ONE DIMENSIONAL ENGINE MODELING OF SINGLE CYLINDER FOUR STROKE ENGINE FOR DIFFERENT CNG INJECTION STRATEGY

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JUNE 201

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project report and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering

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DEDICATION

Specially dedicated to my beloved family, and those who have guided and inspired me throughout my journey of study at University Malaysia Pahang. Thank you very much and your concerned. I'll be remember until the end of my life.

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Last but not least, to my beloved family, my parent and my siblings who always stand by my side concerning the ups and downs of my life. Home is where I find comfort.

ABSTRACT

A simulation work was conducted to compare the effect performances in the cylinder with different injection strategy using compressed natural gas (CNG). The study was based on one dimensional simulation using GT-POWER software. The dimensioning was made on a motorcycle model FZ150i with single cylinder four-stroke engine. The engine was simulated in variations injection strategy with constant speed 4000 rpm with pre-chamber added. The study is focused on characterization of in cylinder pressure and temperature of performance profile for every injection strategy. The other characteristic that has been observed are emissions of CO and NOx between using compressed natural gas (CNG) with gasoline fuel. The output data are post-processed using by the GT-POST software. The analysis of the simulation data showed the improvements in the emissions using compressed natural gas (CNG) where reduction in CO and NOx. The results also are shown that the characteristics in the cylinder pressure and temperature versus crank angle engine with constant speed 4000 rpm using compressed natural gas (CNG) with pre-chamber was added is lower than base gasoline engine.

ABSTRAK

Satu kerja simulasi telah dijalankan untuk membandingkan prestasi kesan di dalam silinder dengan strategi suntikan yang berlainan dengan menggunakan gas asli termampat (CNG). Kajian ini berdasarkan simulasi satu dimensi menggunakan perisian GT-POWER. Pendimensian ini dibuat ke atas model motosikal FZ150i dengan enjin satu silinder empat lejang. Enjin telah disimulasi di dalam pelbagai strategi suntikan dengan kelajuan malar 4000 rpm dengan pra-ruang menambah. Kajian ini memfokuskan profil prestasi pada ciri-ciri tekanan dan suhu di dalam silinder bagi setiap strategi suntikan. Ciri-ciri lain yang telah diperhatikan adalah pelepasan CO dan NOx apabila menggunakan antara gas asli termampat (CNG) dengan bahan api petrol. Data keluaran selepas pemprosesan adalah menggunakan dengan perisian GT-POST. Analisis data simulasi menunjukkan penambahbaikan di dalam pelepasan gas menggunakan gas asli termampat (CNG) di mana pengurangan CO dan NOx. Keputusan turut menunjukkan bahawa ciri-ciri tekanan dan suhu di dalam silinder melawan sudut engkol enjin dengan kelajuan malar 4000 rpm menggunakan gas asli termampat (CNG) dengan pra-ruang telah ditambah lebih rendah daripada enjin petrol asas.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

The alternative fuel usage has been growing due to concerns that the reserves of fossil fuel all over the world are finite and at the early decades of this century will run out completely. Compressed Natural Gas (CNG) is one of the alternative fuel that find can be use as the vehicle fuel to replacing the gasoline (petrol) or diesel fuel. This alternative fuel was having advantages in environment and air pollution control. The exploitation of full potential of CNG as an alternative fuels is means of reducing exhaust emissions. In this study, the engine used is four-stroke engine with single cylinder used on gasoline fuel that is converted to the CNG fuel engine. The different fuel injection strategy is about injection fuel with air that through the new design of pre-chamber, where it causes the effects of parameters in engine performances and emissions. The simulation of engine modeling is based on the software of GT-Power.

1.2 PROBLEM STATEMENT

The main problem in compressed natural gas (CNG) engine with pre-chamber combustion is to achieve the mixing air and fuel with the exact quantity ratio. The other problem is the effects in single cylinder four-stroke engine performances and emissions between gasoline and Compressed Natural Gas (CNG).

1.3 OBJECTIVE

To design and simulate one dimensional model engine for different injection strategy analysis based on single cylinder four-stroke engine.

1.4 SCOPES

In order to achieve the study objective stated above, the following scopes of study have been defined:-

1. All the works are based on single cylinder four-stroke engine.
2. The operation of engine is at the same speed (4000 rpm).
3. Air-fuel mixture ratio method is using high pressure fuel injection.
4. The fuel is Compressed Natural Gas (CNG) and gasoline in simulation of GT-Power software.
5. The study is using new design of pre-chamber method of injection.
6. The simulation is to observe and analysis the parameters of speed, pressure, temperature, Indicated MEP, Brake MEP, emissions from Compressed Natural Gas (CNG) and gasoline and crank angle data.
7. The validation is from the results of different injection fuel of Compressed Natural Gas (CNG) and gasoline.

1.5 THESIS STRUCTURE

Thesis structure is briefly explanation to every chapter in this thesis. The structure of the thesis is as below:-

1. Chapter 1 - This chapter discuss briefly on the project background, problem statement, project objective, and project scope. The main purpose of this chapter is to give early understanding of the overall project.
2. Chapter 2 - This chapter includes all the information acquired regarding on the project which includes the quotes and summary from the journals, reference books and other types of article review. All of the information including the principles, explanations and parameters related to this project were shown in this chapter for future reference.
3. Chapter 3 - All the methodologies are discuss clearly in this chapter and was illustrated in flow chart for better understanding.
4. Chapter 4 - All the data collected will be further to result analysis. The data was interpreted and will be analyze detail. The simulation test result will be discussed and analyzed. The validation of the predict results against experimental results of the different injection strategy.
5. Chapter 5 - This chapter is the conclusion for the whole project and determines whether this project had achieved its objectives as stated in chapter 1. Further work such as design improvement also has been discussed in this chapter and recommendation for future project development.

1.6 FLOW CHART OF STUDY

1.6.1 Flow Chart PSM 1

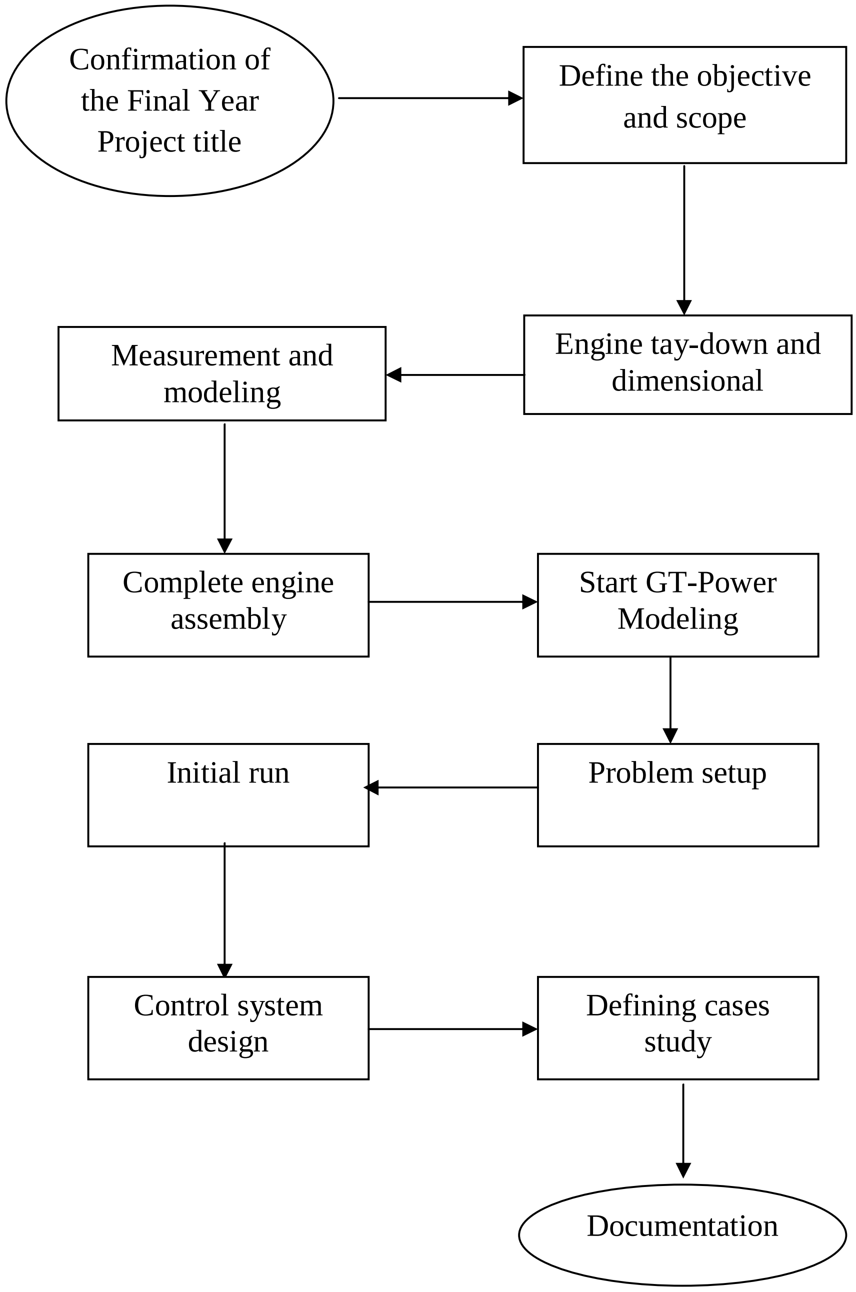


Figure 1.1 : Flow Chart PSM 1

1.6.2 Flow Chart PSM 2

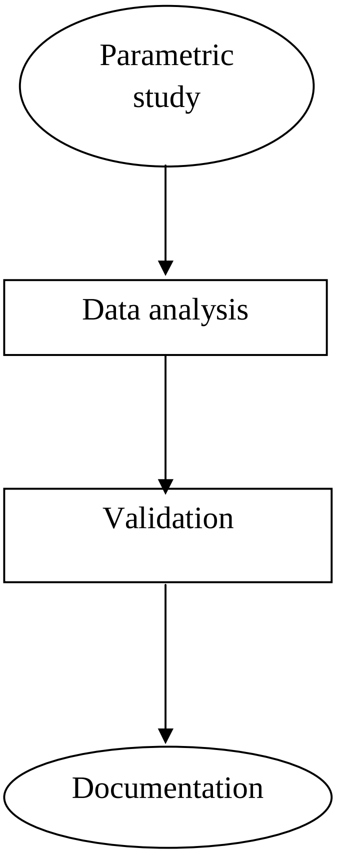


Figure 1.2 : Flow Chart PSM 2

1.7 SUMMARY

This study is proposed for the new design of injection strategy a pre-chamber engine. The design is simulated by GT-Power software where we focus in analyze to the parameters in the cylinder of engine.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter explains about basic principles in the internal combustion engine, four-stroke operation, the intake valves operation, part with new improvement and importance process in the combustion engine.

