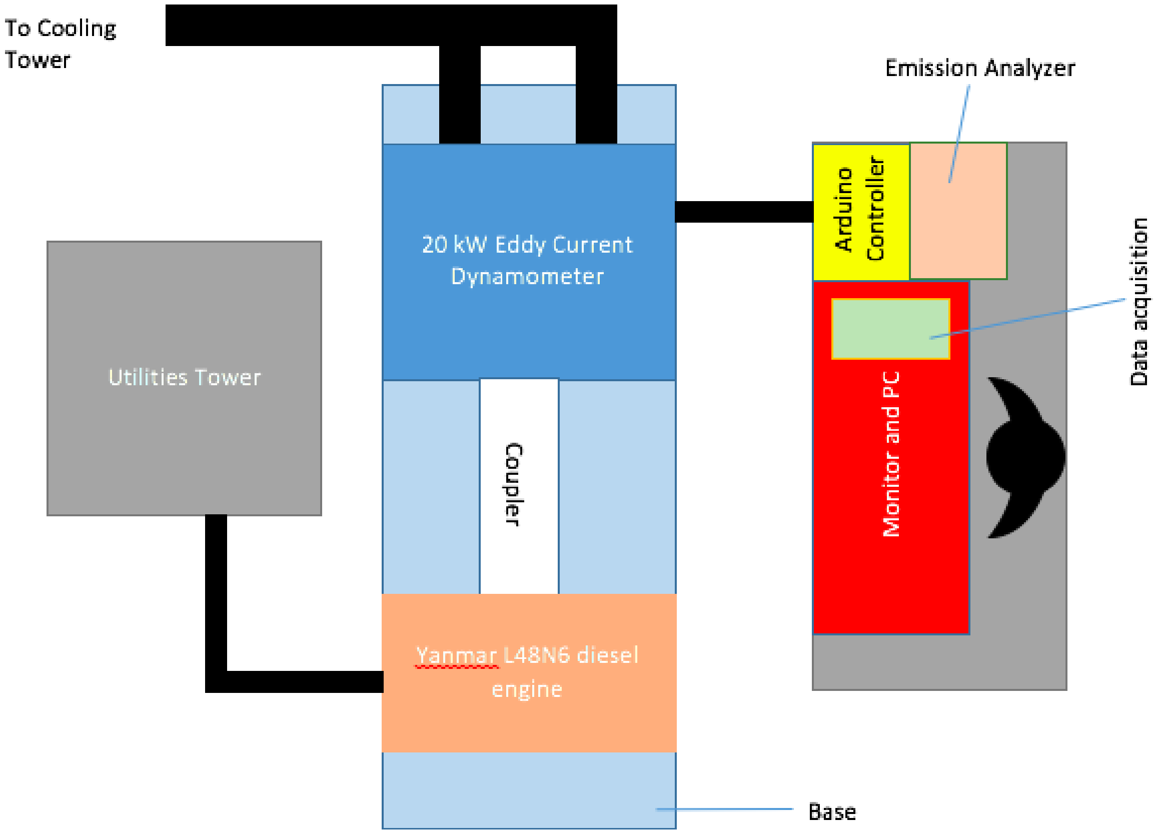


Figure 3.3: Test Cell Layout

3.4 Engine Mount

To mount the engine on the test cell, an engine based is designed and constructed to fit for the design of single cylinder Yanmar diesel engine and dynamometer by using

SOLIDWORK CAD software. Engine based is designed by using SOLIDWORK CAD software and the design is shown as below in Figure 3.4 while the detail design is shown in appendices A.

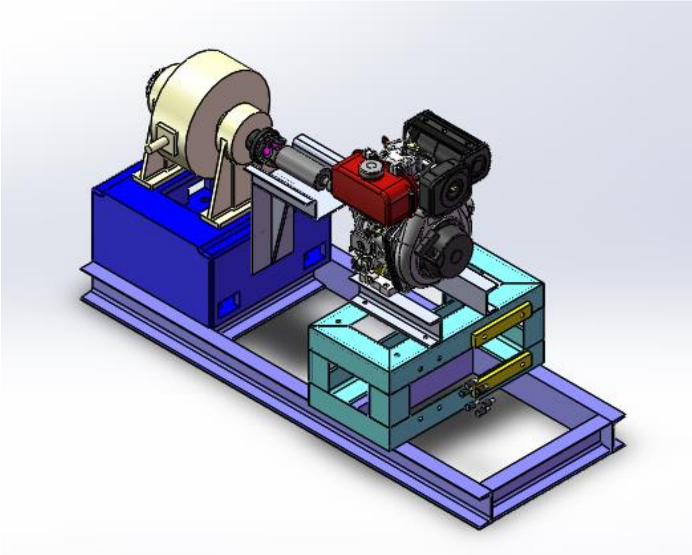


Figure 3.4 :CAD model showing Engine mounted on the engine base together with dynamometer

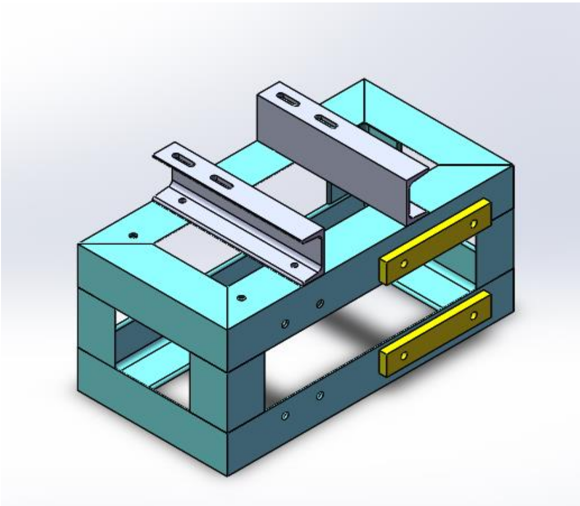


Figure 3.5: Engine Based structural L

The design of the Engine based is using structural member of L beam with the profile size of 50x50x6mm which will be enough to support all components including the Yanmar L48 diesel engine.

Figure 3.6 : Mounting of engine on the engine base together with the base c structure.

In order for engine to rotate the shaft of dynamometer while running, a coupler is used connected the shaft of engine to the shaft of dynamometer. An engine coupler is designed to fit the design of the universal joint which is connected to the dynamometer coupler on the other end. The coupler is designed by using SOLIDWORK CAD software and is then fabricated. The coupling used to join between engine shaft and dynamometer shaft is U (Universal) Joints. The two ends of the joints able to offset the misalignment between the shaft of the engine and the shaft of the dynamometer.

3.5 Fuel supply

As different blends of biodiesel will be tested, a 5 little fuel tank is used. The fuel tank is removed from the body of the diesel engine and relocated at the utilities tower for the ease of fuel replacement when tested with different type of fuel. The fuel supply tube is modified to accommodate spaces for automated fuel measurement by using burette and photo-interrupter sensor.

Figure 3.7:Fuel Tank placed on the ultilities tower

3.6 Dynamometer

A 20kW Model E-5 eddy current dynamometer is used to apply the engine load on the engine in order to measure the power output of the engine. The dynamometer is operated in the clockwise direction.

The load apply to the dynamometer is controlled by using Pulse-width modulation (PWM). PMW control the current going to the coils by pulsed on and off at a high frequency. In the ‘high’ state the full current is applied to the coils while in the ‘low’ state the coils are off. The resulting load is therefore proportional to the duty cycle of the pulses.

Figure 3.8: Specification of 20kW Eddy Current Dynamometer

3.5.1 Dynamometer cooling system

Heat generated in the eddy current dynamometer must be continuously remove from it to prevent it to overheat and affect the testing operation. The dynamometer is connected to the cooling tower through piping. Water provides cooling for the eddy current dynamometer and is pump through the dynamometer by cooling tower. Cooling tower is placed on the side of engine lab as shown in Figure 3.9. The water supply is a closed loop system to prevent water from wasting.

Figure 3.9: Cooling Tower placed outside engine lab

3.7 Wiring, sensors and electronics

The electronics and wiring for the tell cell is shown in Figure 10 to simplify the explanation and understanding of the wiring diagram.

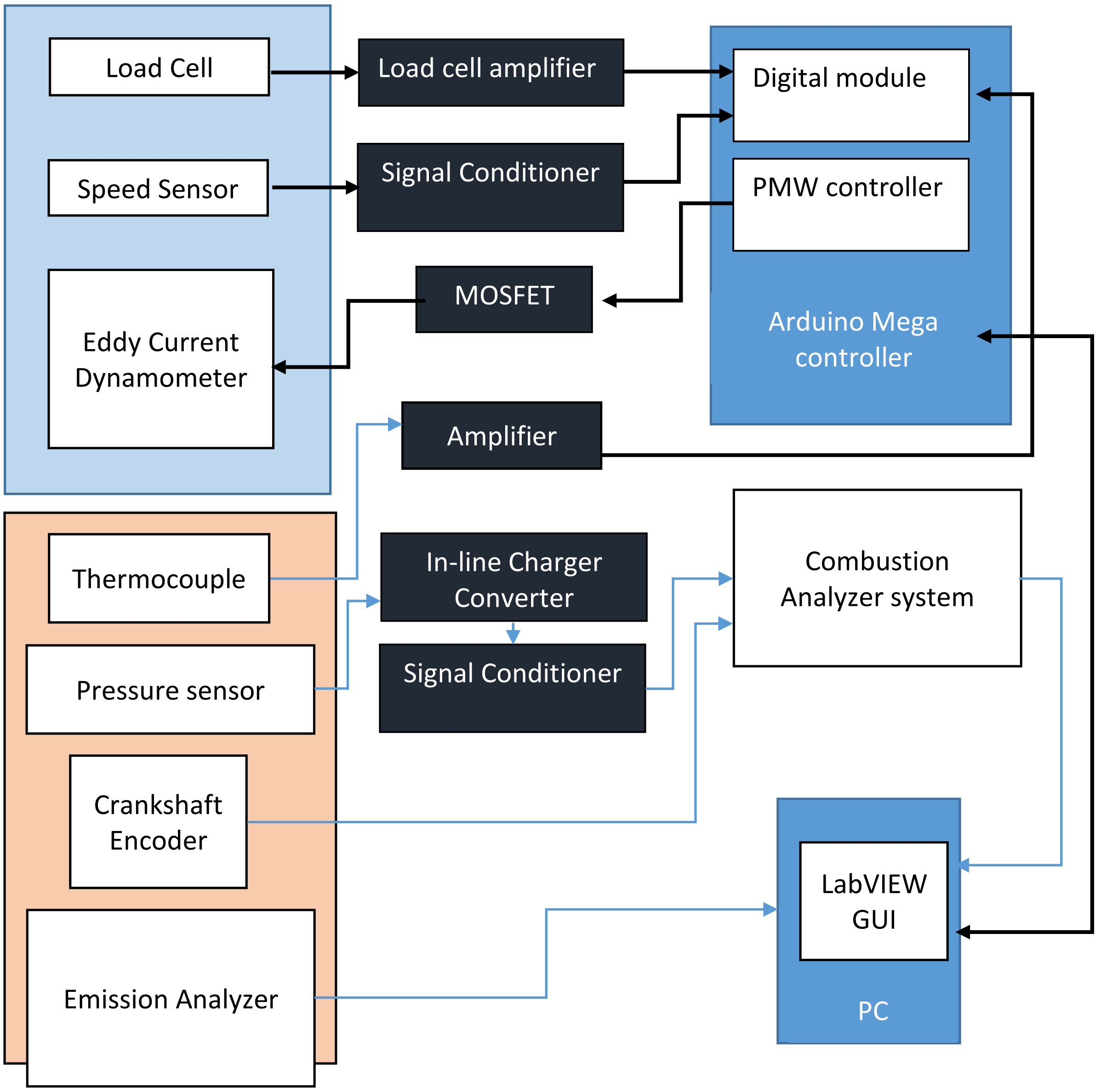


Figure 3.10: Schematic Diagram of electronics wiring and connection

3.8 Pressure, Crank shaft Rotary Encoder

The installation of pressure transducer and crankshaft rotary encoder is setup according to Figure 3.11

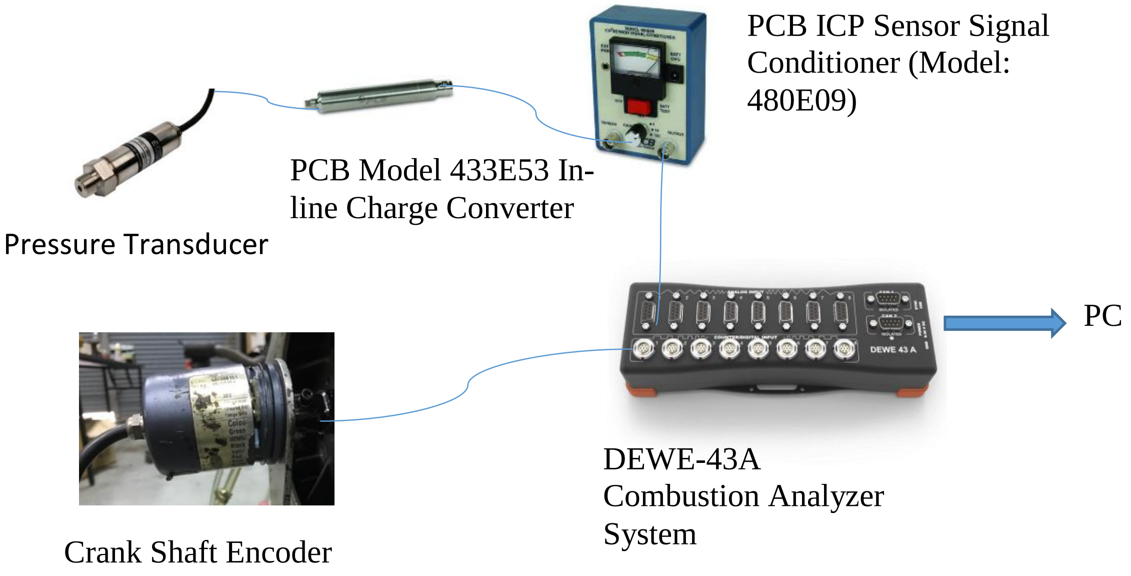


Figure 3.11: Pressure transducer and crankshaft rotary encoder setup

A pressure transducer is used to measure the pressure in the engine cylinder The pressure transducer used is Kristler pressure sensor. The cylinder head of the Yanmar Engine L48N6 is drilled with a hole to place the pressure sensor as shown in Figure 3.12.

