# ANALYSIS OF ENGINE POWER USING 3 TYPES OF PRE-COMBUSTION CHAMBER'S DESIGN

**AMARUL AFIQ ADLI BIN ROSLI**

**Report**

**Projek Sarjana Muda II**

**Supervisor : Assoc. Prof. DR. MUSTHAFAH BIN MOHD. TAHIR**

**Faculty of Mechanical Engineering**
**Universiti Teknikal Malaysia Melaka**

**2017**

## APPROVAL

"I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive)."

Signature: ..................................

Supervisor: Assoc. Prof. MUSTHAFAH BIN MOHD. TAHIR

Date: ..................................

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**AMARUL AFIQ ADLI BIN ROSLI**

**This report is submitted in partial fulfillment of the requirements for the award of a Bachelor in Mechanical Engineering (Automotive) with honours**



**Faculty of Mechanical Engineering**
**Universiti Teknikal Malaysia Melaka**

**May 2017**

**DECLARATION**

“I hereby declare that the work in this thesis is my own except for the summaries and quotations which have been duly acknowledge.”

Signature :…………………..

Author : AMARUL AFIQ ADLI BIN ROSLI

Date :..………………….

## DEDICATION

I dedicated this report to my parents, family, to my supervisor Assoc. Prof. Dr. Musthafah bin Mohd Tahir, to my friends and all those who knew me. Not to forget to Universiti Teknikal Malaysia Melaka (UTeM) and all staff that had helped me a lot in completing this project.

# ABSTRACT

In this report, the characteristics of the engine performance consuming the gasoline fuel and Compressed Natural Gas (CNG) fuel is measures. Using CNG as fuel to the engine, the power of the engine drops compared to gasoline fuel. The engine was modified to a dual-fuel system which can be operated either by gasoline fuel or CNG fuel. Besides that, the head of the engine is also had been modified for suitability to attach the PCC on to the head. For this case study, there are three types of PCC used to test the engine power output of each PCC. The PCC will be run using CNG fuel and each PCC output are compared to choose the best PCC among the three types of PCC tested. The engine was tested at engine speed between 1500 rpm to 4000 rpm. Therefore, the power of the engine can be studied so the performance result of PCC are compared. However, the experiment of CNG without PCC was also been tested and the result is compared with the three types of PCC. Besides using PCC for the experiment, we are also using the high pressure sensor to determine the power output and other parameters needed for the experiment. The result from the experiment done shown that with the application of the PCC, the power increased to 3.4 kW at the top performance of the engine while without PCC the power value is only 3.1 kW. The research is important as applying the CNG reduces the pollution to the environment but reducing the engine performance. The effect of those PCC are expected to increase the performance of the engine while using the CNG as it fuel.

# ABSTRAK

Di dalam laporan ini, ciri-ciri prestasi enjin tersebut yang menggunakan minyak gasolin dan juga "Compressed Natural Gas (CNG)". Dengan penggunaan CNG pada enjin tersebut, "power" yang dikeluarkan oleh enjin tersebut menurun berbanding dengan penggunaan gasolin sebagai bahan bakarnya. Enjin tersebut telah diubahsuai supaya menjadi "dual-system" yang mana membenarkannya untuk menggunakan minyak gasolin dan CNG. Selain dari itu, "head" enjin juga telah diubahsuai bersesuaian dengan penggunaan PCC pada enjin. Dalam uji kaji ini terdapat tiga jenis PCC yang bakal digunakan untuk menguji "power" pada enjin yang di hasilkan untuk setiap satu PCC. PCC akan diuji menggunakan CNG dan setiap PCC akan dibandingkan bagi menentukan PCC yang terbaik antara ketiga-tiga PCC yang diuji. Enjin telah diuji pada kelajuan 1500 rpm hingga 4000 rpm. Oleh yang demikian, "power" pada enjin dapat dikaji dan keputusan prestasi bagi PCC dapat dibandingkan. Walau bagaimanapun, uji kaji bagi CNG tanpa menggunakan PCC juga telah dijalankan dan hasilnya dibandingkan dengan hasil dari tiga PCC yang telah diuji. Selain menggunakan PCC pada enjin, "high pressure sensor" juga digunakan bagi mengetahui "power" dan lain-lain parameter yang perlu untuk uji kaji ini. Keputusan yang dikeluarkan dari uji kaji ini telah menunjukkan bahawa dengan penggunaan PCC, nilai bagi "power" untuk enjin tersebut telah meningkat kepada 3.4 kW pada kemuncak prestasi enjin berbanding hanya 3.1 kW tanpa menggunakan PCC. Uji kaji ini sangat penting di mana CNG telah pun digunakan bagi mengurangkan pencemaran yang berlaku pada persekitaran tetapi, ia juga telah mengurangkan prestasi enjin. Kesan dari PCC yang diuji diharap dapat meningkatkan prestasi enjin tersebut walaupun dengan penggunaan CNG sebagai bahan bakarnya.

**ACKNOWLEDGEMENT**

In the name of Allah, the Most Beneficent and The Most Merciful. It is deepest sense gratitude of the Almighty that give me strength and ability to complete this "Projek Sarjana Muda (PSM)" report. A special gratitude I give to my final year project supervisor, Assoc. Prof. Dr. Musthafah bin Mohd Tahir, whose give me a valuable guidance and support that helped me to coordinate my project especially in writing this report. Special thanks go to my father Mr. Rosli Basiron and my mother Mrs. Rosliah Talib and also my family for their moral support to me in the process of completing this project. Besides that, I would also like to acknowledge with much appreciation to all my friends who help me a lot in order to complete this project especially to Mr. Khairil Amri Tajuddin and Mr. Muhammad Afiq Mohd Nor Azinan for their help regarding the project. Furthermore I would also like to express my gratitude to the staffs of Univesiti Teknikal Malaysia Melaka (UTeM), who gave me the permission to use all required equipment and necessary materials in laboratory to complete my final year project.

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## LIST OF SYMBOLS AND UNITS

| | |
|---|---|
| kJ/kg | kilo Joule per kilogram |
| MJ/kg | Mega Joule per kilogram |
| Pa | Pascal |
| m/s | meter per second |
| $Q$ | Flow rate |
| $^{o}C$ | Degree Celsius |
| S | Stroke length |
| N | engine speed per one revolution |
| rpm | revolution per minute |
| kg/mol | kilogram per mol |
| $CO_2$ | Carbon Dioxide |
| $NO_x$ | Nitrogen Oxide |
| CO | Carbon Oxide |
| HC | Hydrogen Carbon |
| % | Percent |
| vol | Volume |
| $kg/m^3$ | kilogram per meter cube |

| | |
|---|---|
| cc | centimeter cubic |
| mm | milimeter |
| N.m/rpm | Newton meter per revolution per minute |
| g/kW.h | gram per kilo watt hour |
| kW/rpm | kilo watt per revolution per minute |
| kpsi/bar | kilo per square inch per bar |
| pC/psi | pico coulomb per per square inch |
| $mm^3$ | milimeter cube |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| **PSM** | Projek Sarjana Muda |
| **CFD** | Computational Fluid Dynamic |
| **PCC** | Pre-Combustion Chamber |
| **CNG** | Compressed Natural Gas |
| **LNG** | Liquid Natural Gas |
| **SI** | Spark Ignition |
| **ICE** | Internal Combustion Engine |
| **ECU** | Electronic Control Unit |
| **NG** | Natural Gas |
| **CI** | Compression Ignition |
| **BDC** | Bottom Dead Centre |
| **TDC** | Top Dead Centre |
| **2D** | 2-Dimension |
| **3D** | 3-Dimension |
| **MPV** | Multi-Purpose Vehicle |
| **etc.** | Etcetera |

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

Most vehicle's engines around the world are Internal Combustion Engine (ICE). Normally Spark Ignition (SI) engine and Compression Ignition (CI) engine. For standard SI and CI engine, its normally use gasoline fuel and diesel fuel. In this modern world, people now are more concern on environmental health.

SI and CI engine that use gasoline and also diesel fuel create more pollution. The combustion of gasoline fuel will produce $CO_2$, HC, and $NO_x$ (Engerer and Horn, 2010, Jääskeläinen and Wallace, 1993) that are hazardous to the environment.



One of the solution to overcome this problem, is the modification mostly on SI engine had been done by replacing the combustion fuel from gasoline fuel changed to Natural Gas (NG) fuel. NG are well known as Compressed Natural Gas (CNG) or Natural Gas Vehicle (NGV). By using this CNG, the emission of those dangerous gases by gasoline fuel can be reduce. Moreover, the price of the NG fuel in the market is way cheaper compared to both gasoline and diesel fuel.

However, there are several disadvantages using the Natural Gas(NG). NG are known to have lower performance output compared to the normal gasoline fueled engine. Besides that, NG fuel lead towards a decreased of power for the engine at low speed.

## 1.2 PROBLEM STATEMENTS

The present SI engine in the market are using gasoline fuel as their combustion fuel. It give enough power as the output to any vehicle that use this kind of engine usually from Sedan model to Multi-Purpose Vehicle (MPV).The main problem of SI engine that use gasoline fuel is that it produce more pollution and it is not an environmental friendly fuel. Nowadays, engineers had done research to overcome this problem and had started to use NG as to replace the gasoline fuel in the SI engine. NG is a better emission fuel compared to gasoline in terms of pollution(Amorim et al., 2005). In fact, one of the advantages offered by this Natural Gas (NG) is emission in $CO_2$, HC and NOx (Engerer and Horn, 2010; Jahirul et al., 2010; Jääskeläinen and Wallace, 1993; Ma et al., 2009). But it is not as good as gasoline fuel when it come to the output power. Natural Gas (NG) produce low power output by 18% less than gasoline (Yamamoto et al., 1994). Moreover, based on previous research, the pressure inside the cylinder for gasoline fuel, in comparison to CNG is higher during ignition stage (Sera et al., 2003; Sasaki et al., 2002; Zheng et al., 2009; Zareei et al., 2012). From the research done, the application of Pre-Combustion Chamber(PCC) to improve the performance of the engine had only been done on the L-type of engine and there are some limitations using this type of engine. Besides that, the PCC used is limited to only one type of PCC.

Research on this problem had come to an invention of Gas Engine With Pre-Combustion Chamber (Matsuoka et al., 2000). The main purpose of the PCC in an SI engine is to shorten the combustion duration and thereby enhance performance. (Matsuoka et al., 2000). Different design or types of PCC will result to different outcomes. The study on the Pre-Combustion Chamber is still on going to invent the best PCC design with the best result.

## 1.3 OBJECTIVES

There are three objectives that are used as the guideline of the study. The objectives are :

- To investigate the effect using PCC in single cylinder overhead cam that use CNG as it fuel.
- To determine the output performance produce using different types of bolted PCC.
- To validate the best bolted PCC geometry when using CNG.

## 1.4 SCOPE

In the case study, a single cylinder SI engine powered by CNG was used. An experiment is conduct by using a SI engine single cylinder with overhead cam. Different designs of Bolted PCC been used to experiment the best output result. The range for the experiments is in between 1500 rpm until 4000 rpm.

- Apply the Bolted Pre-Combustion Chamber(PCC) to a single cylinder Spark Ignition(SI) engine.
- Use Compressed Natural Gas (CNG) as fuel into the single cylinder SI engine.
- Record the output performance of the CNG fueled for SI engine.
- Analyze and study the performance result of the CNG fueled SI engine.
- Compare the effect of different design of PCC on the performance of the CNG fueled SI engine.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 OVERVIEW

In this chapter, it will cover on the information gained from variety resources of information such as jurnal, engineering books, internets and etc. The main topic to be discuss in this chapter will be on the SI engine which will cover on the type of combustion. Besides that, we also will discuss on the working fuel used by the SI engine to be tested which is Compressed Natural Gas (CNG). Other than that we also will cover the Pre-Combustion Chamber (PCC) used in this project. The project will use the Bolted types of PCC with 3 different designs to be tested. The output of the experiments are expected to be different among those three designs. The optimum output will be taken as the best result for the project.

## 2.2 NATURAL GAS

Most of the present SI engine vehicle uses gasoline as their working fuel. The amount of vehicle that uses SI engine type grows by year. The statistic is shown in Figure 2.1 (Ong, H.C. *et* al.2012). The demand of the gasoline fuel in the market is getting higher. As the demand increasing, there are some problems occurs. The gasoline use as the fuel to most of the vehicles in this world is not a renewable and yet is harming the environment. This kind of power source has reduced gradually . Many researcher try to find the solution for the problem and come with solution by changing the working fuel use. One of the alternative found is by using NG as the working fuel to the SI engine.

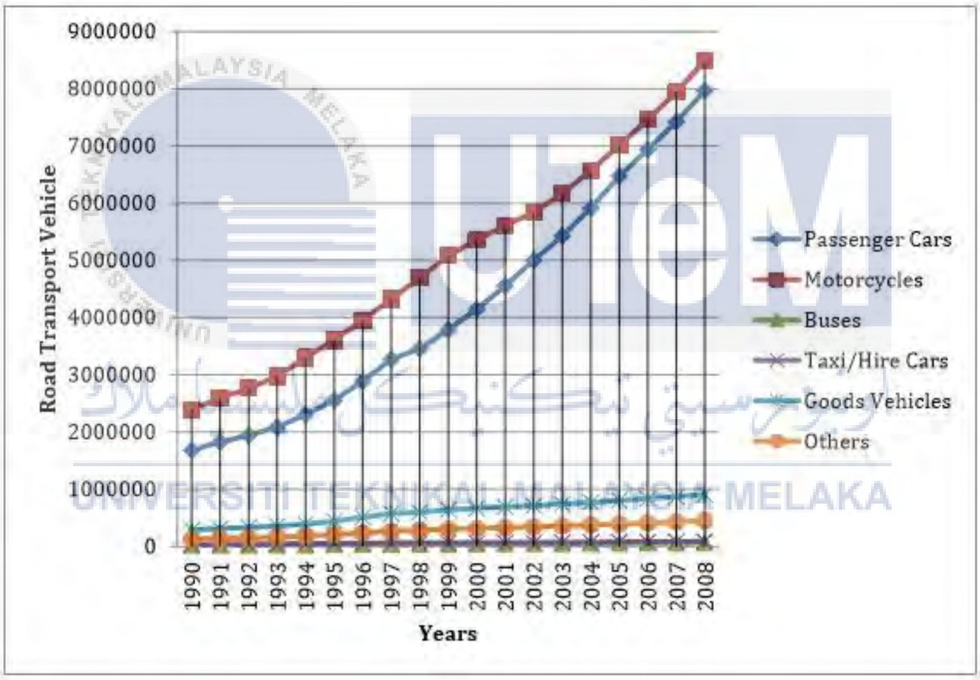



**Figure 2.1 :** Road transportation statistic (Ong. 2012)

Natural Gas is a natural fuel produced in a million years of time process from the fossil of animal and plants stored the underground reservoir. The component is mainly contain of methane but there are also some other mixture. NG is colorless and also odorless that make it more environmental and user friendly. Besides that, the emission produces is lower compared to liquid fuel and diesel (Cho and He, 2007). It also have a lower specific gravity than air which is between the range of 0.6 to 0.8 and that make it dissipated into air quickly.

Besides that, NG is a safety gas fuel as it only burns with more than 15% of volume. It's self-ignition temperature is at 537 – 540$^{\circ}$C. For overall, NG is a much better fuel compared to any other fuel in term of environmental friendly. And because of that, it has been used for over than 150 years in many kind of industry. Besides been used as a working fuel in the transportation field, it also had been used as a cooling system and used to produce glass, steel, papers, cloth and many more. Figure 2.2 shows the Natural Gas used in United States of America in2007.