2.2 INTERNAL COMBUSTION ENGINE

2.2.1 Historical Perspective

The history of internal combustion engine is started by Abū al-'Iz Ibn Ismā'īl ibn al-Razāz al-Jazarī from 1136-1206. He described, the first suction pipes, suction pump, double-action pump, and made early uses of valves and a crankshaft-connecting rod mechanism, when he invented a twin-cylinder reciprocating piston suction pump. This pump is driven by a water wheel, which drives, through a system of gears, an oscillating slot-rod to which the rods of two pistons are attached. The pistons work in horizontally opposed cylinders, each provided with valve-operated suction and delivery pipes. The delivery pipes are joined above the centre of the machine to form a single outlet into the irrigation system. This water-raising machine had a direct significance for the development of modern engineering (Hill, D.R. May 1991 and 1996).

2.2.2 Classification Of Internal Combustion Engines

Internal combustion engines may be divided into general groups according to: the type of fuel used the method of ignition, and the number of strokes that constitute a working cycle. The three major types of fuels used are gasoline, gaseous fuels, and fuel oils. The fuel, gasoline, is in liquid form and is vaporized by being drawn through fine jets by the powerful suction of the engine during the intake stroke. At the same time, air is drawn in to mix with the vaporized fuel. Gaseous fuels include natural gas, blast furnace gas, sewage gas, and producer gas. Natural gas is the most commonly used of these and engines burning natural gas are used in locations where this fuel is plentiful and particularly as the drive units for gas compression machinery. Similarly, engines burning the other types of gaseous fuels have become common in sewage treatment plants and steel plants where gaseous fuels are readily available. Fuel oils include light oils such as kerosene and heavier oils such as diesel fuel. The heavy oil engine, commonly called the diesel engine, has many applications such as a prime mover for electrical generation in capacities up to 15 000 kW (Industries News. 2010).

2.2.3 Principle Operation Of Internal Combustion Engine

The Spark Ignition (SI) engines work on the principle of cycle of operations invented by Nicolaus A. Otto in the year 1876. The Compression Ignition (CI) engines work on the principle founded by Rudolf Diesel in the year 1892. For the engine to work properly it has to perform some cycle of operations continuously. The principle of operation of the spark ignition (SI) engines was invented by Nicolaus A. Otto in the year 1876; hence SI engine is also called the Otto engine. The principle of working of compression ignition engine (CI) was found out by Rudolf Diesel in the year 1892, hence CI engine is also called the Diesel engine.

The principle of working of both SI and CI engines are almost the same, except the process of the fuel combustion that occurs in both engines. In SI engines, the burning of fuel occurs by the spark generated by the spark plug located in the cylinder head. The fuel is compressed to high pressures and its combustion takes place at a constant volume. In CI engines the burning of the fuel occurs due to compression of the fuel to excessively high pressures which do not require any spark to initiate the ignition of fuel. In this case the combustion of fuel occurs at constant pressure. Both SI and CI engines can work either on two-stroke or four stroke cycle.

In the four-stroke engine the cycle of operations of the engine are completed in four strokes of the piston inside the cylinder. The four strokes of the four-stroke engine are: suction of fuel, compression of fuel, expansion or power stroke, and exhaust stroke. In four-stroke engines the power is produced when piston performs expansion stroke. During four strokes of the engine two revolutions of the engine's crankshaft are produced. In case of the two-stroke, the suction and compression strokes occur at the same time. Similarly, the expansion and exhaust strokes occur at the same time. Power is produced during the expansion stroke. When two strokes of the piston are completed, one revolution of the engine's crankshaft is produced.

In four-stroke engines the engine burns fuel once for two rotations of the wheel, while in two-stroke engine the fuel is burnt once for one rotation of the wheel. Hence the efficiency of four-stroke engines is greater than the two-stroke engines. However, the power produced by the two-stroke engines is more than the four-stroke engines (Khemani, H. 2008a).

2.2.4 Four-Stroke Spark Ignition (SI) Engine Cycle

In a four-stroke spark ignition (SI) engine the cycle of operations of the engine are completed in strokes of the piston inside the cylinder. The four strokes of the piston are: suction, compression, expansion or power, and exhaust. Each stroke will be described in detail.

In a four-stroke engine the cycle of the operation of engine is completed by four strokes of the piston inside the cylinder. During these four strokes fuel is once injected and burnt inside the engine and two revolutions of the crankshaft are obtained. In a four-stroke spark ignition (SI) engine the burning of the fuel occurs by the spark generated from the spark plug.

Here are the four strokes that occur inside the SI engine during its operation:

1) **Suction stroke**: At the beginning of this stroke the piston is at the top dead center or near the cylinder head and is about to move down. At this instance the inlet valve fitted in the cylinder head is opened and the exhaust valve remains closed due to the pressure difference. As the piston moves down the suction pressure is created inside the cylinder, drawing an air-fuel mixture into the cylinder. When the piston reaches the bottom most position or bottom dead center, the suction stroke ends and the inlet valve is closed.

2) **Compression stroke**: During this stroke the piston starts moving from bottom dead center to top dead center. As the piston moves up, the air-fuel mixture gets compressed into the clearance volume of the cylinder. At the end of the stroke the spark is generated by the spark plug, which causes the burning of the fuel and the release of large amounts of thermal energy. Due to this heat, high pressures are generated.

3) **Expansion or power stroke**: The large amount of pressure generated at the end of the compression stroke pushes the piston towards the bottom dead center. It is during this stroke that the actual power is produced by the engine, hence this stroke is called the power stroke and since the expansion of gases occurs during this process, it is also called the expansion stroke. During this stroke, both the inlet and exhaust valves remain closed.

4) **Exhaust stroke**: Towards the end of the expansion stroke the inlet valve remains closed while the exhaust valve opens due to the internal and external pressure difference. The piston starts moving in an upward direction and all the residual gases that are left after the expansion stroke are swept outside the cylinder and escape through the exhaust chamber. At the end of the exhaust stroke, the piston reaches top dead center position and then starts moving in the downward direction to suck the air-fuel mixture and complete the suction stroke.

In this way the cycle of operations of a four-stroke engine keeps repeating until your vehicle is running. During these four-stroke, or two revolutions of the crankshaft, the fuel is injected only once. For the maximum efficiency of the vehicle it should produce maximum power during the power stroke and produce minimum exhaust during the exhaust stroke (Khemani, H. 2008b).

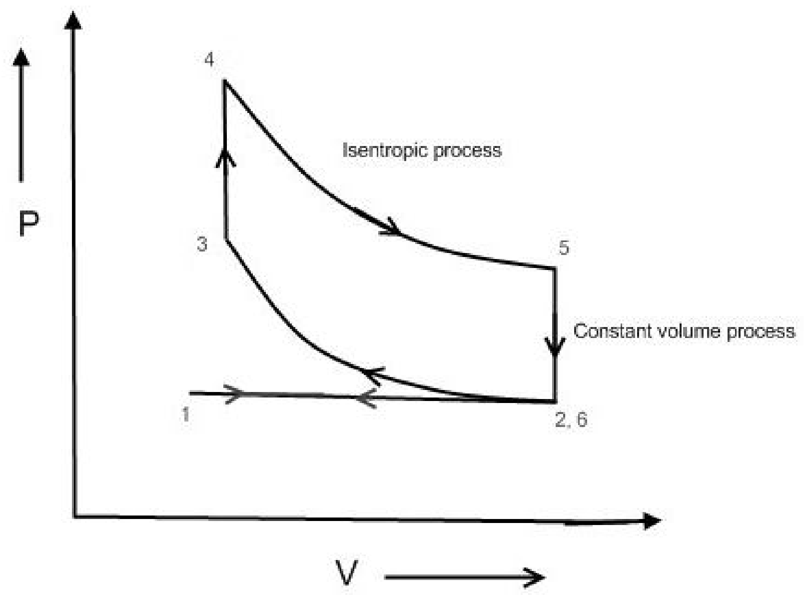


Figure 2.1 : Idealized Pressure/volume diagram of the Otto cycle.

Source : Khemani, 2008c

From figure 2.1, shown the ideal Otto cycle comprises of two isentropic (constant entropy) and two constant volume processes. The Otto cycle is an open cycle or non-cyclic process since the fresh air-fuel is mixture is inducted inside the engine during each cycle and the burnt mixture is released to the atmosphere. To understand these processes let us consider piston and cylinder engine air-fuel mixture as the working fluid. Refer the P-V diagram given at above:

1) Air-fuel intake process 1-2: During this process the inlet valve of the engine is open, the piston moves towards the bottom position inducting air-fuel mixture at constant pressure.

2) Isentropic compression process 2-3: During this process the inlet and exhaust valves of the engine remain close and the air-fuel mixture, which has been inducted inside the cylinder, is compressed to the minimum volume.

3) Combustion of air-fuel mixture at constant volume 3-4: Thereafter, the air-fuel mixture inducted inside the cylinder is combusted by the spark at constant volume; hence these engines are called spark ignition engines. This leads increase in temperature and pressure inside the cylinder.

4) Isentropic expansion process 4-5: Due to extremely high pressure, the piston is pushed again towards the bottommost position of the cylinder. It is during this process that the actual work is produced from the engine.