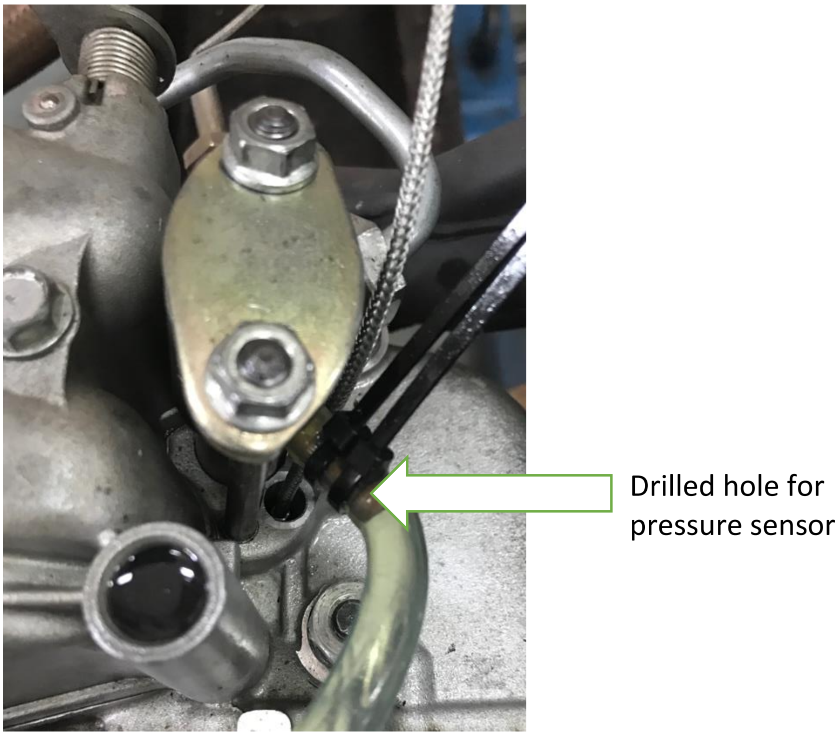


Figure 3.12: Pressure sensor

A rotary encoder is used to determine the crank angle and speed the engine and was installed on the engine's crankshaft as shown in Figure 3.13.

Figure 3.13: Crankshaft rotary encoder

Crank angle, speed and pressure are important in determining the parameters such as ignition timing, combustion pressure, HRR. The output of the pressure sensor is first is connected to PCB Model 433E53 In-line Charge Converter to converts the charge signal from the high impedance pressure sensor into a voltage signal at low impedance. The voltage signal is then sent to PCB ICP Sensor Signal Conditioner (Model: 480E09) before hook up to DEWE 43A combustion analyzer system.The data collected is sent to the computer and recorded by Dewesoft as combustion data (eg. Pressure, heat released rate, temperature).

The rotary encoder is also hooked up to DEWE 43V Combustion analyser system. Pulse A,B and Z will be sent from the encoder to the connector block. Dewesoft is then takes the signal and used in the Dewesoft combustion data measurements.

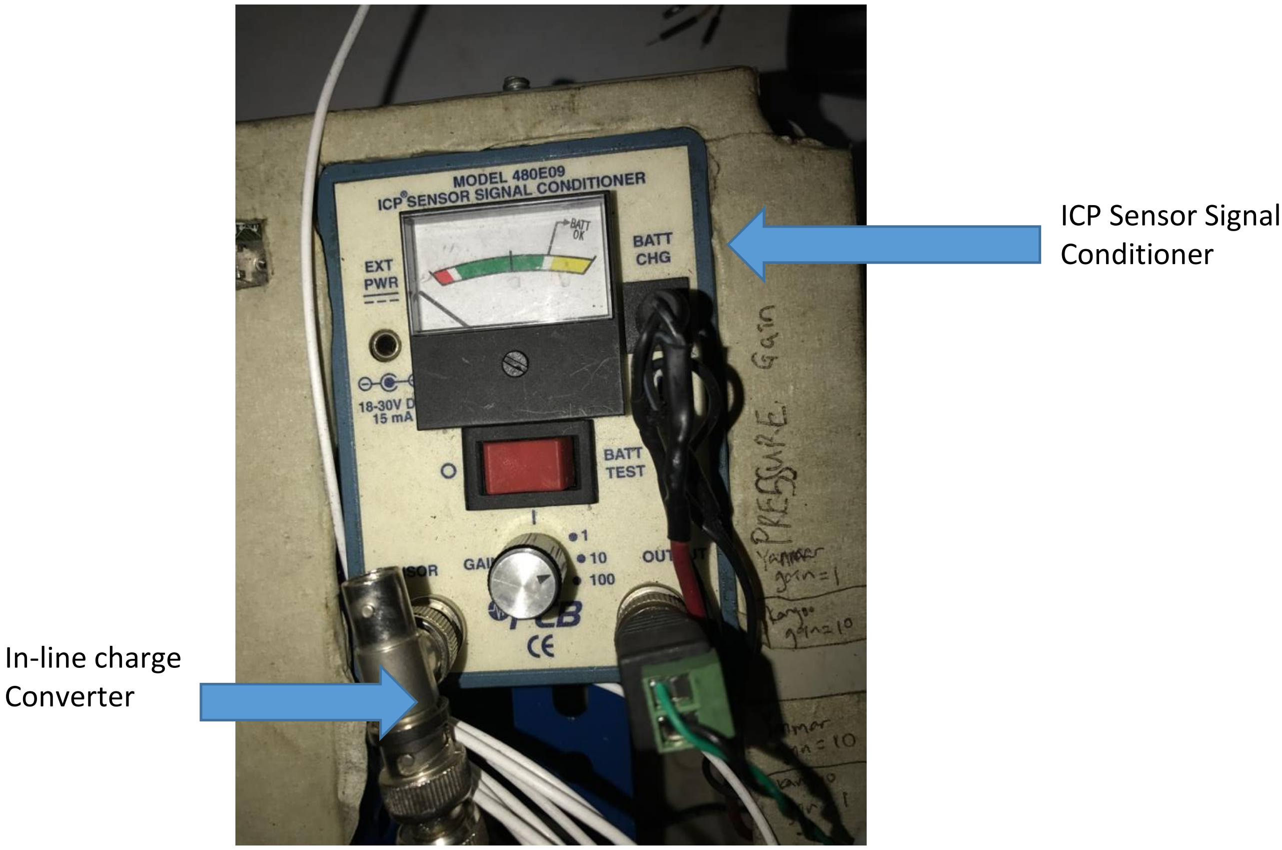


Figure 3.14: In-line chare converter connected to sensor signal conditioner

Figure 3.15: DEWE 43V combustion analyzer system

3.9 Temperature measurement

A thermocouple is used to measure the exhaust temperature in the cylinder. The thermocouple used is Type-K thermocouple. The exhaust of the Yanmar diesel engine is modified to integrate the thermocouple by drilling hole at the exhaust. Since the output of the thermocouple is very small, so an amplifier is connected in between before connect to Arduino Mega controller.

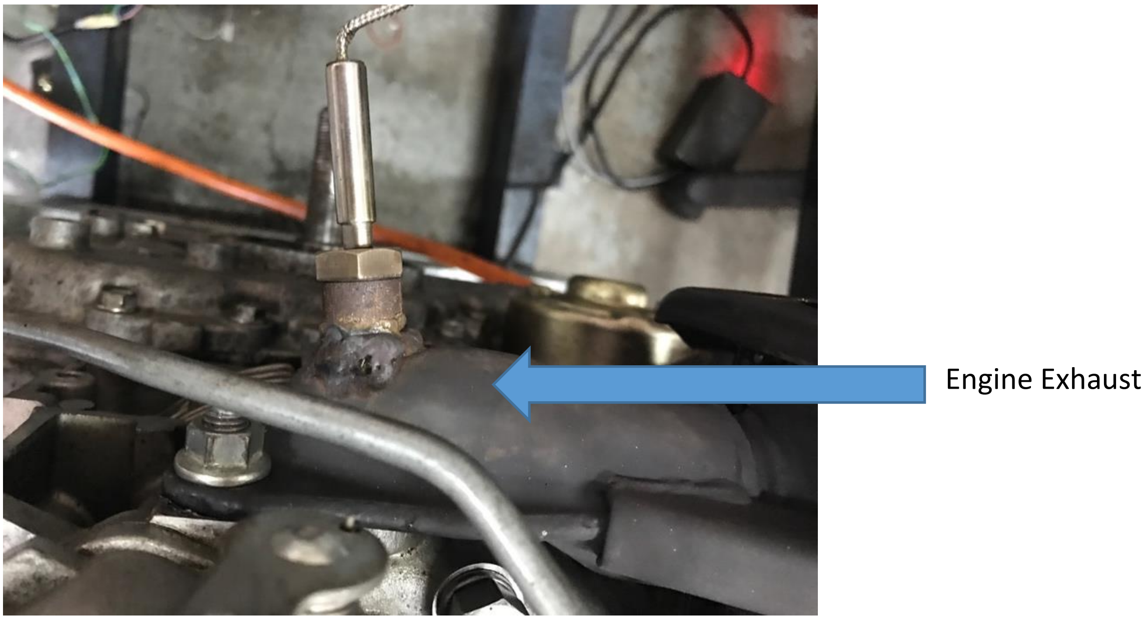


Figure 3.16: Thermocouple probe placed in the engine exhaust

3.10 Load cell

Load cell is used to measure torque produced by the engine. The rotation of the dynamometer from the engine is resisted by the load cell hence causes a compression or tension force on the load cell. The load cell was installed by using rod end ball-joint on the side of dynamometer as shown in Figure 3.17

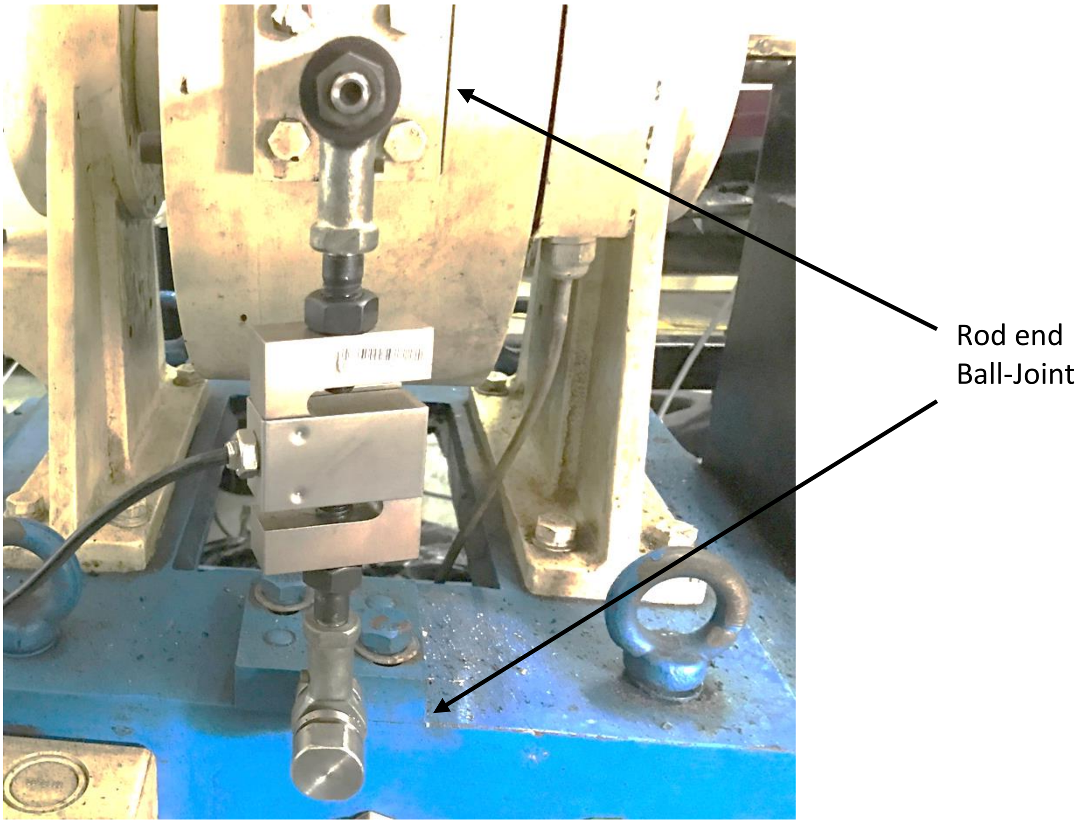


Figure 3.17: Load Cell mounted on the dynamometer with rod end ball joint

After the load cell is mounted on the dynamometer, the load cell is connected to load cell amplifier in order to generate electrical output to be read by Arduino mega controller. Load cell amplifier is undergoing calibration process by first adjust the zero output voltage where no load applied to the load cell after mounting on the dynamometer. VR1 or VR3 on the load cell amplifier is adjusted with screwdriver to the intended value. Once zero output voltage is set, the max output voltage is set by apply full-scale torque on the load cell and then adjust VR2 with screwdriver to the intended value to coupe with range of torque produce by the engine.

Once the load cell amplifier is calibrated, calibration process on the load cell is held by using torque arm and weight. Load cell is first connected to Arduino controller to read the signal produce by it. The indicated torque is calculated for each calibration weight by using the the formula:

$$\tau = calibration\ weight\ (N) \times\ length\ of\ calibration\ moment\ arm(m)$$

The length is measured from the center of the dynamometer to the end of the moment arm where the load is applied to it.

The relationship between the digital output of the load cell and indicated torque is set to be linear since the operated torque is within the range of load capacity of the load cell. Linear formula is applied in order to calibrate the load cell:

$$Y = mX + c + correction$$

Where:

Y = indicated torque

X = digital output

m = gradient

c = constant

Correction = calibration moment arm correction

The digital output reading before the placing the moment arm is recorded as constant in the formula while the digital output reading after placing the moment arm is recorded as calibration moment arm correction. Five calibration weight is placed separately on the moment arm and the digital output reading for each calibration weight is then recorded. The gradient of the formula is then calculated. The formula obtained is inserted into Arduino controller for the torque measurement.