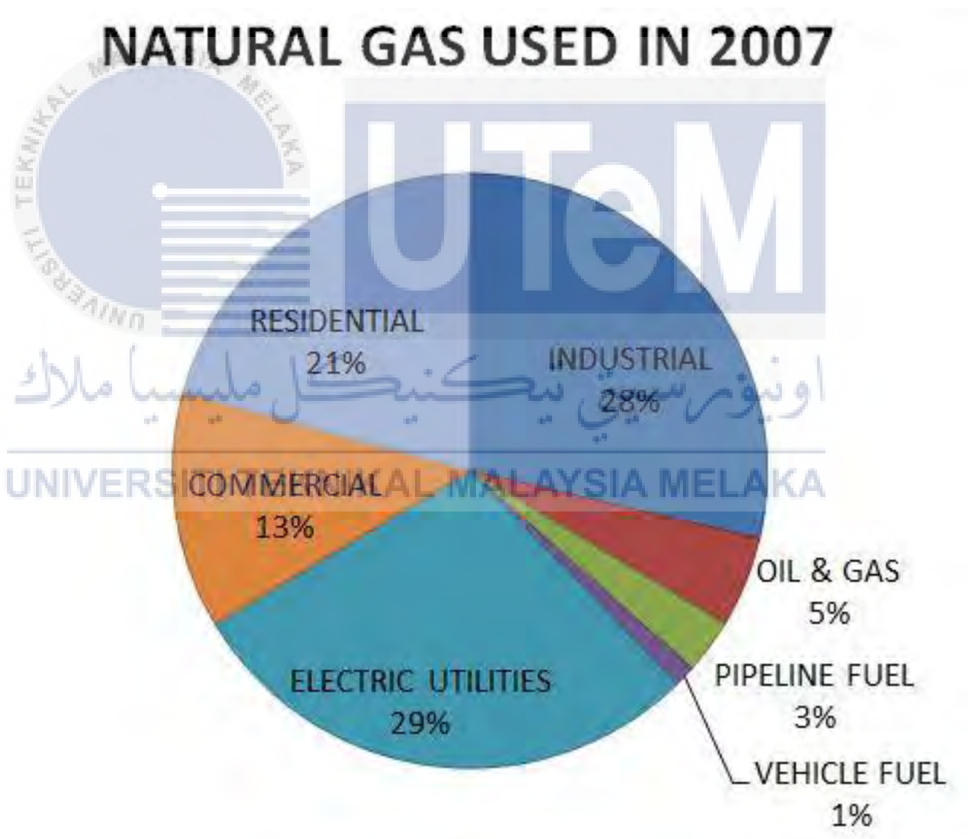



**Figure 2.2** : Natural Gas used in United State of America(www.eia.gov>kids)

## 2.3 SPARK IGNITION ENGINE

SI Engine stands for Spark Ignition engine. The word "spark ignition" tells the principle of the engine. This type of engine needed an additional force to ignite the working fuel used to start the combustion. The first engine was developed by Abu al-'IZ Ibn al-Razaz al Jazari (1136-1206) then during 1860, Lenoir (1822-1900) developed the first spark plug engine. In 1876, Otto proposed four cycles engine called four strokes engine. Figure 2.3 shows the simplification of the engine types.

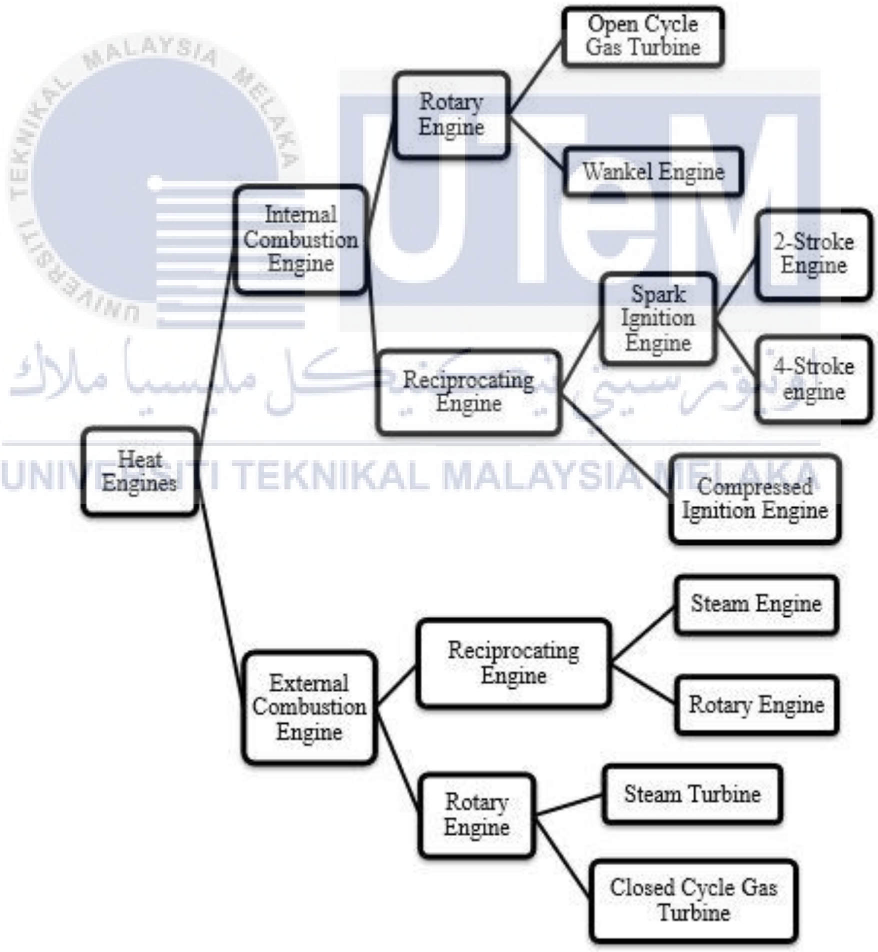



**Figure 2.3 :** The simplification of the engine based on type and operation (Ganesan. 2010)

In almost every SI engine, the working fuel is gasoline. Gasoline has a higher self-ignition temperature compared to diesel which used by the Compression Ignition (CI) engine. For gasoline fuel, the self-ignition temperature is in between 450° C to 550° C. The compression of the piston in the cylinder will not achieve the self-ignition temperature due to its stoke is short, thus it need a spark to ignite the combustion of the fuel. Table 2.1 shows the properties of gasoline and Compressed Natural Gas (CNG).

**Table 2.1 :** Properties of Gasoline and Compressed Natural Gas (CNG)

| **Properties** | **Gasoline** | **CNG** |
|---|---|---|
| Motor octane number | 80-90 | 120 |
| Molar mass (kg/mol) | 110 | 16.04 |
| Carbon weight fraction (mass %) | 87 | 75 |
| Stoichiometric air fuel ratio (A/F)s | 14.6 | 16.79 |
| Stoichiometric mixture density (kg/$m^3$) | 1.38 | 1.24 |
| Lower heating value (MJ/kg) | 43.6 | 47.377 |
| Lower heating value of stoic. Mixture (MJ/kg) | 2.83 | 2.72 |
| Flammability limits (vol% in air) | 1.3-7.1 | 5-15 |
| Spontaneous ignition temperature °C | 480-550 | 645 |

(Source : Heywood, 1988)

The four strokes cycle in the SI engine started with the Intake Stroke. In the intake stroke, the piston is in Bottom Dead Centre (BDC) where the volume cylinder is in the maximum value. In this stroke, the air and fuel are allowed to enter the cylinder as the intake valve opened. Next is the Compression Stroke, in this stroke the piston move upwards toward the Top Dead Centre (TDC) position and compress the air and fuel mixture in the cylinder. As the volume decreases, the temperature of the mixture increases. This will cause the Power Stroke. In Power Stroke, the piston is at the TDC position and left only with the clearance volume which is a very compact place for the mixture. In this little volume, the mixture's temperature will be high and approximately to the self-ignition temperature. With the help of the spark plug, that will ignite the mixture compression occurs in the cylinder. The propagation of the combustions occur randomly that will cause the piston to be pushed downward. The final stroke is the Exhaust Stroke which is in this stroke, the piston is in the BDC position. As the piston move downwards, the exhaust valve will open and the combustion product will release to the exhaust as the residual. This will complete the four cycles and the process will repeated from the Intake Stroke. The cycle of the four strokes engine is illustrated in Figure 2.4.

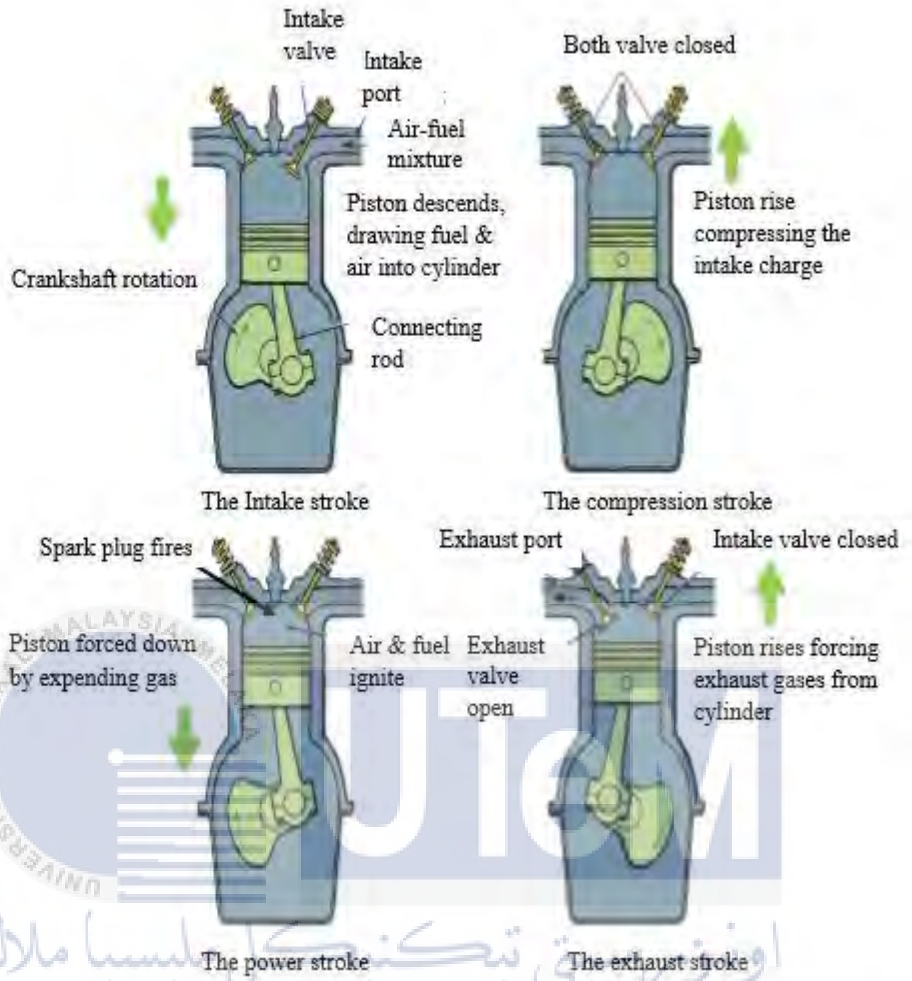





**Figure 2.4 :** Four Stroke engine cycle (Halderman. 2012)

## 2.4 PRE-COMBUSTION CHAMBER

In the present invention, Pre-Combustion Chamber (PCC) only used in Compression Ignition (CI) engine. The main function of the PCC is to bring the diesel fuel a small compartment where the fuel are compression before it enters the main chamber where the combustion occurs. It usually used to enable super lean mixture during combustion (Toulson et al., 2010). The Pre-Combustion Chamber (PCC) is typically installed in the spark plug well of ta standard engine (Black, 1998).

In this experiment, the PCC will be used in the Spark Ignition(SI) engine. The SI engine will be coupled with the Compressed Natural Gas (CNG) as the working fuel. As known, Natural Gas (NG) has lower self-ignition temperature compared to gasoline fuel that usually used in the SI engine. Therefore, the function of the PCC is very useful in order for the NG to be more efficient. As for the experiment, the experiment will be use CNG which is a natural gas that had been compressed and for the combustion the mixture of fuel and air is moved into pre-chamber volume (Daniah, 2012). Combine with the second compression, the self-ignition for the gas will be way higher compared to the normal natural gas in present usage.

## 2.5 EFFECT OF PCC TO THE ENGINE POWER FROM PREVIOUS CASE STUDY RESULT

In the experiments done previously on the L-type of engine, the application of PCC has given a big effect on the power of the engine. In this part of the preliminary results, we are going to shows the result on the engine power and the effect of the PCC to the engine power. Figure 2.5 shows to effect of the PCC on the engine power at various engine speed:

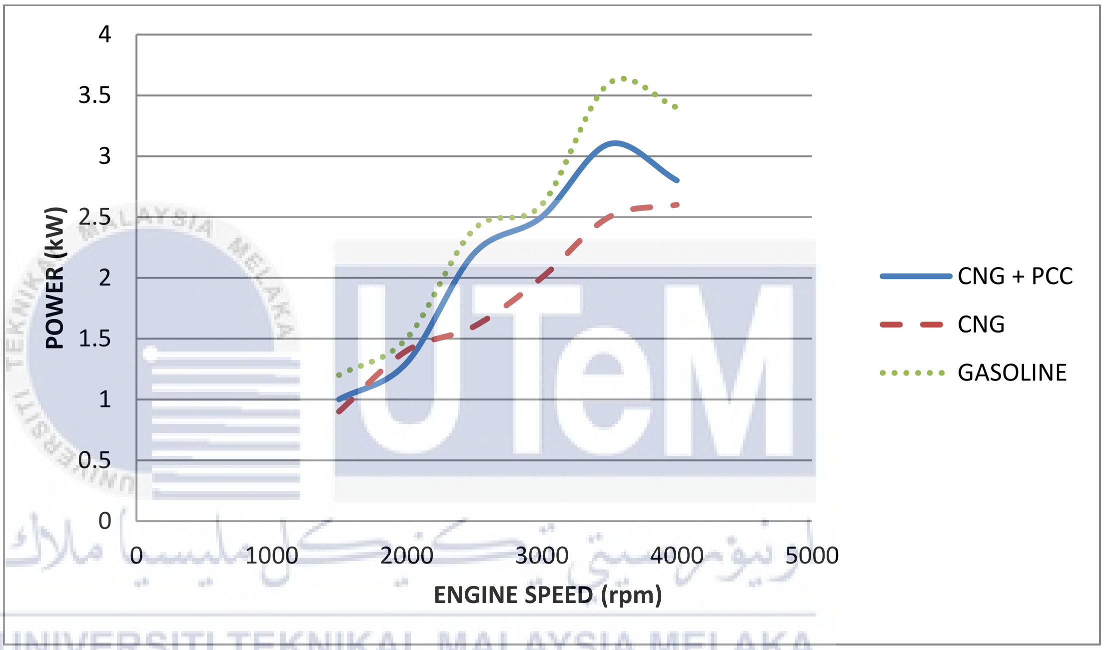



**Figure 2.5 :** The effect of different engine fuel on the engine power at various engine speed

In Figure 2.5 above, the graph illustrated the different fuel used in the engine and the power for each of the fuel. The experiment done starting from the engine speed of 1500 rpm and stopped at engine speed of 4000 rpm. In the graph shown, the gasoline fuel has higher power compared to other type of fuel which is the CNG. From the research done by some researchers, the lower power output by the CNG is caused by its natural properties which is the gaseous form compared to the gasoline fuel which is in the liquid form (Maji S *et* al., 2005). In the graph, it also shows that the increasing value for the power only between engine speed of 1500 rpm until 3500 rpm. the value than decreasing after 3500 rpm.