5) Constant volume process 5-6: During this process the exhaust valve opens and all the exhaust gases are ready to be released to the atmosphere. The pressure inside the cylinder falls drastically.

6) Exhaust process 6-1: During this process the exhaust valve is open and the piston moves upwards and removes all the exhaust gases inside the cylinder at constant pressure.

Thereafter the exhaust valve closes, the piston starts moving in downward direction, the inlet valve opens and fresh air-fuel mixture is inducted. The whole cycle is completed in four strokes of engine, hence it is called four-stroke engine (Khemani, H. 2008c).

2.2.4.1 Indicated Power (*ip*)

Power is defined as the rate of doing work. In the analysis of cycles the net work is expressed in kJ/kg of air. This may be converted to power by multiplying by the mass flow rate of air through the engine in kg per unit time. Since, the net work obtained from the p-V diagram is the net work produced in the cylinder as measured by an indicator diagram, the power based there on is termed indicated power, *ip*.

$$ip = m_a \text{ x net work} \tag{2.1}$$

where,

m_a = kg/s

net work =kJ/kg of air

ip = kW

In working with actual engines, it is often desirable to compute *ip* from a given p_{im} and given engine operating conditions. The necessary formula may be developed from the equation of net work based on the mean effective pressure and piston displacement.

Indicated power is then given by;

Indicated power = Indicated net work $\times$ cycles/s

$$ip = \frac{p_{im} SAnK}{6000} \tag{2.2}$$

where,

ip = indicated power (kW)

p_{im} = indicated mean effective pressure (N/ m^2)

S = length of the stroke (m)

A = area of the piston (m^2)

n = number of power strokes per minute per cylinder (rpm/2 for a four-stroke engine)

K = number of cylinders

2.2.4.2 Brake Power (*bp*)

Indicated power is based on indicated net work and is thus a measure of the forces developed within the cylinder. More practical interest is the rotational force available at the delivery point, at the engine crankshaft, and the power corresponding to it. This power is interchangeably referred to as brake power, shaft power or delivered power. In general, only the term brake power, *bp*, has been used to indicate the power actually delivered by the engine. Friction power is that part of the total power necessary to overcome the friction of the moving parts in the engine and its accessories.

The relationship between them is,

$$bp = ip - fp \tag{2.3}$$

It may also be stated that *bp* is that part of the total power developed by the engine which can be used to perform work. (Ganesan, V. 2008)

2.3 COMPRESSED NATURAL GAS (CNG) ALTERNATIVE FUEL

The use of Compressed Natural Gas (CNG or simply NG), is a clean and cheap solution for domestic use. Although it is widely available for residential use, the case with natural gas vehicles (NGV) is completely different. The advantages of natural gas (NG) as a vehicle fuel outnumber the ones of gasoline. Just to name a few, it only costs half the price of gasoline, it is safer because it is less likely to cause an explosion or fire after an accident, and engines are less prone to wear.

Although NG is much cheaper than gasoline, vehicles that use it as a fuel are not very popular. One of the major reasons is the lack of an adequate number of NG refueling stations, making long distance travel for cars and light trucks very difficult. The situation however could improve and a number of companies have recently undertaken the task to build such stations and supply fleets with significantly lower costs than gasoline. Another option is the use of a refueling appliance connected to the home's supply (Aggeliki, K. 2011).

Compressed Natural Gas (CNG) is increasingly seen as an effective alternate fuel for internal combustion engine. Based on (Bakar, R. A. 2002) benefit using CNG include:

- Higher octane number in the range of 120 to 130.
- Higher flammability compared to gasoline.
- Burns cleaner than most fuel.
- Safer; it is lighter and dissipates quickly. It ignites quickly, it ignites only when the gas to air ratio is between 5 – 15% by volume.
- Because it is a clean burning fuel, it reduces the required maintenance of vehicle.
- Plenty of reserve; there is an estimated 65-70 year supply of natural gas. Besides made from fossil, natural gas can also be made from agricultural waste, human waste and garbage.
- Cheaper per litre equivalent than gasoline, less than gasoline and 12% to 74% less expensive than diesel. In Malaysia, the CNG price is half less expensive compared to gasoline.

Table 2.1: Fuel Requirements for Various Alternative Fuels

Fuel	Storage Pressure (bar)	Fuel Storage Volume (litres)	Fuel Container Weight (kg)	Fuel Storage Temperature (Deg C)	Calorific Value NET (MJ/kg)
Diesel	1	135	30	15	42.9
Petrol	1	160	35	15	43
CNG	200	540	460	15	47.2
LPG	8	230	70	15	46.1
LNG	6	260	80	-161	47.2
Methanol	1	300	70	15	19.7
Electric	1	-	5000+	15	-
Hydrogen	300	270	950	15	119.8

Source : Stratton, 1996

The United Kingdom bus manufacturer has already evaluated eight promising alternative fuels as shown in Table 2.1. The results showed that natural gas altogether with biomass, electric and hydrogen have an opportunity to replace gasoline and diesel. There are three forms of natural gas: liquefied natural gas (LNG), liquefied petroleum gas (LPG) and compressed natural gas (CNG). Both LNG and CNG are based on methane. The difference is LNG made by refrigerating natural gas to condense it into a liquid while CNG still in the gaseous form. LNG is much more denses than CNG. Therefore, LNG is good for large trucks that need to go a long distance before they stop for more fuel. LPG is based on propane and other similar types of hydrocarbon gases. These hydrocarbons are gases at room temperature, but turn to liquid when they are compressed.

2.3.1 The Potential of CNG

CNG is the most common form on-board storage of natural gas. It is a mixture of hydrocarbons consisting of approximately 80 to 90 percent methane in gaseous form. CNG is colorless, odourless, non-toxic but inflammable and lighter than air. This is due to low energy density and compressed to a pressure of 200 to 250 bars to enhance the vehicle on-board storage in a cylinder (Aldrich and Chadler, 1997).

CNG has a low carbon (C) weight per unit of energy. As a result emissions of CO2, a greenhouse gas, can be reduced by more than 20% compared with gasoline at equivalent level of work. Moreover, there is a little wall flow fuel in the intake manifold even at low temperature because of the gaseous state of CNG. Combustion temperature for CNG fuel also tends to be lower than with gasoline engine.

Table 2.2 : Emissions reduction by CNG

Emissions	Reduction against Gasoline	Reduction against Diesel
Carbon Monoxide	22-24%	10%
Carbon Dioxide	76%	Natural gas and diesel both low
Nitrogen Oxides	83%	80%
Non Methane Hydrocarbons	88%	80%
Benzene	99%	97%
Lead	100%	Not applicable
Sulphur	Nearly 100%	Nearly 100%

Source : Bakar, 2002

In addition, CNG was expected from HC emission counts because it is harmless for living things. This was accomplished taking advantage of the HC emission level counted by non-methane hydrogen carbon (NMHC), a newly stipulated measurement of HC emission level, and can be reduced by more than 80% compared with gasoline. Detail comparison between CNG and gasoline can be seen in Table 2.2 and 2.3.

Table 2.3 : Methane and Gasoline Characteristics

Characteristics	Methane	Conventional Gasoline
Octane Rating	Up to 130	95
Mass Heating Value (kJ/kg)	50,009	42,690
Energy content of the carburetted mixture (kJ/dm^3)	3.10	3.46
Lower inflammability limit (m/s)	0.50	0.60*
Laminar flame speed (cm/s) at an equivalence ratio of 0.80	30	37.5*
Minimum ignition energy (mJ)	0.33	0.26**
Adiabatic flame temperature (K)	2,227	2,266

* Data for isooctane ** Data for butane

Source : Guibet and Faure-Birchem, 1999

However, CNG fuel has some disadvantages that limited its potential to achieve the optimum engine performance, such as:

- Since CNG is in gaseous form, it has a low density. CNG in the mixture drawn into the cylinder displaces approximately 8 to 10% of oxygen. This reduces the volumetric efficiency due to larger space occupied in the combustion chamber available for combustion.
- CNG has a low flame speed. Its burns slower than conventional fuels, such as gasoline and diesel. These effects the total combustion duration prolonged compared with diesel and gasoline. This can cause a further reduction in the engine output of 5 to 10%.
- Absence of fuel evaporation. When gasoline evaporates (required before combustion), the energy required for the phase change decrease intake charge temperature and air partial pressure. The decrease in temperature offsets the decrease in air partial pressure and results in a positive increase to volumetric efficiency of about 2%. CNG does not evaporate before combustion, losing any potential gain from the heat vaporization (Andrew and Bradley, 1975).

CHAPTER 3

METHODOLOGY

3. INTRODUCTION

In this chapter, all the methodologies are discuss clearly and illustrated in flow chart for better understanding. The specification of Yamaha FZ150i engine also stated to do the further study on engine performances and others parameters.

3.1 SPECIFICATION ENGINE

The engine specification is shown in Table 3.1. Two types of fuel will be used; gasoline and compressed natural gas (CNG). These fuels will be used at different simulation.