3.11 Fuel consumption

In order to measure the fuel consumption of the engine for each specific fuel, a fuel consumption measuring device is built. The fuel consumption is measured volumetrically by using 4 photo-interrupter sensor and burette (Figure 3.18). Each photo-interrupter sensor is operated on 5V DC. The burette is placed between the slotted photo-interrupter sensor and the distance between two photo-interrupter sensors is fixed with the interval of 2.85ml. The fuel consumption measuring device is mounted on the utilities tower on the left side of the engine test cell as shown in Figure 3.19 below.

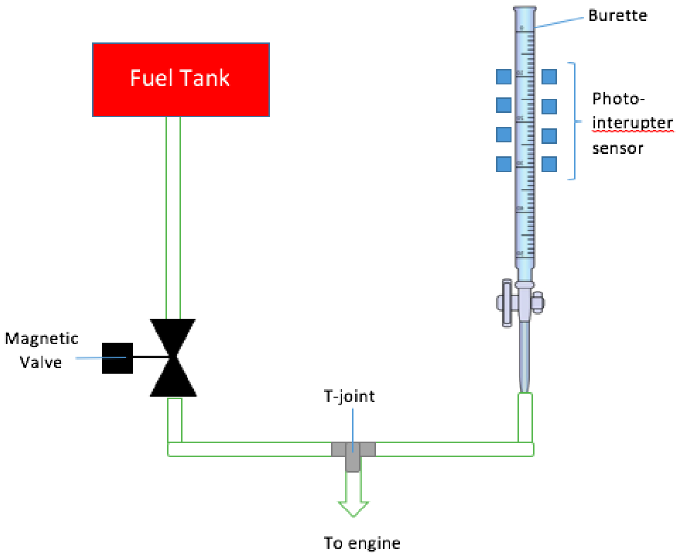


Figure 3.18: Schematic diagram of fuel flow measurement installation

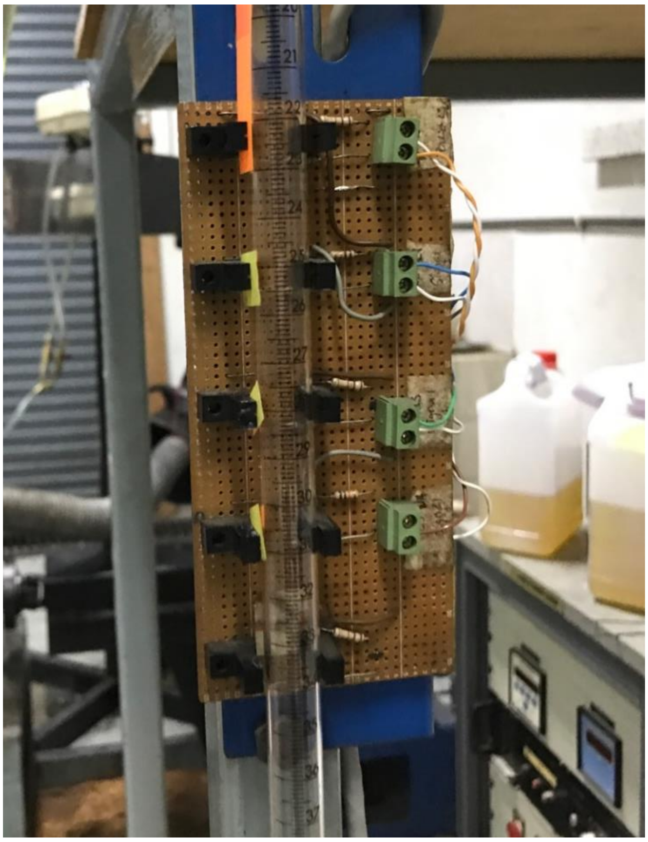


Figure 3.19 : Fuel flow measurement by using burette and photo-interrupter sensor

For the calibration process, each of the photo-interrupter sensor is hooked up to the Arduino Mega controller to read their digital output. The digital output for each photo-interrupter sensor is recorded when the fuel is presented and when fuel is absented in the burette. With the value obtained, a value is set for each photo-interrupter where if the digital output reading is lower than that specific value, a reduction of value 50 will be recorded in the LabVIEW software which indicated that there is no fuel detected by the respective interrupter sensor.

As for fuel consumption operation, each of the specific photo-interrupter is set with the specific value which determined the presence of fuel in the burette at that level. The fuel consumption measuring device measured the time taken between two photo-interrupter sensor when there're change in value of the output of photo-interrupter sensor indicated that there're no fuel detected. Once the time taken between two photo-interrupter sensor is recorded, fuel consumption is calculated based on equation

$$FC = \frac{2.85}{t \times 3600} \times \rho \qquad \text{(Equation 1)}$$

Where:

FC = Fuel Consumption (g/h)

T = Average time taken for 2.85 ml of fuel to consume

ρ = density of fuel (g/cm^3)

3.12 Refilling valve

The fuel consumption measuring device is designed and programmed to refill the burette automatically once the fuel level is lower than the last photo-interrupter sensor. The refilling mechanism is realized by using magnetic refilling valve controlled by Arduino Mega with the use of 4-channel MOSFET electronic building block. The refilling valve used is normally-closed magnetic refilling valve while the 4-channel MOSFET electronic building block switch is built specially for it to control the on and off of the value and realize the refilling valve mechanism. The electrical valve and 1-channel MOSFET electronic building block are shown in Figure 3.22

For the operation of the magnetic refilling valve, there were a working refilling mechanism where the refill valve closed when the fuel level decrease until it was lower than last photo-interrupter sensor. The refill valve is then opened for the fuel level to increase and closed until it reached the level 1 photo-interrupter sensor.

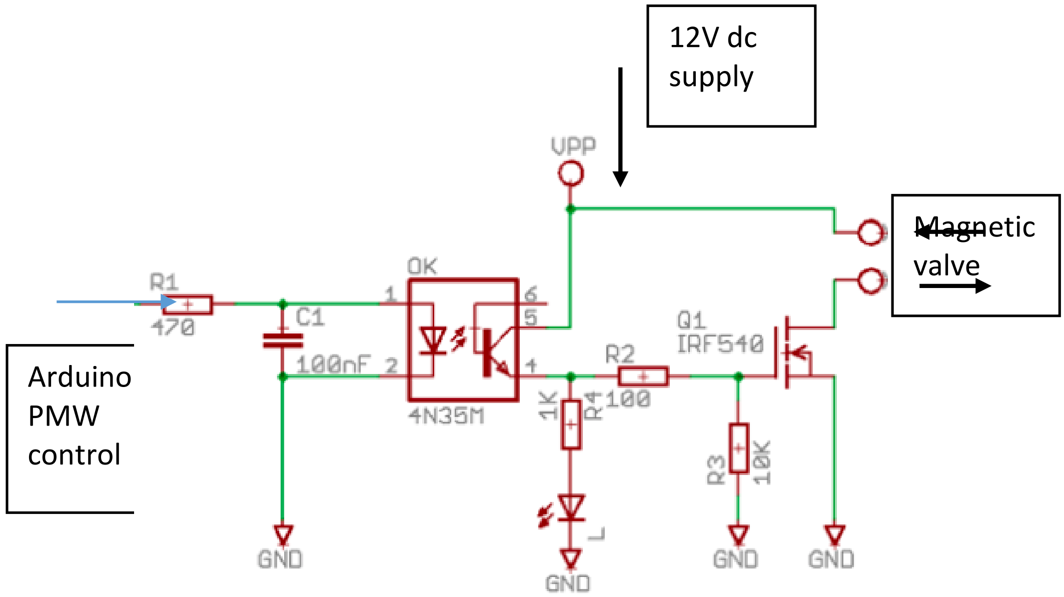


Figure 3.20: Schematic diagram of 1-channel MOSFET.

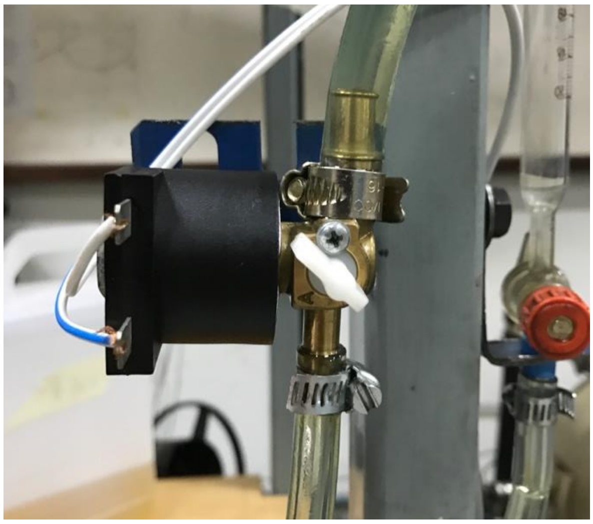


Figure 3.21 : Normally closed magnetic refill valve

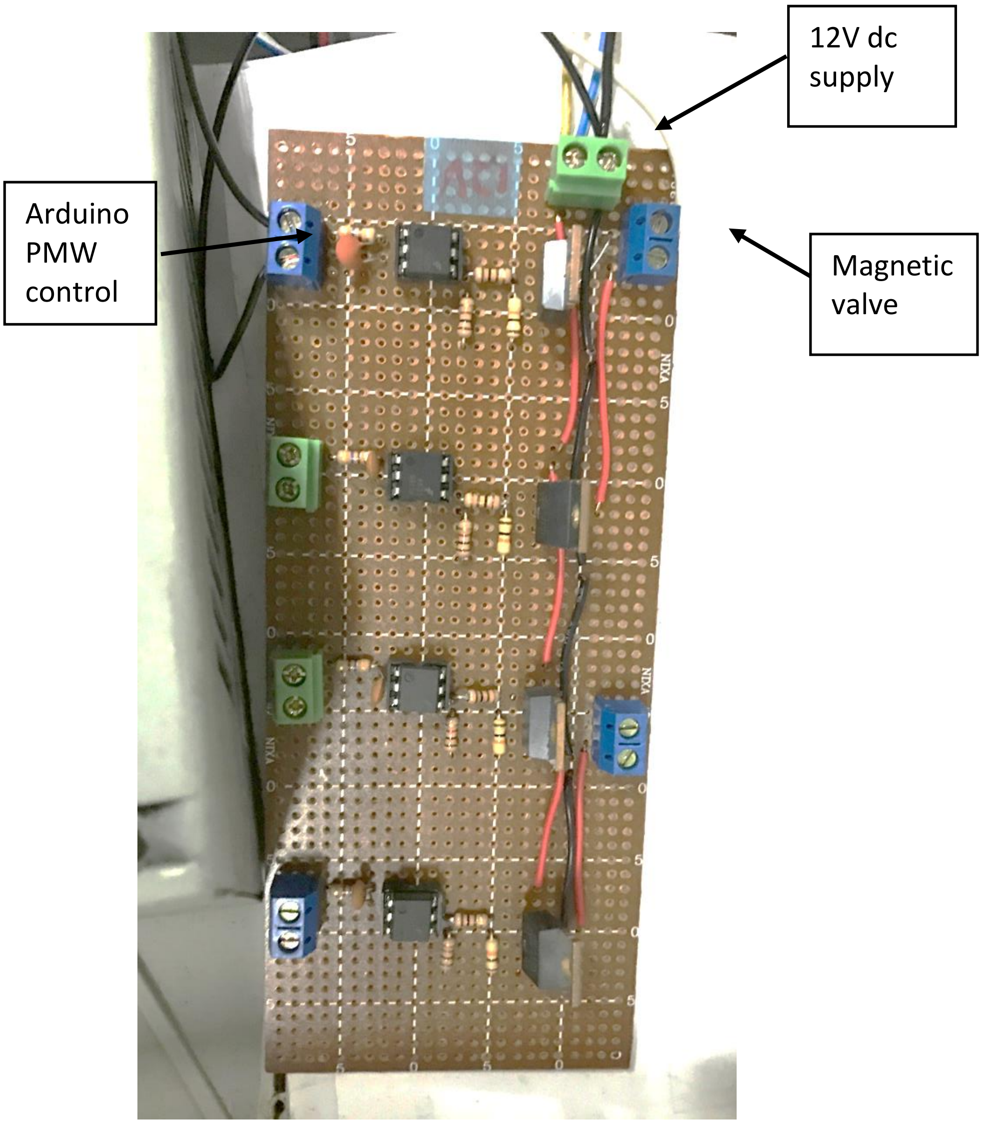


Figure 3.22: 4-channel MOSFET

3.12 Emission Analyzer

Emission Analyzer system is commonly used for testing stationary engines, generators, compressor, burners, turbines and lab equipment to analyze the emission from the engine. The emission analyzer used in this research is KANE Auto 5-3 emission analyzer.

Figure 3.23 : KANE Auto 5-3 Emission Analyzer

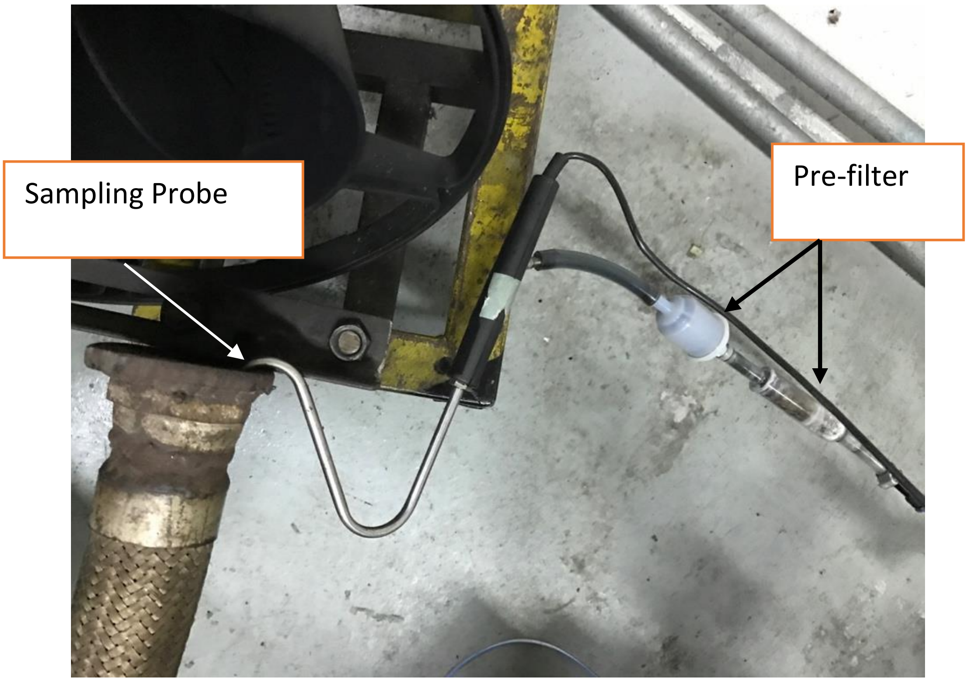


Figure 3.24: The sampling probe is placed at the end of the engine gas exhaust together with two pre-filter

The emission analyzer has the capability to measure O_2, CO, NO_x, HC and PM along with the calculations of air fuel ratio, lambda. Data from the emission analyzer is logged into computer and recorded by using software LabVIEW.