Figure 2.6 illustrated the power of the engine and the effect of the PCC. The engine is fueled with the same fuel type which is the CNG but the first data to be taken is the power of the engine without applying the PCC to the engine. After the data taken, the PCC is applied to the engine and the result of the engine power is taken. From both data collected, from graph shown above, the result of the engine power with the application of PCC shows higher value compared to the CNG fuel without the PCC applied to the engine. The PCC can increase the power of an engine with CNG fuel.

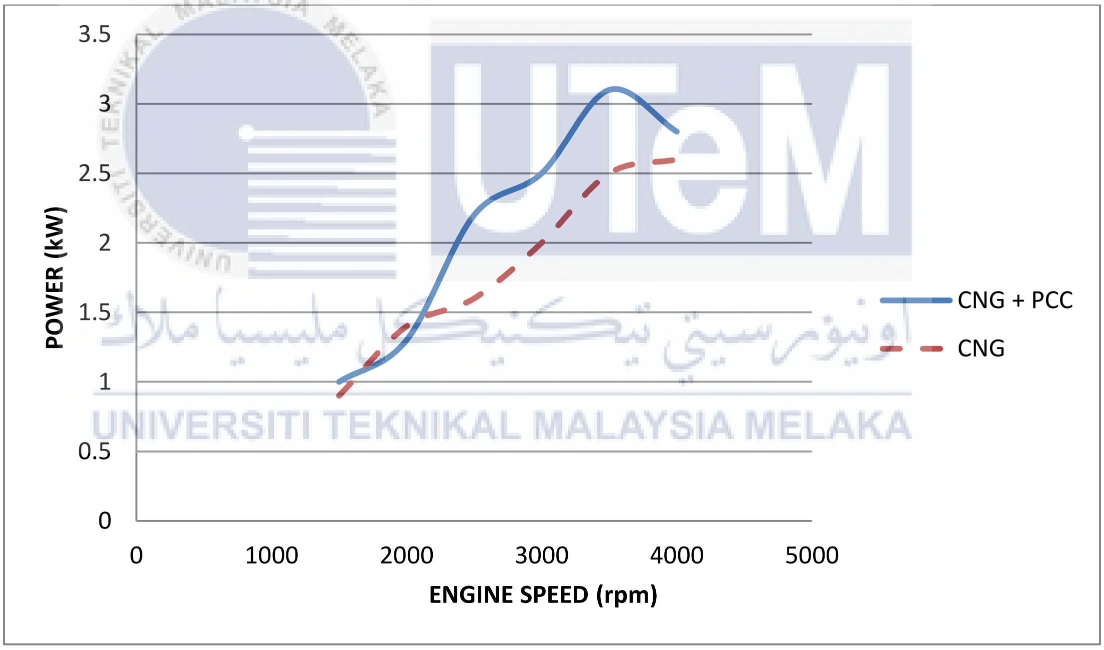



**Figure 2.6 :** Effect of PCC on the engine power at various engine speed

CNG is a natural gas fuel and research proven that it is a better fuel compared to the gasoline fuel when it comes to the pollution produced by both fuels. The less percentage of CNG fuel used for the vehicle is because this type of fuel has lower power compared to the conventional fuel which is the gasoline. Figure 2.7 shows the comparison of the power output of the engine of gasoline fuel and the CNG fuel without PCC applied to the engine. From the graph, the power for the CNG is proven to be lower compared to the gasoline fuel. The power from the gasoline fuel engine shows increasing value from engine speed of 1500 rpm until 3500 rpm and started decreasing after that, but for the CNG fuel the power of the engine did not shows decreasing value for the engine speed of 1500 rpm way until 4000 rpm. Although the power is lower, but the consistency of the fuel is better with the CNG fuel.

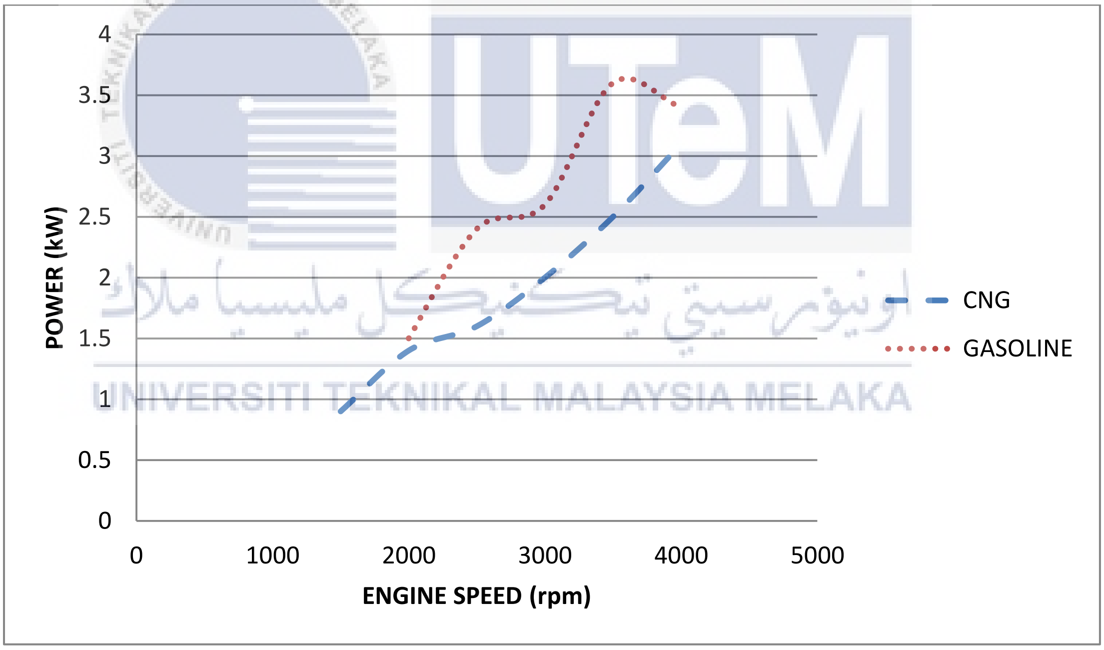





**Figure 2.7 :** Effect of the engine power with CNG and gasoline fuel on the engine at various engine speed

From Figure 2.8, the gasoline shows a big different of the output power produced compared to the CNG fuel. In Figure 2.8, the PCC is applied to the engine to see the effect of the PCC to the engine power. From the graph shown, the gasoline still has a higher power output for the engine, but compared with the CNG fuel to the engine without applying the PCC it is a small different with the power output from the engine. The PCC had increasing the power output for the CNG fuel up to 70% according to the specific engine speed. The application of the PCC to the engine fueled with CNG had increasing the power output almost the same as the output power for the engine fueled with the gasoline fuel. With a different and better design of PCC the power output for the engine may be similar or much better to the gasoline fuel.

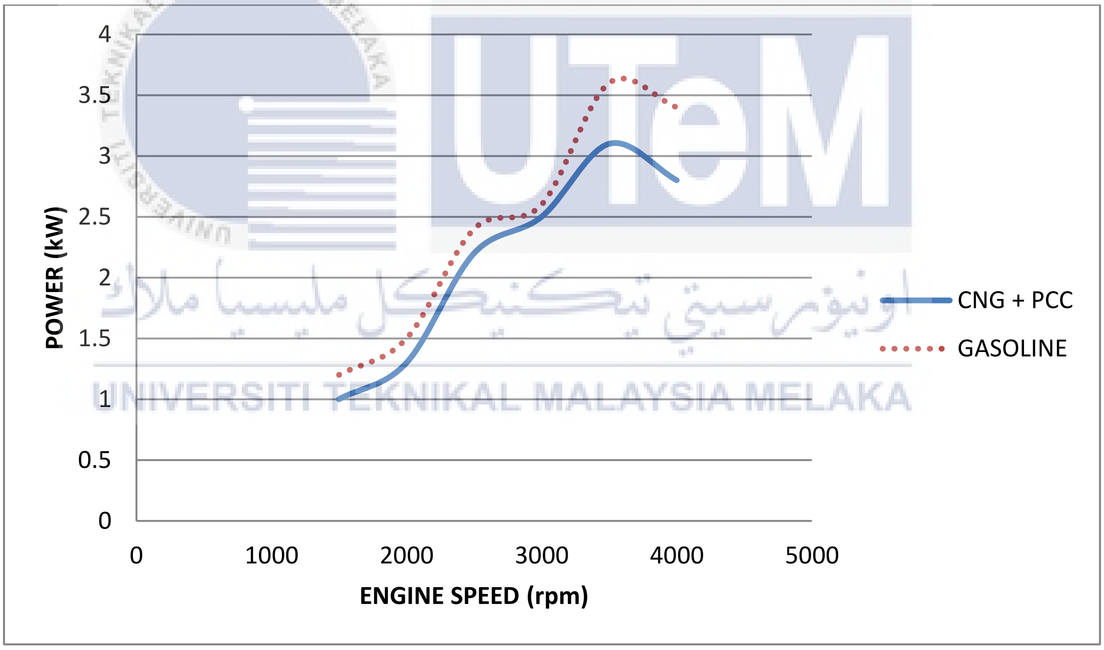





**Figure 2.8 :** Effect of PCC to the engine power compared to gasoline fuel on the engine at various engine speed

## 2.6 EFFECT OF PCC TO THE ENGINE TORQUE FROM PREVIOUS CASE STUDY RESULT

Besides the power output of the engine, the engine torque also need to be taken to consideration. The different fuel used to the engine and the application of the PCC to the engine will also bring effect for the torque of the engine.

Figure 2.9 shows the torque of the engine with different type of fuels used. The torque of the gasoline fuel shows the highest value among those two fuels. The gasoline fuel is the best fuel with the highest output when it comes to torque and power of the engine. Another alternative fuel for the SI engine is the CNG. From Figure 2.9, we can see that the torque of CNG is clearly lower than the gasoline fuel but the application of PCC coupled with the CNG produced a better output for the engine. For the pattern of the engine torque, all of the fuel shows the same pattern. With the engine speed from 1500 rpm until 3500 rpm, the torque values shows increasing values. The value change from increasing value to decreasing value started from 3500 rpm onwards.

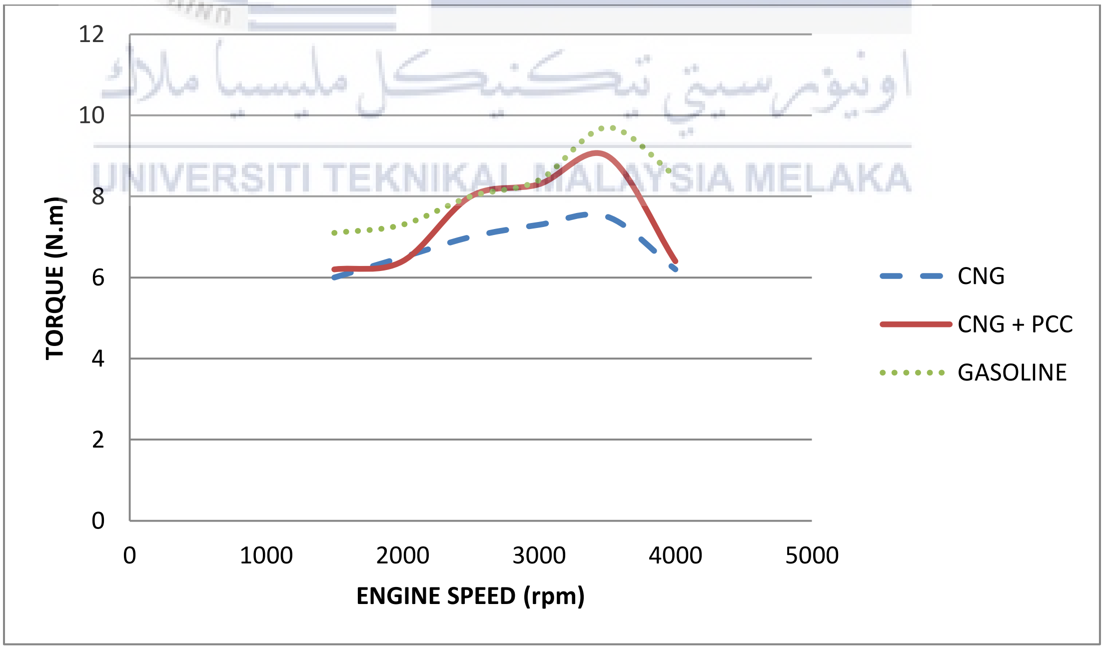



**Figure 2.9 :** Effect of different type of fuel on the engine torque at various engine speed

The effect of the PCC had been proven to increasing the power of the engine. Meanwhile for the torque of the engine, the effect of the PCC is not obviously can be seen for engine speed of 1500 rpm and 2000 rpm. The PCC started to prove its effect at engine speed of 3000 rpm by increasing the torque to 7.8 N.m, while the torque of the CNG without the help of the PCC is only at 6.5 N.m. From the graph, it is proven that the PCC can produce a better torque to the engine compared to the CNG without PCC. Figure 2.10 shows the effect of PCC on the engine torque.

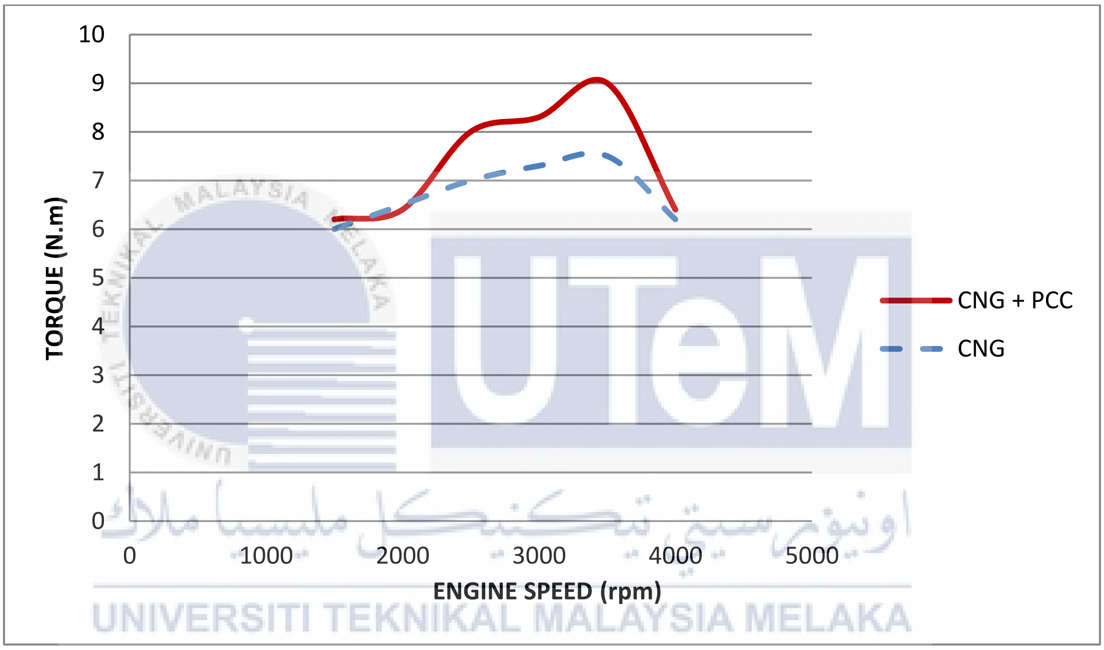




**Figure 2.10 :** Effect of PCC on the engine torque at various engine speed

CNG shows a lower torque produce compared to the gasoline fuel. From Figure 2.11 for the engine speed of 1500 rpm, torque for CNG fuel it only at 6 N.m, while for the gasoline fuel the torque is at 6.5 N.m. In the engine speed of 2000 rpm, CNG fuel has a torque of 6.2 N.m, but for the gasoline fuel, the torque value is at 6.7 N.m. The torque values continue to increase for both CNG and gasoline until at engine speed of 3500 rpm. The torque for the CNG fuel decrease to 6.1 N.m and for the gasoline fuel, the torque is 8.3 N.m. The torque for the gasoline is still higher than the torque of CNG fuel although it decreases after the engine speed of 3500 rpm.

