# Combustion of a Controlled Condition Synthetic Gas with Diesel in a Single Cylinder Compression Ignition Engine

By

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Dissertation is submitted in partial fulfillment of
requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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# CERTIFICATE OF APPROVAL

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Approved by,

(Ir. Dr. Shaharin Anwar Sulaiman)

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TRONOH, PERAK

SEPTEMBER 2011

# CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD HUSNI BIN MUHAMMAD SANI

# ABSTRACT

The application of diesel engine is very wide since it is suitable for heavy-duty applications. Besides that, it is also reliable since it can last for a long period under proper maintenance. However, there are two big issues related to diesel engine nowadays, which are the depletion of liquid fuel sources and also the emission of hazardous gases from its operation. Replacing diesel fuel with another alternative like syngas is one of the many possible solutions for the problems. However, syngas from biomass gasification is known for its fluctuation of content and composition. Hence, parameters like syngas composition, combustion temperature, emission and calorific value are still questionable. In this project, imitated syngas is burned in a diesel engine and the performance and the emission of the engine is analyzed. The emitted gas from the engine is analyzed with a gas analyzer unit to observe the compositions of the exhaust gas. As for the performance, the engine unit is equipped with an instrumentation unit which will provide important parameters like engine torque and speed. The engine results in the dual fuel mode will be compared to the datum which fully diesel engine operation. At the end of the project, it is found that the engine performance is dropped as the syngas is introduced into the operation. However, it is compensated by less hazardous gases emission from the engine exhaust.

# ACKNOWLEDGEMENT

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# ABBREVIATIONS

| | |
|---|---|
| CI | Compression-ignition |
| CO | Carbon monoxide |
| FYP I | Final Year Project 1 |
| FYP II | Final Year Project 2 |
| NGO | Non-governmental organization |
| $NO_x$ | Oxides of nitrogen |
| SI | Spark-ignition |
| $SO_x$ | Oxides of sulphur |
| VOC | Volatile organic compound |
| WBS | Work breakdown structure |

# NOMENCLATURES

| | |
|---|---|
| $AFR$ | Air to fuel ratio |
| $HV_{syngas}$ | Syngas heating value |
| $HV_f$ | Diesel heating value |
| $\dot{m}_a$ | Air mass flow rate at 27°C and 1013 kPa |
| $\dot{m}_{a,c}$ | Corrected air mass flow rate |
| $\dot{m}_f$ | Diesel mass flow rate |
| $\dot{m}_g$ | Mass flow rate of syngas |
| $M_g$ | Molecular weight of the syngas |
| $n_B$ | Brake thermal efficiency |
| $n_g$ | No. of mole of the syngas |
| $n_T$ | Total no. of mole of the syngas |
| $N$ | Angular velocity in rad/s |
| $P_a$ | Ambient pressure |
| $P_B$ | Brake power |
| t | Time, in s |
| $T_a$ | Ambient temperature |

# GREEK SYMBOLS

| | |
|---|---|
| $\bar{x}$ | Average from the set of data |
| $x_i$ | Corresponded data |
| $\rho_g$ | Density of the syngas |
| $\hat{\sigma}$ | Standard deviation |
| $\hat{\sigma}^2$ | Variance |

# CHAPTER 1

# INTRODUCTION

## 1.1 Project Background

The idea of implementation of syngas arises when the environmental factors like petroleum liquid fuel depletion and emission of hazardous gases are taken into consideration. Syngas can be produced from gasification of biomass. Therefore, it is expected that syngas can be a suitable alternative to face the depletion of petroleum liquid fuel problem. However, the implementation of syngas still requires many researches since the technologies existed are not fully enhanced. Apart from that, currently there are no engines that can run on fully syngas. It is because certain amount of diesel is still required to initiate the operation of the engine (Thayagarajan and Babu, 1985). Due to that, the aim of this project is to help in finding the possibility to implement syngas with the means of experimental works and data analysis.

## 1.2 Problem Statement

Diesel engine is very popular for heavy-duty applications like lorries, trucks and electrical power generation. However, similar to gasoline engine, diesel engine depends largely towards liquid fuels, which comes from petroleum. Since petroleum depletion issue is heavily discussed nowadays, an alternative source of energy is really needed to cope with this problem. Apart from that, diesel engine also emits hazardous gases during its operation. Syngas from gasification of biomass is one of the possible alternatives for the diesel liquid fuels. Biomass is one the most available alternative energy nowadays. In addition, syngas also emits less hazardous gases compared to diesel fuel. However, for syngas, which is produced by gasification of biomass, its composition and content fluctuates. Due to this, a direct comparison cannot be done since the composition of the syngas used by different users might not be the same. In addition, there are no current technologies that allow the diesel engine to run fully on syngas. A small portion of diesel fuel is still needed especially during the combustion initiation process.

## 1.3 Objectives and Scopes of study

The objective of the project is to study the effect of controlled syngas-diesel fuel conditions on the performance and emission of a single cylinder diesel engine. Even though syngas is one of the possible alternatives for diesel fuel replacement, the information about it in the application is still limited. In this project, the combustion of syngas is studied by the means of imitation. The imitation is done to encounter the problem of syngas composition and content fluctuation. Since syngas is produced from the gasification of biomass, the composition usually depends on the type of raw material and the gasification process itself (Hassan, 2010).

The scopes of study in this project is largely involved the studies in energy area. The aim of the project is to provide an alternative fuel as a replacement due to depletion of fossil fuels. The project consist mainly the application of thermodynamics to understand the basic of diesel engine operation. Besides that, the thermodynamics concept also is used to determine the efficiency of the system. As for the practical works, series of experimental works are conducted to understand the performance and emission of a dual-fuel engine. In the experiment, the syngas compositions are varied and it is gradually replaced the diesel during the engine operation.

## 1.4 Significance of Project

Issues of fossil fuel depletion are one of the important considerations for most of the world community nowadays. Since the fossil fuel is a non-renewable fuel, the future shortage of supply cannot be avoided. Due to that, the implementation of other energy sources is required to reduce the dependency on fossil fuel. By the year 2025, the world fossil fuel usage needs to be reduced up to 33 % to cope with shortage of fossil fuel (Emery, 2010). One of the possible alternative energy sources is biomass. In this project, syngas is used to run an engine which fully runs on diesel initially. This syngas is the imitation of a producer gas produced in a biomass gasification process. From the project, it is a hope that world community would start to see the potential of biomass as one of the alternative energy. Besides, the performance and emission of diesel engine in dual fuel mode is expected to be studied in the project.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Global Warming

Global warming is defined as the raise of Earth temperature due to heat which is trapped inside Earth atmosphere due to high amount of greenhouse gases. Greenhouse gases are gases which block the infrared radiation from sun from escape back to space. As a result, this radiation traps and causes a rise in Earth surrounding temperature. Figure 2.1 shows the graphical representation for this issue. The term greenhouse is used since the same effect is observed in a greenhouse for plantations in four season's country. Some examples of greenhouse gases are carbon dioxide, nitrous oxide and methane. The amount of these gases increase in Earth atmosphere due to several human activities like emission from vehicles and factory. Based on Boostels et. al, for every 4000 km travel distance, a diesel passenger car will emit 205.3 g/km of carbon dioxide. Due to that, it can be observed the amount of carbon dioxide emit are very high if every diesel passenger car in this world is taken into consideration. Therefore, solutions to minimize this emission as example must be found to ensure sustainability of Earth for future generation.

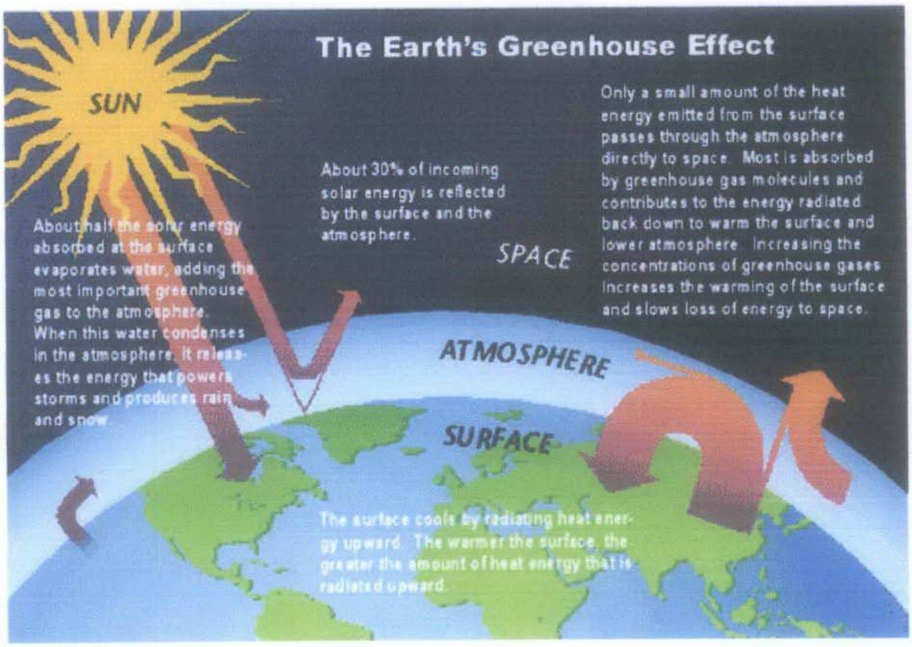


Figure 2.1: The Earth's Greenhouse Effect (Strickland and Grabianowski, 2009).

## 2.2 Diesel Engine

Diesel engine is first proposed by Rudolph Diesel back in the middle of 1980's. The engine is almost the same as spark-ignition engine but mainly different in the method of initiating the combustion. The diesel engine is classified as compression ignition (CI) engine since the combustion initiation. In CI engines, the air is compressed to a temperature that is above the auto ignition temperature of the fuel. The combustion then starts as the fuel is injected to the hot air mentioned previously (Cengel, 2007). Contrary to spark ignition engine (SI) e.g.: gasoline engine, the CI engine does not require any additional firing from a spark plug. Therefore, in term of configuration, the spark plug is replaced with a fuel injector. Besides that, the carburetor also is excluded from diesel engine assembly since the compressed fluid is only air. Figure 2.2 shows the combustion initiation process in gasoline and diesel engine as well as the differences between these two engines.

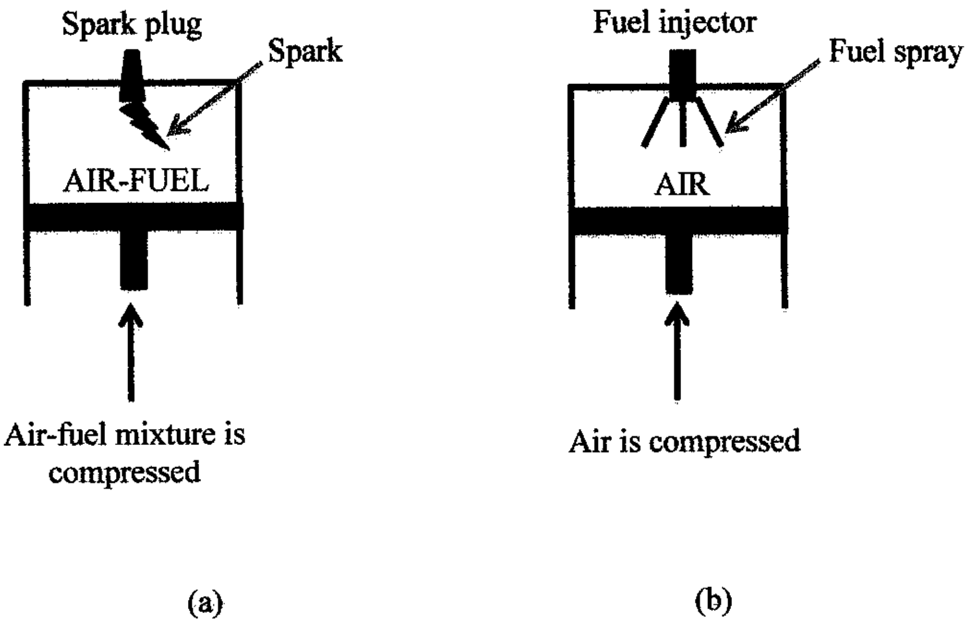
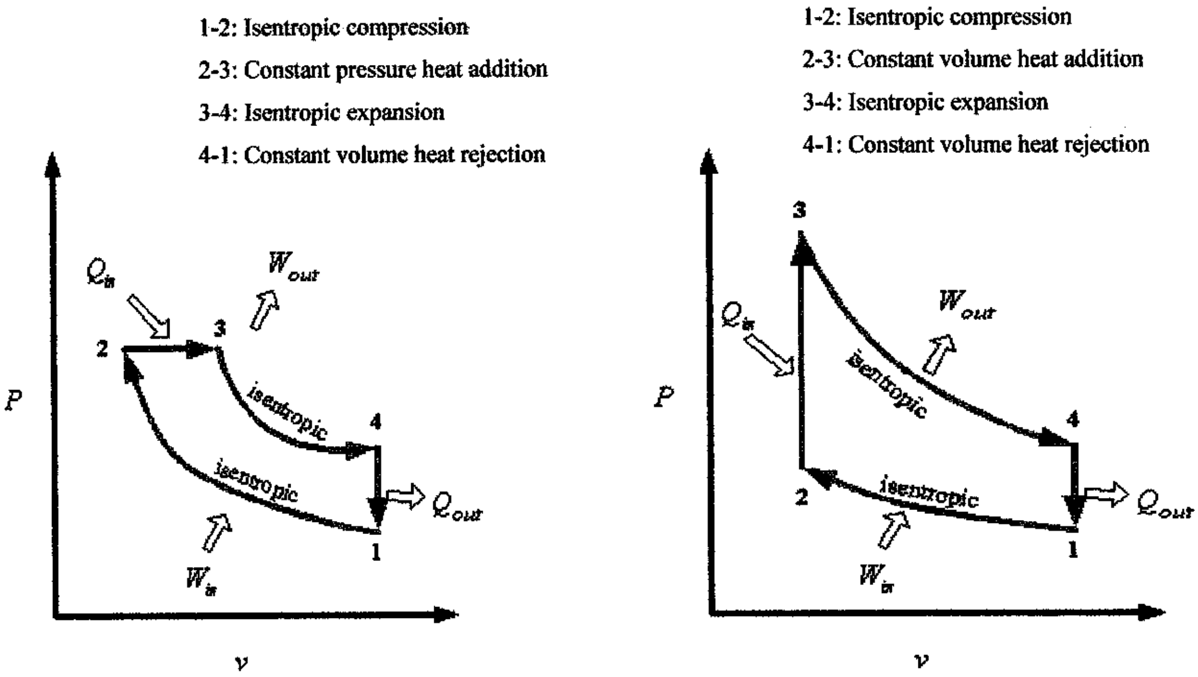


Figure 2.2: Combustion initiation process of (a) gasoline engine and (b) diesel engine.