Table 3.1 : Specification Of The Engine

Specification	Data Details
Engine type	Liquid-cooled 4-stroke ,SOHC, 4-valve
Cylinders	Single cylinder
Displacement	149.8 cm^3
Bore × stroke	57.0 × 58.7 mm
Compression ratio	10.4:1
Volume Compression Space	9.9 ~ 10.5 cm^3
Intake valve clearance	0.1 ~ 0.14 mm
Exhaust valve clearance	0.2 ~ 0.24 mm
Injector Type	6 holes, 125 cm^3/min, 250 Kpa

The dimension for piston also stated for used in parameter of GT-Power software. The data dimension is shown below:-

Table 3.2 : The Dimension Of Piston

Dimensions	Data
Diameter	57 mm
Height	32.1 mm
Pin axis distance	18.1 mm
Piston weight	78.2 mm

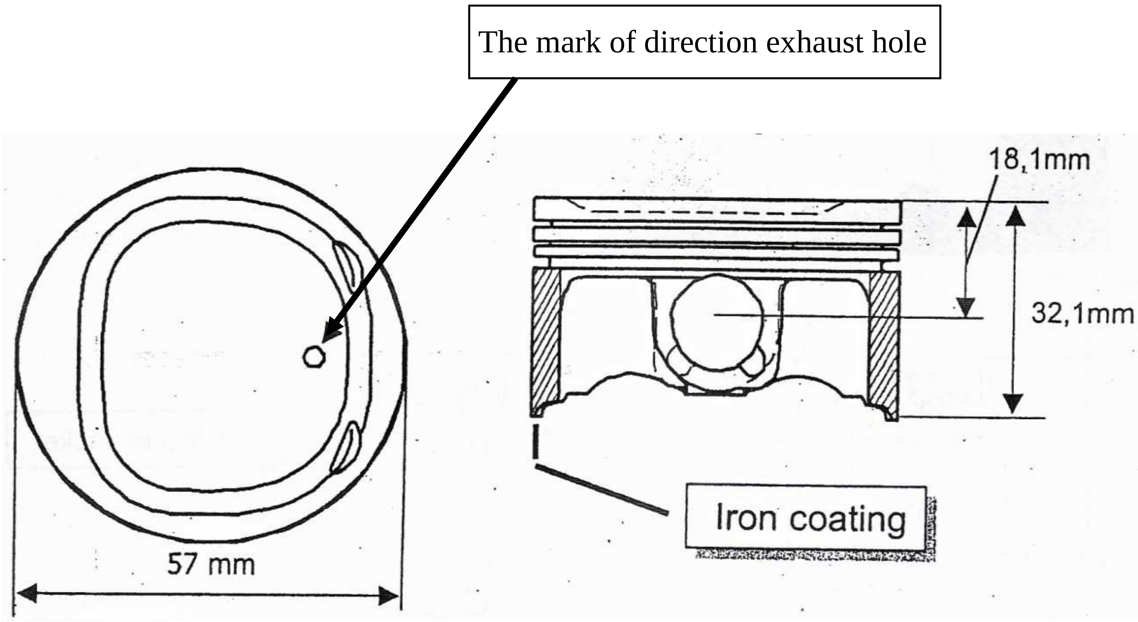
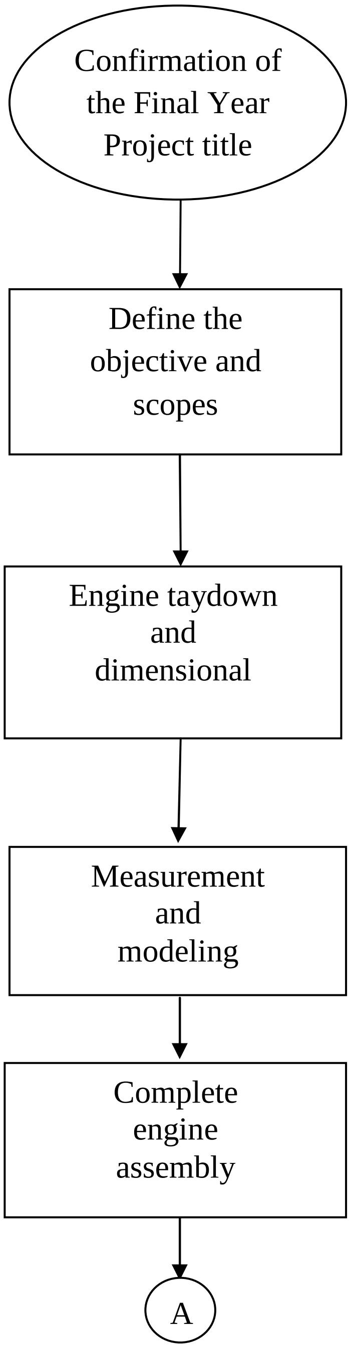


Figure 3.1 : The piston of engine motorcycle type FZ150i

3.2 FLOW CHART

In this chapter, the flow chart will be shown in more details from chapter 1. The flow chart of FYP 1 is shown below:-



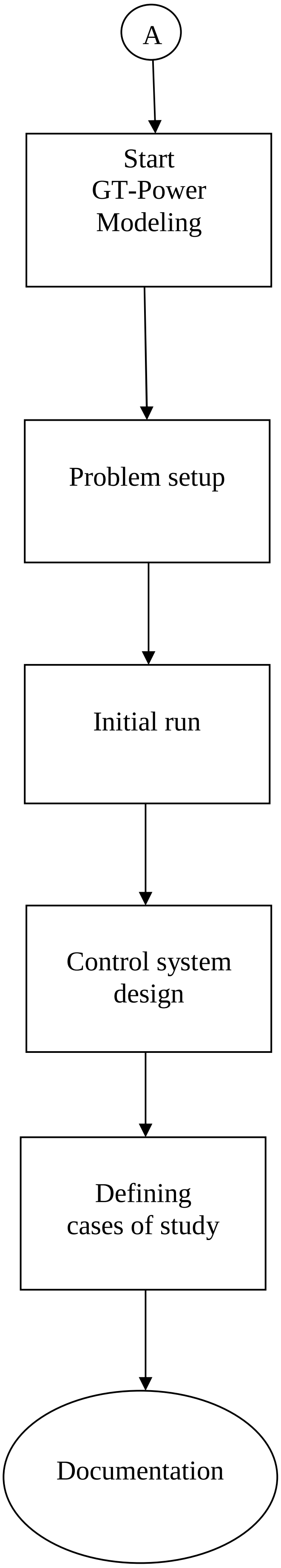
WEEK 2 - In this week, student must find the supervisor to do the confirmation of the FYP title and discuss about the title that has been given.

WEEK 3 - The student must discuss with supervisor to define the objective of study and scope to make further study about FYP title.

WEEK 4 & 5- The taydown of engine will be done in this week and the model engine is Yamaha FZ150i is used. The dimensional of engine will be taken after the engine is detached into part.

WEEK 6 - The measurement on the parts of engine must be done in this week. The modeling of engine will be created by the SolidWork software.

WEEK 7 & 8 - After done the measurement and modeling on the parts of engine, the engine will be assembly in two weeks.



WEEK 8 - The modeling of engine on GT-Power software will be doing on this week. The modeling engine will be refers to the measurement that has been taken. The engine modeling will create in 1 Dimensional model.

WEEK 9 - In this week, the problem setup will be doing after the modeling of engine done on the GT-Power software. The parameters that will be observe on the one dimensional modeling engine, will be discuss with supervisor to ensure the selected parameters is correct.

WEEK 10 - The initial run on the model of engine in the GT-Power software will be doing on this week. The initial run will be implemented when all the problem setup is done and has been identified.

WEEK 11 - The control system design will be implemented on this week. This work will be discussed with the supervisor to ensure the all works in GT-Power software is following the procedures.

WEEK 12 - In this week, the defining the cases of study by student will be ensure and approved by observation and checked of supervisor. The supervisor will check the works and cases study that will be done by student.

WEEK 13 - The documentation for all works and study by student will be check and approval by supervisor.

3.3 GT-SUITE

GT-Power is an application included in GT-Suite developed by Gamma technologies, Inc. GT-Power is used by many engine/vehicle manufactures and developers to simulate and analyze the working principles of engines. GT-Power can be combined with several other simulation software packages (Gamma Technologies, 2004).

GT-Power uses one dimensional gas dynamics to represent the flow and heat transfer in the components of the engine model. These components are linked together with connection objects. Within the components the properties must be defined by the user. GT-Power works with a pre-processor (GT-ISE), in this environment the model is built and the properties are defined. The solver calculates the mass and energy flow through the different components and the results of the calculations are shown in a pre-processor (GT-Post).

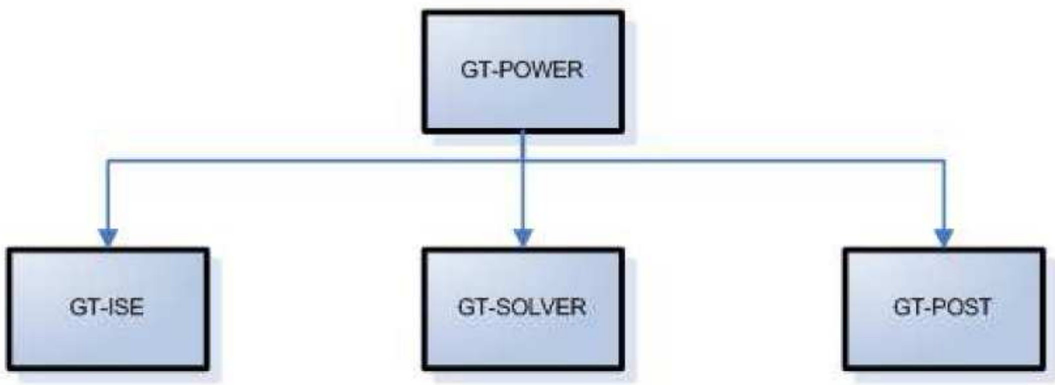


Figure 3.2 : Block diagram GT-Power

3.3.1 Engine Modeling In GT-Power Software

In this study, the computer simulation method using GT Power software is used. The model of gasoline engine and Compressed Natural Gas (CNG) engine have been developed using GT-Power software based from the real engine data of measurements. The engine specification is according to table 3.1 that have shown above. The engine model using GT-Power software is shown below:

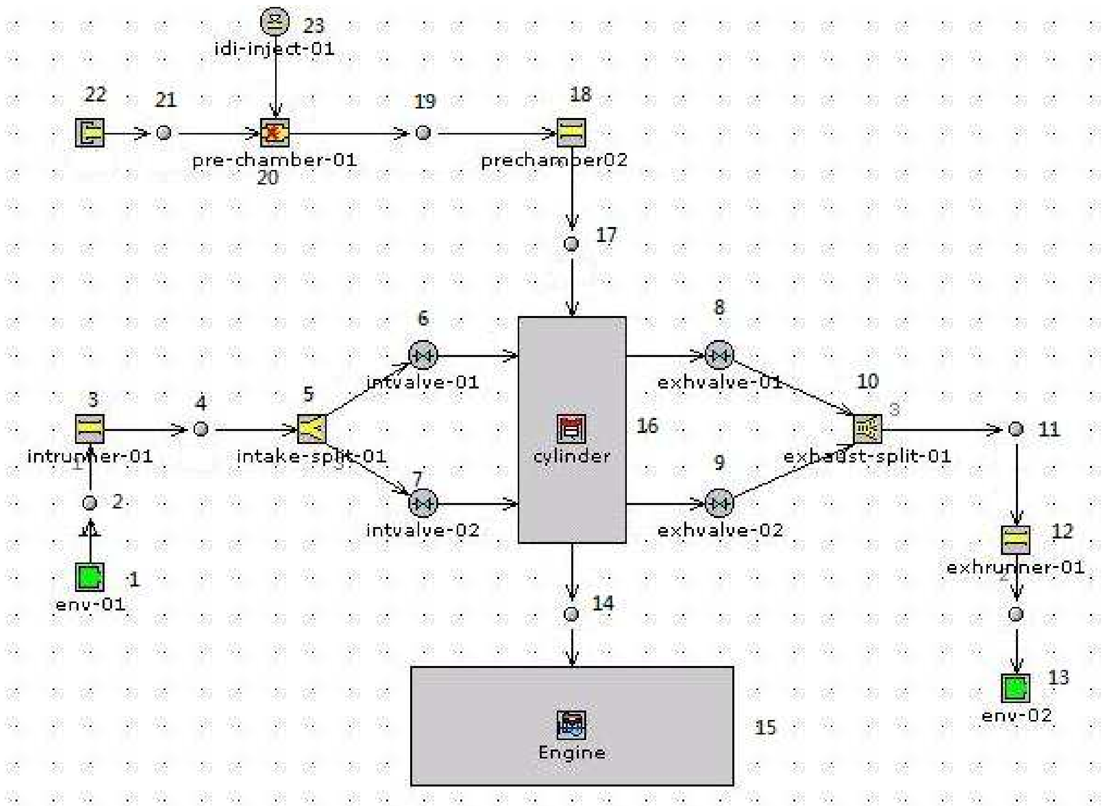


Figure 3.3 : The One Dimensional of engine model that has been developed in GT-Power software.

In the figure 3.3, each name of parts is shown in the table 3.3 by numbers.

Table 3.3 : Names of Parts of Model Engine in GT-Power Software

Parts of Model Engine	Numbers
The Intake Environment	1
The Exhaust Environment	13
The Intake And Exhaust Orifice Connection	2 ,4 ,11 ,17, 19, 21
The Intake And Exhaust Pipe Connection	3 , 12
The Intake Valve	6 , 7
The Fuel Injector	23
The Exhaust Valve	8 , 9
The Intake And Exhaust Pipe Split Connection	5 , 10
The Engine Cylinder	16
The Engine-To-Cylinder Connection (Crank)	14
The Engine Crankshaft	25
The Pre-Chamber	20
The End Flow Cap For Pre-Chamber	22

3.4 MODELING METHODOLOGY

A model of 1 dimensional single cylinder four stroke SI engine with different injection strategy using CNG fuel is built within GT-Power. The model is build up from several different parts that all will be discussed in this chapter.

3.4.1 Engine Cylinder Part

The first part will represent the single cylinder four stroke SI engine. Within the engine model specifications must be given in. The start of cycle is the point in which the calculation is started. This point should be equal to or slightly after intake valve close of cylinder number one. This value does not affect the simulation predictions. It only specifies the starting and ending angle within a cycle over which integrated and averaged predictions are measured.

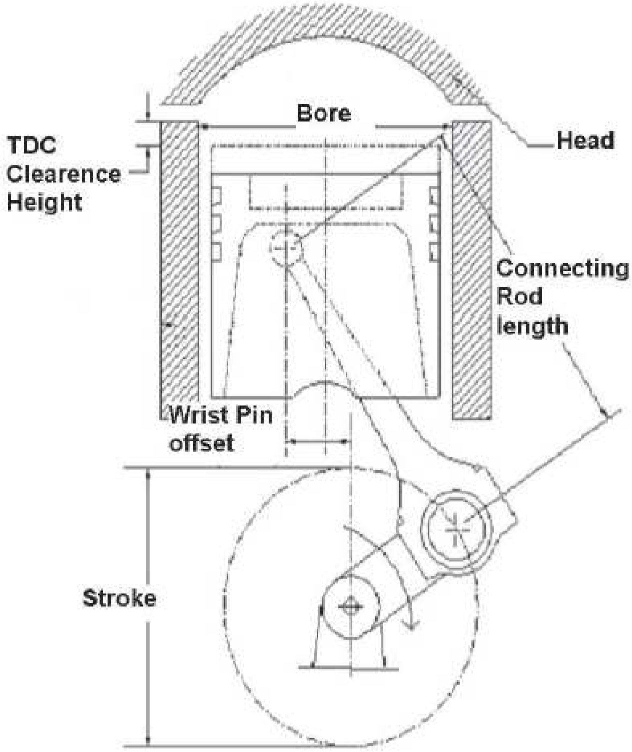


Figure 3.4 : Engine setup GT-Power

Here the bore is the bore as defined in figure 3.4. Then, the connection rod length between the centers of the rod and piston-pin bearings is shown. The wrist-pin offset relative to the crankshaft axis when the wrist-pin bearing position on the piston end is projected toward the crankshaft on a line parallel to the cylinder axis as is shown in figure 3.4. The compression ratio is the ratio of the maximum cylinder volume divided by the minimum cylinder volume and the cylinder clearance height from the top of the piston to the top of the cylinder wall when the piston is at top dead center. This attribute is used to calculate the cylinder wall surface area used for in-cylinder heat transfer calculations.

These parameters are collected and correspond with the data shown in the table 3.4. The reference state for volumetric efficiency is used strictly as a reference to calculate volumetric efficiency. This object usually corresponds to the ambient conditions.

Table 3.4 : Engine parameters

Parameters	Values
Bore [Mm]	57.0
Stroke [Mm]	58.7
Connection Rod Length [Mm]	100
Number Of Cylinders	1
Compression Ratio	10.4
Intake Open BTC	29
Intake Close ABC	59
Exhaust Open BBC	59
Exhaust Close ATC	29
Intake Center	105
Exhaust Center	105
Degrees Overlap	58

3.4.2 Burner Part

This object is used to model a cylindrical pipe in which any combustible mixture passing through is burned (with no ignition delay). This part is defined as pre-chamber in these cases of study. Fuel may flow into the burner from an adjacent flow component or may be injected directly into the burner. For non-zero values some fuel may completely pass through the burner without being burned. This attribute does not have a precisely physical implementation, and thus must be calibrated to achieve the desired rate of combustion. A Burner (pre-chamber) may be placed between any two flow components and may be connected by any flow connection. The port numbers may be arbitrarily assigned, but they must be numbers 1 and 2.

3.5 PROBLEM SETUP

The problem setup is focusing on different compressed natural gas (CNG) injection strategy analysis based on single cylinder four-stroke engine. The same speed is applied on all case of study which 4000 rpm.

3.5.1 Case One

a) For this case study, the model engine is using two different fuels which is compressed natural gas (CNG) and gasoline fuel on the normal engine. The injection duration (crank angle array) is set to 30 crank angles (CA), the injection pressure (profile array) is set to 25 bars and the injection timing (start of injection) is set to 30 crank angles (CA). This data is set to default value. The difference result that we get is to compare the performance and emission in the cylinder of engine.

b) The other study that we running in the simulation is using direct injection (DI) engine compare with the pre-chamber SI engine. The data of injection duration (crank angle array), the injection pressure (profile array) and the injection timing (start of injection) is set to the default value. The difference result that we get is to compare the performance in the cylinder of engine focus on the pressure versus volume in the cylinder. The validation is in this case study.

3.5.2 Case Two

In this case study, the model engine is using pre-chamber SI engine with variance injection pressure (profile array). The variance injection pressure (profile array) is start with 25 bars until 100 bars. The data of injection duration (crank angle array) and the injection timing (start of injection) is set to the default value. The difference result that we get is to compare the performance in the cylinder engine, focus on the characteristics of pressure and temperature in the cylinder.

3.5.3 Case Three

In this case study, the model engine is using pre-chamber SI engine with variance injection timing (start of injection). The variance injection timing (start of injection) is start with 25 crank angles (CA) until 40 crank angles (CA). The data of injection duration (crank angle array) is set to the default value but the data in injection pressure (profile array) is set based on the result of highest or maximum pressure from the case two. The difference result that we get is to compare the performance in the cylinder engine, focus on the characteristics of pressure and temperature in the cylinder.

3.5.4 Case Four

In this case study, the model engine is using pre-chamber SI engine with variance injection duration (crank angle array). The variance injection duration (crank angle array) is start with 25 crank angles (CA) until 40 crank angles (CA). The data of injection timing (start of injection) is set based on the result of highest or maximum pressure in case three and the data in injection pressure (profile array) is set based on the result of highest or maximum pressure from the case two. The difference result that we get is to compare the performance in the cylinder engine, focus on the characteristics of pressure and temperature in the cylinder.

CHAPTER 4

RESULT AND DISCUSSION

4.0 INTRODUCTION

This chapter deals with the result from simulation of one dimensional engine models of single cylinder four stroke engine with different injection strategy using CNG fuel. The plotted parameters results are cylinder pressure, temperature and concentration emission species versus crank angle and also P-V diagram in every case.

4.1 COMPARISON GASOLINE ENGINE WITH COMPRESSED NATURAL GAS (CNG) ENGINE

A comparison between CNG and gasoline fuel with original model SI engine are studied. The second comparison is between using pre-with using direct injection. The specification of engine is same with normal model of single cylinder four stroke SI engine (model FZ150i) in every case. In figure 4.1, the modeling of normal engine which following the specification are completed and has been simulate with different fuel.