3.13 Arduino controller

Arduino Mega is used to sample all analogue and digital channels as well as provide various voltage and current output control. Arduino Mega consist of 16 analogue inputs and 54 digital I/O pins which can accommodated various inputs and outputs including the LED display. Arduino Mega also provided PMW output from 15 of it digital I/O pins which best used to control the load apply to the dynamometer. In this research, Arduino Mega is used as dynamometer controllers. It is programed to operate in 3 modes: Manual, Torque mode, and Speed mode. It provided PMW control over the load applied to the dynamometer in order to reach desired speed or torque. Arduino communicated with Computer through serial port communication.

Figure 3.25: Arduino Controller built with led display, turning knob, buttons and on-off switch

3.14 Software and automation

Three software packages is installed: Arduino, LabVIEW and Dewesoft. Arduino is used to program the Arduino Mega controller while LabVIEW and Dewesoft are programmed to sample and store the data and to automate the test cell.

3.14.1 Arduino

To realize automated test control, Arduino software is used to program the Arduino Mega controller to pick up and analyze signal from speed sensor, load cell and photo-interrupter sensor and provide control over the load applied to the dynamometer. Arduino code written is separated to 3 parts which included (i) mode of operation and PID tuning for each mode (ii) LCD real-time control (iii) communication between Labview and controller.

3.14.2 LabVIEW

LabVIEW (Laboratory Virtual Instrument Engineering Work Bench) is a visual programming language developed by National Instruments (NI). It is commonly used for data acquisition, instrument control and automation.

Arduino mega interfaced with Labview by using NI-VISA drivers and LIFA (NI LabVIEW interface for Arduino Toolkit). They form a communication bridge in order for Arduino mega to communicate with LabVIEW. LabView's graphic user interface (GUI) is optimized for the automated engine test cell. It is programmed to provide real time control and automated control over the dynamometer. The interface is shown in Figure 3.26-3.30 and is labelled followed by an explanation.

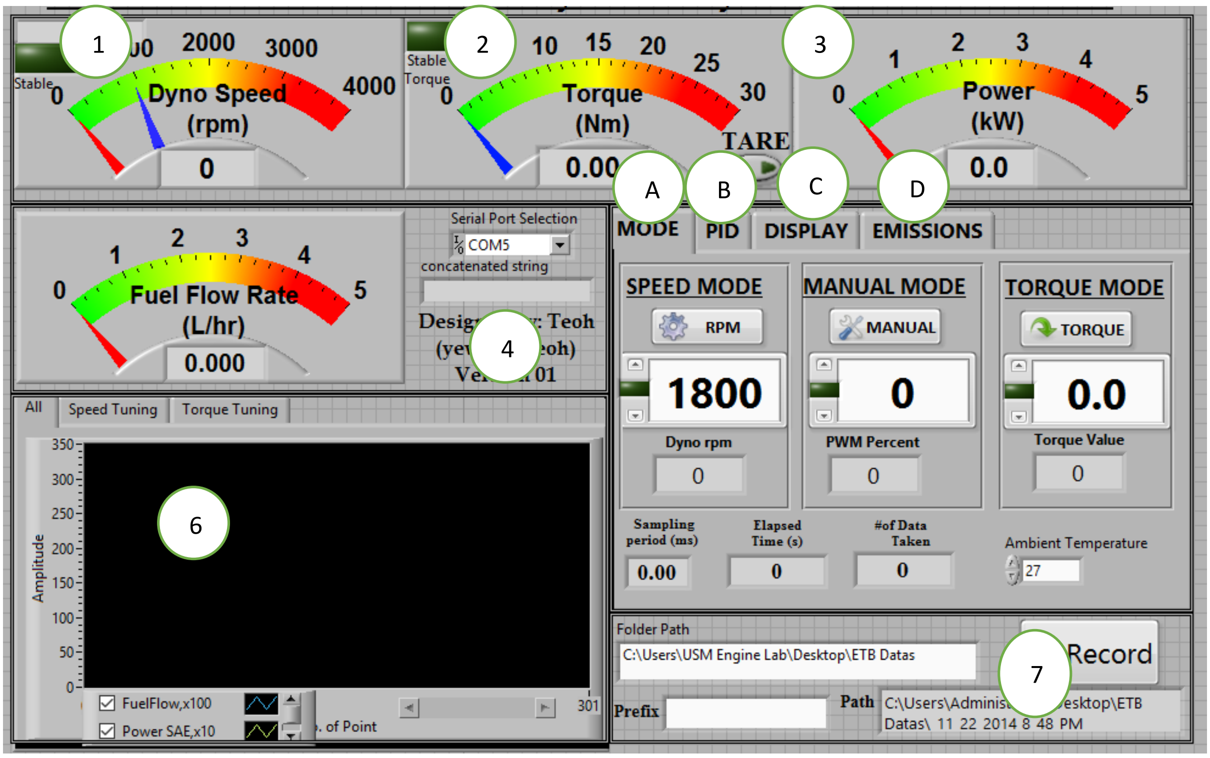


Figure 3.26: GUI interface programmed by using LabVIEW

1. Dials and digital for graphic indication Dyno Speed
2. Dials and digital for graphic indication Dyno Torque, equipped with a tare button to tare the torque before the engine start
3. Dials and digital for graphic indication Power
4. Serial Port Selection and concatenated string
5. Real-time graph consisted of fuel level, dyno speed, speed set point and power
6. Data Recording panel

A. MODE SELECTION

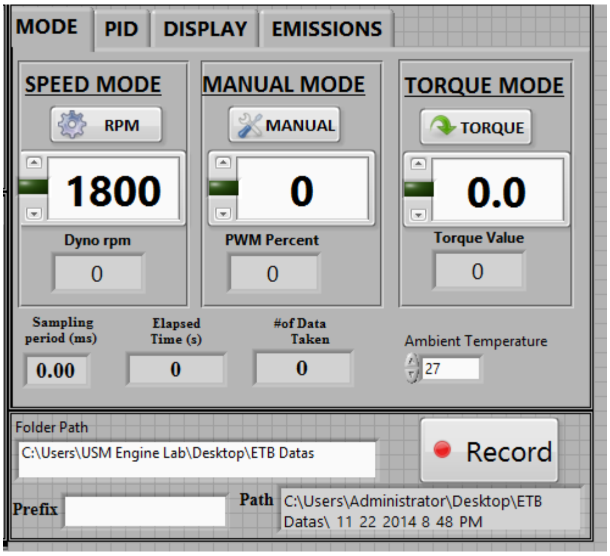


Figure 3.27 : Mode Selection

B. PID tuning of Speed Mode and Torque Mode

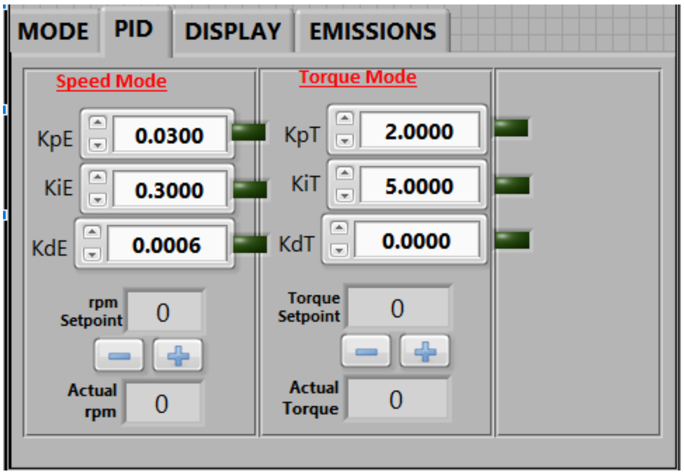


Figure 3.28: PID tuning mode

C. Preset speed setpoint, graphic indication of fuel level, photo-interrupter and refill valve on/off.

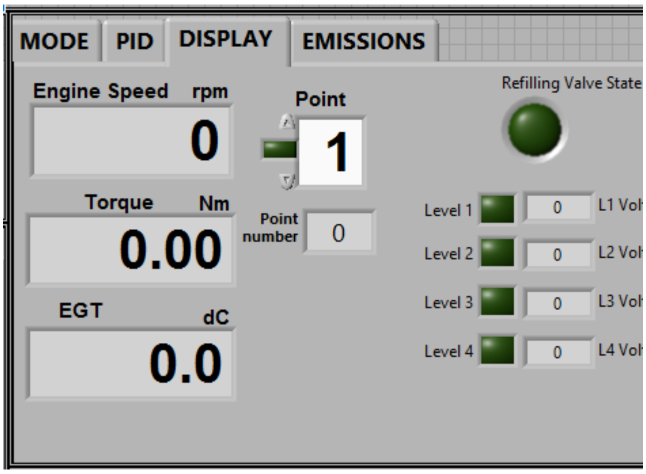


Figure 3.29 Speed setpoints and fuel flow level

D. Emission data

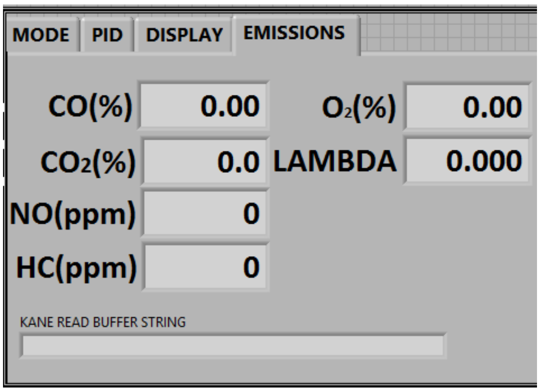


Figure 3.30 : Emission data interface

3.14.3 Devesoft

Devesoft Combustion analysis is used for the analysis of internal combustion engine. Both pressure and rotary signal signal is picked up by the Devesoft software. The software used to record both of the data for numbers of drive cycle. In this research, Crank angle position and pressure are exported into excel in the form of cycle averaging data and the main indication values for engine development and testing like maximum pressure, position of maximum pressure, heat release rate, 50% hrr and knocking can be calculated. The interface is shown in Figure 3.31 and is labelled followed by an explanation.

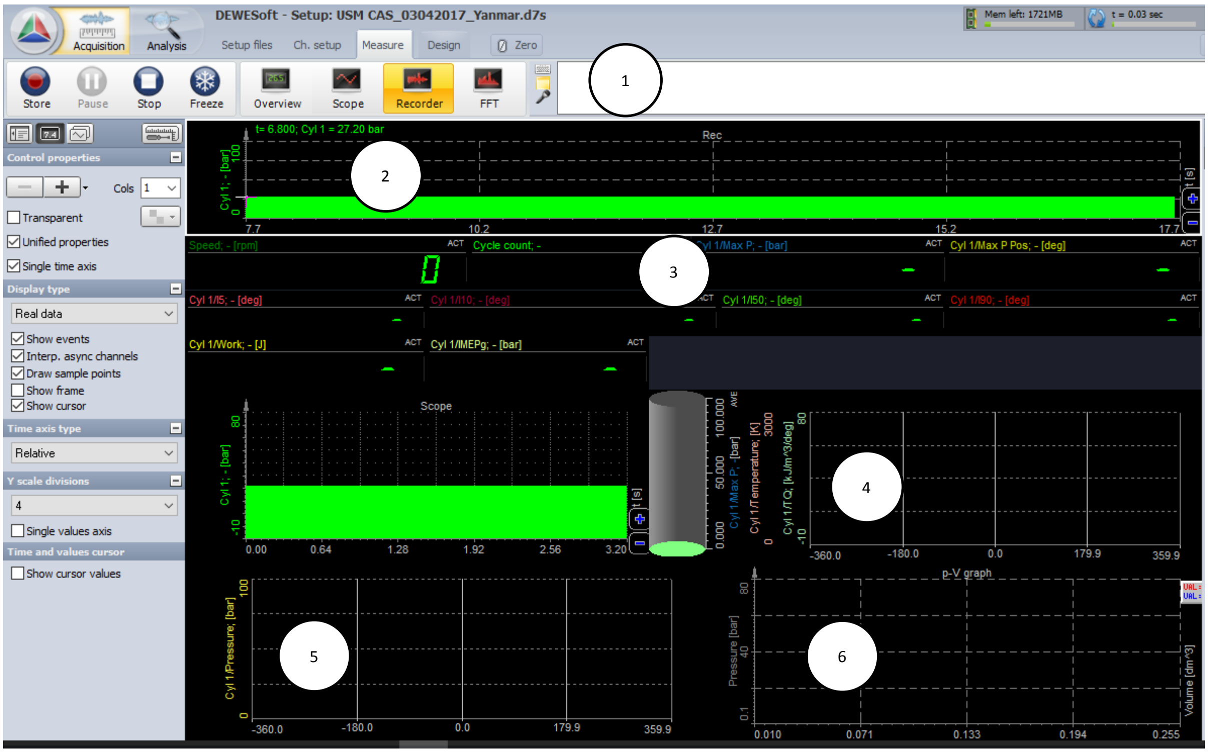


Figure 3.31 : DEWESoft GUI Combustion data collection

1. Measure tab which provide the function of start store, stop
2. Cylinder pressure per Cycle count
3. Digital indication of engine speed, cycle count, Cylinder Pressure and Crank angle at maximum Pressure
4. Real-time HRR over crank angle plot
5. Real-time cylinder pressure against crank angle plot
6. Real-time P-V plot

3.15 PID tuning

In speed mode and torque mode, the output is undergoing PID tuning in order for the output (engine speed or torque) response to the desired set points quickly and with small error. PID tuning is the process of finding the values of proportional, integral, and derivative gains of a PID controller to meet the desire performance. Since the testing is operated in steady state, the speed response is tuned to be responsive and small error between the set points in speed mode. While in torque mode, torque response is tuned to be stable and consistent. The Arduino controller has under PID tuning for speed mode and torque mode before the testing start.