The ideal cycle of CI engine is represented by the diesel cycle. The cycle can be divided into four different processes as shown in Figure 2.3. Based on Figure 2.3, process 1-2 is isentropic compression, 2-3 is constant pressure heat addition, 3-4 is isentropic expansion, and 4-1 is constant heat rejection. In diesel cycle, the combustion process is approximated as a constant pressure heat addition (process 2-3). With comparison to the Otto cycle (spark-ignition ideal cycle), the only difference process is only at process 2-3. In Otto cycle, rather than constant pressure heat addition, the combustion process is approximated as constant volume heat addition. Figure 2.3 shows P-v diagram for both Otto and Diesel cycle to illustrate the difference between those two cycles. The higher efficiency and lower fuel costs make diesel engine really popular in application, which requires relatively large amount of power like in locomotive engine.



**Diesel Cycle**

**Otto Cycle**

Figure 2.3: Diesel and Otto cycle P-v diagram.

## 2.3 Dual – Fuel Concept

Due to environmental effects, the interest in generating alternative fuels for internal combustion engines is continuously developing. The high emission of carbon dioxide, $CO_2$ and hazardous gases like sulfur dioxide, $SO_2$ is the major drawback for the conventional internal combustion engine. Based on previous researches, a dual-fuel engine is one of the possible alternatives to overcome this problem. In this concept, the gaseous fuels are used as a supplement for liquid diesel fuel (Sahoo et al., 2008). The term dual is used since the engine cannot run with the gaseous fuel only. Based on Sahoo, the liquid diesel fuel is a necessity for the duel-fuel engine operation. It is because, the compressed mixture of air and gaseous does not auto ignite due to high auto-ignition temperature. Hence, liquid fuel is used to fire the mixture spontaneously during the combustion phase (Thayagarajan and Babu, 1985). However, the duel – fuel engine is expected to run with 100 percent gaseous fuel provided that diesel liquid fuel is available during the ignition and its amount is gradually decreasing throughout the process.

In term of emission, the dual – fuel engine produces virtually insignificant amount of $SO_x$ and relatively low amount of $NO_x$. Both of these gases are the main constituents of acid rain. In addition, it also produces substantially less $CO_2$, one of the main greenhouse gases (Henham and Makkar, 1998). Based on experiment conducted by Uma et al (2004), the emission of $NO_x$ in duel fuel is lower compared to diesel engine alone. In addition, the emission of $SO_2$ is also significantly lower for dual-fuel engine. However, the emission of carbon monoxide, CO is higher for dual-fuel engine. The high amount of CO represented the incomplete combustion in the dual-fuel engine. Therefore, the utilization of dual-fuel concept must come with another extra effort to overcome this problem. One of the possible solutions is by producing a specific engine which suitable for gaseous fuel combustion rather than modifying the existing diesel engine. Table 2.1 shows the full result obtained from Uma et al. (2004) experiment.

The brake thermal efficiency of a dual fuel engine is found to be lower compared to the engine run in fully diesel. This might be due to the lower charge temperature at the end of cylinder compression process, low flame velocity of the gaseous fuels-air mixture and enough time available for the heat to transfer to the adjacent cylinder walls (Lata and Misra, 2010). Besides that, the performance of the dual fuel engine also depends on the composition of the secondary fuels (Saleh, 2008).

Table 2.1: Concentration of pollutants from diesel engine in diesel alone and dual-fuel mode (Uma et al, 2004).

| Parameter | Load (kW) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10 | | 20 | | 30 | | 40 | |
| | Diesel | Dual fuel | Diesel | Dual fuel | Diesel | Dual fuel | Diesel | Dual fuel |
| CO | 181 | 635 | 207 | 640 | 284 | 734 | 323 | 904 |
| (ppm) | 174 | 661 | 218 | 681 | 275 | 693 | 303 | 941 |
| | 172 | 672 | 232 | 696 | 294 | 705 | 336 | 922 |
| $CO_2$ | 3.1 | 6.2 | 4.2 | 7.1 | 5.7 | 9.2 | 6.1 | 11.0 |
| (ppm) | 3.0 | 6.0 | 4.1 | 7.2 | 5.8 | 9.1 | 6.1 | 10.9 |
| | 3.2 | 6.2 | 4.2 | 7.2 | 5.9 | 9.3 | 6.2 | 11.1 |
| HC | 109 | 119 | 132 | 141 | 180 | 182 | 270 | 262 |
| (ppm) | 112 | 127 | 125 | 136 | 188 | 178 | 271 | 288 |
| | 103 | 113 | 116 | 121 | 187 | 192 | 276 | 284 |
| $CH_4$ | 7.0 | 18 | 8.4 | 24 | 10.2 | 21 | 12.1 | 32 |
| (ppm) | 7.2 | 12 | 9.2 | 27 | 10.1 | 32 | 12.3 | 30 |
| | 7.0 | 14 | 8.7 | 30 | 10.2 | 25 | 11.8 | 36 |
| $SO_2$ | 4.6 | 1.1 | 5.4 | 1.2 | 6.8 | 1.5 | 9.6 | 2.3 |
| (ppm) | 4.2 | 1.2 | 5.0 | 1.2 | 6.9 | 1.6 | 9.6 | 2.3 |
| | 3.9 | 1.2 | 5.8 | 1.3 | 8.4 | 1.9 | 10.3 | 1.9 |
| $NO_2$ | 172 | 93 | 230 | 140 | 279 | 170 | 412 | 240 |
| (ppm) | 181 | 98 | 229 | 145 | 282 | 161 | 403 | 249 |
| | 188 | 101 | 224 | 137 | 279 | 171 | 405 | 253 |
| Particulates | 22 | 18 | 26 | 24 | 29 | 24 | 33 | 28 |
| ($mg/m^3$) | 20 | 20 | 20 | 27 | 23 | 18 | 27 | 22 |
| | 27 | 22 | 32 | 24 | 32 | 29 | 36 | 40 |

## 2.4 Syngas

Syngas (derived from synthetic gas) is a term given to the gas mixture, which contains varying amount of carbon monoxide and hydrogen. One of the possible methods to produce this syngas is by gasification of biomass. Examples of biomass which can be used in this method are residues from forest, agricultural and organic processing. Gasification process generally converts biomass through partial oxidation into a gaseous mixture of syngas consisting of hydrogen ($H_2$), carbon monoxide (CO), methane ($CH_4$), and carbon dioxide ($CO_2$) (Lijun et. al., 2008). Generally, the gasification can be divided into four main processes, which are drying, pyrolysis, gasification and reduction (oxidation) and it is conducted in a gasifier. In the gasifier, each of these processes is divided by a hypothetical imaginary boundary. Figure 2.4 shows the four gasification processes with respect to their position in a gasifier.

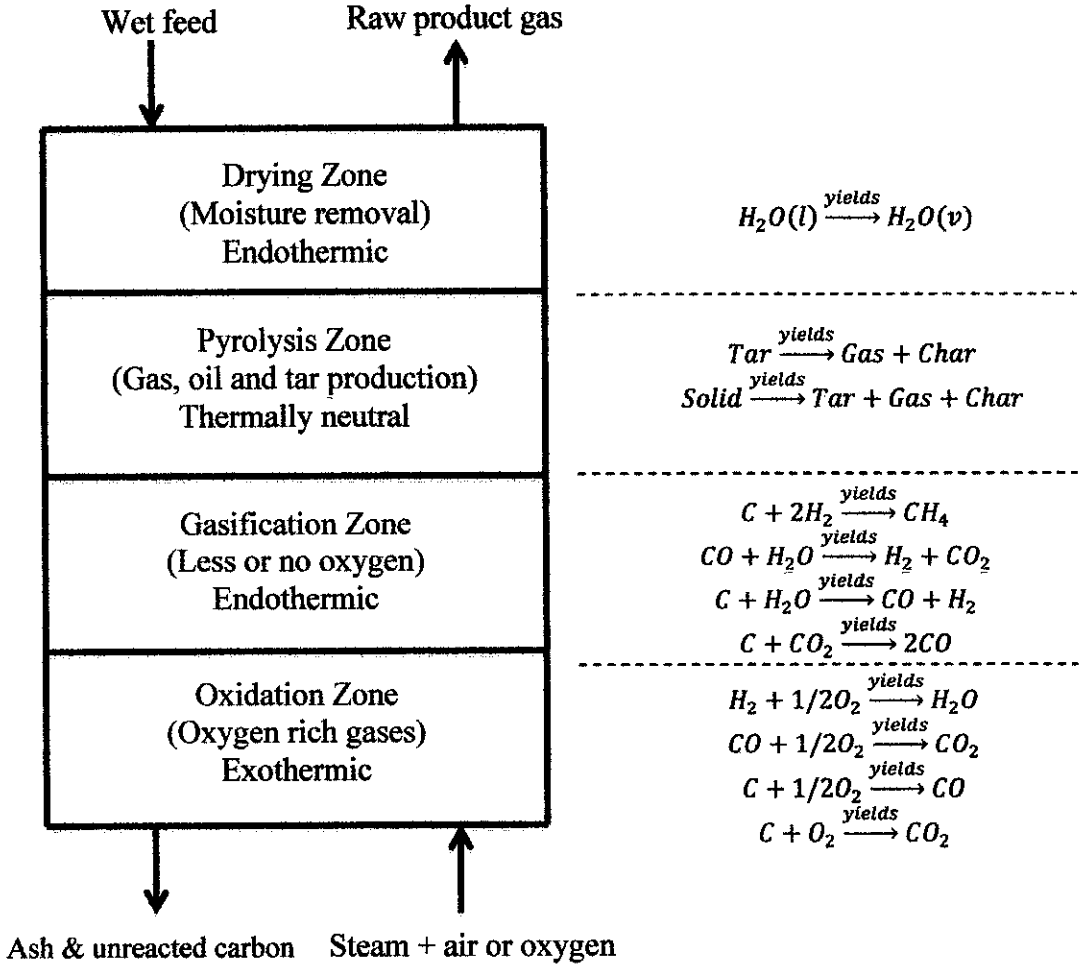


Figure 2.4: Gasification process in an updraft gasifier (Lee, 2010).

Gasification process is conducted in a gasifier and there are three main types of gasifiers: fixed bed, moving bed and fluidized bed. Fixed bed gasifier can be further divided into three different configurations which are updraft, downdraft and cross-flow. The term used to describe these gasifiers is based on the location of the syngas outlet in the gasifiers. Figure 2.5 shows all of these fixed bed gasifiers. Generally, fixed bed gasifiers produce syngas with large amount of tar due to low and non-uniform heat and mass transfer between solid and gasifying agents (Lijun et al., 2008). However, fixed bed gasifiers are simple and economically suitable for small and in-situ applications. Contrary to fixed bed gasifiers, fluidized bed gasifiers are relatively requires a very high financial investment. However, the fluidized bed gasifiers can achieve a higher heating rate, uniform heating and higher productivity compared to fixed bed gasifiers. Hence, this type of gasifier is more suitable for big scale applications.

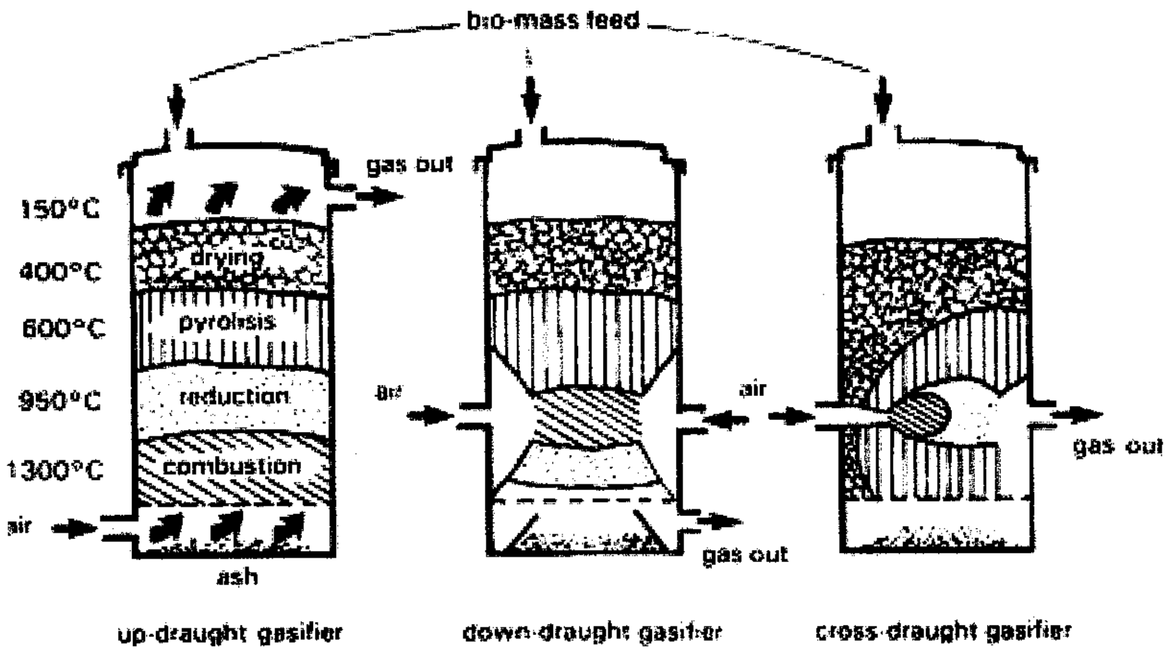


Figure 2.5: Fixed bed gasifiers; up draught, downdraught, and cross draught gasifiers (Lee, 2010).

In order to produce a high quality syngas at the end of gasification process, several quality control procedures have been proposed. Generally, syngas quality control can be divided into two categories, which are treatments during gasification and gas cleaning after gasification (Lijun et al., 2008). For the treatments during gasification, the process can be further classified into three different methods, which are gasifier modifications, proper selection of operating parameters and use of additives or catalysts. In term of design, the gasifier should be able to have highest heating rate possible to avoid the formation of coke/char. Basically, the design aspect is the main reason for fluidized bed advantage over fixed bed. During gasification, there are three parameters, which affect the formation of char and the tar formulation. These parameters are temperature, pressure and equivalence ratio. Higher gasification temperature can produce high carbon conversion (Devi et al., 2003). However, excessive gasification temperature would decrease the conversion efficiency.

For utilization, the syngas from biomass gasification can be used in power generation system. As an example, the syngas can be used in a combustor of coal based power generation. Compared to direct biomass, syngas from biomass gasification can increase the bio-based fuel percentage used in pulverized coal combustors without any concern about plugging of coal feeding system during co-firing of biomass coal (Lijun et al., 2008). Besides that, syngas is usually preferable compared to direct combustion since it produces lee ash and sluggish. It is because, the gasification temperature is lower compared to combustion and a clean syngas is supplied to the gasifiers. Besides that, it is also possible to directly burn syngas in a gas turbine. However, the syngas must be in high quality with almost no tar and dust. In addition, syngas also can be used in a diesel engine in a duel fuel concept as mentioned in Section 2.2. Other utilizations of syngas include synthesis of Fischer-Tropsch fuels, synthesis of methanol and dimethyl ether and fermentation for bio-based products production (Lijun et al., 2008).