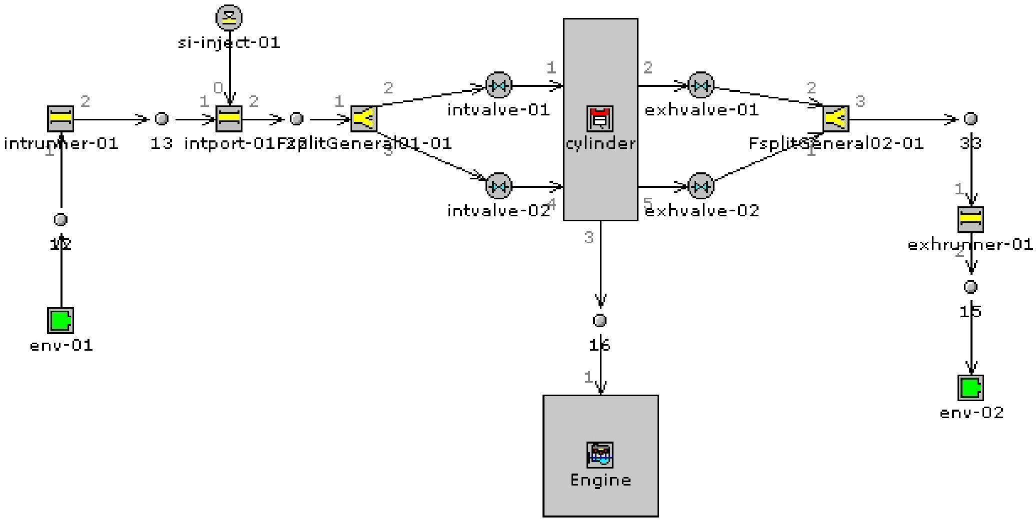


Figure 4.1 : The original Engine Configuration With Indirect Injection SI Engine

4.1.1 P-V Diagram Comparison

In figure 4.2, the Pressure versus Volume diagram from single cylinder four stroke SI engine with indirect injection are shown. From the figure, the gasoline fuel is produced higher pressure in the cylinder with 50.324 bars, while the CNG fuel is produced below than 40.973 bars after combustion or TDC. This is because the energy of density CNG fuel is lower than gasoline fuel.

In this case, the temperature is decrease where it causes the decreasing of pressure in the cylinder and the other effects in the cylinder are the mean effective pressure (MEP), where it is decreased and affects to the power and torque. We can conclude that the characteristic in the cylinder and the performance of CNG engine is lower than gasoline engine.

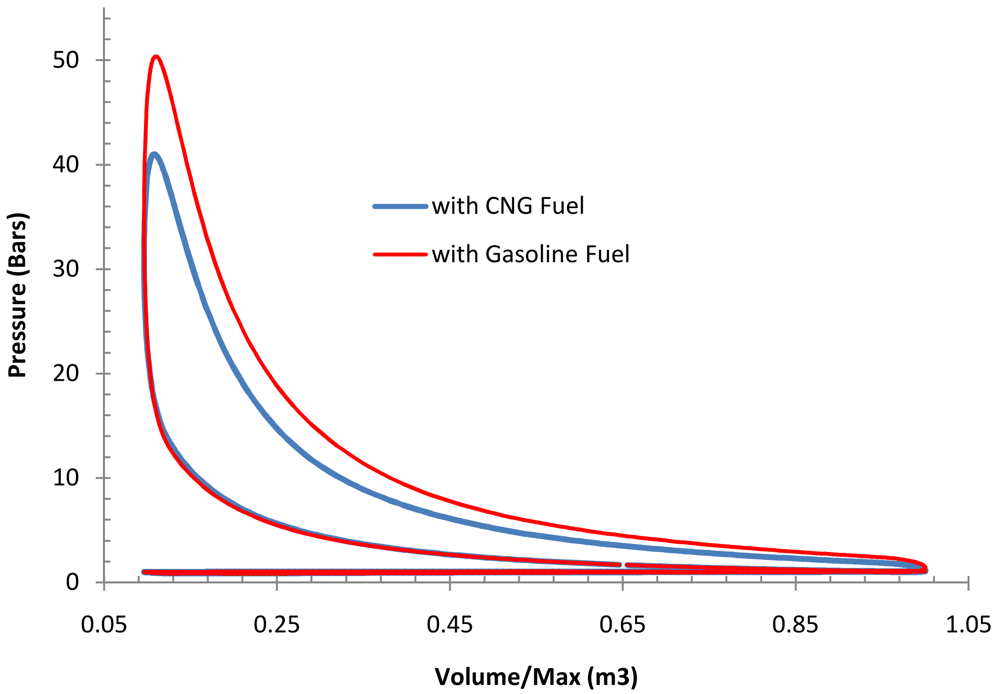


Figure 4.2 : P-V diagram in the cylinder SI Engine between CNG fuel and Gasoline fuel.

4.1.2 NOx Emission Comparison

From figure 4.3, we can see that the gasoline fuel is produced emission of NOx higher than CNG fuel which it is 108.225 ppm concentration. While, the CNG fuel just produced 0.4338 ppm concentration in the cylinder after TDC (after combustion). From here, we can conclude that the CNG produced less emission is because when changing the fuel from gasoline to natural gas, its H/C ratio is approximately changed from 1.8 to 3.7 to 4.0. The very low levels of NOx and carbon monoxide (CO) emissions can be achieved at lean equivalence ratios.

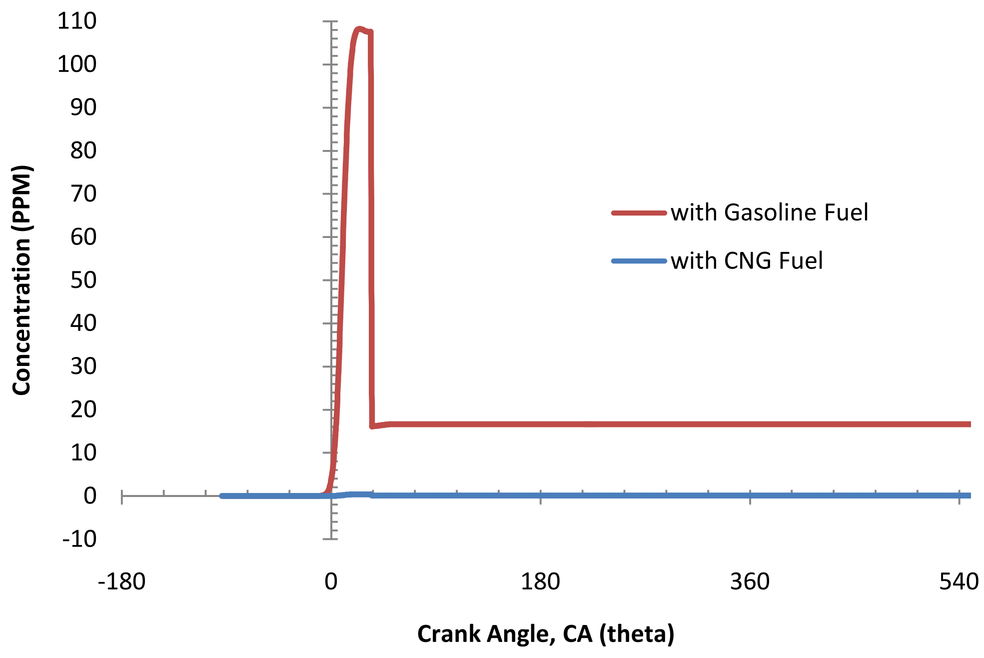


Figure 4.3 : Average in the cylinder NOx concentration between CNG fuel and Gasoline fuel.

4.2 COMPARISON BETWEEN PRE-CHAMBER AND DIRECT INJECTION

The comparison between pre-chamber and direct injection (DI) on single cylinder four stroke SI engine are studied. The figure 4.4 and 4.5 present a physical comparison of one dimensional direct injection engine model with the pre-chamber SI engine, where we want to show the different design of one dimensional model of engine.

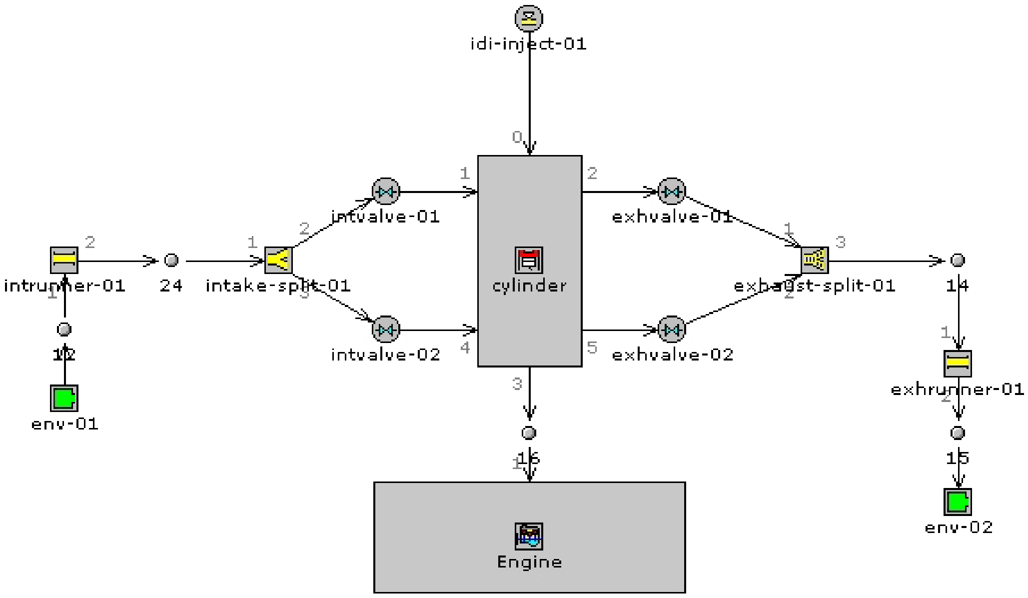


Figure 4.4 : Model One Dimensional Direct Injection On Single Cylinder Four Stroke SI Engine.