3.16 Experiment Procedure

3.16.1 Fuel Preparation

To study the performance, emissions and combustion characteristic of baseline diesel and Biodiesel Blend. The biodiesel fuel B100 with the compositions of 100% Palm Methyl Ester and 2 litter of B100 is prepared. The mixture was then shaken for a couple of minutes to ensure proper mixing.

Density of diesel and B50 biodiesel blend was obtained by measuring the volume and weight of the fuel by using electronic weighing machine and measuring cylinder. From the result, the weight and the volume obtained was used in calculation of the density. Bomb calorimeter device was used to determine both the calorific value of diesel and biodiesel B50.

3.16.2 Engine Test Procedure

The engine tests were performed under steady state condition with wide open throttle(WOT). Hence, all tests of diesel and biodiesel were conducted at full load-varied speed conditions. The engine was run in idle for a sufficient time until the exhaust gas and engine temperature was sufficiently warmed. The engine was then set to operate in speed mode. The engine was set to run for 4 speed from 1600rpm to 2800rpm with increment of 200rpm. For each speed, the torque, speed, fuel consumption, emission data and exhaust temperature are automatically recorded by using LabVIEW once the engine reach steady state. For combustion data, the pressure data is recorded for 300 cycle and cycle average is then exported to excel.

The parameters were determined based on equation below.

$$Brake\ Power, BP\ = \frac{2\pi NT}{60000}$$

$$BSFC\ = \frac{\dot{m}}{BP}$$

$$BTE = \frac{3600}{LHV \times BSFC} \times 100$$

Where,

BP = Brake Power(kW)

N = Engine Speed (rpm)

T = Torque (N.m)

$\dot{m}$ = Fuel Consumption (g/h)

BTE = Brake Thermal Efficiency (%)

LHV = heating value (MJ/kg)

Chapter 4 RESULT AND DISCUSSION

4.1 PID Tuning

To operate in speed mode, the speed output were PID tuned for the response to the desired setpoints. In speed mode, the response is tuned to be responsive and small error. From Figure 4.1, it indicated that the speed response is set to be stable and with minimum error of +-15rpm. At the beginning of the tuning process, it can be observed that the response show inconsistent response and unstable oscillation behavior at 900s when a step input from 2150 to 1950rpm is applied. At 1000s when a step input from 2000rpm to 2250 rpm is applied, the speed responses show overdamped behavior and take a long time to reach the target speed setpoint. Once the PID parameters is set to optimum (Kp= 0.0136, Ki = 0.0365, Kd=0.0006), the speed responses show stable and quick response and with minimum error range of ±15rpm which is acceptable.

To operate in torque mode, the torque output had undergone the PID tuning for the output to desired behavior in response to torque setpoint. From Figure 4.2, it is observed that the torque output showed overdamped behavior and take longer time to reach the target torque setpoint. After PID tuned, the torque output responded with a shorter time and showed underdamped behavior. It have a small error which deviate the output with ±0.03N.m. The PID parameters is set to optimum with Kp= 3.88, Ki= 7.75 and Kd= 0.0043.

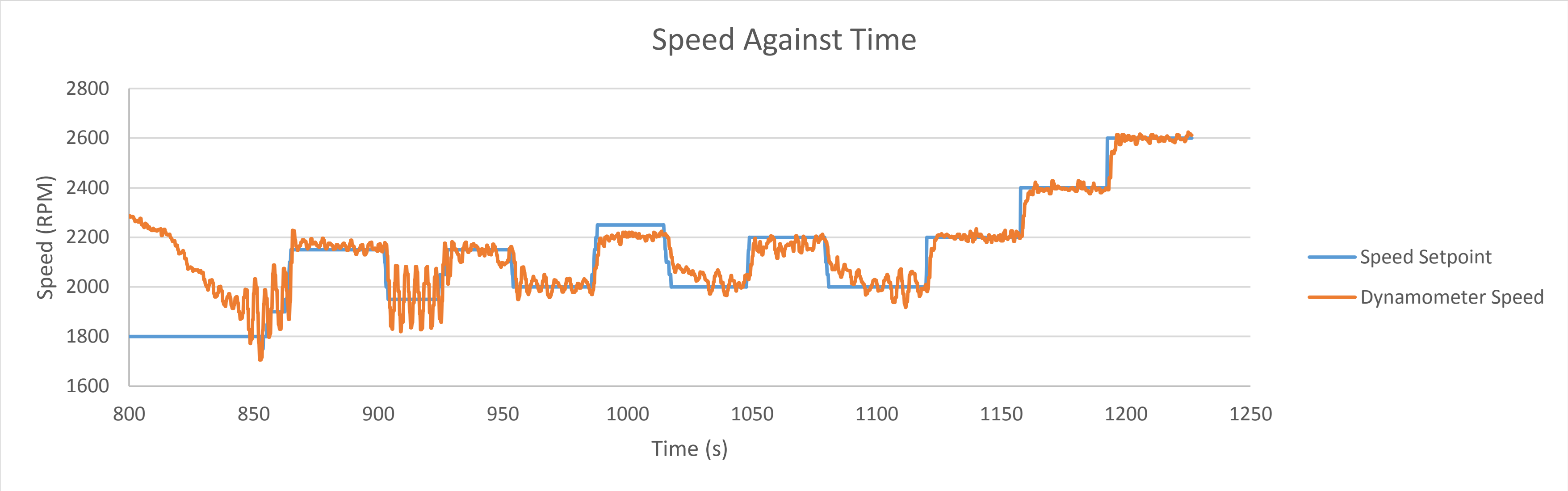


Figure 4.1: PID Tuning for speed mode

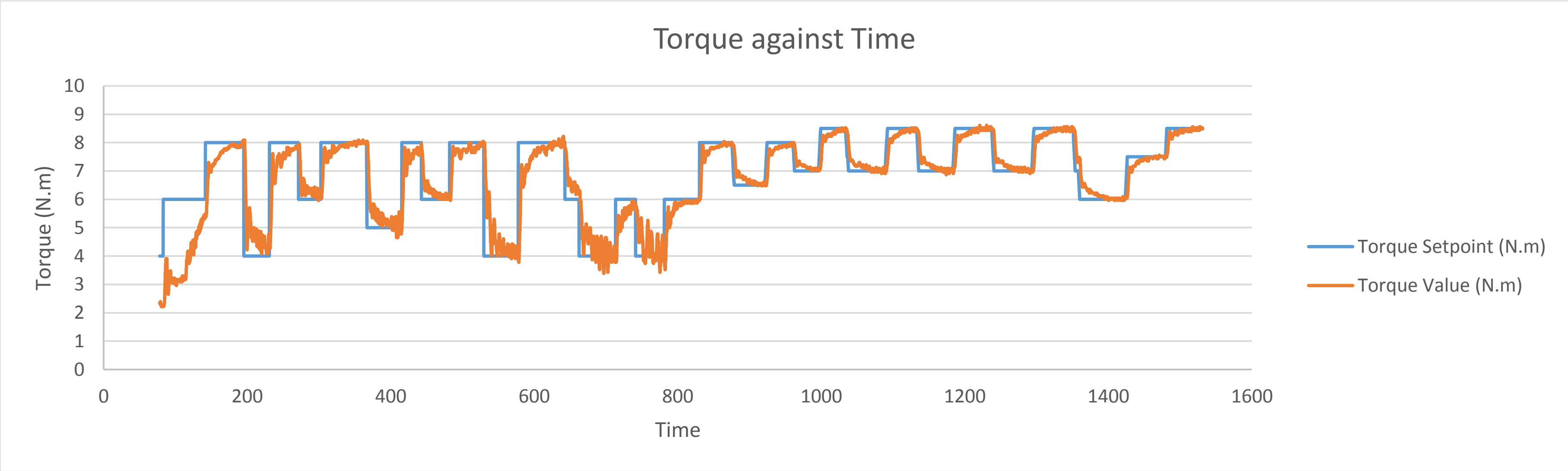


Figure 4.2: PID tuning for torque mode

4.2 Fuel Consumption Measurement Mechanism

The fuel consumption is measured by the time between two fuel levels. From figure 4.3, the inclination of the fuel level indicated the fuel refilling process and the process stop when the fuel is detected by the 1st photo-interrupter sensor. The fuel level stay at 200 and show declination of fuel level from 200 to 0 with the interval of 50. The fuel consumption is then measured by the time between two fuel levels, T1, T2 and T3 as shown in the figure below. Hence, the average fuel consumption is then calculated and obtained for the respective engine speed.

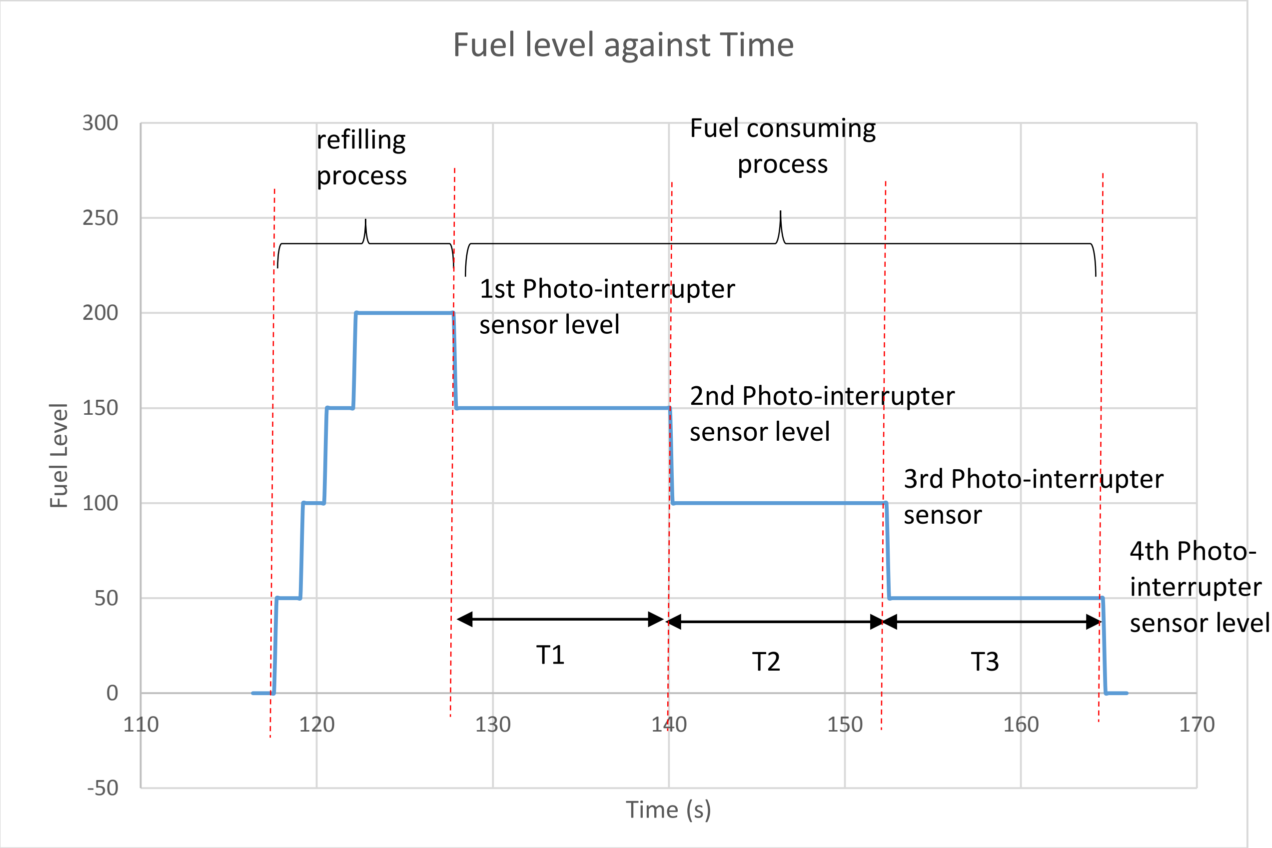


Figure 4.3: Fuel consumption measurement mechanism

4.3 Fuel Properties

From table 1, biodiesel B100 is denser than diesel by 16.5% while B100 have a much lower calorific value of 45.31MJ/kg which will show significant effect on the parameters.

Table 1: Fuel Properties of Diesel and Palm Methyl Ester B100

Fuel properties	**Diesel**	**Palm Methyl Ester (PME) B100**
Density [g cm-3]	0.8519	0.99
High Calorific Value[MJ kg-1]	45.31	39.81

4.4 Performance and Torque Curve

Diesel and Biodiesel B100 were tested and the power and torque curve results plotted illustrates the performance of engine. Based on Figure 4.4, the torque shows a steady curve line without much variation within the range of 10.05 Nm to 9.58 Nm. On the other hand, the torque produced varies with the engine speed and is comparatively lower than diesel except at engine speed2400rpm. Biodiesel B100 reaches peak torque at 2400rpm and start to decrease to 8.42Nm.

At Figure 4.5, both the fuel shown an increment as the speed increase except for high peak power shown by B100 fuel at 2400rpm. As the same trend as torque curve, B100 fuels generally have lower power as compared to diesel. The decrease in brake power and torque of B100 fuel as compared to diesel fuel us due to the low heating value of B100. The lower energy level of the B100 fuel produce less torque and power which reach an agreement with other studies on biodiesel (Raheman & Phadatare, 2004), (Aydin & Bayindir, 2010), (CHOI & OH, 2006) and (C Kaplan, 2006).The noticeable higher peak power and torque of B100 may be explained as torque and power recovery due to higher fuel mass flow of the denser and viscous biodiesel .In the studies by Qi. DH and Al-Widyan, the result shows the similar increase in torque and power for biodiesel (Qi et al., 2009), (Al-Widyan, Tashtoush, & Abu-Qudais, 2002).

From Figure 4.6, brake specific fuel consumption (BSFC) indicated that the B100 fuel has larger fuel consumption per unit energy output compared to diesel B50 in all of the speed. Overall, B100 is 18% higher BSPC as compared to diesel fuel. The trend matches with the research done by Buyukkaya which show that B100(100% soy biodiesel) had a higher brake specific fuel consumption(Buyukkaya, 2010). There are other authors have found out the same trend in their research and explained that the increase in BSFC is due to the high viscosity of biodiesel which higher viscosity and lower heating value results in poorer atomization and hence poorer combustion (Yadav, Khan, Dubey, & Pal, 2016),(Ramadhas, Jayaraj, & Muraleedharan, 2004).