# CHAPTER 3

# THEORIES

A two-stroke diesel engine is named based on the number of strokes involved in one complete cycle of the engine operation. Based on Figure 3.1, when the piston is at the top of its travel, the air inside the cylinder is highly compressed. Then, the diesel is injected to start the combustion. Due to the pressure, the piston would move downward. Then, as the piston near the bottom of the cylinder, exhaust valve is opened to release the exhaust gas. After the exhaust valve is closed, the piston travels upward and the whole cycle is repeated again. Based on the operation cycle of the engine, there are several important parameters which are highly related to the diesel engine operations. Some of the parameters are exhaust temperature, the mechanical power produces by the engine and also the rate of air and diesel introduce to the engine. In this section, the methods for calculating all of the mentioned parameters are discussed.

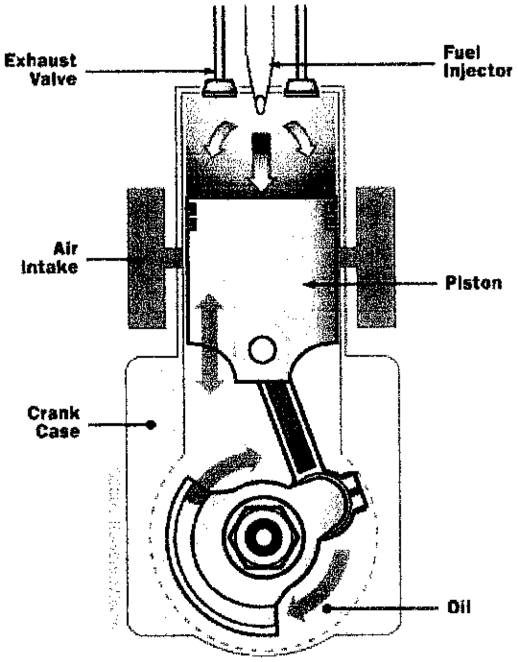


Figure 3.1: Schematic of a two-stroke diesel engine (Brain, 2007).

## 3.1 Speed Measurement

The engine speed is measured by the mean of pulse counting system. In this system, an infrared transmitter and receiver are mounted on the dynamometer chassis. Then, a rotating disc is placed between the transmitter and the receiver. As the disc rotates together with the engine shaft during operation, the beam from transmitter is interrupted. The resulting pulse from the interruption then is electronically processed for the engine speed measurement.

## 3.2 Torque Measurement

The torque in the project is measured by a dynamometer. The schematic of the dynamometer layout on the system is shown in Figure 3.2. Based on Figure 3.2, as the engine shaft drives the paddle (D), the vent casing (B) would chum up the water inside the dynamometer. Without restrain, the casing will rotate almost at the same speed as the paddle. In the experimental setup, the restrain is provided by spring (F), which is in the same tension and stiffness. In this arrangement, the angular position of casing (B) depends on the engine torque and the stiffness of the spring (F). The relationship between the casing (B) displacement and the torque is measured by a rotary potentiometer (Kamal, 2010). The output from the potentiometer then is used as an input for the torque meter on the instrumentation unit.

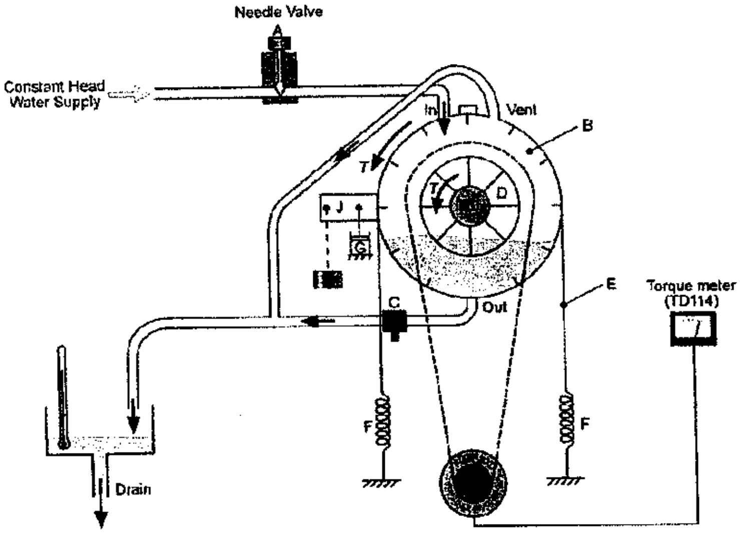


Figure 3.2: Schematic of the dynamometer (Kamal, 2010).

### 3.3 Exhaust Gas Temperature Measurement

The exhaust gas temperature is measured with a thermocouple. The thermocouple is placed into the exhaust pipe and it is connected to the instrumentation unit. The measurement of the thermocouple is indicated on the reading meter in degrees centigrade.

### 3.4 Diesel Mass Flow Rate

The diesel consumption $\dot{m}_f$ is determined by measuring the rate of consumption of 8 ml fuel by the engine as shown in Equation (3.1). In the calculation, the time for 8 ml pipette, $t$ is recorded for the mass flow rate calculation. The diesel supply comes from a tank located on the top of the instrumentation unit. Mass flow rate gives an indication on how fast the fuel is consumed during the operation. Diesel specific gravity in kg/ $m^3$ is termed as $SG_f$ in Equation (3.1).

$$\dot{m}_f = \frac{SG_f \times 8 \, x \, 10^{-3}}{t} \tag{3.1}$$

### 3.5 Air Mass Flow Rate

Mass flow rate of air is directly proportional to the average velocity for a given air density. Hence, the pressure drop across a viscous element is proportional to the flow rate. The pressure drop is usually calibrated by inclined tube monometer. Figure 3.3 shows the typical calibration curve for air at 1013 mb and 20°C. For different temperature and pressure, Equation (3.2) is used to obtain the corrected air mass flow, $\dot{m}_{a,c}$. From Equation (3.2), air mass flow rate at 27°C and 1013 kPa is represented as $\dot{m}_a$ while ambient temperature is represented as $T_a$. Air mass flow rate is important to know how much air is consumed in the combustion process. Low amount of air will disturb the ideal fuel to air ratio, which results in incomplete combustion.

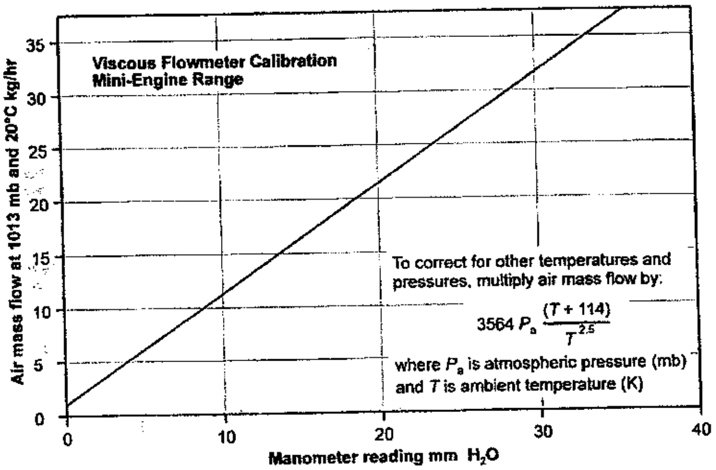


Figure 3.3: Viscous flow meter calibration (Zakaria, 2010)

$$\dot{m}_{a,c} = \dot{m}_a P_a \frac{(T_a+114)}{T_a^{2.5}} \tag{3.2}$$

### 3.6 Air to Fuel Ratio

Air to fuel ratio, $AFR$ is obtained by dividing the air mass flow rate, $\dot{m}_{a,c}$ with the fuel mass flow rate, $\dot{m}_f$ (3.3). The ratio then is compared with the ideal ratio for the diesel engine operation.

$$AFR = \frac{\dot{m}_{a,c}}{\dot{m}_f} \tag{3.3}$$

### 3.7 Brake Power

Brake power, $P_B$is a term given to the power at the output shaft since the dynamometer acts as a brake on the engine. The power is calculated by multiplying the torque, $T$ with the angular velocity, $N$ of the output shaft (3.4).

$$P_B = \frac{2\pi N}{60} T \tag{3.4}$$

## 3.8 Syngas Density

The syngas density, $\rho_{syngas}$ is obtained from series of calculations. In the experimental work, the syngas is fed into the system based on volume basis percentage. First, the mass of the syngas, $\dot{m}_g$ is obtained by multiplying its density, $\rho_g$ with its respective volume, $\dot{V}_g$ (3.5). Then, the mass is converted into the number of mole, $n_g$ (3.6). Molecular weight is represented as $M_g$ in (3.6). Since the syngas consists of many constituents, the mole fraction is obtained for each of the constituents, $\%n_g$ (3.7). The total no. of mole is represented as $n_T$ in (3.7). Finally, the density is obtained by multiplying the mole fraction with the density of the respective constituents (3.8).

$$\dot{m}_g = \dot{V}_g \rho_g \tag{3.5}$$

$$n_g = \frac{\dot{m}_g}{M_g} \tag{3.6}$$

$$\%n_g = \frac{n_g}{n_T} \text{x } 100\ \% \tag{3.7}$$

$$\rho_{syngas} = \sum \%n_g\, \rho_g \tag{3.8}$$

## 3.9 Syngas Mass Flow Rate

Syngas mass flow rate, $\dot{m}_g$ is obtained by multiplying the syngas volume flow rate obtained from the instrumentation unit with the density of the syngas (3.9).

$$\dot{m}_g = \dot{V}_g \rho_{syngas} \tag{3.9}$$

### 3.10 Heating Value of Syngas

The total heating value of syngas, $HV_{syngas}$ is a summation of all of the syngas compositions heating value respectively. Heating value can be obtained by multiplying the mole fraction with the heating value of each gas, $HV_g$ (3.10).

$$HV_{syngas} = \%n \times HV_g \tag{3.10}$$

### 3.11 Brake Thermal Efficiency

Brake thermal efficiency, $n_B$ is obtained by dividing the brake power obtained from the engine with the overall heating value of the fuel which is supplied to the engine (3.11). Brake thermal efficiency is important to see the percentage of the heat supply to the engine which is converted into the mechanical energy.

$$n_B = \frac{P_B}{\dot{m}_f HV_f + \dot{m}_g HV_{syngas}} \tag{3.11}$$

### 3.12 Variance and Standard Deviation

Since there are many data to be calculated in the experiment, the variance, $\hat{\sigma}^2$ and standard deviation, $\hat{\sigma}$ is used to measure how far the data are spread from each other. Variance for a set of data is calculated based on equation (3.12). On the other hand, standard deviation is the square root of the variance (3.13). The data average is represented as $\bar{x}$, no. of data as $N$, and corresponded data as $x_i$.

$$\hat{\sigma}^2 \cong \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2 \tag{3.12}$$

$$\hat{\sigma} \cong \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2} \tag{3.13}$$

# CHAPTER 4

# METHODOLOGY

## 4.1 Project Plan

The project is mainly divided into two different parts, which are FYP II and I respectively. The tasks for both FYP II and I are shown in Table 4.1. The sequence of tasks in the project is illustrated in a form of flowchart as shown in Figure 4.1. The correlation between the task and the project timeframe is shown in Figures 4.2 and 4.3.

Table 4.1: Tasks conducted during the project.

| No. | Task / Activity | Objectives of the task(s) | Remarks |
|---|---|---|---|
| 1. | Preliminary research | Obtaining basic understanding for extended proposal preparation | Conducted from Week 1 till Week 5 on semester May 2011. |
| 2. | Preliminary work | To provide basic requirement for the project.<br>• Lab scheduling.<br>• Obtaining permission for equipment usage.<br>• Understanding the procedure of the experiment.<br>• Preparing the extended proposal. | By the time of this proposal submitted, only approval from laboratory executive is still in process. |
| 3. | Replication of previous work done. | To understand the system mechanism.<br>To observe the effect of human error in conducting the experiment.<br>To find suitable improvement for the system. | Commenced after Mid-Semester break. |
| 4. | Data analysis | To observe the outcome from the previous task.<br>To determine the required parameter for the second experimental work. | Included in the interim report. |
| 5. | System improvement | To provide better results compared to previous work done. | Commenced during FYP 2. |
| 6. | Experiment with new parameters | To conduct the experiment under new parameter compared to previous work done. | The core of the project, consumed most of the time. |
| 7. | Data analysis | To analyze the data obtained from the experimental work. | Conducted simultaneously with the experimental work. |
| 8. | Preparation for presentation and report writing | To provide means of delivering the result from the experiment to people. | Part of project evaluation. |