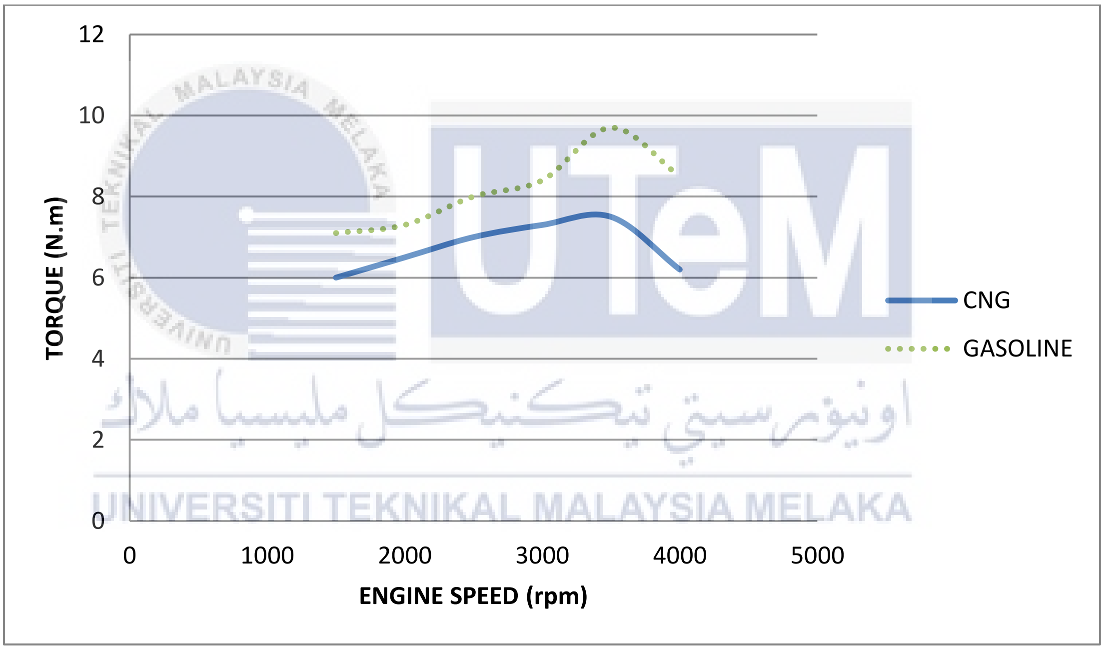



**Figure 2.11 :** Effect on torque of the engine with CNG fuel and gasoline engine at various engine speed

In Figure 2.12, the graph shows the result of the engine torque of the CNG with the application of PCC and also the torque of the engine fueled with gasoline. Compared to the result of the engine torque of the CNG fuel, the PCC applied while the engine is fueled with CNG produced much better result. The PCC application with the CNG fuel increases the torque for the engine. The torque for the PCC application on the engine fueled with CNG almost reach the value of the gasoline fueled engine’s  torque. The torque values between the CNG fuel with the PCC and the gasoline fuel on the engine does not have much different until the engine speed of 4000 rpm. At engine speed of 4000 rpm, the torque of the CNG with the PCC dropped in a large value compared to the gasoline fueled engine although both torques of the fuel drops.

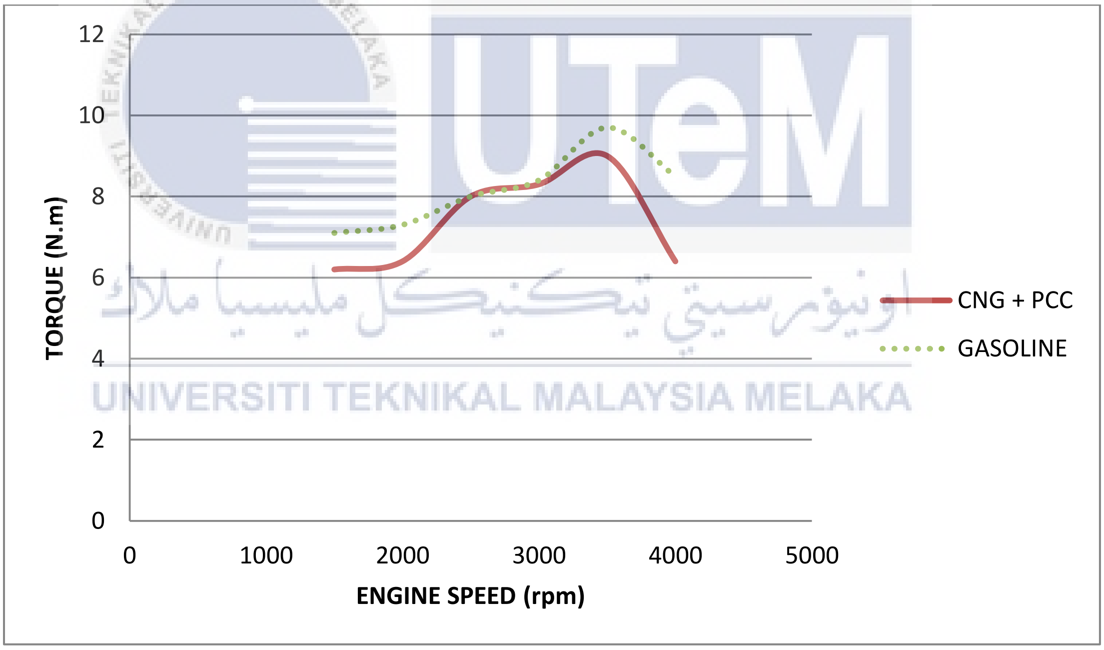



**Figure 2.12 :** Effect of PCC on the torque of the engine compare to gasoline fuels at various engine speed

## 2.7 SUMMARY

This section will be the summary of this chapter. The usage of the Natural Gas (NG) in the Internal Combustion Engine (ICE) had develop in every country especially the developed country. It is because they are very concern on the environmental health. The usage of NG instead of gasoline had been proven to be such more healthy to the environment.

The limitation of using the NG as the working fuel of IC Engine is that the performance of NG is lower compared to gasoline fuel and also diesel fuel. Many technologies had been developed to overcome this limitation and the most interesting method they used in by applying the Pre-Combustion Chamber or the PCC into the IC Engine. Application of the PCC had been improve the performance on the L-type of engine using CNG as the engine fuel. In the next chapter, we will be discussing on how this PCC will effects the performance of the IC Engine that uses NG as it working fuel.

# CHAPTER 3

# METHODOLOGY

## 3.1 OVERVIEW

In this chapter, we will discuss on the equipment used and the experiment procedure. In the beginning of the work, we started with the installation of the sensor into the tested engine. Besides that, the fabricated Bolted Pre-Combustion Chamber (PCC) is then installed at the engine block head. The engine is also equipped with the Compressed Natural Gas (CNG) kit as the engine uses Natural Gas (NG) as their working fuel. Hydraulic Pump is also connected to the engine as a functioning load to the engine. Number of experiments run to obtain reliable data.

## 3.2 PROJECT FLOW

Figure 3.1 shows the flow chart of the project.

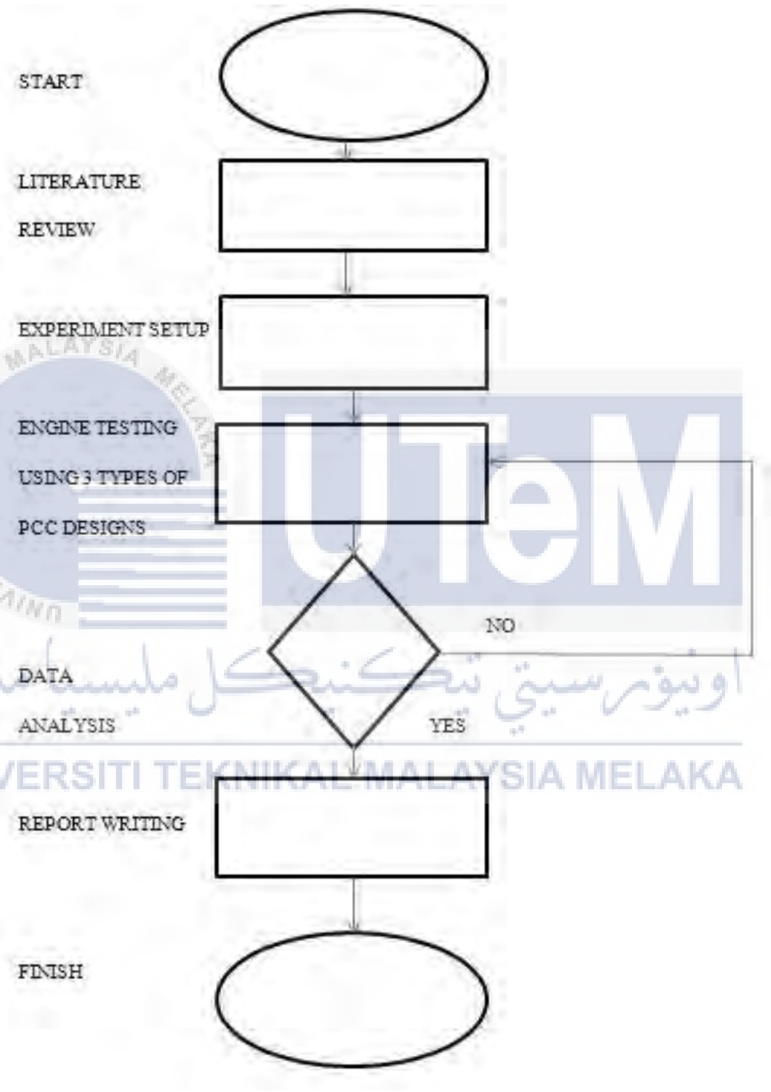



**Figure 3.1 :** Flow Chart for the research activity

## 3.3 APPARATUS & EQUIPMENT

The equipment that are used in this study are a single cylinder of 4-stroke engine, a high pressure sensor and data acquisition (DEWEsoftX), Pre-Combustion Chamber (PCC) and Compressed Natural Gas (CNG) kit. The detail on those equipment are explained in the following sections.

### 3.3.1 SINGLE CYLINDER ENGINE

In this case study, we are using a single cylinder of 4-stroke engine to determine the performance of the engine by installing a load at specific speed of the tested engine. To test the engine performance, a small engine dynamometer is used in this case study. The engine dynamometer is a hydraulic dynamometer where a hydraulic pump is coupled with the engine. The hydraulic pump will act as a functional load to the engine at certain speed.

The main purpose of using the single cylinder engine because it is low cost and could be easily modify for the sensor and CNG kit setups. The engine specifications are shown in Table 3.1.

**Table 3.1 :** Single Cylinder Engine specifications

| **Specifications** | **Values** |
|---|---|
| Model | G200F(D) |
| Bore × Stroke (mm) | 68 × 54 |
| Displacement (cc) | 196 |
| Compression Ration | 8.5 : 1 |
| Idle Speed | 1400 ± 150 |
| Max. Torque (N.m/rpm) | 13<br>3000 |
| Fuel Consumption (g/kW.h) | ≤ 395 |
| Rated Power (kW/3600rpm) | 3.8 |
| Length (mm) | 312 |
| Width (mm) | 376 |
| High (mm) | 335 |
| Net Weight (kg) | 16(19) |



As to measure the engine performance, a high pressure sensor coupled with a crank angle encoder is used. These sensors were connected to the data acquisition. The data acquisition is used to calculate the raw data from the high pressure sensor and the crank angle encoder. The data calculated are transformed into power, torque, etc. Besides those sensors, a CNG kit is also used to supplied the Natural Gas (NG) to the engine.

### 3.3.2 PRESSURE SENSOR

In this case study, the high pressure sensor is used to determine the power, torque, work and pressure in the engine cylinder while the engine is running. The pressure sensor can also be used to determine the combustion studies such as the heat release and the mass burned fuel fraction from the engine. The pressure sensor model used is 112A05. Figure 3.2 shows the high pressure sensor used.



**Figure 3.2 :** 112A05 High Pressure Sensor

Among many other types of pressure sensor that are available, this 112A05 type of high pressure sensor was selected because it can be use either for the Spark Ignition (SI) engine and also Compression Ignition (CI) engine. The specifications of the sensor is shown in Table 3.2.

**Table 3.2 :** 112A05 High Pressure Sensor specifications

| **Specifications** | **Values and Geometry** |
|---|---|
| Measurement range | 5 kpsi / 345 bar |
| Max. Pressure Range (static) | 10 kpsi / 689 bar |
| Sensitivity | 1.1 pC / psi |
| Operating Temperature Range | -240°C - 316°C |
| Max. Flash Temperature | 1649°C |
| Sensing Geometry | Compression |

Considering the specification of the sensor, it is suitable to be used for the case study. There is one problem using this sensor for this case study, it on the temperature range for the sensor. The engine combustion temperature is higher and out of the temperature range that can be sustain by the sensor. Therefore, to overcome this problem an additional accessories were installed with the sensor. A water adaptor was installed to ensure the sensor can be operate in the engine temperature and it preventing the sensor form getting damage while operating due to the high engine temperature.



Another safety feature that we had considered while running the experiments using the high pressures sensor is the additional of the water excess mount. This water excess mount will prevent the sensor from being exposed to the high temperature of the combustion in the engine. The water excess mount will circulates the sensor body and the sensor diaphragm which exposed to the combustion. This additional safety feature will not effects the sensor data as it only reduced the temperature of the body of the sensor. The water excess mount is installed at the head of the engine thus is will not effects the engine performance and also the data obtained.

### 3.3.3 CRANK ANGLE ENCODER

Crank angle encoder shown in Figure 3.3 is an equipment that been coupled with the high pressure sensor in order to be used. It is a sensor that is used to measure the engine crank angle and also the engine speed based on the angle encoder disc.

In this case study, the total incremental used at this crank angle encoder disc was 360. The rotation of the angle encoder disc of the crank angle encoder will be capture by the optical angle encoder.

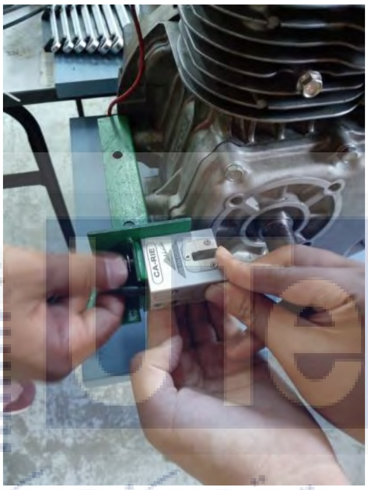


**Figure 3.3 :** Optical Angle Encoder installation



The data from the angle encoder disc is passed to the optical angle encoder which then been converted into engine speed, and also engine crank angle. In this case study, the engine shaft rotation was set to 20 cycles. After 20 cycles, the offset value was reset by the system.