Figure 4.7 shows brake thermal efficiency B100 is slightly higher than diesel fuel at engine speed of 1600rpm and 2400rpm while diesel fuel is higher than B100 at speed 2000rpm and 2800rpm. The increase in brake thermal efficiency can be explain as the oxygen content in biodiesel higher hence result to a more complete combustion.

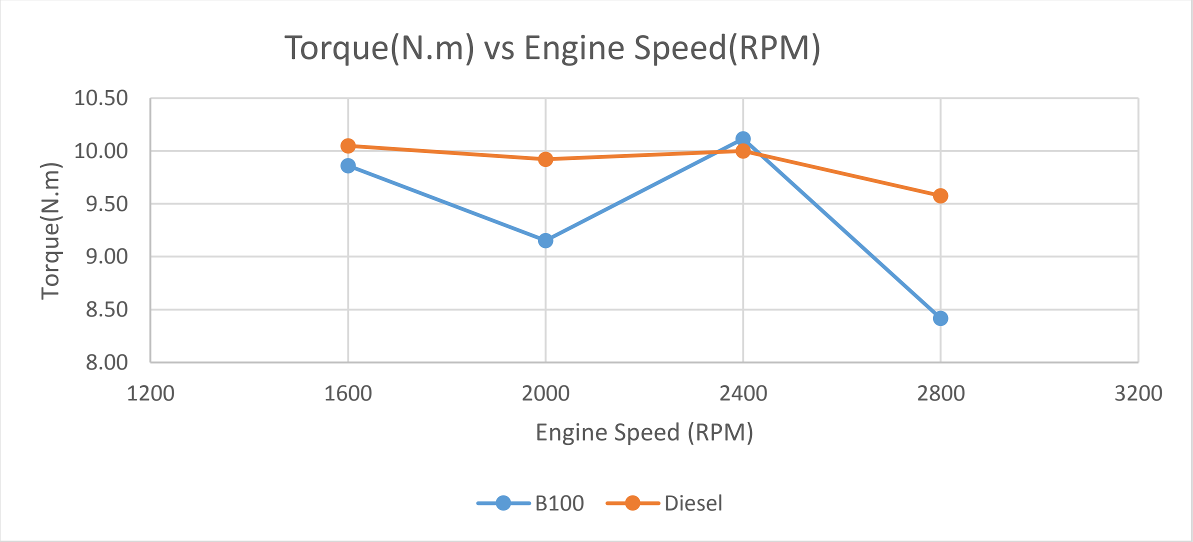


Figure 4.4: Torque against Engine Speed for B100 and Diesel

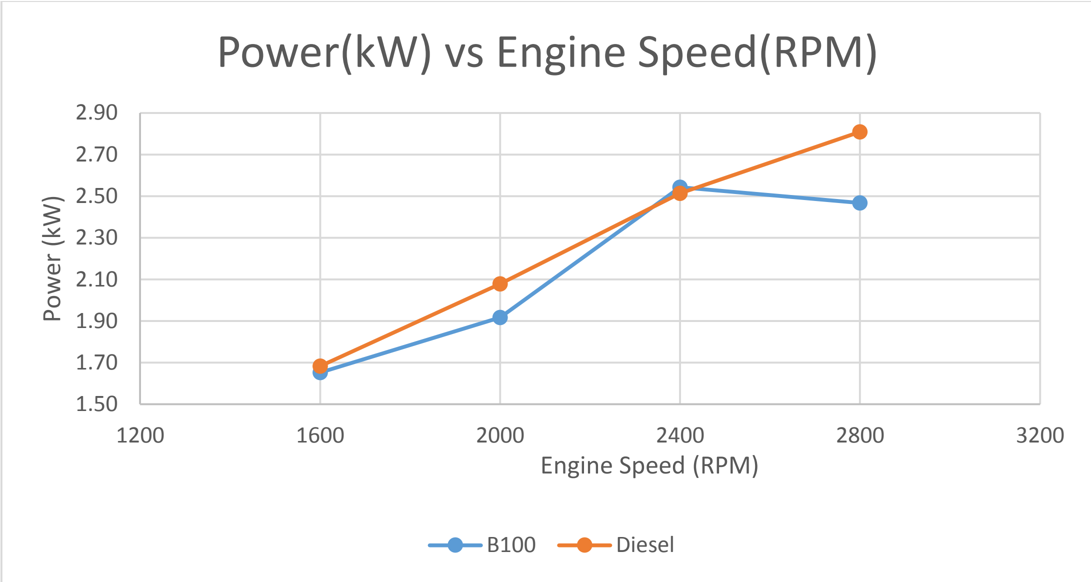


Figure 4.5: Power against Engine Speed for B100 and Diesel

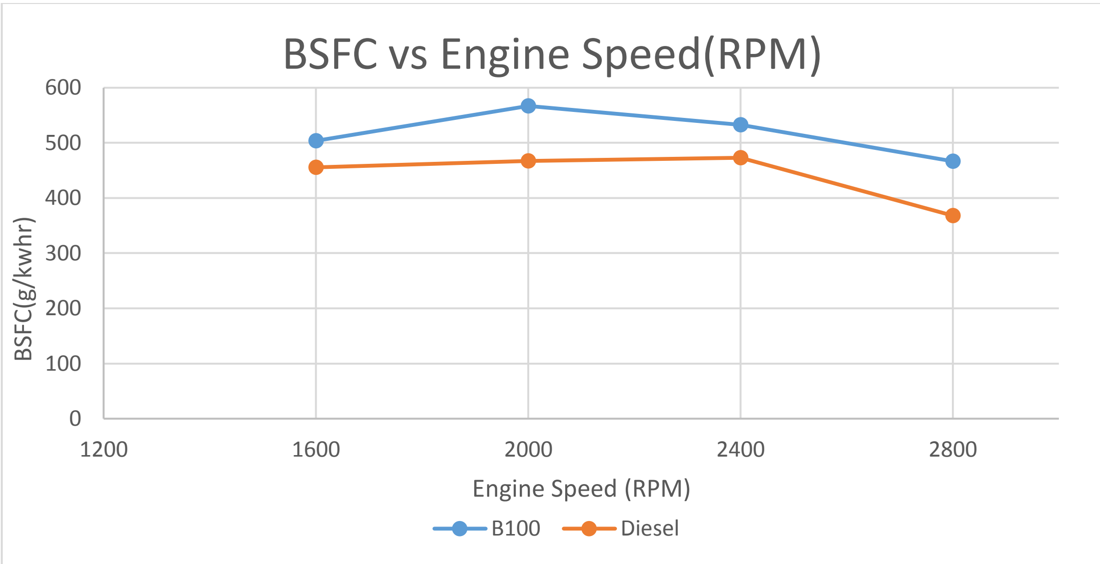


Figure 4.6: BSFC against Engine Speed for B100 and Diesel

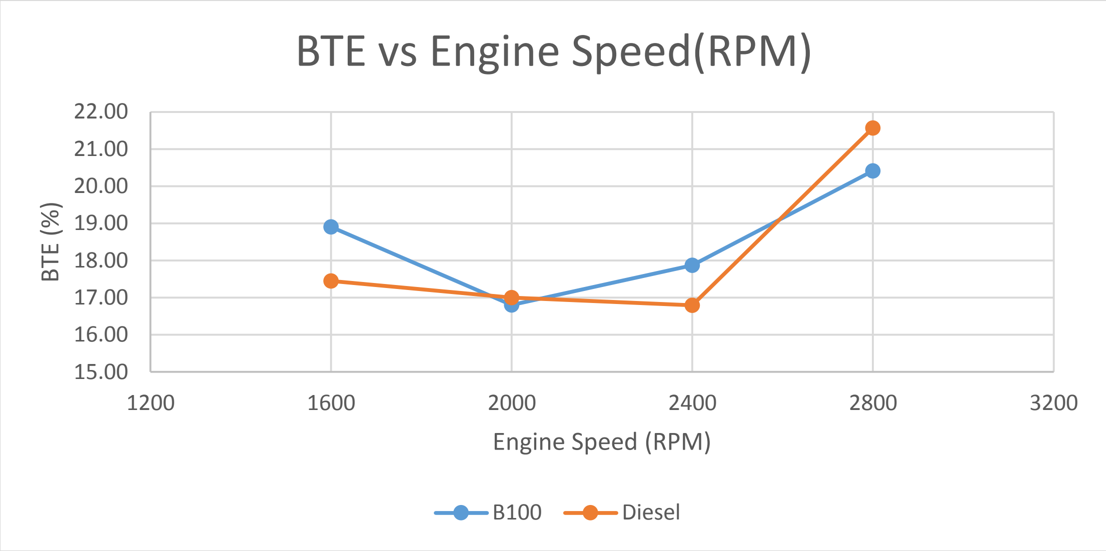


Figure 4.7: BTE against Engine Speed for B100 and Diesel

4.5 Emission Analysis

Exhaust gas temperature (EGT) in different engine speed for both fuel is shown in figure. From the 4.8, it is observed that the exhaust gas temperature is higher with B100 compared to the baseline diesel. This can be explained that biodiesel has higher oxygen content which lead to more complete combustion. Lin have the similar trend of exhaust gas temperature in the research of performance of biodiesel(Lin & Lin, 2006). The more complete combustion is then reducing the emissions of unburned hydrocarbons and carbon monoxide.

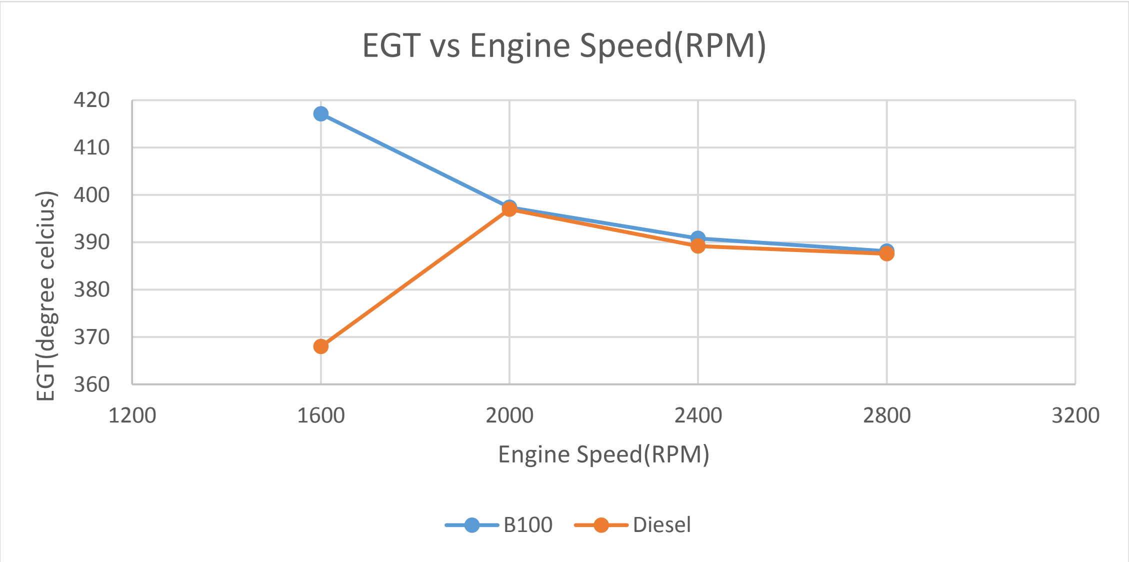


Figure 4.8: EGT against Engine for B100 and Diesel

Figure 4.9 indicated that both HC, CO and Carbon dioxide emission are lower with the B100 fuel at all engine speed as compared with baseline diesel. As for HC, B100 output a 17 to 45% reduction HC emission indicated that a more complete combustion in B100 due to the higher oxygen content in B100. Besides, the increase exhaust gas temperature and decrease in combustion delay also allowed the combustion combustion of fuel. For CO emission, it was observed that the CO emission increase with the increase in engine speed to 2000rpm and decrease at the subsequent engine speed. Reduced CO emissions can be found on H.Raheman, AG Phdatare and Ekrem Buyukkaya' studies (Buyukkaya, 2010; Raheman & Phadatare, 2004). They both stated that the reduced CO emissions is due to the oxygen in biodiesel make it easier for combust at higher temperature in the cylinder. In the research of S.Senthilkumar on palm methy-ester biodiesel on performance and emission, he also concluded that CO emissions are higher for fuel rich mixtures implying that B100 is running at leaner fuel-air ratio(Senthilkumar, Sivakumar, & Manoharan, 2015).

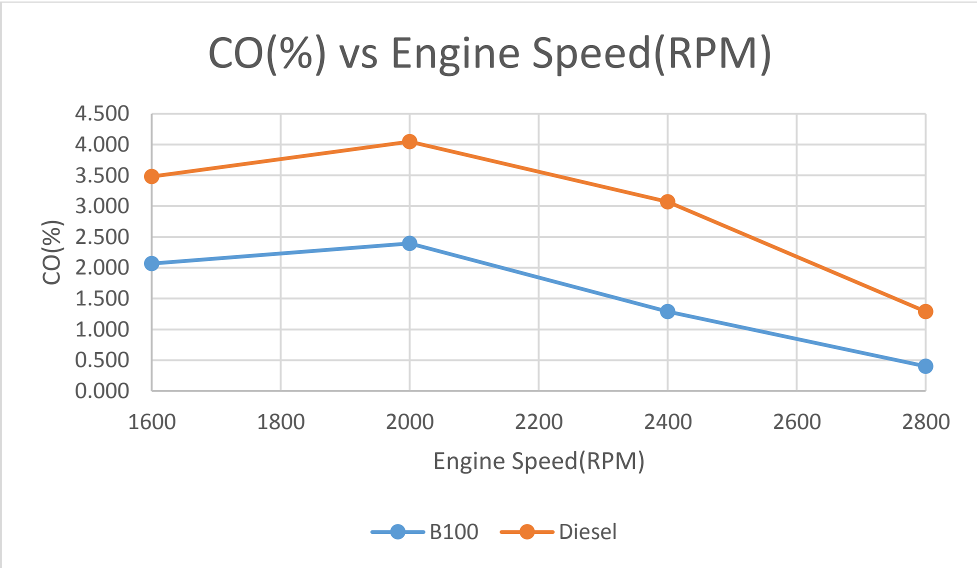


Figure 4.9: CO against Engine speed for B100 and Diesel

By referring Figure 4.10, both the fuel shows the increase in emission of CO2 at lower speed of 2000rpm and decrease. The graph also shows that the CO2 emission of B100 is 25% to 43% lower than diesel.