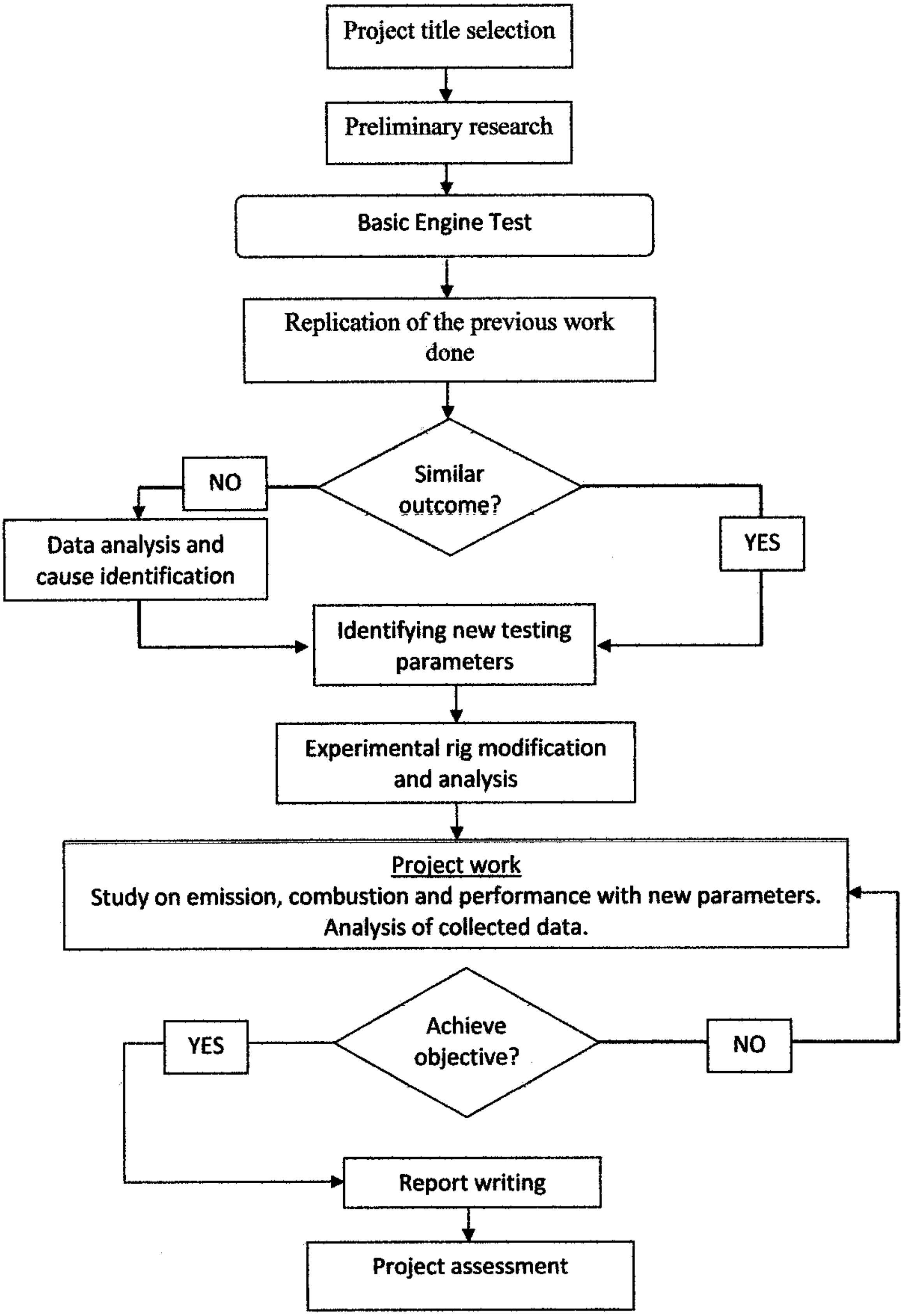
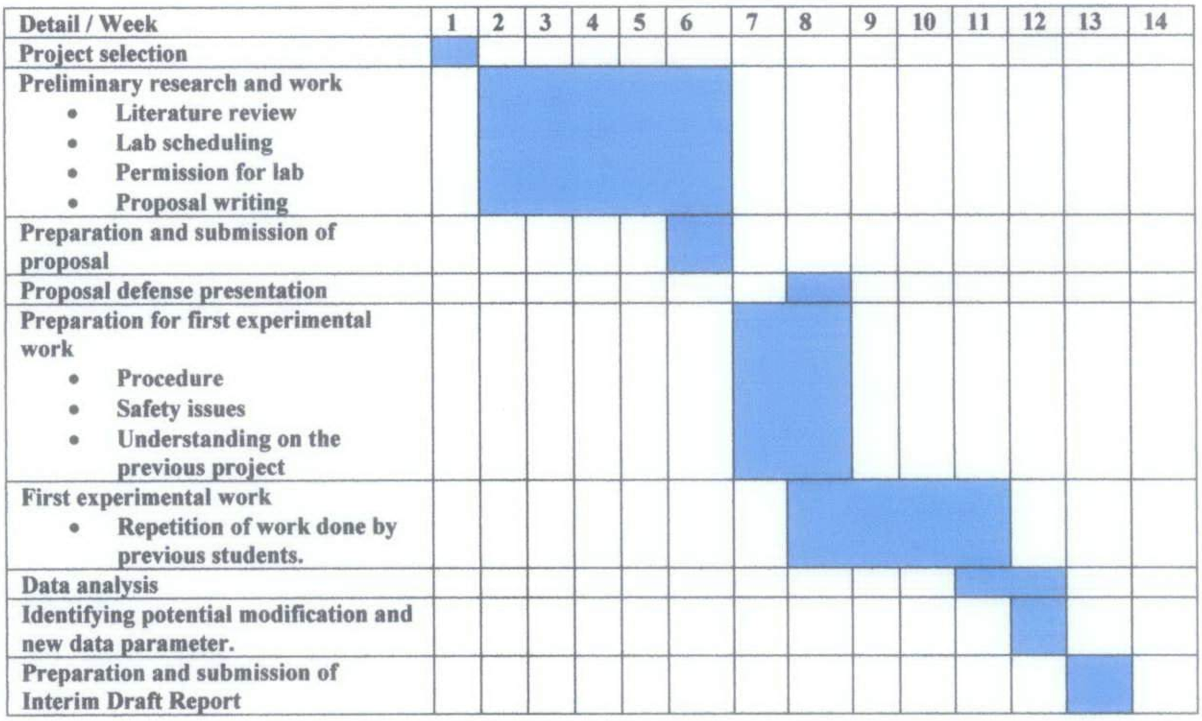
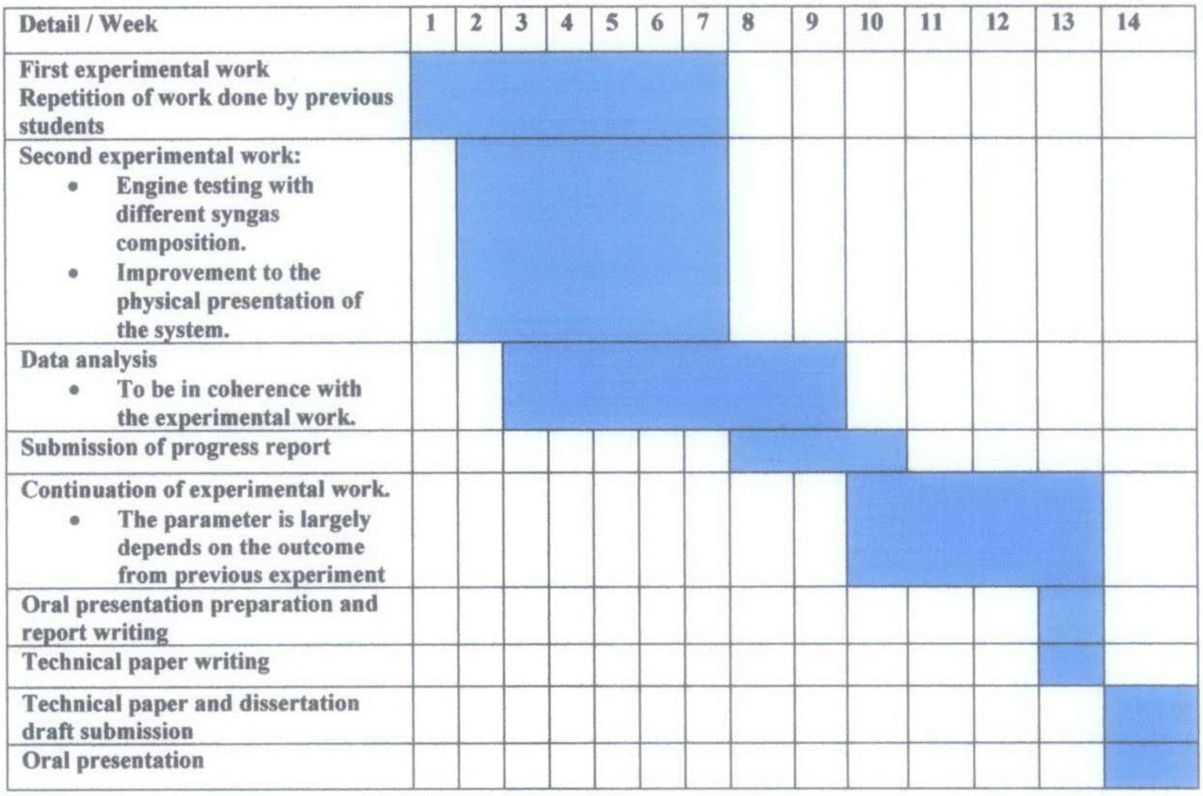


Figure 4.1: Flow chart of the project.



| Detail / Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Project selection | ■ | | | | | | | | | | | | | |
| Preliminary research and work<br>• Literature review<br>• Lab scheduling<br>• Permission for lab<br>• Proposal writing | | ■ | ■ | ■ | ■ | ■ | | | | | | | | |
| Preparation and submission of proposal | | | | | | ■ | | | | | | | | |
| Proposal defense presentation | | | | | | | | ■ | | | | | | |
| Preparation for first experimental work<br>• Procedure<br>• Safety issues<br>• Understanding on the previous project | | | | | | | ■ | ■ | | | | | | |
| First experimental work<br>• Repetition of work done by previous students. | | | | | | | | ■ | ■ | ■ | ■ | | | |
| Data analysis | | | | | | | | | | | ■ | ■ | | |
| Identifying potential modification and new data parameter. | | | | | | | | | | | | ■ | | |
| Preparation and submission of Interim Draft Report | | | | | | | | | | | | | ■ | |

Figure 4.2: Gantt chart for FYP 1



| Detail / Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| First experimental work<br>Repetition of work done by previous students | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | |
| Second experimental work:<br>• Engine testing with different syngas composition.<br>• Improvement to the physical presentation of the system. | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | |
| Data analysis<br>• To be in coherence with the experimental work. | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | |
| Submission of progress report | | | | | | | | ■ | ■ | ■ | | | | |
| Continuation of experimental work.<br>• The parameter is largely depends on the outcome from previous experiment | | | | | | | | | | ■ | ■ | ■ | ■ | |
| Oral presentation preparation and report writing | | | | | | | | | | | | | ■ | |
| Technical paper writing | | | | | | | | | | | | | ■ | |
| Technical paper and dissertation draft submission | | | | | | | | | | | | | | ■ |
| Oral presentation | | | | | | | | | | | | | | ■ |

Figure 4.3: Gantt chart for FYP 2

## 4.2 Experimental Apparatus

Schematic shown in Figure 4.4 illustrates the system. The engine used in the project is a single cylinder diesel engine. The engine air intake is modified to supply the syngas to the engine. Besides, it is also equipped with hydraulic dynamometer and instrumentation unit. The instrumentation unit is used to measure the torque, speed, exhaust temperature, fuel consumption and air flow rate. At the beginning of the operation, the engine is operated with one percent diesel fuel. Then, the amount of diesel fuel is gradually reduced and the syngas is added. The rotational speed of the engine is maintained at 2000 rpm. The syngas is controlled with a one-way valve and its flow is measured with a gas flow meter. The load of the engine is provided by a flow of water from the water supply. This mechanism still requires a lot of improvement since the pressure of the water is not constant.

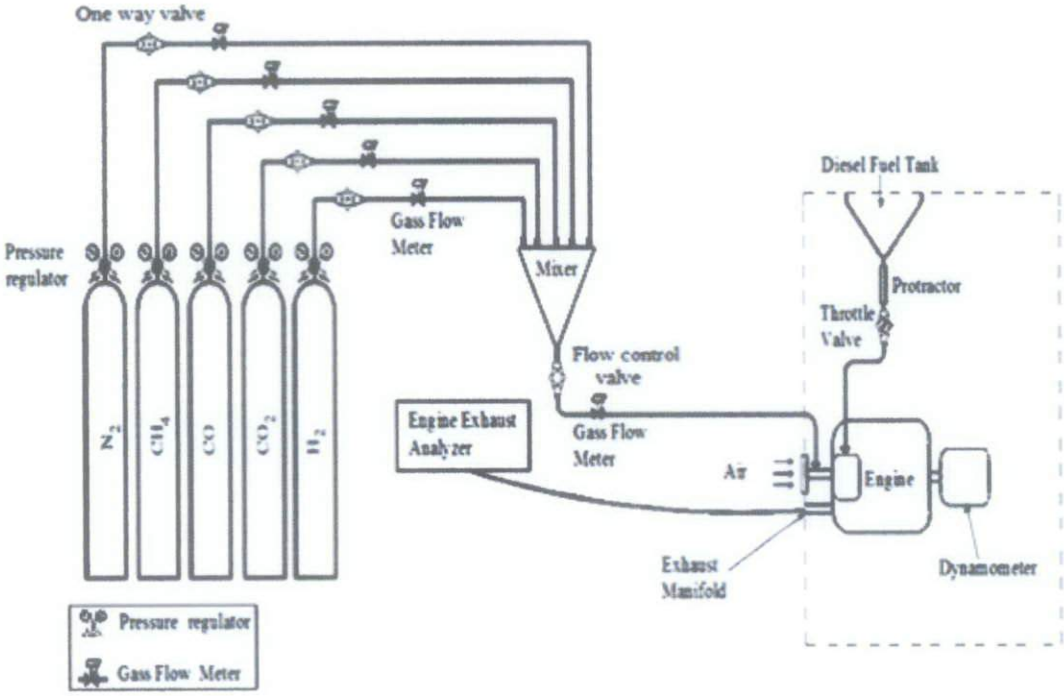


Figure 4.4: The schematic of the system (Kamal, 2010).

### 4.2.1 Diesel Engine

The single cylinder diesel engine used in this project is the TECUMSEH 5HP diesel engine. The engine has a bore with the dimension of 67 mm and a stroke of 49 mm. The normal speed operation of the engine is between 1000 to 3400 rpm with the maximum power output of 5.5 hp. Figure 4.5 shows the diesel engine. The air intake of the engine is modified to supply the syngas to the engine as shown in Figure 4.6.

Figure 4.5: TECUMSEH 5HP diesel engine used in the project.

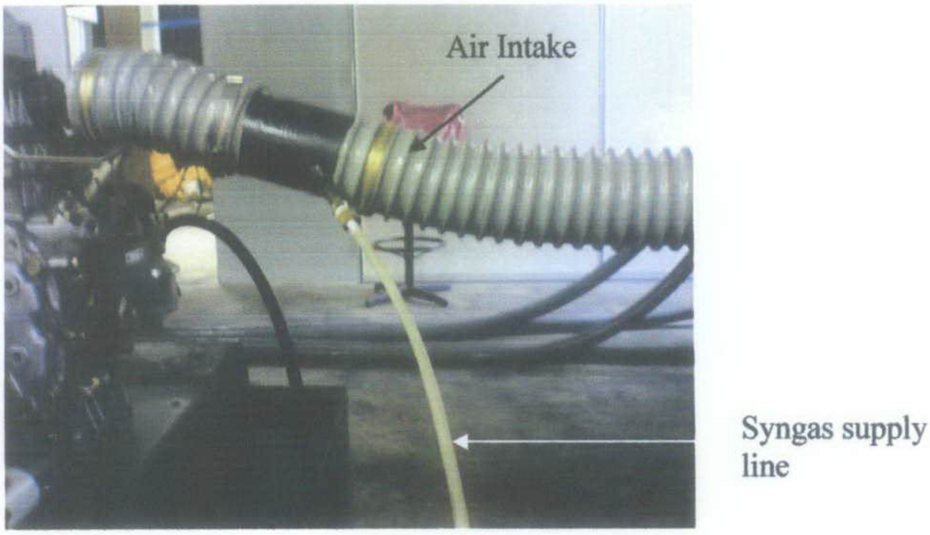


Figure 4.6: Modified air intake for syngas supply.

### 4.2.2 Instrumentation Unit

The instrumentation unit of the system provides all of the required information during the experimental work. The instrumentation is equipped with a torque meter, air flow manometer, fuel flow pipette, tachometer and the exhaust temperature meter. Figure 4.7 shows the graphical representation of the instrumentation unit.