### 3.3.4 COMPRESSED NATURAL GAS KIT

Compressed Natural Gas (CNG) kit is a representative of the CNG system installation to the engine. In the CNG kit, there are consist of CNG tank, a pressure regulator, and finally the fuel switch.

In the CNG tank, the natural gas used is methane. The internal pressure of the tank in estimated to be approximately 200 bar. The high pressured natural gas was reduced by the CNG regulator before entering the engine. According to the specification of the regulator, the pressure of the CNG can be reduced down to 1 bar and it is a suitable pressure for this engine. The pressure range for the engine is from 1 bar up to 1.8 bar. For the case study, the pressure is fixed at 1 bar.

The pressure was monitored by a small pressure gauges that were installed between the inlet of the engine and the outlet of the pipe. For modern type of engine, the CNG are injected according to the Electronic Control Unit (ECU) reading but for this case study, the engine was a carburetor operated engine thus the ECU was omitted. The CNG fuel is switched manually at specific engine speed. For the case study, the most optimum engine speed to switch to CNG is in range of 2000 rpm to 2500 rpm.

### 3.3.5 THREE TYPES OF PRE-COMBUSTION CHAMBER (PCC)

In this experiment, we used three type of different Pre-Combustion Chamber (PCC). The PCC is have different dimensions that will effects the result and give different output. Based on the literature review, the function of the PCC is to increase the output performance of the engine by increasing the effectiveness of the combustion in the engine.

This PCC uses the force produced by the piston in the engine to ensure that the fuel are mixed in the it pre-chamber. The PCC installation on to the engine uses the plug-in concept where the PCC is attached to the head of the engine. The PCC is placed at the hole where previously for the spark plug. As the input hole of the PCC is attached to the engine's head, the output is where the spark plug are now installed. Figure 3.4 shows the PCC to be used in the experiment.



**Figure 3.4 :** Pre-Combustion Chamber (PCC)

The PCC working mechanism is depends on the piston movement. As the piston move from bottom to top, it forces the mixture of the working fuel into the PCC volume. This volume of the PCC that make the three type of PCC will result to different outcome.

The previous experiment done, they used a type of PCC with volume of 3232.7 $mm^3$. In this case study, we developed three type of new PCC referring from the previous design of PCC. The first type of PCC's design shows in Figure 3.5 that we used for this case study, the outer diameter is 22 mm and the inner diameter is 12 mm. This give the total volume for the chamber of 2488.1 $mm^3$. The volume of the chamber is where the mixture of the fuel from the engine will be placed.

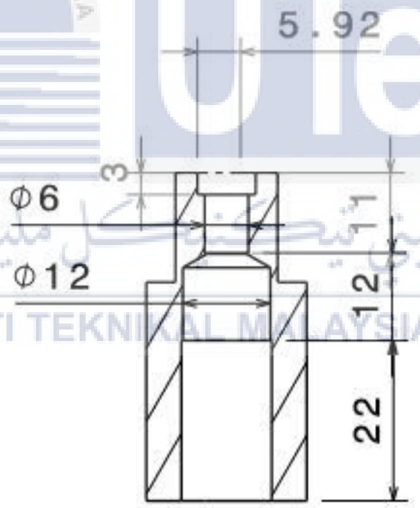



**Figure 3.5 :** Design of PCC 1

The second design of the PCC has the outer diameter of 22 mm$^3$ and the inner diameter of 14 mm$^3$. For the total volume of the chamber of the PCC, it have 3386.6 mm$^3$. This total volume of the chamber for the second PCC is larger than the first PCC. This means that this PCC can contain more mixture of the fuel in a time. Figure 3.6 shows the PCC 2 design.

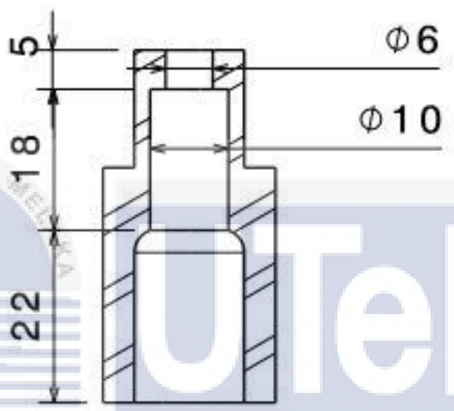



Figure 3.6 : Design of PCC 2



The final design of the PCC is designed and shows in Figure 3.7 with the outer diameter of 22 mm. The inner diameter is design for 14 mm and the chamber's volume is 3848.5 mm$^3$. The third design of the PCC giving the most largest chamber volume compared to the other type of PCC that are considered in this case study. With the highest volume among the other PCC, this PCC will hold the most largest amount of mixture at a time.

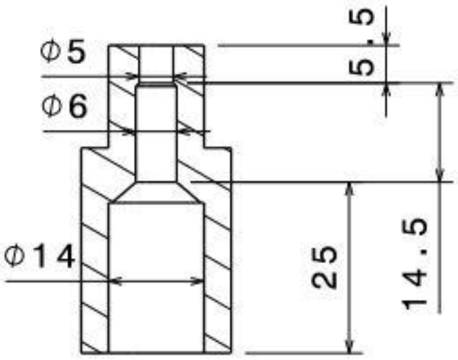



**Figure 3.7 :** Design of PCC 3

Among the three design of PCC, experiment will be done to determine which design of PCC among this three that are considered in this case study that have the most optimum output. The outputs of those all PCC will be compared with the simulation done from other experiment to observe the different. The most validated result will be consider to be the optimum result for this case study.

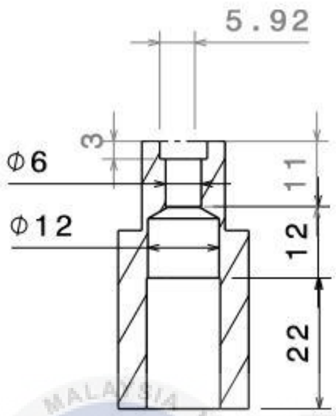
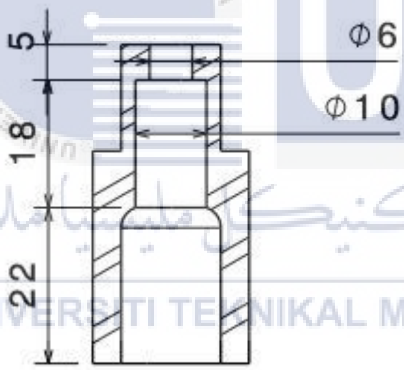
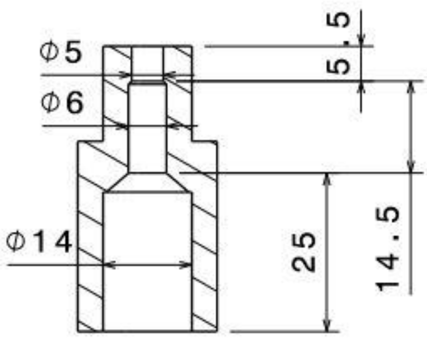
## 3.4 SUMMARY

This chapter discussed in detail on how the experiment are run to get the result from the objective in the first chapter. The main purpose of this case study is to improve the performance output of Internal Combustion Engine (ICE) that uses Natural Gas (NG) as the fuel.

The research engine for this case study is a 4-stroke single cylinder engine that had been modified so that is could run by using NG. This engine is also attached with a hydraulic pump as its load to ensure the result from the experiment done is accurate. The engine had also been installed with a bolted Pre-Combustion Chamber (PCC) functioning to increase the efficiency of the NG thus increase the performance of the engine output.

There are three different designs of PCC used in this case study and the comparisons is shown in Table 3.3. The aimed of using different designs of PCC is to determine the best PCC design that will increase the effectiveness of the NG for the engine. The performance of the NG is determined from the performance of the engine. The most optimum result from the engine performance will result to the best PCC design.

**Table 3.3 :** Differences and comparison of the three PCC design used in the experiment

| **PCC design used** | **Descriptions** |
|---|---|
|  | PCC 1 has a bigger combustion chamber's size compare to PCC 2 and PCC 3. The bigger the chamber may result to a better power due to much more fuel to be press into the PCC during the compression stroke. The inlet of the PCC is also been design shorter so that the fuel may enter the PCC smoothly and with shorter time taken to combust. |
|  | The second PCC design has a combustion chamber size less than PCC 1. Beside that, the inlet of the PCC also had been design to be longer. This will effect to a longer time taken for the fuel to be combust. |
|  | The third PCC design has a longer inlet. The longer inlet of the PCC, the longer the time taken for the fuel to be combust as the spark plug is placed at the other ends of the PCC. Compare to PCC 1 and PCC 2, PCC 3 has bigger combustion chamber that may result to a higher power output. |

# CHAPTER 4

# RESULTS AND ANALYSIS

## 4.1 COMPARISON OF THE PERFORMANCE OF THE ENGINE FUELED WITH GASOLINE, CNG AND ALSO CNG WITH PCC

In this chapter, a comparison of the engine performance will be done and will be discussing in detail of the result gained from the experiments done. The engine are fueled with gasoline, CNG without applying the PCC on the engine and also fueled with CNG but this time we are applying three type of PCC on to the engine. All the data are represented in a graphical visualization method. The result from the experiments done are focusing on the power and torque.



## 4.2 EFFECT OF PCC TO THE ENGINE POWER

As the used of PCC in an Internal Combustion (IC) engine has been proven to improve the performance of the engine in term of the power and also the torque of the engine, the next research is to used various types of PCC and to investigate the effect of the different design to the performance of the engine. In the experiment done, we are using three types of different PCC design and observe the effect by the different geometry designs to the power performance outcome.

In Figure 4.1, the gasoline fuel shows a remarkable performance with a high power output among others but the power decrease with large value at higher engine speed. For the CNG fuel, the power output of the engine is much lower compared to the gasoline fuel. Although the performance of the engine is lower but the pattern of the graph shows the same pattern with decreasing value of power at higher engine speed.

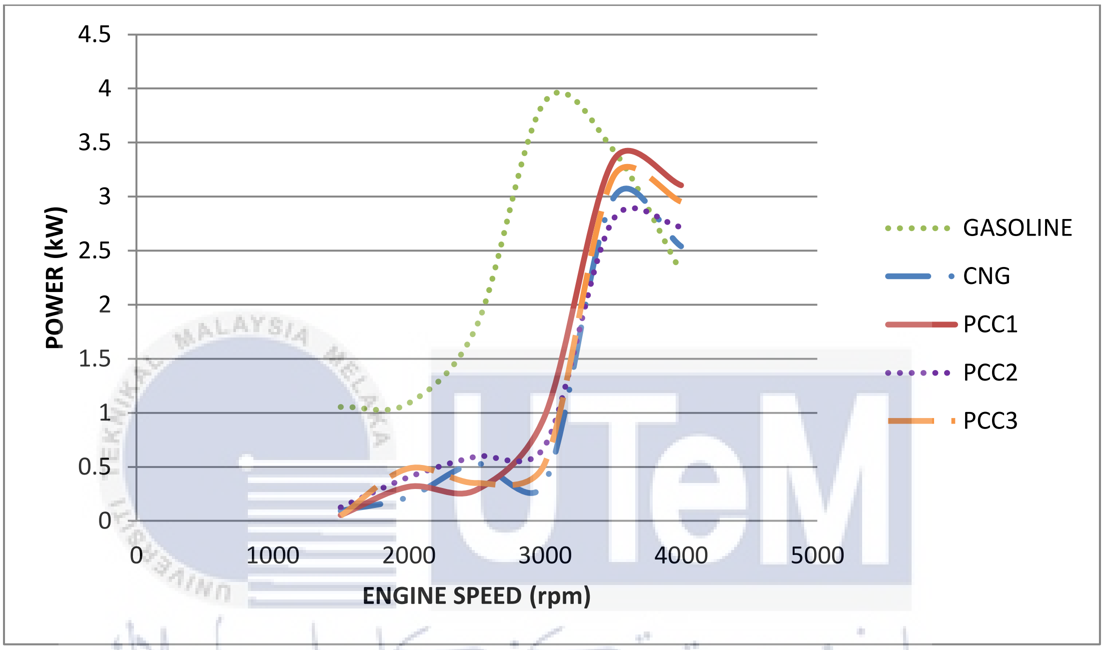





**Figure 4.1 :** Power output of engine using Gasoline, CNG, three types of PCC at various engine speed

Adding a PCC to the engine while its running with the CNG fuel had increasing the power of the engine to a higher value. From the graph, we can see that PCC 1 shows the most optimum performance among other PCC used. Although at the beginning of the test, it has a low value of power output compared to the other two type of PCC used but it started to increase at a higher engine speed.

For the second PCC used in the experiment, it has the most stable performance compared to other type of PCC used. From the beginning of the test until the end of the test, there is not much changes in term of the power output of the engine. At lower engine speed, the power output of the engine is the highest among other PCC but with a higher engine speed, the power output show a little bit lower compared to other type of PCC used in this experiment.

The third PCC used is the most unstable PCC. It is because the power output for the engine keep on changing with higher value to a lower value and again rise up to a higher value. At the beginning of the test, the power increases rapidly but suddenly decreases to lower value and increase again as the engine speed is increase. But although at a higher engine speed, the power output value is still lower compared to the first PCC.

In Figure 4.2, it shows more detail on the comparison between the CNG and also the three types of PCC used and the performance of the engine in term of the power output. In any gasoline engine, using CNG as it fuel decreases the performance of the engine by almost 80%. In order to have a higher performance, PCC is used. But different geometry design of the PCC will result to a different outcome of the performance.



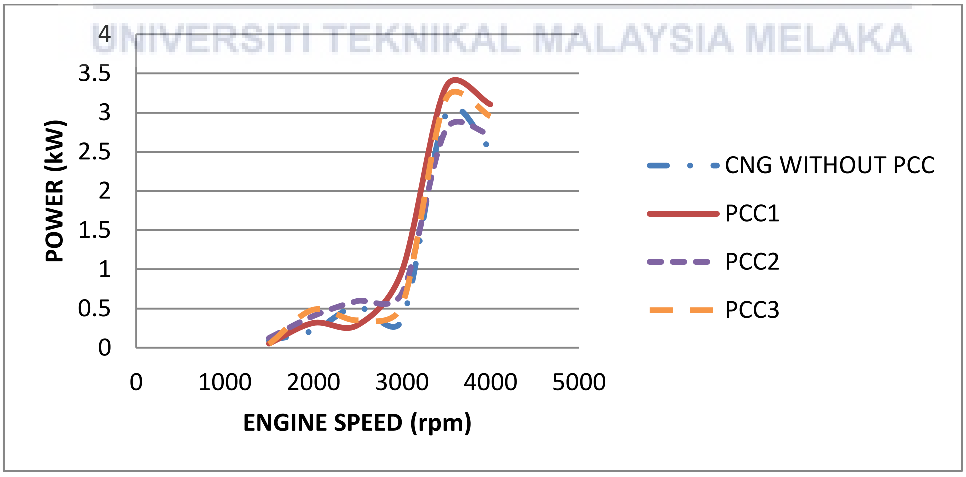



**Figure 4.2 :** Power of the engine using CNG and three type of PCC at various engine speed

The first PCC started the test with a small value of power output compared to PCC 2 and PCC 3. But at the engine speed of 3000 rpm, the power started to increase to a very high value and produce a highest power output value compare to other PCC.