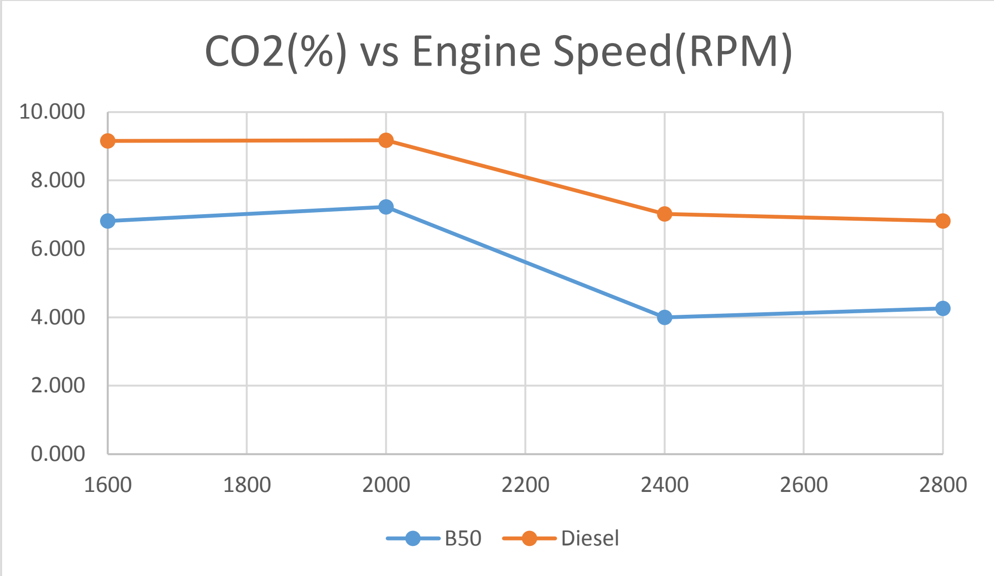


Figure 4.10: CO2 against Engine speed for B100 and Diesel

Figure 4.11 show that as the engine speed increase, HC emission decrease until it reaches almost zero. This is because at higher speed, fuel combustion efficiency increase as the air-fuel ratio increase lead to a more complete combustion. B100 generally have a lower HC emissions as compared with diesel. This indicated that B100 undergo a more complete and cleaner combustion. Besides, the reduction in ignition delay also related to decreased in HC emission.

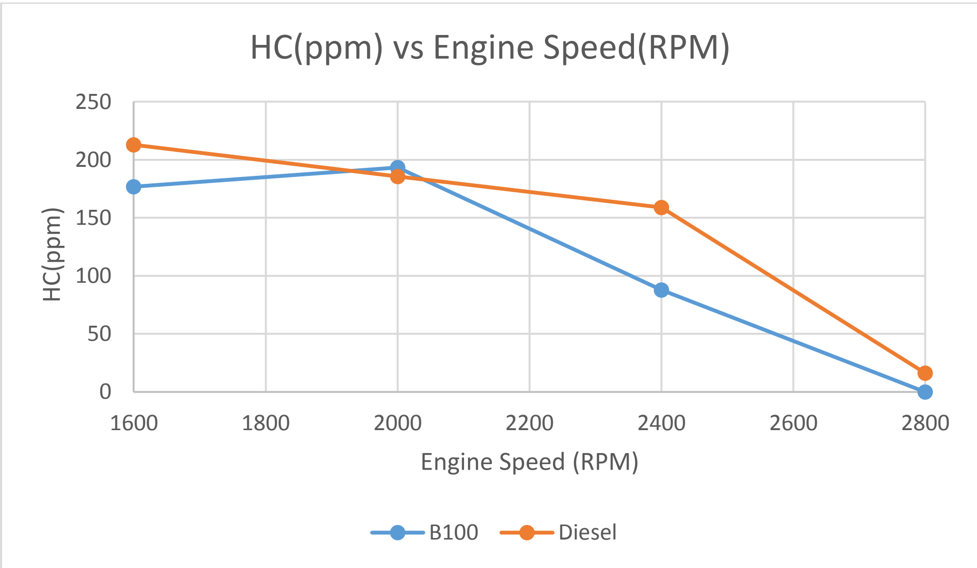


Figure 4.11: HC emission against Engine Speed for B100 and Diesel

In Figure 4.12, the emission NO shows different trend for both of the fuel. B100 show an increasing of emission NO from engine speed 1600rpm to 2000rpm and decreasing from 2000rpm to 2400rpm and lastly increase to 196ppm at 2800rpm. While for baseline diesel, the emission NO shows constant decreasing as the engine speed increase. It is also observed that NO emission for B50 is 28% to 52% lower as compared to diesel fuel. Although it is unusual that NO emission for biodiesel to be lower as seen in Karabektas and Zhu L's studies, there are also studies that shows decrease in NO emission for biodiesel(Dorado, Ballesteros, Arnal, Gómez, & López, 2003; Karabektas, 2009; Puhan, Vedaraman, Sankaranarayanan, & Ram, 2005). M.A Kalam explained the difference was mainly due to the reduction in heat release rate at premix combustion phase which lower the peak combustion temperature hence reduce NOx emission(Kalam, Husnawan, & Masjuki, 2003). S. Kalligeros also explained the decrease in NOx emission was due to the higher cetane numbers of biodiesel shortens the ignition delay hence peak combustion temperature decrease(Kalligeros et al., 2003).

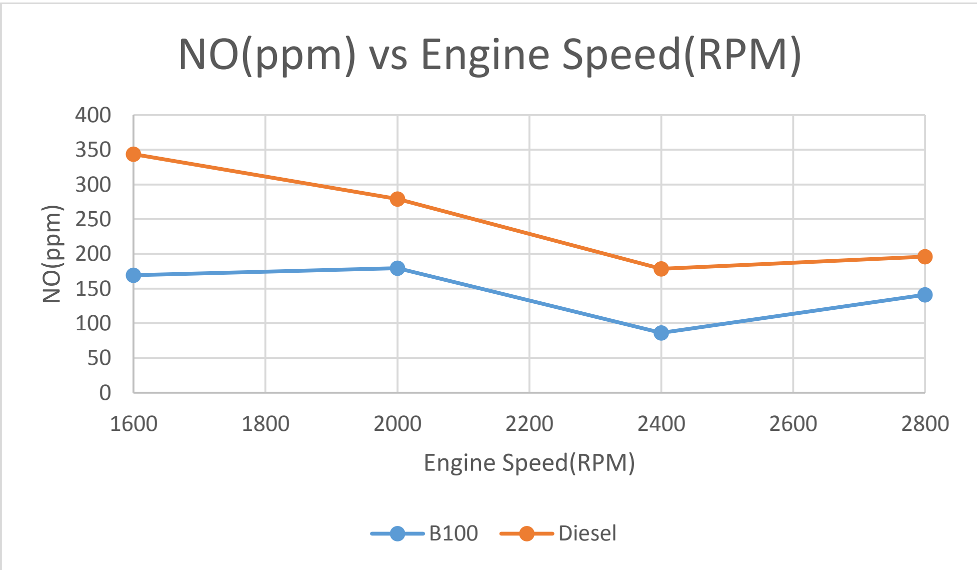


Figure 4.12: NO emission against Engine Speed for B100 and Diesel

4.6 Combustion data

Figure 4.13 shows the variation of cylinder pressure with crank angle for B100 and diesel at engine speed 2400rpm. It can be observed risen of cylinder pressure for B100 as compared to diesel indicated that combustion start earlier. From the figure, it is shown that both the peak pressure and pressure curve shown less differences with 74.89

bar for diesel and 74.34 bar for B50. The decrease in peak pressure is due to high viscosity of B100 (Palm Methyl ester) biodiesel fuel. It is observed that the pressure of B100 at 0-5 degree is higher than diesel which indicated that early ignition of fuel cause pre-combustion to occur earlier.

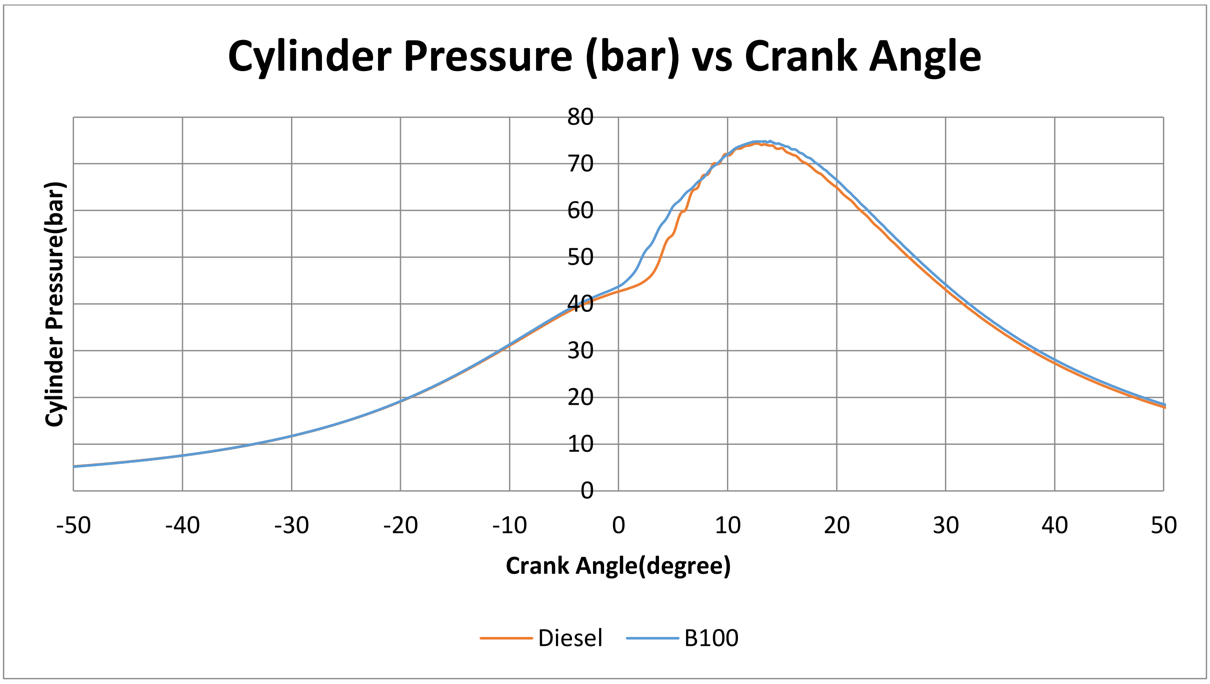


Figure 4.13: Cylinder Pressure against Crank Angle for B100 and Diesel at engine speed 2400rpm

Figure shows the heat release rate of Diesel and B100 at engine speed 2400rpm. From the 4.14, it is indicated that the ignition delay for B100 was shorter than for diesel. Besides diesel also have a higher premixed combustion peak as compared to B100. This is because as a consequence of shorter ignition delay as shown in Table 4.2, the premix combustion phase for B100 is less intense. Ekrem Buyukkaya. The lower heat release for B100 compared with diesel is because of its lower heating value and higher viscosity. The observation supported the fact that shorten ignition delay resulted in lower heat release caused the reduction in NOx emission(Buyukkaya, 2010). After the premixed combustion phase, a distinct diffusion flame combustion phase which there are double peak in the HRR curve shown by B100.

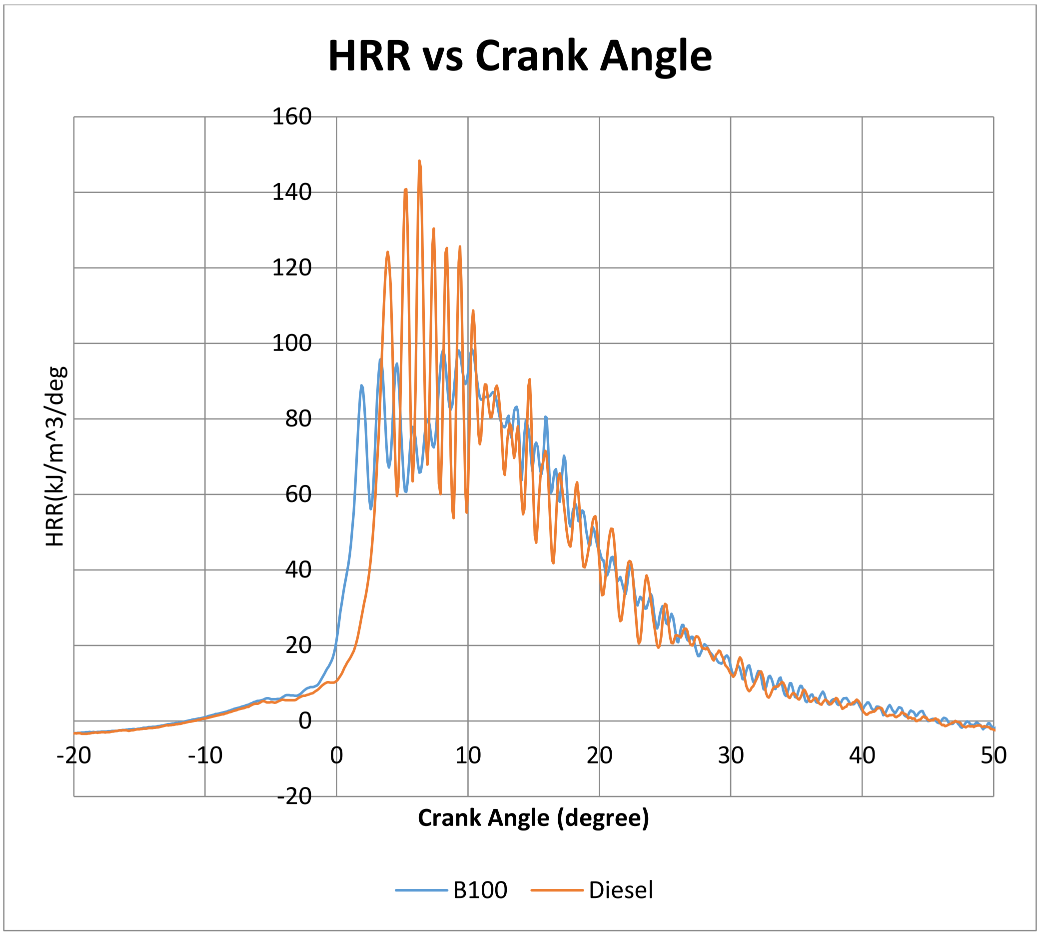


Figure 4.14: HRR against Crank Angle for B100 and diesel at 2400rpm

The table 2 indicated that B100 have a shorter ignition delay of 0.5 degree as compared to diesel. The ignition delay could be caused by increased viscosity, density and fuel oxygen content since it affects the volatility of the fuel therefore reducing the ignitability of fuel.