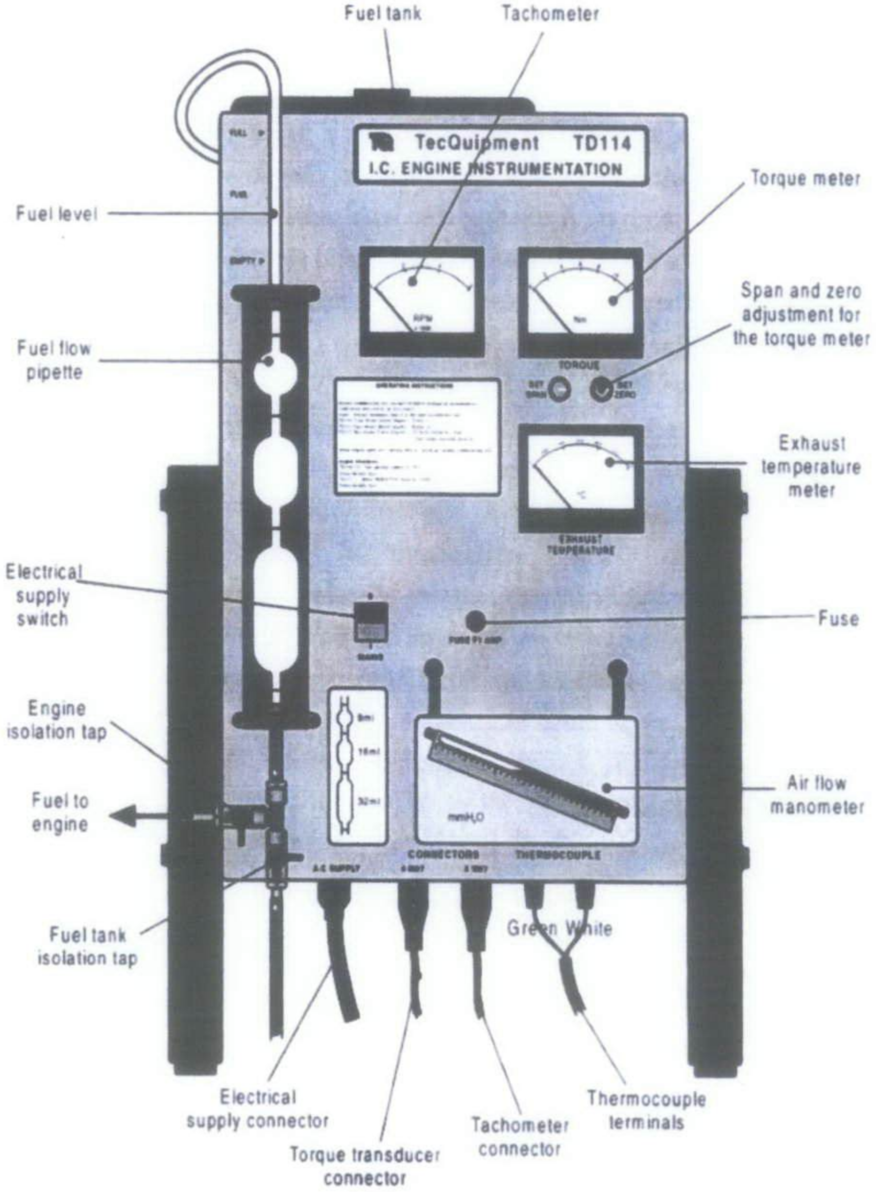


Figure 4.7: Instrumentation unit of the system (Kamal, 2010).

### 4.2.3 Gas Analyzer Unit

The gas analyzer unit is used to analyze the gas composition of the exhaust gas. The data from the analyzer is important to compare the emission of dual-fuel engine with the diesel engine operation. The gas analyzer is manufactured by Emerson Corporation. The unit consists of gas cooling unit, digital gas analyzer, pump and a filter. During its operation, the emission gas is supplied to the gas cooling unit inlet for cooling process. Then the gas is filtered in the filter before it is pumped into the gas analyzer. The gas analyzer unit then will analyze the composition of the gas. The analyzer is capable to detect for different gases which are carbon dioxide, hydrogen, methane and carbon monoxide. Figure 4.8 shows the overall setup of the gas analyzer.

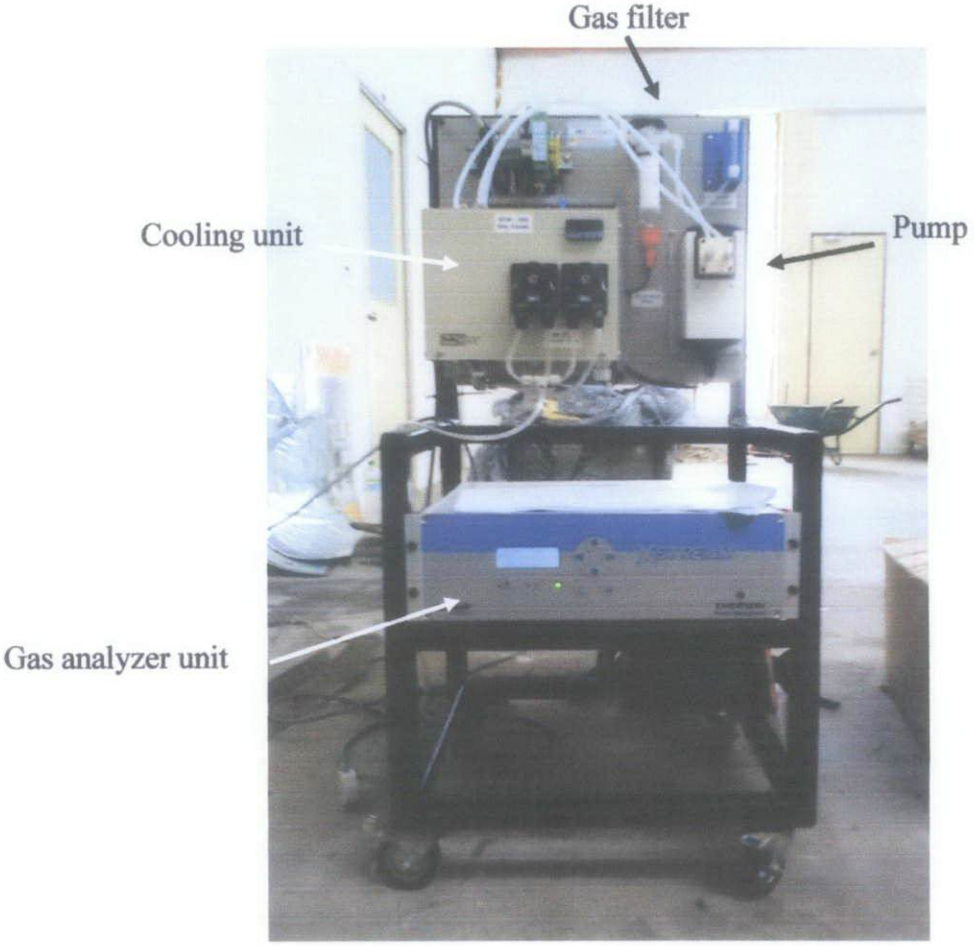


Figure 4.8: The overall setup of the gas analyzer unit.

### 4.2.4 Imitated Syngas

There are five gases used in this project to imitate the syngas. The gases are nitrogen, hydrogen, carbon monoxide, carbon dioxide and methane. All of these gases are stored in a rigid vessel and placed properly in the Power Generation Laboratory, Block N. The gases are mixed in a five way mixer before it is supplied to the diesel engine. Figure 4.9 shows the five way mixture of the gases.

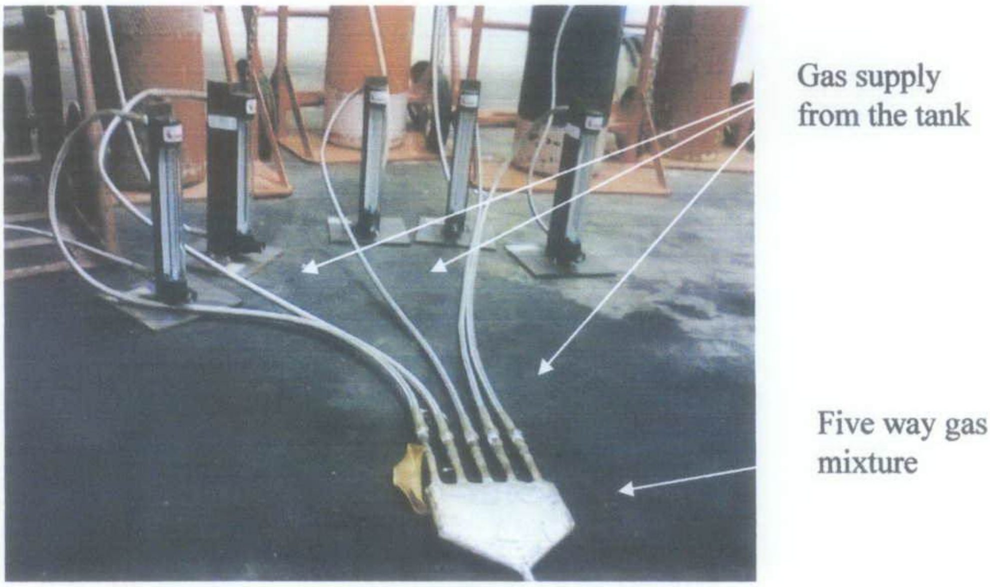


Figure 4.9: Five way mixture of the syngas.

### 4.3 Project Progress and Implementation

Based on Figure 4.3, the experimental work should start as early of Week 1 based on UTP September academic semester. However, due to lack of nitrogen supply, the work was shifted to Week 3. Besides that, some of the redundant session with another student also causes the schedule to be changed. The summary of experimental work progress is shown on Table 4.2. However, all of the experimental works are still can be conducted within the proposed timeframe.

Table 4.2: Summary of experimental work progress done during the project implementation.

| Date | Day | Planned Activities | Actual Activities | Week |
|---|---|---|---|---|
| 5-Oct | Wed | Replication | Equip. calibration (No Nitrogen) | 2 |
| 6-Oct | Thu | | | |
| 7-Oct | Fri | | | |
| 8-Oct | Sat | | | |
| 9-Oct | Sun | | | |
| 10-Oct | Mon | Composition 1 | Basic Engine Run | 3 |
| 11-Oct | Tue | | | |
| 12-Oct | Wed | | | |
| 13-Oct | Thu | | | |
| 14-Oct | Fri | Composition 2 | Replication 1 (2000 rpm) | |
| 15-Oct | Sat | | | |
| 16-Oct | Sun | | | |
| 17-Oct | Mon | Composition 3 | Replication 2 (1200 rpm and 2500 rpm) | 4 |
| 18-Oct | Tue | | | |
| 19-Oct | Wed | | | |
| 20-Oct | Thu | | Composition 1 | |
| 21-Oct | Fri | Composition 4 | Meeting with supervisor | |
| 22-Oct | Sat | | | |
| 23-Oct | Sun | | | |
| 24-Oct | Mon | Backup day | Composition 2 | 5 |
| 25-Oct | Tue | | | |
| 26-Oct | Wed | Backup day | Composition 2 | |
| 27-Oct | Thu | Backup day | Composition 3 | |
| 28-Oct | Fri | Backup day | Composition 3 | |
| 29-Oct | Sat | | | |
| 30-Oct | Sun | | | |

Apart from that, issues of lack of equipment also occurred during the implementation of the project. For an example, the limited availability of the gas filter for exhaust gas analyzer has caused the number of emission test conducted to be limited. Besides that, the exhaust gas analyzer also needs to be calibrated again in a maintenance session since it is already reached the limit of its usage.

# CHAPTER 5

# RESULTS AND DISCUSSIONS

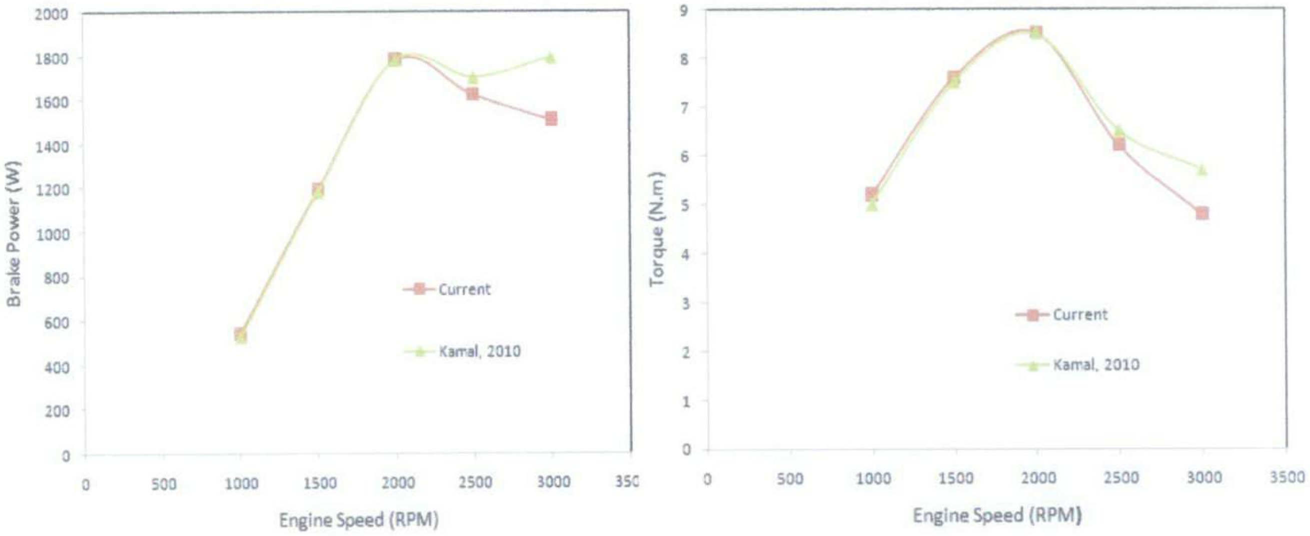
## 5.1 Basic Engine Test

Basic engine test is conducted to obtain the engine performance under fully diesel operating condition. The results obtained are used as a datum of the project. The engine speed is varied from 1000 RPM to 3000 RPM with 500 RPM increment during the test. The results obtained also are compared with results from Kamal (2011) to determine the precision of the engine.

The results obtained are summarized in Table 5.1. Then, the results are represented in a form of graph to obtain the pattern for each parameter with respect to engine speed increment. The red line on the graph represents the current results while green line represents result from Kamal (2011) findings. The graphs are represented from Figure 5.1 to Figure 5.3.

Table 5.1: Results from basic engine tests.