When PCC 2 is used on the engine, at the beginning of the test the value of the power of the engine increases smoothly and then the value decreases, it decrease with a small changes of value. Starting at 3000 rpm, the power of the engine increases to a higher value and start to decrease at 3500 rpm. Although the engine experienced changes in the values of the power output, with PCC 2 the performance of the engine is very stable compared to PCC 1 and PCC 3.

In order to complete the objective of the research, the third PCC is used on the engine and the performance of the engine in term of the power output is measured. PCC 3 started the test with a high value of power compared to PCC 1 and PCC 2. But at a higher engine speed, the PCC cannot produce a higher value of power to the engine. The power of the engine for PCC 1 is much higher than what produced by PCC 3 but compared to PCC 2 it has much better result as the value of the power output is higher to PCC 2.

For the comparison between the three type of PCC used in the test, PCC 1 is the have the most optimum performance in term of the power produce by the engine followed by PCC 3 and finally PCC 2. It may be the effect of the geometry of the combustion chamber of PCC 1 is bigger compare to PCC 2 and the inlet of PCC 1 is shorter compare to PCC 3.

## 4.3 EFFECT OF PCC TO THE ENGINE TORQUE

Besides the power of the engine, the torque is also important to determine the performance of an engine. PCC is used to increase the performance of the engine and from the result, PCC had increase the power of the engine. Will the PCC effect the engine torque and how far does will its improve the torque of the engine?

Gasoline is the present fuel for the engine and the torque value is high. When the engine fuel changed to CNG fuel, the torque went down to a smaller value. This prove that using CNG instead of gasoline fuel decrease the performance of the engine. To increase the performance, PCC are used coupled with CNG fuel and the torque is measured. Figure 4.3 shows the torque of the engine result.

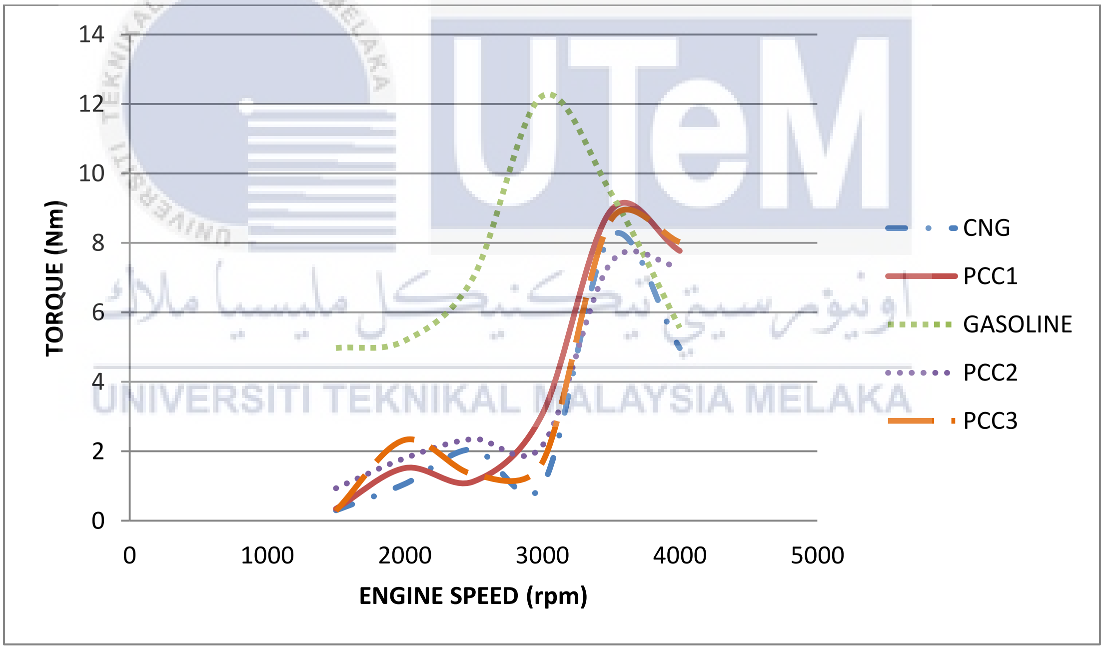



**Figure 4.3 :** Torque of the engine using Gasoline, CNG, three types of PCC at various engine speed

From Figure 4.3 PCC 1 shows the most optimum outcome which has the highest torque produce by the engine at the peak of the graph compared to PCC 2 and PCC 3. Although at the beginning of the test it started slow and have the lowest value of torque, the performance change as the engine speed increases.

The next PCC used for the test is PCC 2. From the power of the engine, PCC 2 proven to have the most stable performance for the engine compared to PCC 1 and PCC 3. The result for PCC 2 in term of torque measured from the engine shows almost the same compared to the power result. PCC 2 produce a stable value of torques by the engine throughout the test is run. The torque of the engine keep changes at certain engine speed. The torque values increases and decreases as the engine speed varies but for the PCC 2, the changes for the torque values is smaller than PCC 1 and PCC 3. PCC 2 have advantage for stability of the performance because it produced a consistent result but it is not the most best PCC among the three PCC as the torque produce at the peak of the graph is the smallest than PCC 1 and PCC 3.

The torque for PCC 3 is high for low engine speed. PCC 3 shows the highest value of torque compared to PCC 1 and PCC 2. But as the engine speed is increase, the torque value for PCC 3 is lower than PCC 1 with a little gap of different. The value of torque produce by the engine at higher engine speed for PCC 1 and PCC 3 is not much different but PCC 1 still have the highest torque value at the peak of the graph throughout the test.

Without any PCC applied to the engine that been fuel with CNG the torque value is much lower compared to the torque values with an additional of the PCC to the engine. Figure 4.4 shows the result of the engine torque fuel with CNG without application of any PCC, with additional of PCC 1, PCC 2 and PCC 3. The comparison between them is more detail compared to what shows in figure 4.3.

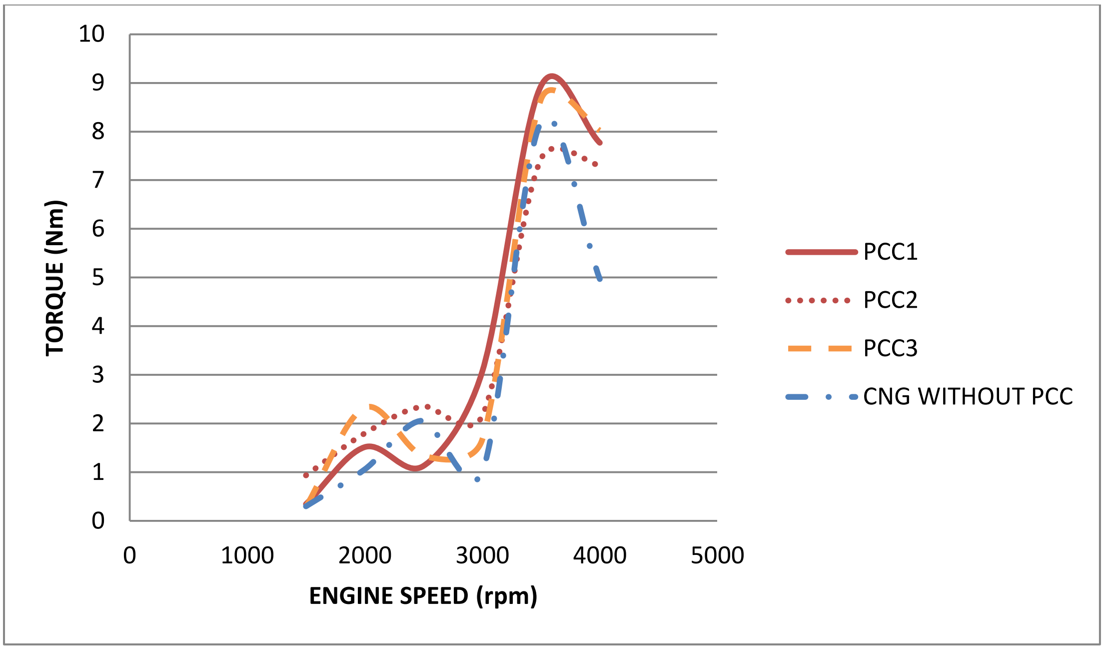



**Figure 4.4 :** Torque of the engine using CNG and three type of PCC at various engine speed

With an additional of PCC 1 to the engine that had been fuel with CNG, the engine torque is increase compared with the value of torque without any application of PCC. At lower engine speed, the value of the torque increase with small amount but as the engine speed increase to a higher speed, the torque value produce by the engine become much higher. The torque value of the application of PCC 1 at higher engine speed shows the highest torque produce by the engine compared to PCC 2 and PCC 3.

For PCC 2, the torque value produce by the engine at the beginning of the test is very high. The torque value experience a little bit of decrease at engine speed of 2500 rpm but increase to its peak at 3000 rpm and started to go down again at 3500 rpm. The value of torque produce at the peak of the graph is the lowest compared to PCC 1, PCC 2 and also the torque value for without any PCC used. This shows that this PCC is very efficient at lower engine speed but the performance decrease at higher engine speed.

From the result above, PCC 3 have a much better performance than PCC 1 at lower engine speed. But at lower engine speed, the torque value increase and decrease with a large value. For the torque at higher engine speed, the torque value started to increase at 3000 rpm and at the peak of the performance at 3500 rpm. At the peak of the graph, the value of the torque is almost the same to the torque value of PCC 1. After 3500 rpm, the torque value started to decrease slowly reaching to 4000 rpm which the end of the test.

In term of torque value for the engine, the comparison between the three types of PCC shows that PCC 1 have a very high efficiency, followed by PCC3 and lastly PCC 2.

## 4.4 EFFECT OF PCC TO THE ENGINE WORK

Besides the power and torque of the engine, the PCC is also have it influence on the work of the engine. By definition, the engine work is the work on the piston inside of the engine block. For any engine, the work done by the piston is different regarding by many factors that would effecting the piston working condition. Some factor that would probably have big effect on the piston work is the size of the engine. Some engine have bigger size and also many number of piston, this will result to less work done by the pistons as the work for the engine is divided to the number of pistons in the engine. For our case study, we are using a single piston four-stroke engine with the engine capacity of 196 cc. The result of the work done by the engine is shown below.

Figure 4.5 shows the result of the work done by the engine using gasoline fuel, CNG fuel and also CNG with additional of three types of different PCC. For the gasoline fuel, the work done by the engine is very high compared to CNG fuel. It is because the power output and also the torque produce by the engine is higher compared to the CNG fuel.



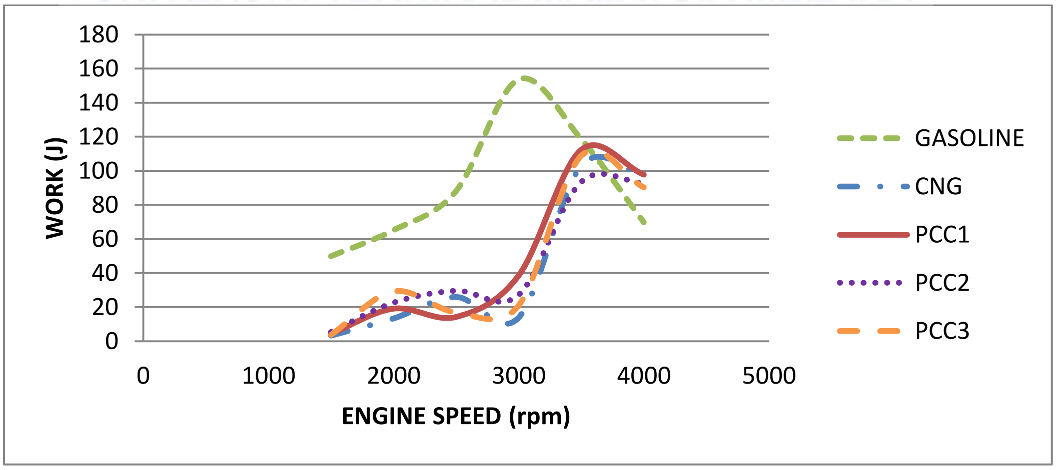



**Figure 4.5 :** Work of the engine using Gasoline, CNG, three types of PCC at various engine speed

As the fuel of the engine from gasoline to CNG fuel, the result is much lower than the gasoline fuel. Using CNG fuel to the engine reduce the work done by the engine to more than 30% from the gasoline fuel. Less work done by the engine has proven to have lower power and torque produce by the engine. This will effects the engine performance and reduce the performance of the engine.

In order to increase the performance of the engine, PCC is used simultaneously with the CNG fuel on the engine. Adding the PCC to the engine has increase the performance of the engine. There are three different type of PCC used in the test and the result for the first PCC shows that the work for the engine increase to a higher value compare to other two PCC use for the test.

The second PCC result is not much different to the first PCC used for the test. At the beginning of the test, the performance of PCC 2 is incredible compare to PCC 1 and PCC 3. It seem that PCC 2 is more suitable to be use at lower engine speed as the work done by the engine reduce as it been tested to a higher engine speed. The work done by the engine at the peak of the graph is the lowest compare to PCC 1 and PCC 3.

PCC 3 is the last PCC used for the test. At lower engine speed, the performance of the PCC is great but decrease a little before it raise high to the peak of the graph with a higher engine speed. At the peak of the graph of the work, the value of the work done by the engine is nearly similar to the value of the first PCC. But the result for PCC 1 is a slightly higher than PCC 3.

Figure 4.6 will be discussing only for the CNG fuel and also the comparison with the three types of PCC used in the test. For CNG fuel, we can see that the work done by the engine is lower at the beginning of the test. The test is done with various engine speed and it started with a lower engine speed and increasing it until the highest performance of the engine. For a higher engine speed, the graph shows that using CNG fuel to the engine still produce work lower than the work done by the engine with additional of PCC.

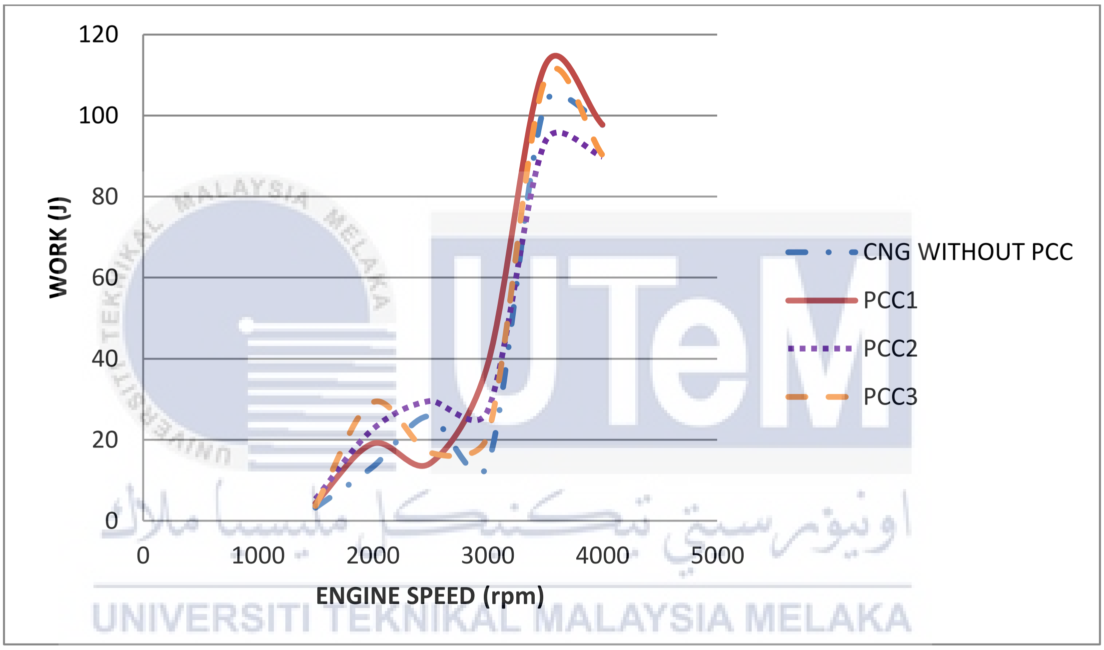




**Figure 4.6 :** Work of the engine using CNG and three type of PCC at various engine speed

At the beginning of the test, PCC 1 produce lower value of work done compare to PCC 2 and PCC 3. The work value increase rapidly as the speed of the engine reaches 3000 rpm. The performance of the engine is at 3500 rpm and at this particular engine speed, the work done by the engine with PCC 1 attached to it shows the most optimum value compare to PCC 2 and PCC 3. The value decreases as the engine speed reaches 4000 rpm and the test stopped at this speed.