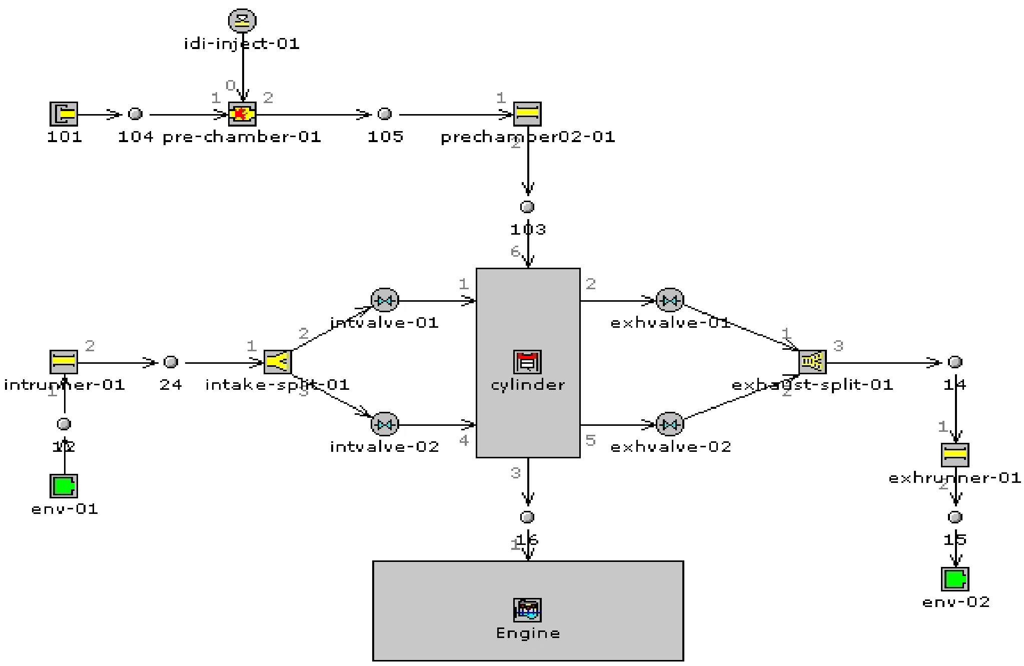


Figure 4.5 : Model One Dimensional Pre-Chamber On Single Cylinder Four Stroke SI Engine.

4.2.1 Comparison Between Pressure And Temperature

The figure 4.6 is presents a comparison of P-V diagram between with pre-chamber and direct injection on single cylinder four stroke SI engine. The pressure with the pre-chamber are lower than direct injection engine, where the direct injection engine is produced 49.75 bars while the pressure of pre-chamber engine are produced 23.225 bars. This is because, the usage of pre-chamber reduce the engine compression ratio.

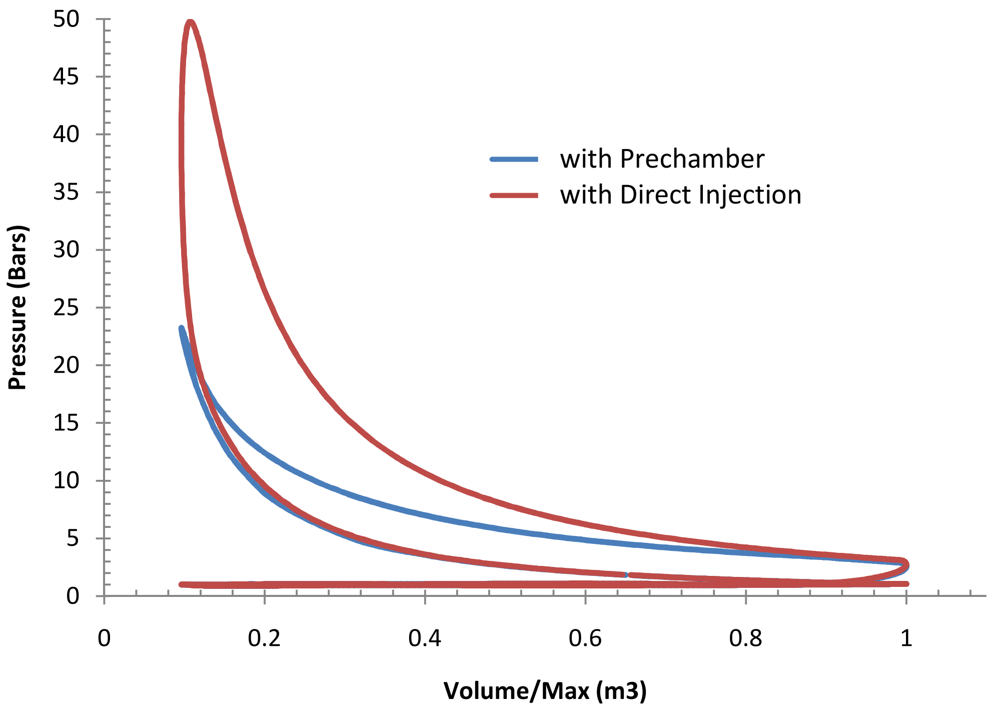


Figure 4.6 : P-V Diagram In The Cylinder SI Engine Between Using Pre-Chamber With Direct Injection.

Based on figure 4.7, the maximum temperature in the cylinder of pre-chamber engine, the maximum temperature is 1040.7137 K while when using direct injection engine, the maximum temperature is 1951.985 K which indicated a rapid combustion with relative to the top dead centre (TDC) but in pre-chamber engine it is not perfectly mixed in the combustion chamber.

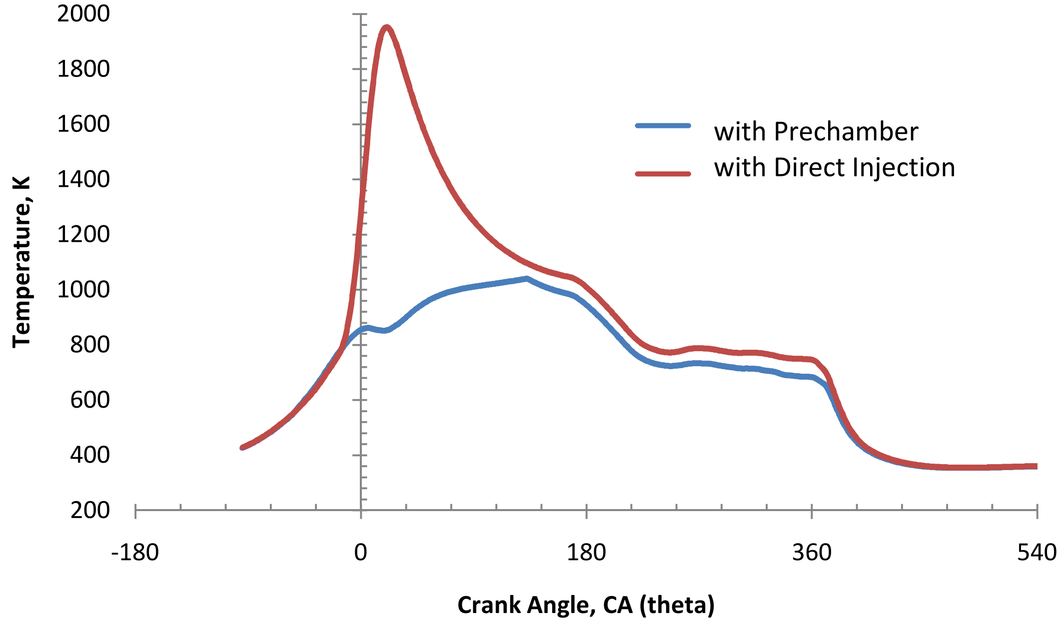


Figure 4.7 : Maximum Temperature In The Cylinder Using With Pre-Chamber And Direct Injection SI Engine.

4.3 DIFFERENT INJECTION PRESSURE USING PRE-CHAMBER ENGINE

In this case, the injection pressure (profile array) of injector will set to 25 bars, 50 bars, 75 bars and 100 bars to see the different performances in the cylinder. The comparison pressure and temperature in the cylinder with different injection pressure (profile array) in injector using CNG fuel with pre-chamber on SI engine is shown.

From the figure 4.8, the graph pressure versus crank angle with different injection pressure (profile array) from 25 bars to 100 bars is shows that the peak is nearly same. The figure 4.9 is shows that the peaks of pressure in the cylinder versus different injection pressure (profile array). The most higher pressure produced by using 25 bars injection pressure (profile array) which 23.23 bars in-cylinder SI engine while using pre-chamber. The pressure in-cylinder decreased to 23.17 bars when the injection pressure (profile array) is increased to 100 bars.

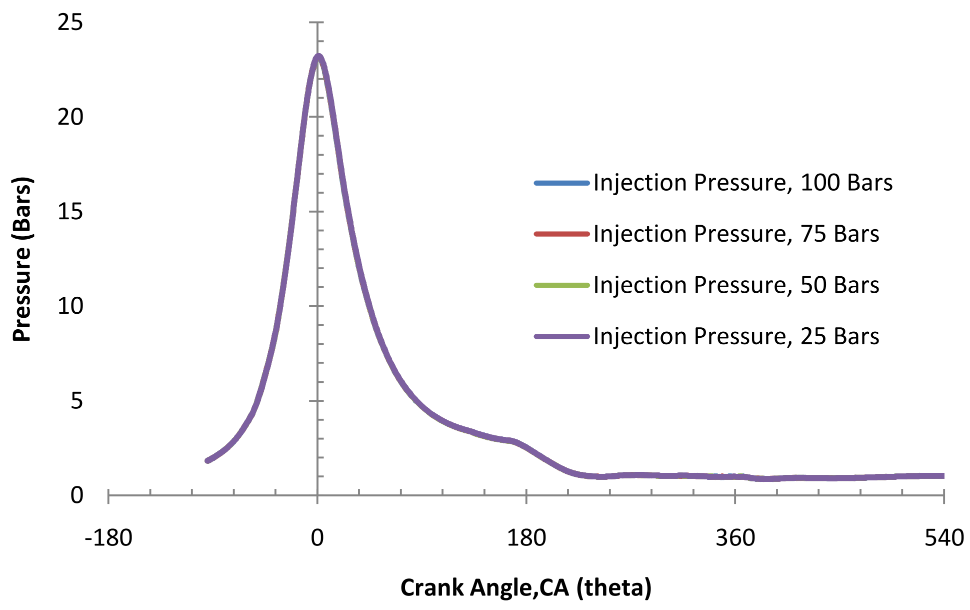


Figure 4.8 : Graph pressure versus crank angle with different injection pressure (profile array) from 25 bars to 100 bars.