Table 2: Maximum pressure, ignition delay and maximum HRR for B100 and Diesel at 2400rpm

Fuel Type	Maximum pressure(bar)	Start of fuel injection	Start of combustion	Ignition delay	Maximum heat release rate(bar)
Diesel	74.89	16.5	10.8	4.7	148.40
B100	74.34	16.5	11.3	4.2	98.41

Chapter 5 CONCLUSION

Automated test cell system for single cylinder diesel engine and the study of performance, emission and combustion characteristic of Palm methyl ester biodiesel B100 compared with baseline diesel fuel have been performed for the current project. Automated data acquisition system was setup to gather quantifiable data including the torque measurement, speed measurement, fuel flow measurement, combustion data acquisition and emission data acquisition. It provides real-time control on the speed of eddy current dynamometer in speed mode and torque of the engine in torque. Steady state test on the engine is proved highly successful during testing.

In the study of performance, emission and combustion characteristic of B100 and diesel, the comparison of B100 with diesel generally shows lower torque, power and brake thermal efficiency. Due to its lower heating value and higher viscosity, B100 was found to burn less efficiently and have a higher specific fuel consumption.

Palm methyl ester biodiesel B100 produced lower emissions of CO with 17 to 45% reduction compared with diesel fuel and CO2 with 25-43% reduction. The biodiesels produced lower emissions of unburned hydrocarbon. Due to reduction in heat release rate at premix combustion phase which lower the peak combustion temperature, B100 exhibit lower NOx emissions that were maximum 52% lower than baseline diesel. The combustion data anaysis shows lower peak pressure and lower heat release rate for B100 which caused by shorter ignition delay which supported the reason of lower NOx emissions.

For future work, a throttle actuator driven by motor can be installed on the engine in order to control the throttle opening. Electronic Throttle opening control benefit the evaluation of performance of engine in both speed and torque mode and fulfill the automation in engine testing. Besides, fuel consumption measuring device developed in this research can be replaced with fuel flow meter to obtain a real-time fuel consumption without post calculation of the fuel consumption. More type of biodiesel fuel or biodiesel blend can be tested in the future to determine the optimum performance of the biodiesel blend so that biodiesel blend use as alternative fuel for diesel engine.

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Appendices

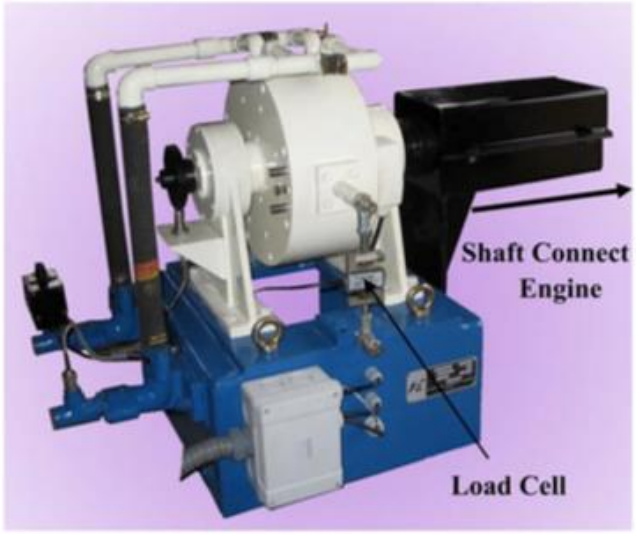
Appendix A

Characteristics of Yanmar L48N6 diesel test engine

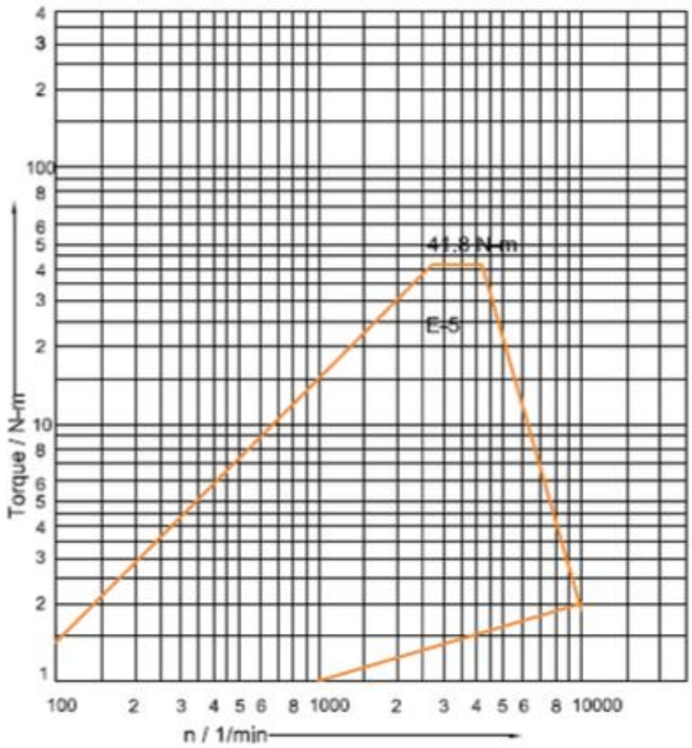
Parameter		Units
Type	Vertical cylinder, 4-cycle air cooled diesel engine	-
Combustion system	Direct injection	
Displacement	219	cm^3
Bore	70	mm
Stroke	57	mm
Compression ratio	20.1 : 1	-
Connecting rod length	91	mm
Rated power	3.1	kW
Rated speed	3600	rpm
Injection system	16.5°	BTDC
Approx. fuel consumption @ full load @ 3600 rpm	1.4	l/hr
dBa @ 7m @ 3600 rpm @ full load	79.5	dBa

Appendix B

Capacity Curve for Eddy-Current Dynamometer Model E-5



The 20kW eddy current dynamometer (Accurate Test Equipment & Engineers, 2010)



Specifications:

Model: E-5

Max. Power: 20 kW

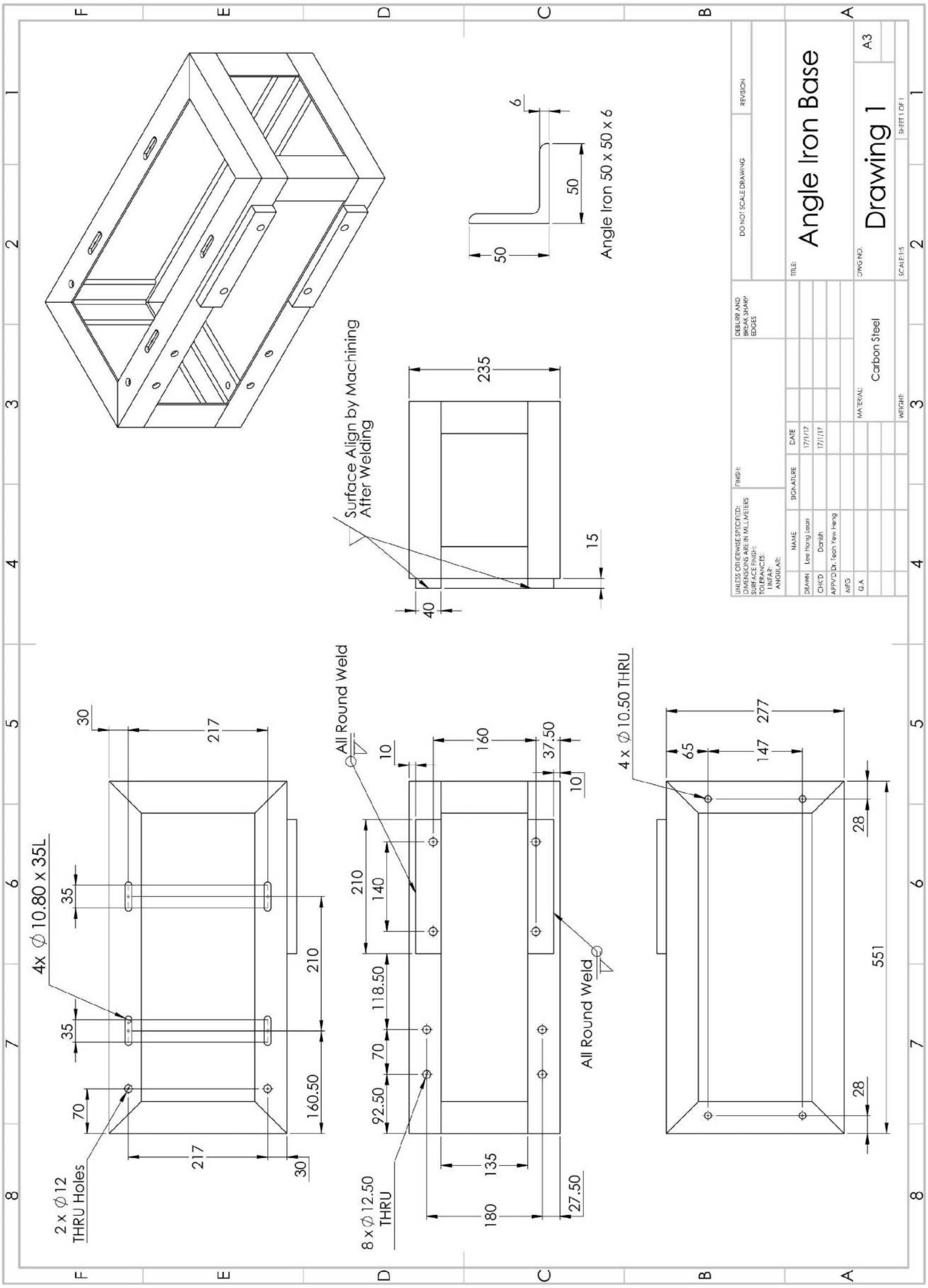
Max. Torque: 41.8 Nm

Max. Speed: 8000 rpm

Compatibility: Low capacity governed engines, motorcycle / scooter / moped engines.

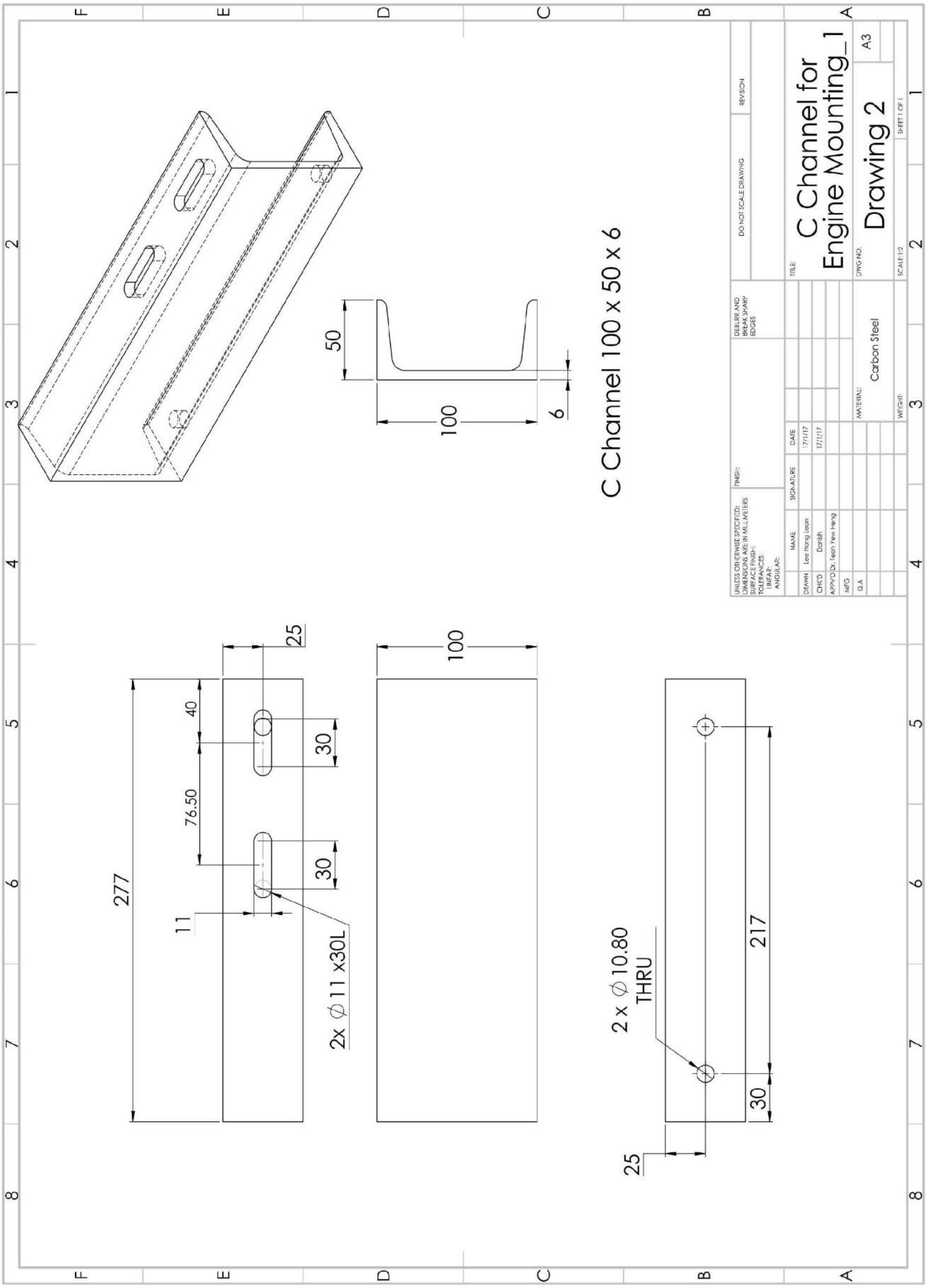
Appendix C-1

2-D Drawing of angle iron base



Appendix C-2

2-D Drawing of C Channel for Engine Mounting



Appendix C-3

2-D Drawing of Engine Shaft