The test continue with the second PCC is applied to the engine. As for PCC 2, at lower engine speed, PCC 2 shows a remarkable performance with high value of work produce by the engine but the value slightly decreases at engine speed of 2500 rpm and started to climb to a higher value at 3000 rpm. For PCC 2, at higher engine speed the performance started to decrease and result to the lowest value for work done by the engine compare to PCC 1, PCC 2 and also CNG. With this result, the PCC 2 have a bad performance at high engine speed.

The test ended with testing the last PCC. For the third PCC, the value for the work done by the engine is higher although the engine speed is lower. It then reduce at 2500 rpm and rising up at 3000 rpm. The performance of the engine is at the top at 3500 rpm. At this engine speed, the value of the work done by the engine is around 150 J. It is almost the same to the first PCC which have a value of around 170 J. Reaching for engine speed of 4000 rpm, the work done is reduce and the test ends at 4000 rpm.

The most optimum result for the engine work done among the three PCC tested is the work done by the engine with PCC 1 applied. PCC 1 produce a highest value for work from the engine at the peak of the graph for the engine compare to PCC 2 and PCC 3.

## 4.5 EFFECT OF PCC TO THE ENGINE PRESSURE

The performance of the engine that has been tested also been evaluated from the pressure of the piston in the engine. From the research done, the less pressure on the piston is better for the engine. But, the problem with smaller piston pressure is that it produce smaller value of power and torque output. Figure 4.7 and Figure 4.8 will show the pressure of the engine tested.

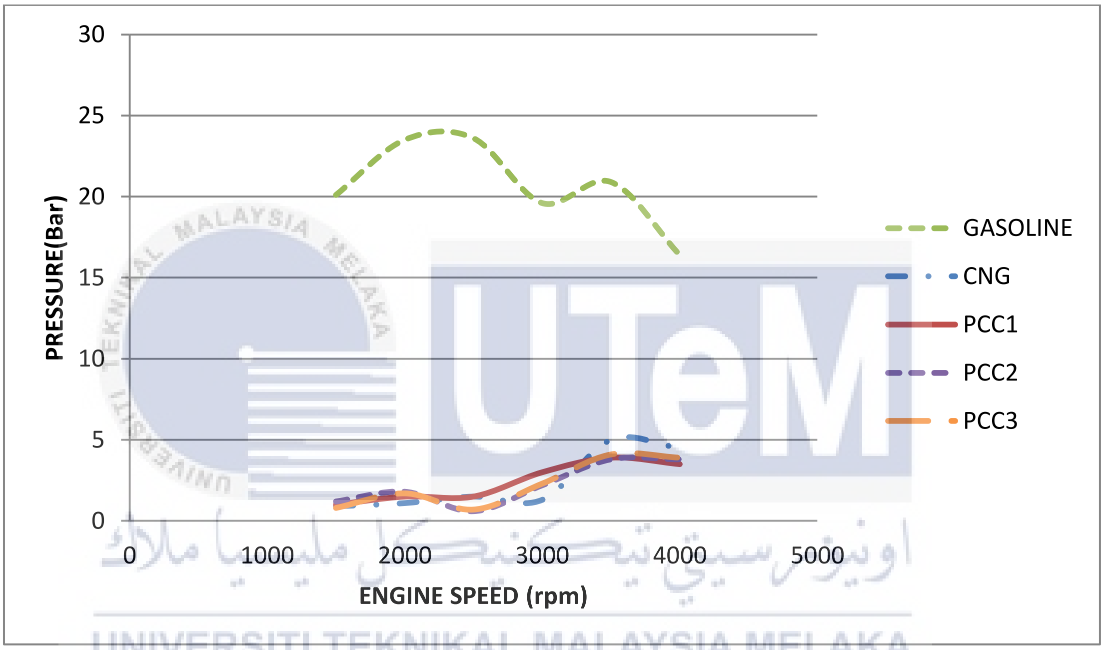





**Figure 4.7 :** Pressure of the engine using Gasoline, CNG, three types of PCC at various engine speed

The engine had been tested using two types of fuel, the first type is gasoline fuel and the second fuel is CNG fuel. After the engine had been tested using the gasoline fuel, the result shows that the pressure of the engine is very high compare to CNG fuel. The high pressure for the engine produce a much higher value for power and torque. As for CNG fuel, the pressure for the engine is much lower than gasoline fuel. The power and torque produce by the engine is also have lower value.

For the pressure of the engine with application of PCC, amazingly that the pressure value went down much lower at higher engine speed. For the first PCC, at lower engine speed the pressure of the engine increasing linearly and continue to increase at higher engine speed. But at a certain engine speed, the pressure started to decrease to a lower value until the end of the test.

The pressure for the engine with the second PCC has lower value compare to PCC 1. The different for the PCC performance is PCC 2 experienced a decrease in value before the pressure started to increase again. This shows that the engine lose some of it pressure. But at a higher engine speed, the pressure for PCC 2 have nearly similar value to PCC 1 and the different of value is very small.

The result for PCC 3 is almost the same with PCC 2. It have the same pattern and the value also nearly the same at low engine speed and high engine speed. There is not much different if compare the pressure value for PCC 2 and PCC 3. This shows that both PCC nearly have the same performance.

Figure 4.8 shows the pressure of the engine using with CNG fuel. There are four different pressures with four different factors that would effects the engine pressure. The first result is the result of the engine pressure without any PCC applied to it. With no PCC apply, the pressure of the engine has a lower value at the beginning of the test. The value decreases at 2500 rpm and increases again at 3000 rpm. At the peak of the graph, the pressure in the engine is high and has the highest value compare to the pressure of the engine with PCC. At engine speed of 4000 rpm, the value of the pressure in the engine started to decreases to a lower value.

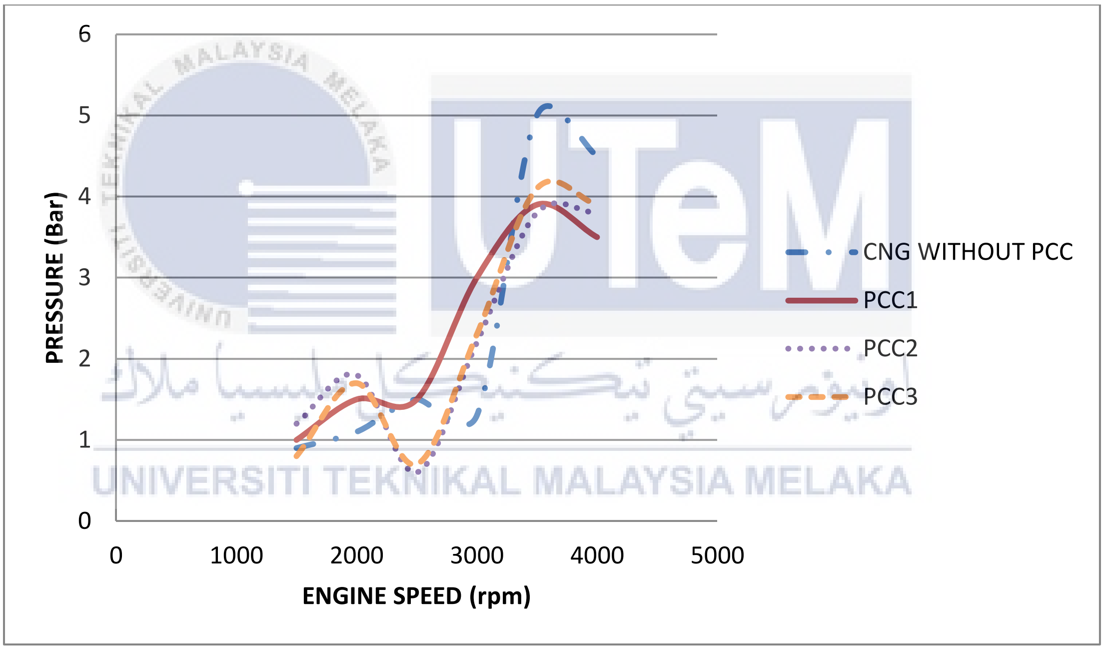



**Figure 4.8 :** Pressure of the engine using CNG and three type of PCC at various engine speed

Meanwhile for the pressure of the engine with additional of PCC to the engine, the value of the pressure for PCC 1 is higher than the pressure without PCC. The pressure than decreases a little bit at engine speed of 2500 rpm. Reaching the top performance of the engine which is at the engine speed of 3500 rpm, the pressure increases to almost 4 Bar but slightly decreases at engine speed of 4000 rpm. The value for the pressure at the peak of the graph is lower than the pressure without PCC.

The pressure for the second PCC has the highest value at lower engine speed. It then decreases with a large value at engine speed of 2500 rpm. At this speed, the engine lost much pressure from the engine. The pressure than soaring up reaching the peak of the graph with pressure nearly the same to the pressure of PCC 1 which is 4 Bar. After engine speed of 3500 rpm, the pressure decreases to a value below 4 Bar and this value is slightly higher than PCC 1.

With PCC 3, the pressure is higher than the value for PCC 1 at the beginning of the test but the value is almost the same to PCC 2. With the same pattern as the PCC 2, the value of the pressure than decreases to the lowest value which is below 1 Bar at engine speed of 2500 rpm. The pressure increases when the engine speed at 3000 rpm and reach the peak of pressure value about 4.2 Bar at engine speed of 3500 rpm. By increasing the engine speed to a higher speed, the pressure started to decreases. Reaching the engine speed of 4000 rpm, the pressure value is slightly below 4 Bar. Although the value started to decrease, the pressure is still higher than PCC 1 and PCC 2.

The engine with lower pressure normally will result to a lower power and torque output. It is an improvement made if the engine pressure for the engine is lower but produce a high value for the power and torque output. In this matter, PCC 1 result is the most optimum result among the three types of PCC that had been tested with the engine. PCC 1 is the best PCC compared to PCC 2 and PCC 3 because with PCC 1, the engine pressure decreases at the top performance of the engine while producing a highest value of power and torque for the engine than PCC 2 and PCC 3. With more improvement to the PCC, it may result to a more ideal result in the future.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

## 5.1 CONCLUSION

Based on the objectives stated in the first chapter, the literature study regarding to the Pre-Combustion Chamber (PCC) efficiency and its effect to the engine fueled with Compressed Natural Gas (CNG) performance had been presented in this report. From the result shown, the engine that used PCC had shown the increased of power, torque, work and improved the pressure in the combustion chamber when using CNG as fuel.

From the experiment conducted, in term of power output for the engine with the application of PCC 1, the power value is 3.4 kW whereas for the PCC 2 is 2.8 kW and PCC 3 is 3.2 kW. The value is taken at the top performance of the engine. While the result for torque of the engine, PCC 1 has the value of 9 N.m, for PCC 2 the value is 7.8 N.m and finally for PCC 3 the value is 8.9 N.m. Table 5.1 shows the result for the engine in term of power, torque, work and pressure at the top performance of the engine which is at engine speed of 3500 rpm.

**Table 5.1 :** Value of power, torque, work and pressure of the engine for three types of PCC's design at engine speed of 3500 rpm.

| **Pre-Combustion Chamber's Design** | **Power (kW)** | **Torque (N.m)** | **Work (J)** | **Pressure (Bar)** |
|---|---|---|---|---|
| PCC 1 | 3.4 | 9.0 | 118.0 | 3.9 |
| PCC 2 | 2.8 | 7.8 | 96.0 | 3.9 |
| PCC 3 | 3.2 | 8.9 | 117.0 | 4.2 |



Among those three types of PCC tested, PCC 1 shows the best performance. The result of PCC 1 shows that the power, torque, work and pressure value is the most ideal compared to PCC 2 and PCC 3. For the main parameters, the comparison power value for the engine without using PCC the value for the power is only 3.1 kW. The power for the engine increased by 0.3 kW or 9.23% of increased if using PCC 1. But using PCC 2, the power decreases to 10.17% from the value of the power without using PCC and for PCC 3 the power increase to 3.17%. All value of the power for the engine are taken at the top performance of the engine. The highest of the performance of the engine is due to different geometry design of each PCC.

## 5.2 RECOMMENDATIONS

Based on the result obtained from the study, it is proven that Pre-Combustion Chamber (PCC) has big influence on the engine performance. Using PCC with Compressed Natural Gas (CNG) increase the performance of the engine compared to without application of PCC. The application of PCC is used on the present gasoline engine. Therefore, in the further studies the development of an engine for the CNG fuel with a build in PCC could be done by developing from the present gasoline engine. Hence, the data from the engine should be more accurate as the engine is built for the use of CNG as it fuel.