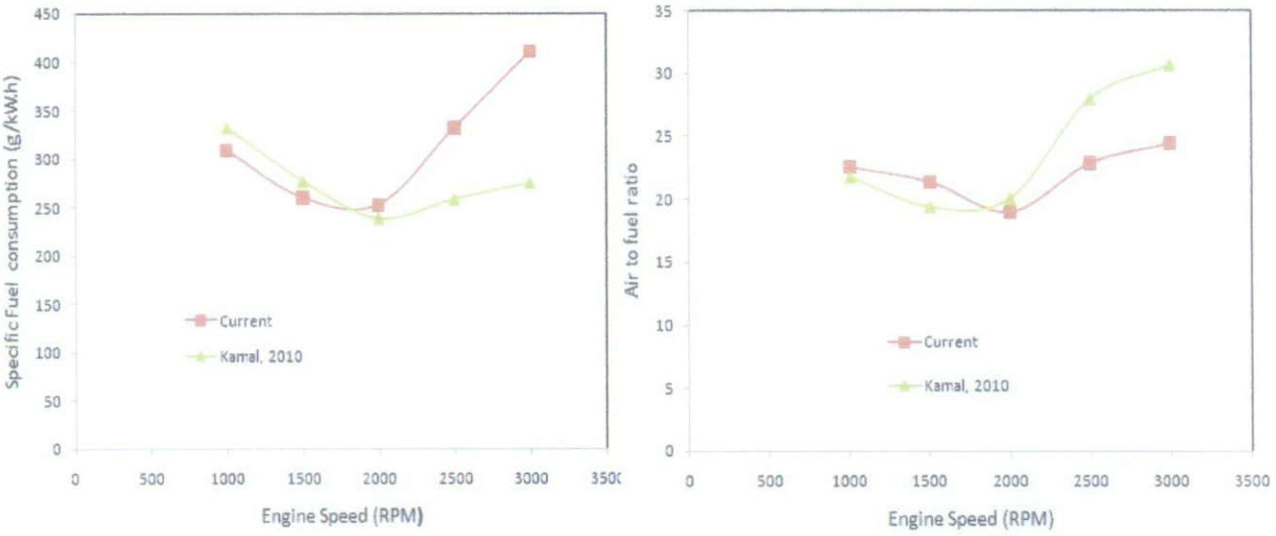
| Engine speed (RPM) | Torque (N.m) | Brake power (W) | Air consumption (kg/hr) | Fuel consumption (kg/hr) | Air to fuel ratio | Brake thermal efficiency (%) | Volumetric efficiency (%) | Exhaust temperature (°C) |
|---|---|---|---|---|---|---|---|---|
| 1000 | 5.2 | 544.76 | 3.79 | 0.17 | 22.54 | 29.94 | 31.37 | 200 |
| 1500 | 7.6 | 1194.29 | 6.63 | 0.31 | 21.37 | 35.56 | 36.60 | 250 |
| 2000 | 8.5 | 1780.95 | 8.52 | 0.45 | 18.97 | 36.61 | 35.29 | 270 |
| 2500 | 6.2 | 1623.81 | 12.30 | 0.54 | 22.85 | 27.83 | 40.78 | 310 |
| 3000 | 4.8 | 1508.57 | 15.14 | 0.62 | 24.42 | 22.45 | 41.83 | 330 |



(a) Engine Brake Power (b) Engine Torque

Figure 5.1: Basic engine test at different engine speed; (a) Engine Brake Power (b) Engine Torque.

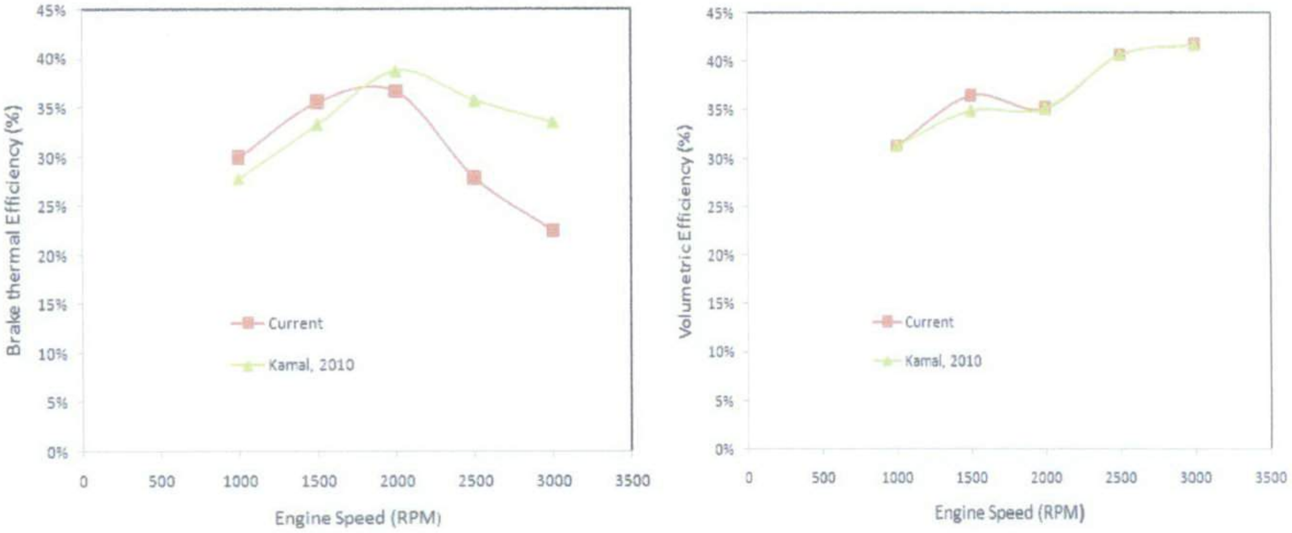
Based on Figure 5.1 (a), it is shown that brake power produced is almost similar for both current and previous findings. Notable variations occur when the engine operating speed is higher than 2000 RPM. From previous finding, the brake power produced is decreasing from 2000 RPM to 2500 RPM and starts to increase again from 2500 RPM to 3000 RPM. On the other hand, the brake power for current findings starts to decrease after engine speed of 2000 RPM. Besides, it is also almost similar to the engine characteristics proposed by the manufacturer. Hence, it can be concluded that some experimental errors might occur during experimental work conducted for previous findings. Similarly to engine brake power pattern, decrement of engine torque starts to occur when the speed is more that 2000 RPM as shown in Figure 5.1 (b). Hence, it can be concluded that the maximum operating condition of the engine is 2000 RPM.



(a) Specific Fuel Consumption

(b) Air to fuel ratio

Figure 5.2: Basic engine test at different engine speed; (a) Specific Fuel Consumption (b) Air to Fuel Ratio.



(a) Brake Thermal Efficiency

(b) Volumetric Efficiency

Figure 5.3: Basic engine test at different engine speed; (a) Brake Thermal Efficiency (b) Volumetric Efficiency.

Based on Figure 5.2 (a), it is observed that the specific fuel consumption exhibits a negative exponential pattern. The specific fuel consumption is decreasing as the engine speed increases from 1000 RPM to 2000 RPM. Then, after reaching its minimum value at engine speed of 2000 RPM, the specific fuel consumption increases. On the other hand, based on Figure 5.2 (b), the air to fuel ratio at 2000 rpm is almost equal to 20 which is the ideal ratio for diesel engine operation. Besides that, the brake thermal efficiency of the engine operation at 2000 rpm is also the highest as shown in Figure 5.3 (a). Contrary to brake thermal efficiency, the volumetric efficiency produces almost a linear pattern as shown in Figure 5.3 (b).

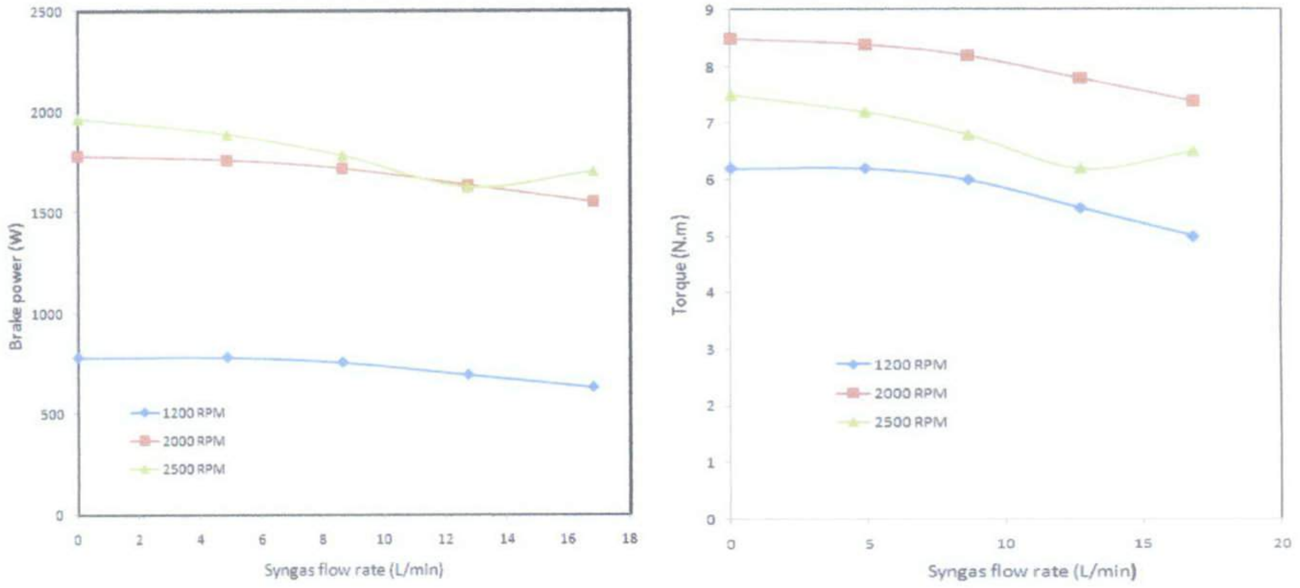
## 5.2 Replication Test

Replication test is conducted as a familiarization process with the experimental setup. Besides, it is also to observe the precision of the system. In this work, the syngas is applied to the system while the operating engine of the system is maintained at 1200 RPM, 2000 RPM and 2500 RPM respectively. The syngas composition is termed as Composition B from Kamal (2011). experimental work. The details of the composition are shown in Table 5.2.

Table 5.2: Syngas composition used in replication test (Kamal, 2010).

| Gases | $N_2$ | $CO_2$ | CO | $H_2$ | $CH_4$ |
|---|---|---|---|---|---|
| Volume Percentage (%) | 51 | 7 | 20 | 20 | 2 |
| Volume (L/min) | 25.5 | 3.5 | 10 | 10 | 1 |
| Volume (mm $H_2O$) | 61 | 7.74 | 23 | 6 | 2 |

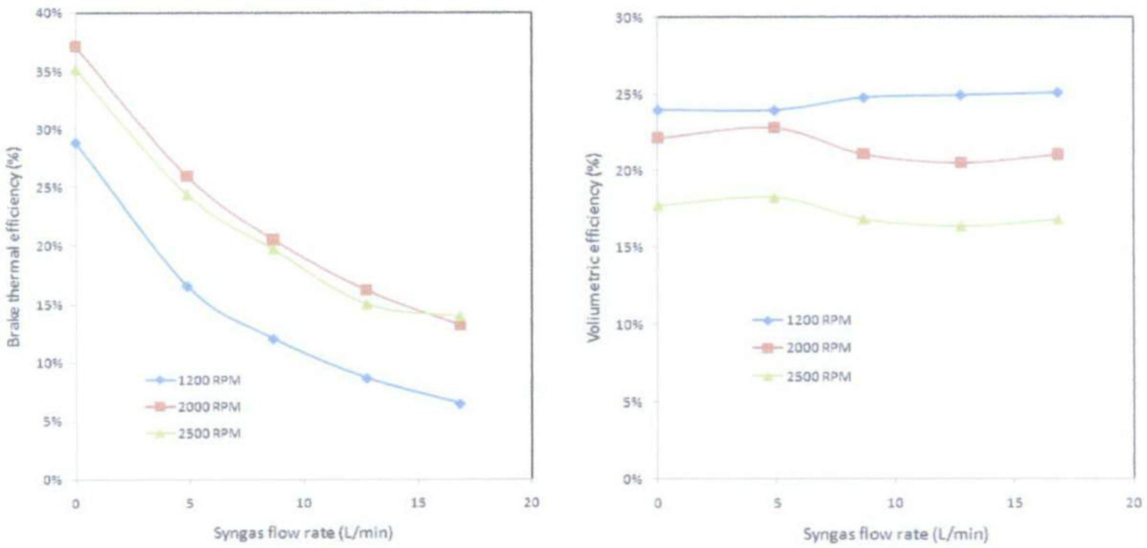
In replication test, the data obtained are treated to get same parameters as basic engine test. However, in a dual fuel mode, another parameter is added which is diesel fuel replacement. This parameter indicates the amount of diesel fuel which has been displaced by the syngas in the engine operation. The results obtained from this test are represented shown from Figure 5.4 to Figure 5.6. The syngas is supplied at a volumetric flow rate of 10 l/min to 50 l/min with l/min increment. From Figure 5.4 (a), it is observed that the brake power declines as the syngas is introduced to the engine. Highest decrement is observed at the engine speed of 2500 RPM. On the other hand, the brake power is more stable at lowest engine speed which is 1200 RPM. Based on Figure 5.4 (b), engine torque also decreases due to the addition of syngas in the engine operation. Highest torque is recorded at engine speed of 2000 RPM.



(a) Engine Brake Power

(b) Engine Torque

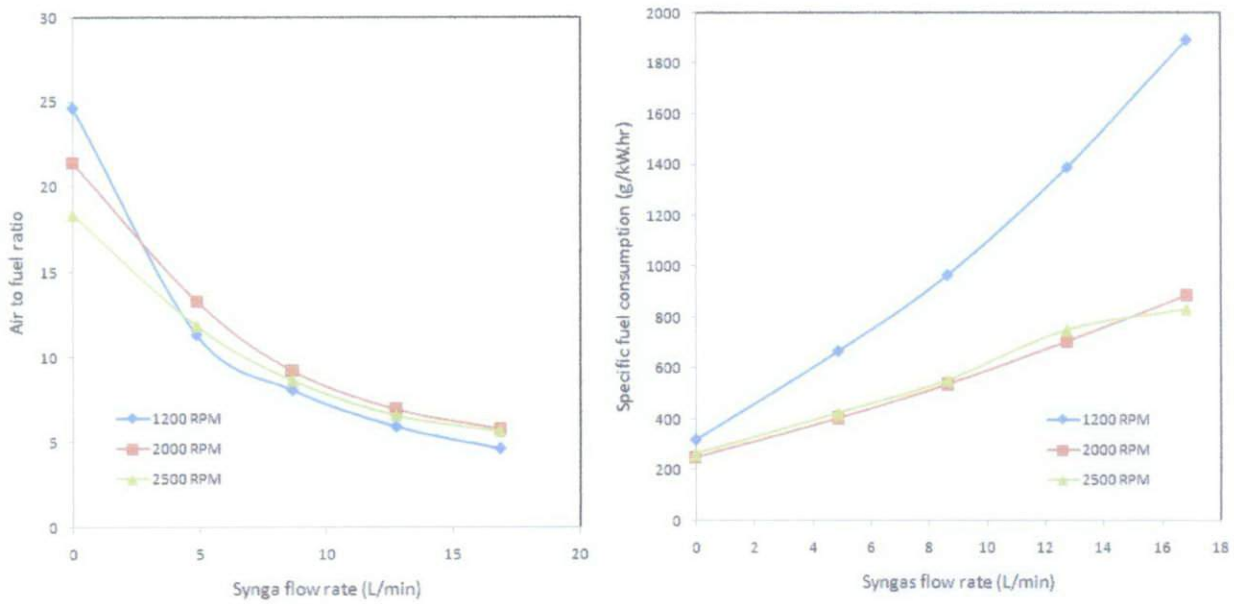
Figure 5.4: Variation of (a) Engine Brake Power and (b) Engine Torque obtained from replication test.