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**APPENDICES**

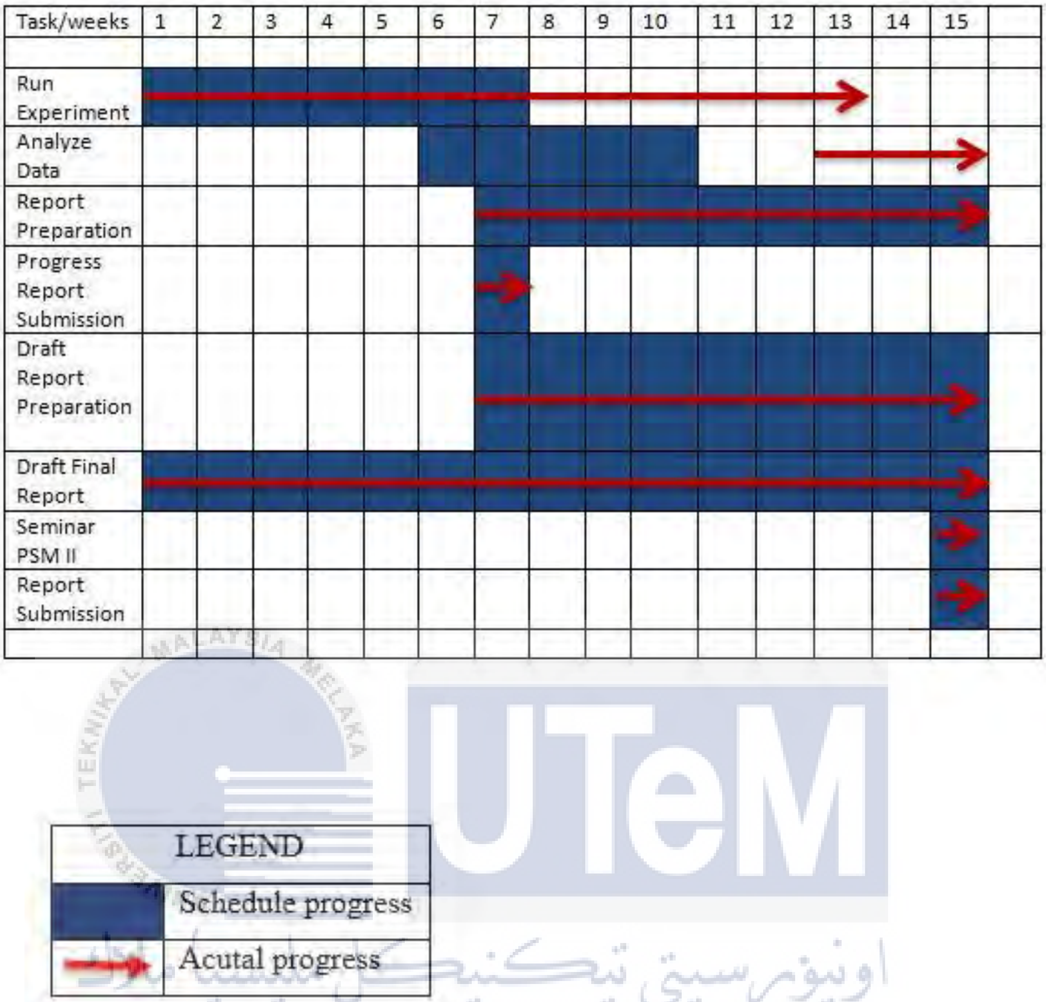
**APPENDIX A**

**Gantt Chart for PSM I**


Task/weeks
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Title selection
Project review, identify objectives & scope of the project
Literature review
Set up engine
Running experiment I
Progress report of PSM I
Seminar PSM I
Report preparation PSM I
Submission report of PSM I
LEGEND
Schedule progress
Acutal progress

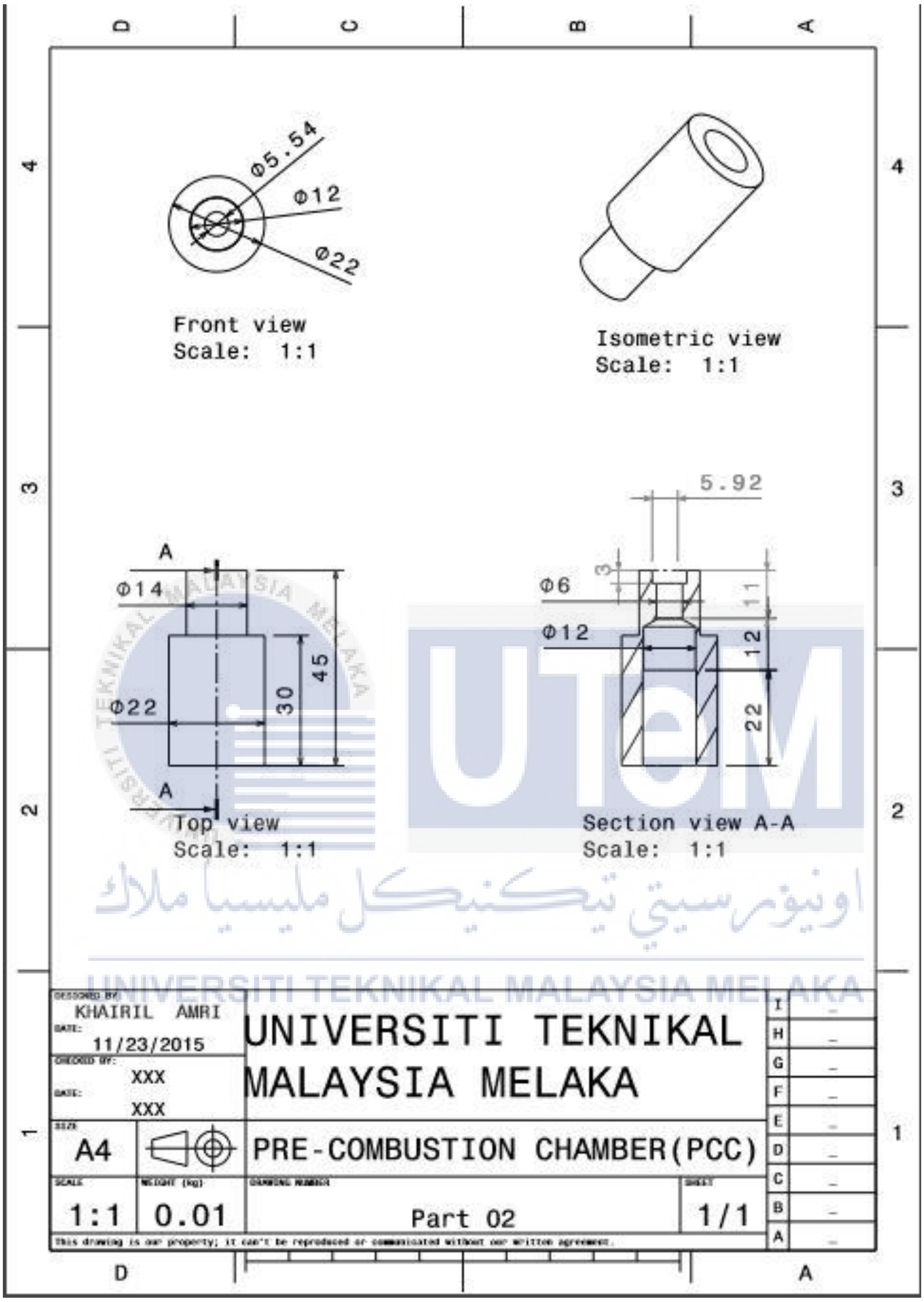
## APPENDIX B

### Gantt Chart for PSM II


Task/weeks
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Run Experiment
Analyze Data
Report Preparation
Progress Report Submission
Draft Report Preparation
Draft Final Report
Seminar PSM II
Report Submission
LEGEND
Schedule progress
Acutal progress

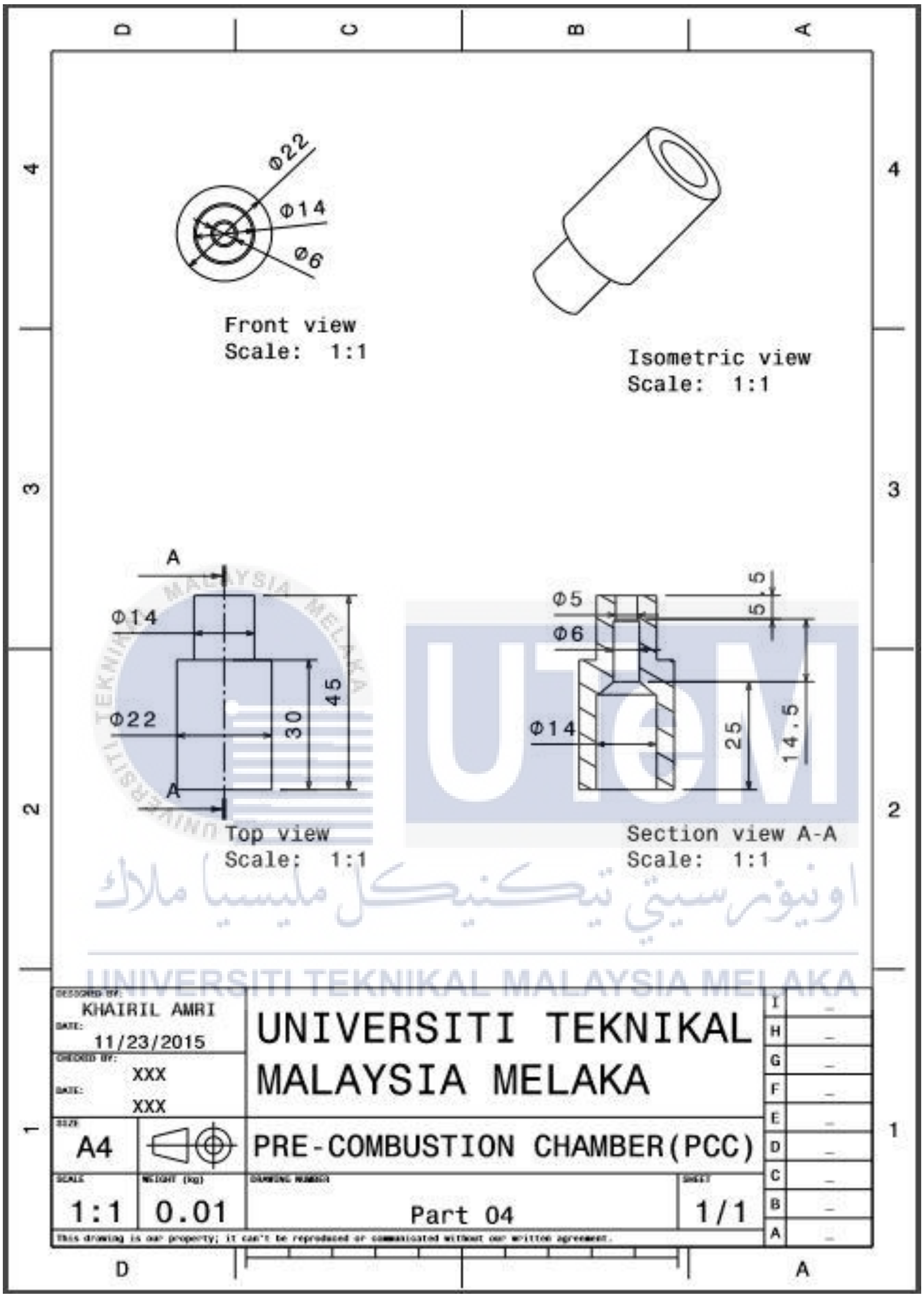
APPENDIX C

Technical Drawing for Pre-Combustion Chamber 1


Ø5.54
Ø12
Ø22
Front view
Scale: 1:1
Isometric view
Scale: 1:1
Ø14
Ø22
45
30
Top view
Scale: 1:1
5.92
3
Ø6
Ø12
11
12
22
Section view A-A
Scale: 1:1
KHAIRIL AMRI
11/23/2015
XXX
XXX
UNIVERSITI TEKNIKAL MALAYSIA MELAKA
A4
PRE-COMBUSTION CHAMBER(PCC)
1:1
0.01
Part 02
1/1

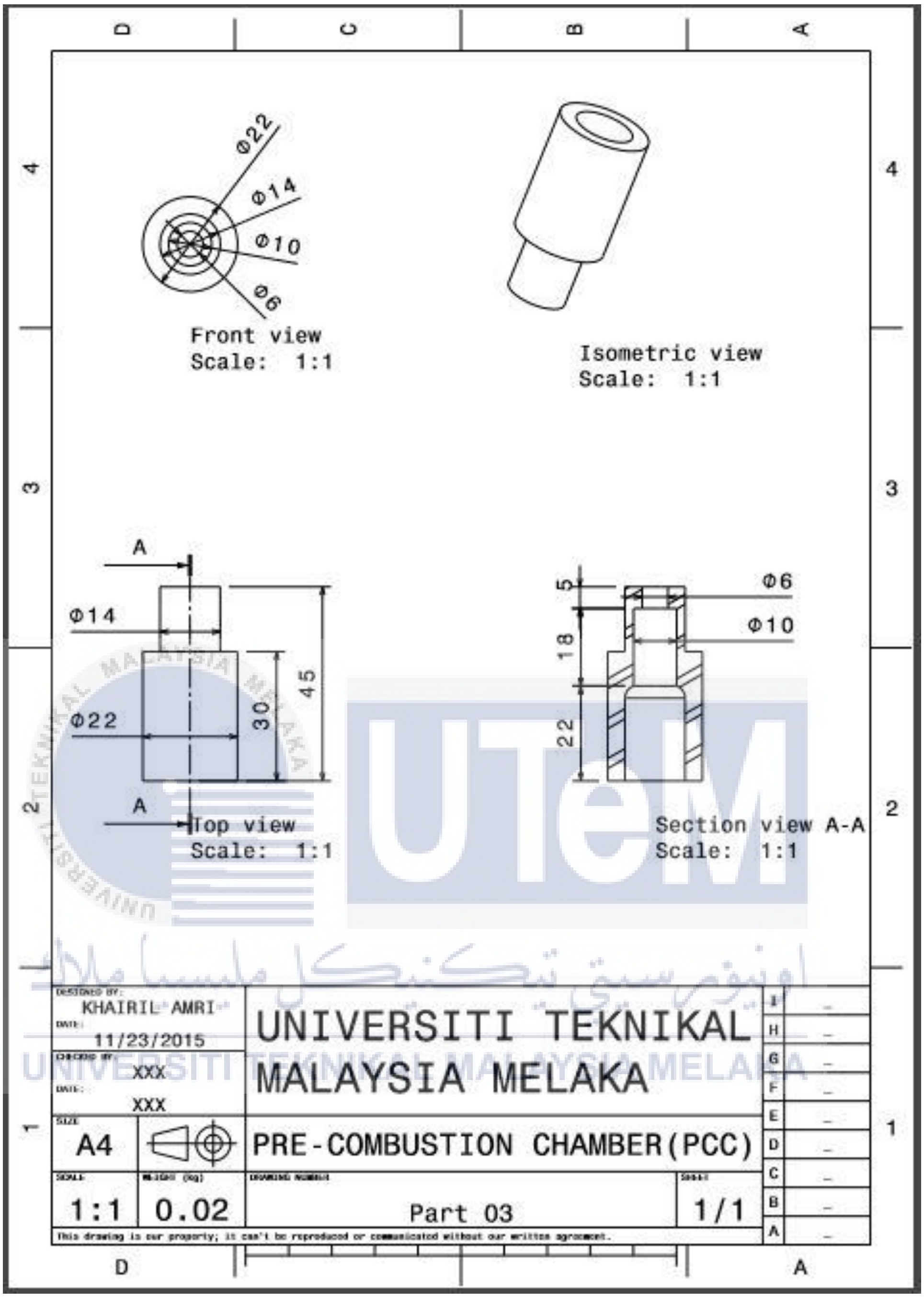
**APPENDIX D**

**Technical Drawing for Pre-Combustion Chamber 2**


Ø22
Ø14
Ø6
Front view
Scale: 1:1
Isometric view
Scale: 1:1
A
Ø14
Ø22
45
30
A
Top view
Scale: 1:1
Ø5
Ø6
5.5
Ø14
25
14.5
Section view A-A
Scale: 1:1
DESIGNED BY:
KHAIRIL AMRI
DATE:
11/23/2015
CHECKED BY:
XXX
DATE:
XXX
UNIVERSITI TEKNIKAL MALAYSIA MELAKA
SIZE
A4
PRE-COMBUSTION CHAMBER(PCC)
SCALE
1:1
WEIGHT (kg)
0.01
DRAWING NUMBER
Part 04
SHEET
1/1
This drawing is our property; it can't be reproduced or communicated without our written agreement.

## APPENDIX E

**Technical Drawing for Pre-Combustion Chamber 3**


Ø22
Ø14
Ø10
Ø6
Front view
Scale: 1:1
Isometric view
Scale: 1:1
A
Ø14
Ø22
30
45
A
Top view
Scale: 1:1
5
18
22
Ø6
Ø10
Section view A-A
Scale: 1:1
DESIGNED BY:
KHAIRIL AMRI
DATE:
11/23/2015
CHECKED BY:
XXX
DATE:
XXX
UNIVERSITI TEKNIKAL
MALAYSIA MELAKA
SIZE
A4
PRE-COMBUSTION CHAMBER(PCC)
SCALE
1:1
WEIGHT (kg)
0.02
DRAWING NUMBER
Part 03
SHEET
1/1
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