(a) Brake Thermal Efficiency (b) Volumetric Efficiency

Figure 5.5: Variation of (a) Brake Thermal Efficiency and (b) Volumetric Efficiency obtained from replication test.

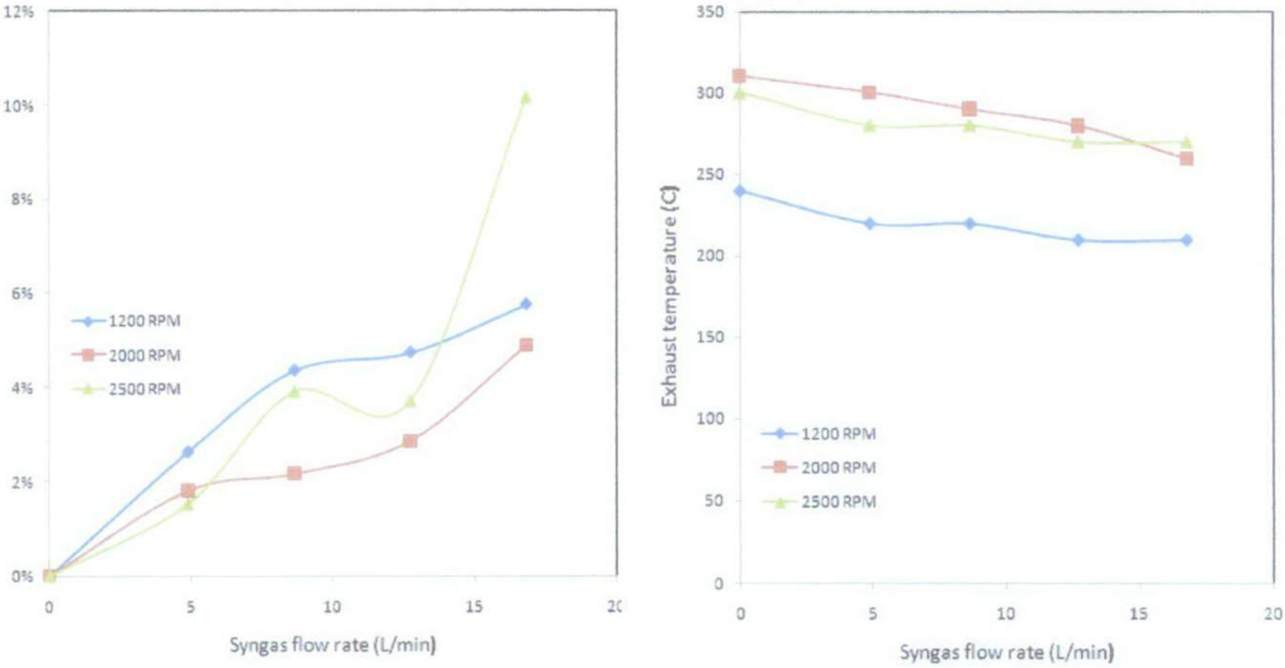
The brake thermal efficiency indicates the percentage of the calorific value of the fuel which is converted into the useful mechanical work during the engine operation. From Figure 5.5 (a), it is observed that the brake thermal efficiency is decreasing as the syngas is introduced into the engine. In the experimental setup, the syngas is supplied to the engine through its modified air intake manifold. Since the syngas is supplied together with the air, the amount of air introduced to the engine is decreasing. Hence, the engine is not operated at its ideal air to fuel ratio. Hence, it is one of possible reasons for the brake thermal efficiency decrement. From Figure 5.5 (b), the volumetric efficiency almost remains constant as the syngas is added to the engine.



(a) Air to Fuel Ratio (b) Specific Fuel Consumption

Figure 5.6: Variation of (a) Air to Fuel Ratio and (b) Specific Fuel Consumption obtained from replication test.

Since the syngas is introduced through the engine air intake manifold, the amount of air introduces to engine is decreasing. Hence, based on Figure 5.6 (a), it is observed that the air to fuel ratio is decreasing as the amount of syngas introduced to the engine is increasing. Besides that, the specific fuel consumption of the operation also is increasing as shown in Figure 5.6 (b). During operation, both diesel and syngas act as fuel to the engine. Therefore, due to the decrement of brake power (as shown in Figure 5.4 (b)), the amount of energy required to produce 1 kW of brake power is increasing after the addition of syngas to the engine. The increment of specific fuel consumption and the decrement of air intake have reduced the amount of air to fuel ratio significantly. As a result, the performance of the engine is reduced. Besides, it is also observed the specific fuel consumption at 1500 RPM increases significantly even though it can produce stable pattern of brake power as mentioned earlier (refer Figure 5.4 (a)).



(a) Diesel Replacement Rate

(b) Exhaust Temperature

Figure 5.7: Variation of (a) Diesel Replacement Rate and (b) Exhaust Temperature obtained from replication test.

As mentioned earlier, for dual fuel mode, diesel replacement rate is another addition parameter to be observed. Based on Figure 5.7 (a), the diesel replacement rate is producing inconsistent pattern for all of engine speeds. However, a very high increment is observed for engine speed of 2500 RPM as the amount of syngas flow rate is increased from 12 l/min to 18 l/min. During dual fuel mode, it is observed that the exhaust temperature is slightly decreased as the amount of syngas is added as shown in Figure 5.7 (b).

### 5.3 Engine Test with Different Compositions

During this test, three new syngas compositions are used. All of these compositions are tabulated based on the respective composition ranges for syngas from biomass gasification. The parameters to be observed and engine operating speeds are same a previous test. The details of each composition are shown in Table 5.3.

Table 5.3: New syngas compositions for engine test.

|  | Composition I |  |  |  |  |
|---|---|---|---|---|---|
| Gases | $N_2$ | $CO_2$ | CO | $H_2$ | $CH_4$ |
| Volume Percentage (%) | 45 | 14.5 | 22 | 16 | 2.5 |
| Volume (L/min) | 22.5 | 7.25 | 11 | 8 | 1.25 |
| Volume (mm $H_2O$) | 54.05 | 20 | 24.92 | 4.8 | 2.5 |

|  | Composition II |  |  |  |  |
|---|---|---|---|---|---|
| Gases | $N_2$ | $CO_2$ | CO | $H_2$ | $CH_4$ |
| Volume Percentage (%) | 49 | 6 | 24 | 18 | 3 |
| Volume (L/min) | 24.5 | 3 | 12 | 9 | 1.51 |
| Volume (mm $H_2O$) | 58.98 | 5.44 | 28.22 | 5.4 | 3 |

|  | Composition III |  |  |  |  |
|---|---|---|---|---|---|
| Gases | $N_2$ | $CO_2$ | CO | $H_2$ | $CH_4$ |
| Volume Percentage (%) | 55 | 12 | 18 | 12 | 3 |
| Volume (L/min) | 27.5 | 6 | 9 | 6 | 1.5 |
| Volume (mm $H_2O$) | 70 | 16 | 20.40 | 3.5 | 3 |

All of the syngas compositions are having different amount of heating value respectively. Heating value of the syngas indicates the amount of chemical energy available from it. The amount of heating value for Composition I, II and III are 22654 kJ/kg, 25505 kJ/kg and 17704 kJ/kg respectively. The method to determine the syngas heating value is explained in Section 3.10 earlier.

Based on Figure 5.8, it is observed that the brake power patterns produced is following the same pattern as replication test. Composition II produces highest brake power for every engine speeds. It is because, Composition II is having much higher heating value compared to other compositions. However, at certain operating point, it is found that brake power produces by Composition I is higher than Composition III even though heating value of Composition III is higher than I. One of the possible reasons is due to inhomogeneous mixture of syngas in a mixture before it is supplied to the engine. Another possible reason is due to excessive vibration of the engine during its operation.

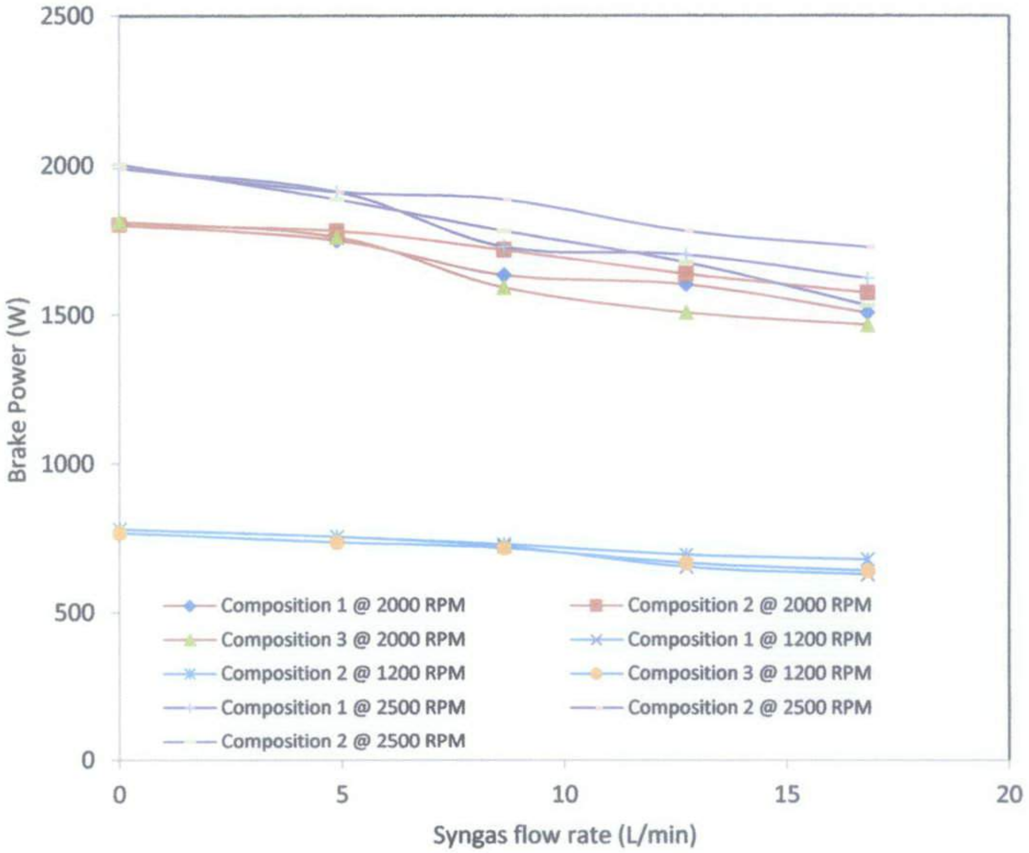


Figure 5.8: Engine brake power obtained during new compositions engine test.

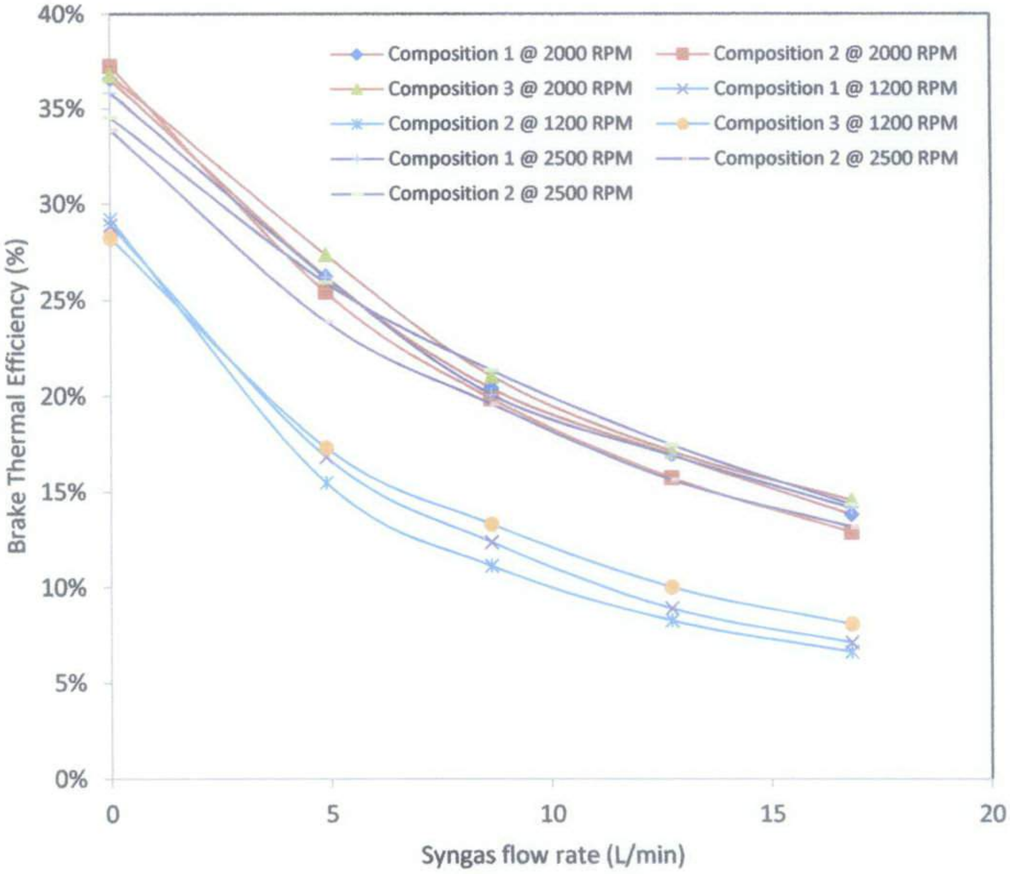


Figure 5.9: Brake thermal efficiency obtained during new compositions engine test.

From Figure 5.9, it is observed that brake thermal efficiency is at the lowest when the engine operating speed is 2000 RPM. Even though, at this point brake power produced is at the highest, it requires much higher chemical energy from the fuel compared to other speeds. Hence, as a result, the brake thermal efficiency drops. Besides that, the difference of the brake power produced is not big enough to compensate the amount chemical energy consumed during engine operation. Overall, it is observed that the deviation in brake thermal efficiency between syngas compositions is not very significant for every engine speed.

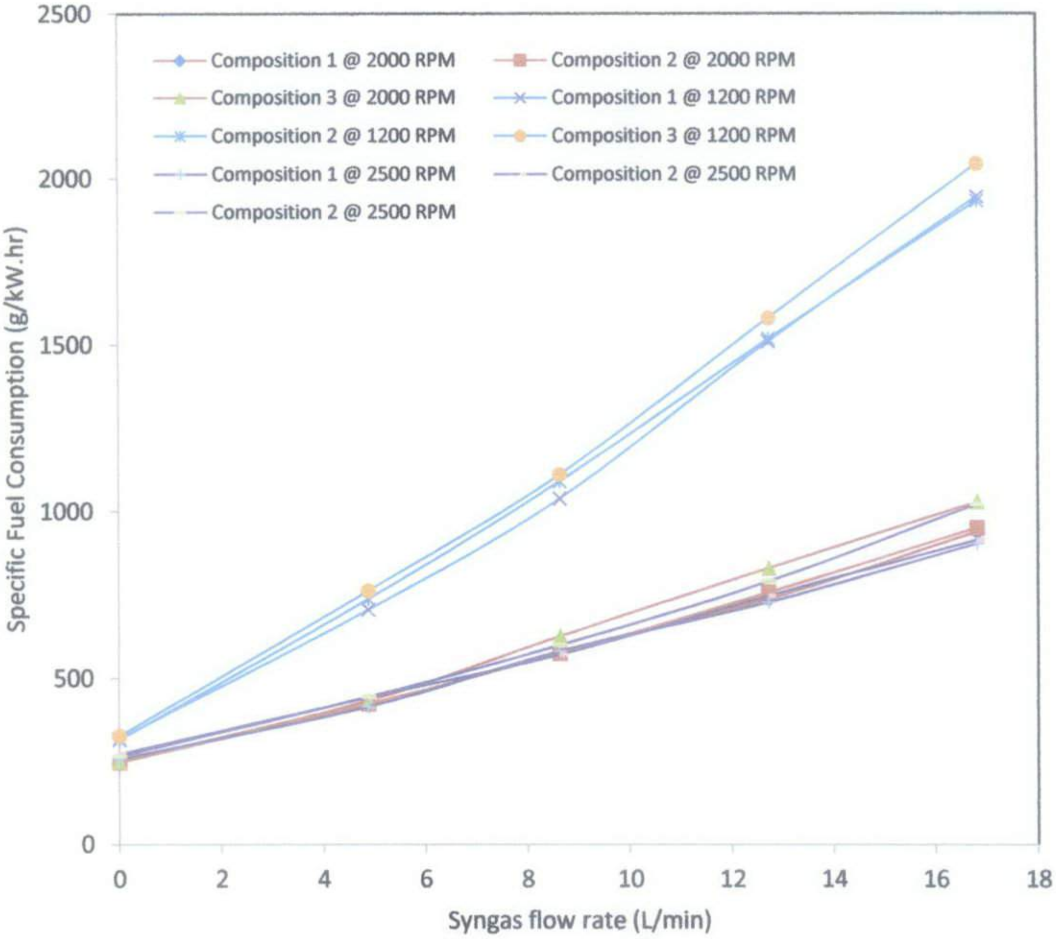


Figure 5.10: Specific fuel consumption for every speed for new compositions engine test.

In dual fuel mode, both engine and syngas are acting as fuel to the engine. Hence, as a result more fuel is supplied to the engine. Based on Figure 5.10, it is observed that the engine specific fuel consumption increases as the syngas is introduce to the engine. Since syngas is introduced together with the air through air intake manifold, the air to fuel ratio decrease as shown in Figure 5.11. Both specific fuel consumption and air to fuel ratio are following same pattern obtained from replication test.

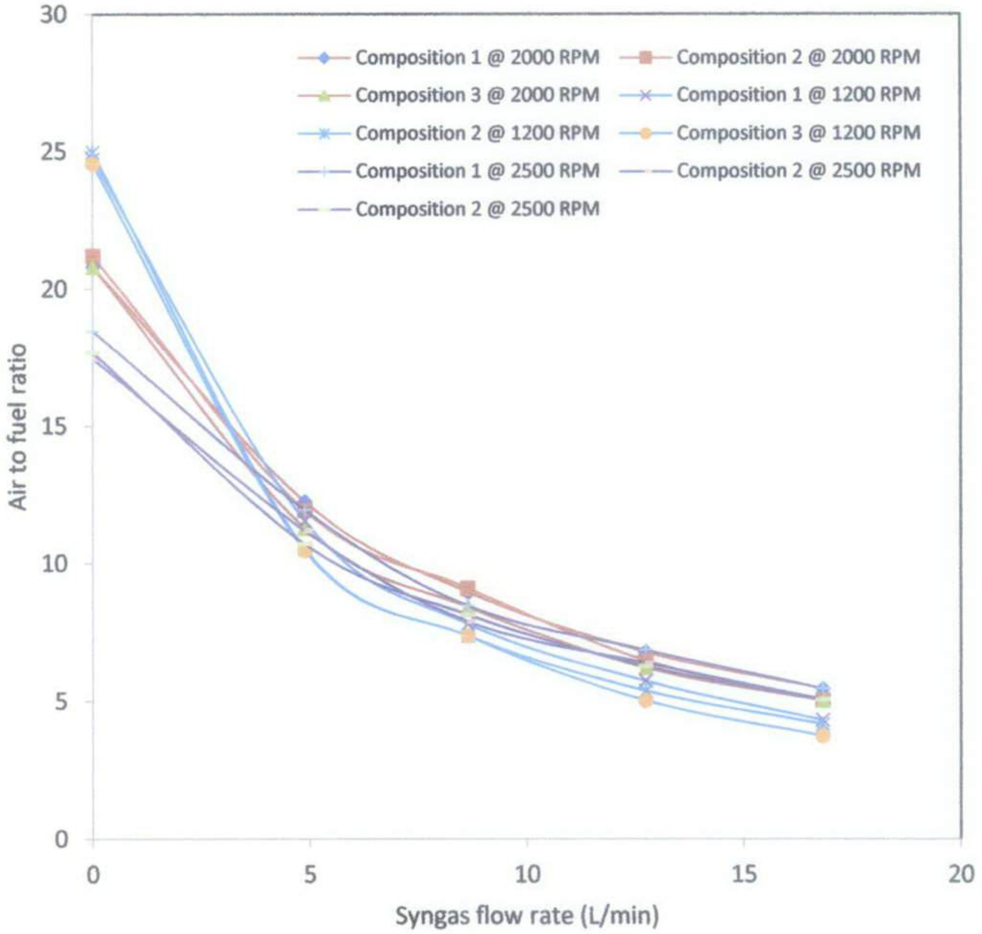


Figure 5.11: Air to fuel ratio obtained during new compositions engine test.

Similarly to finding from replication test, diesel replacement rate obtained from the test exhibits inconsistent pattern as shown in Figure 5.12. Since Composition II is having the highest heating value, it is expected that the displacement rate for Composition II will be higher. However, for engine speed of 1200 RPM, the displacement rate for Composition II is the lowest compared to the others. Inhomogeneous syngas mixture is recognized as one of the possible reasons for the pattern to occur.

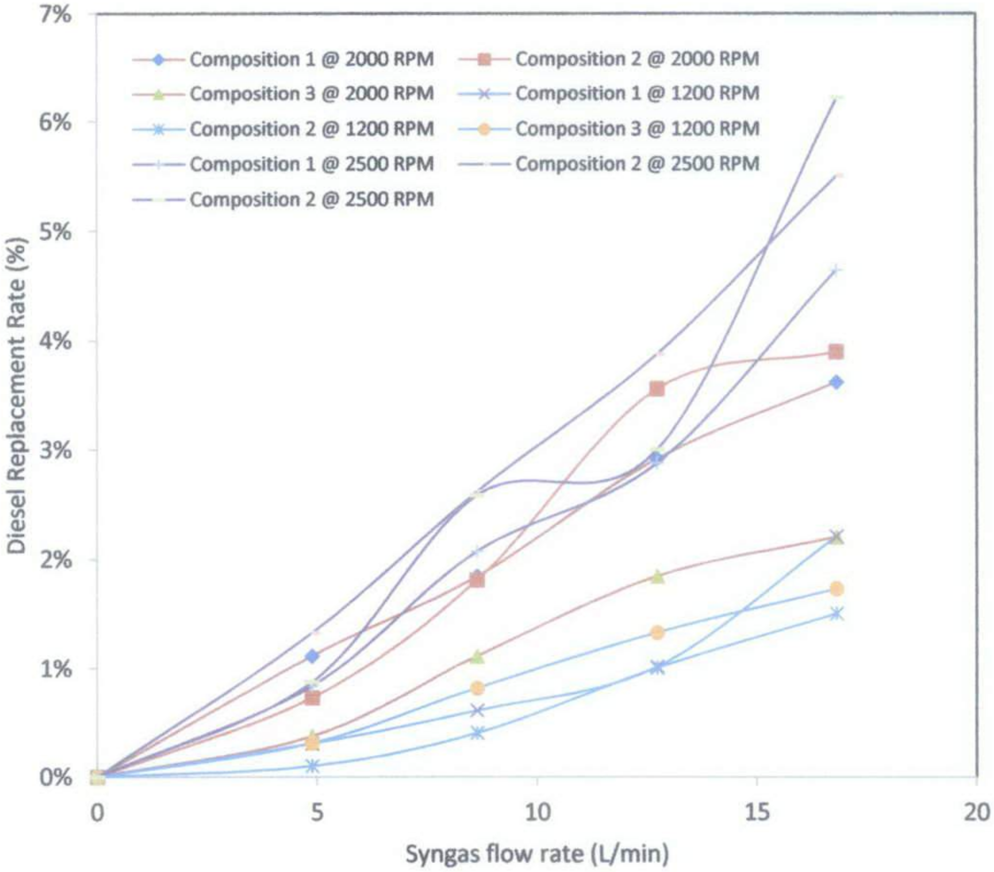


Figure 5.12: Diesel replacement rate obtained during new compositions engine test.

As conclusion, it is observed that the deviation between Compositions I, II and III findings are not very big for every operating speed. However, it is found that syngas with higher heating value provides better performance compared to other compositions. The reason for low deviation might be due to inhomogeneous syngas mixture. As a result, the different between syngas heating value is lower compared to theoretical value.

For emission test, only one test is conducted. The test is conducted only at the engine speed of 2000 RPM. The number of test is limited due to the short of supply for the gas analyzer filter. Besides that, the analyzer also needs to be send to the service center since it already reaches it maximum operating cycles. From emission test, it is found that, the amount of carbon monoxide in exhaust gas composition increases as the syngas is added to the engine as shown in Figure 5.13. The results obtained agree with findings from Uma et al experiment which indicates the existence of incomplete combustion in the engine combustion chamber. However, the value obtained is very small. Besides that, the exhaust gas analyzer also does not detect the existence of carbon dioxide in the exhaust gas. Since carbon dioxide is one of the main products of combustion, it is decided that the exhaust gas analyzer needs to be calibrated again. Hence, the emission test is not continued for the other tests.

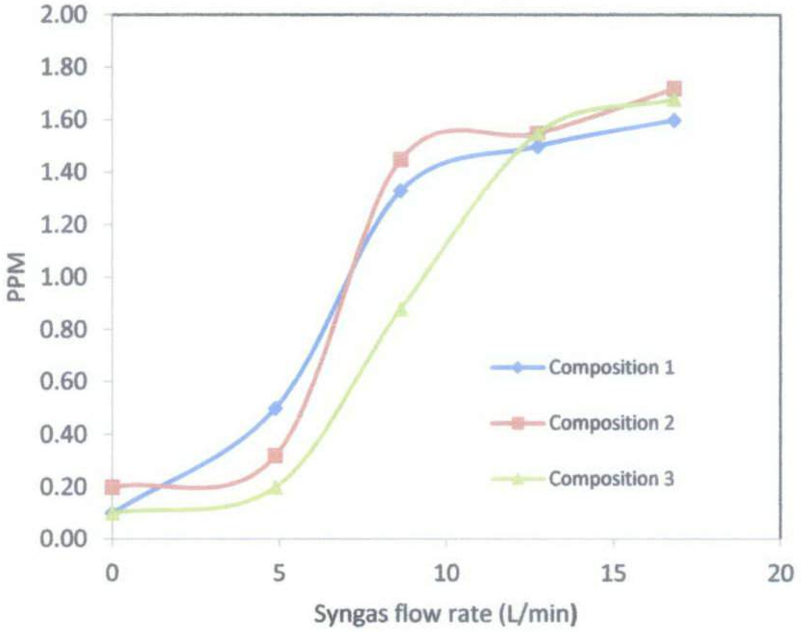


Figure 5.13: Carbon monoxide emitted in the exhaust gas composition.

# CHAPTER 6

# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions

Based on the literature review, it is found that the implementation of syngas from biomass gasification in a diesel engine is possible to be conducted. However, there are certain issues related to the implementation such as high emission of carbon monoxide (Uma et al, 2004) and fluctuation of the syngas composition (Hassan, 2011). Due to that, this study is conducted to study the effect of controlled syngas-diesel fuel conditions on the performance and emission of a single cylinder diesel engine. From the test conducted, it is found that the introduction of syngas will reduce the brake power of the engine. However, this is compensated by less emission of carbon dioxide and nitrous oxide (Uma et al, 2004). Another reason for the brake power reduction is due to the lower charge temperature at the end of the engine compression stroke. Throughout the project, it is found that syngas with composition which is having higher heating value will produce better engine performance. It is because compared to other composition; this composition is providing more chemical energy for the engine operation.

On the other hand, it is also observed that the diesel replacement ratio does not produce any constant pattern throughout the experiment. This pattern is obtained largely due to the inhomogeneous mixture of the imitated syngas. Since the dimension of the mixture is small, it does not provide enough space and time for the gas to homogenously mixing with each other. Besides that, since the mixing is done manually, some of the components might accidentally have a higher volume in the mixture due to human error. In addition to that, inhomogeneous mixture also has caused the results obtained for syngas Composition I, II and III to be almost similar to each other.

## 6.2 Recommendations

As for the recommendations, one of the possible ways to improve the project outcome is by modifying the method syngas delivery to the engine. In the current system, the syngas is introduced together with the air. Since the gas acts as a fuel to the engine, the ratio of air to fuel for the engine is reduced. Besides that, it is also recommended that the mixing process of the syngas to be improved. The five way mixture is found to produce inhomogeneous mixture of gases. As a result, the quantification of the components is not very accurate. Due to this issue, it is found that the result obtained during experimental work to exhibit certain inconsistent pattern as shown by the diesel replacement rate. In addition to that, lack of equipment issues also should be solved. During the project implementation, the lack of exhaust gas filter has caused the number of emission test conducted to be limited. Besides that, the project is also conducted in a period at which the exhaust gas analyzer should be serviced. Therefore, since only one equipment is available, emission test conducted is not enough to provide enough findings for the project.

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