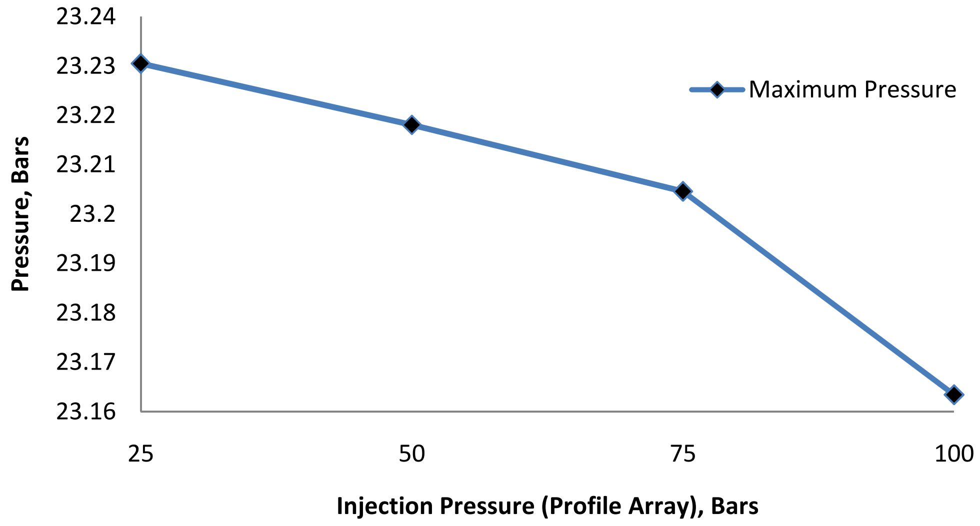


Figure 4.9 : Graph between peak (maximum) pressure in cylinder versus different injection pressure (profile array) in injector.

In figure 4.10, the graph temperature versus crank angle with different injection pressure from 25 bars to 100 bars is shown. From this graph, the difference peaks or maximum also so close. Figure 4.11 are shows that the peaks of temperature versus different injection pressure (profile array) with clearly. The higher temperature is produced by 25 bars of injection pressure (profile array) in injector is 1040.71 K. While when we increased the value of injection pressure (profile array) to 100 bars, the temperature will decreased to 1036.8 K which means the best injection pressure (profile array) in this case is 25 bars in injector.

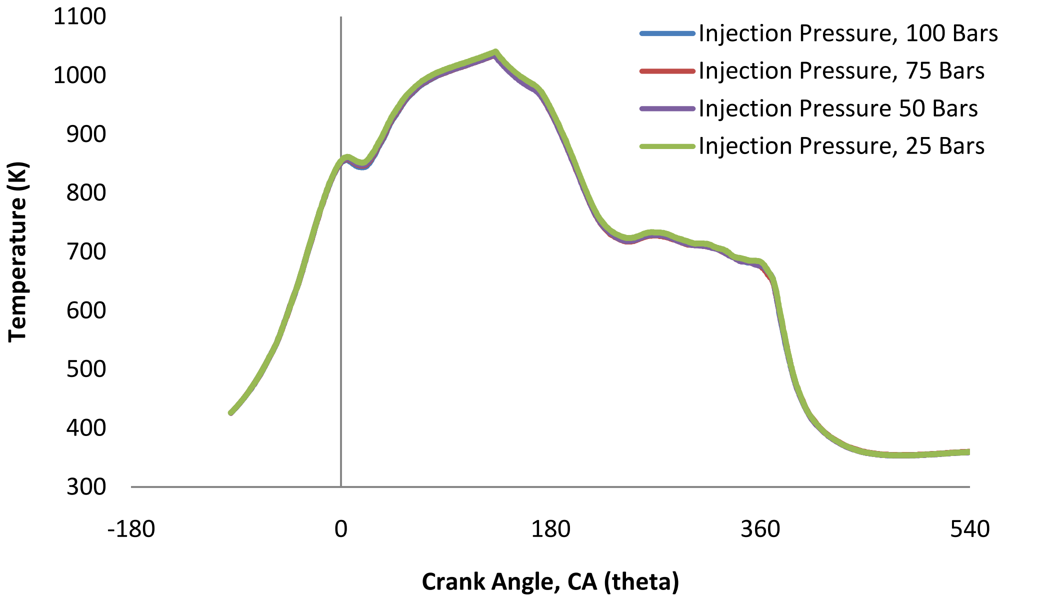


Figure 4.10 : Graph temperature versus crank angle with comparison between injection pressure from 25 bars to 100 bars.

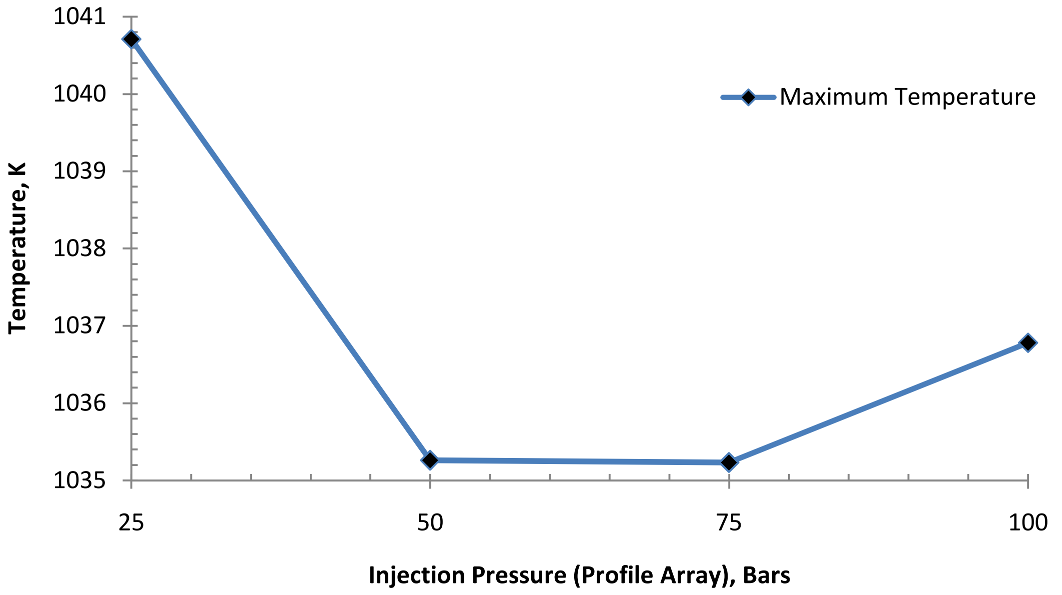


Figure 4.11 : Graph between peak (maximum) temperature in the cylinder versus different injection pressure (profile array) in injector.

4.4 DIFFERENT INJECTION TIMING USING PRE-CHAMBER ENGINE

In this third case study, the injection timing (start of injection) will be set from 25 degrees of CA to 40 degrees of CA. The comparison pressure and temperature in-cylinder with different injection timing (start of injection) in injector using CNG fuel with pre-chamber on SI engine is shown below. The injection pressure (profile array) is 25 bars which selected from second case study where the highest pressure and temperature in the cylinder and will be set to the constant.

From the figure 4.12, graph pressure versus crank angle with different injection timing (start of injection) from 25 degrees of CA to 100 degrees of CA is shows that the peak pressure are nearly same for each case. The figure 4.13 is shows that the peaks of maximum pressure versus different injection timing (start of injection) with clearly. The maximum pressure is when the injection timing (start of injection) is set to 30 degrees of CA which 23.23 bars in the cylinder with pre-chamber.

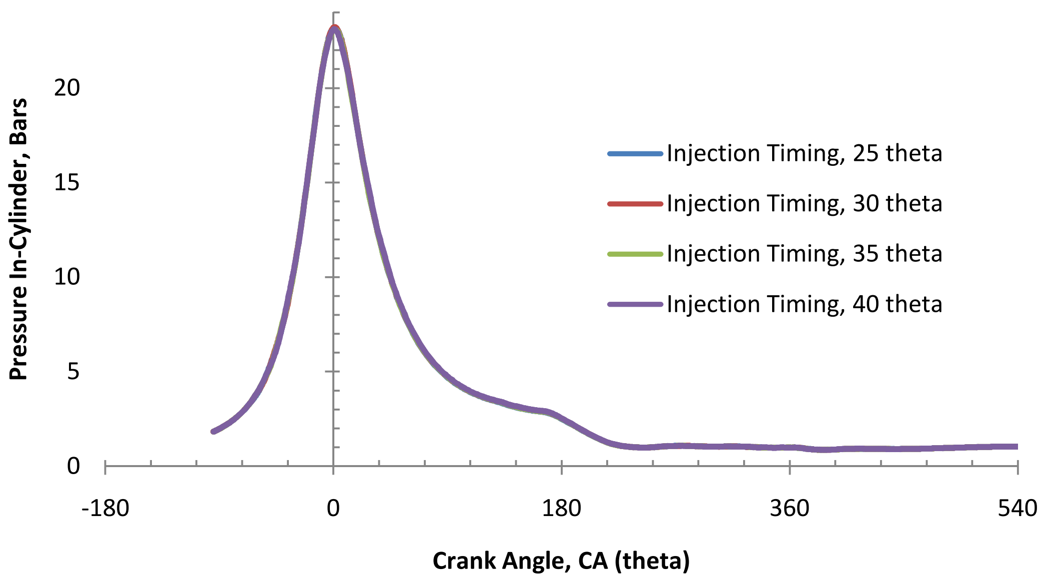


Figure 4.12 : Graph Pressure Versus Crank Angle With Different Injection Timing (Start Of Injection) From 25 Degrees Of CA to 40 Degrees Of CA.

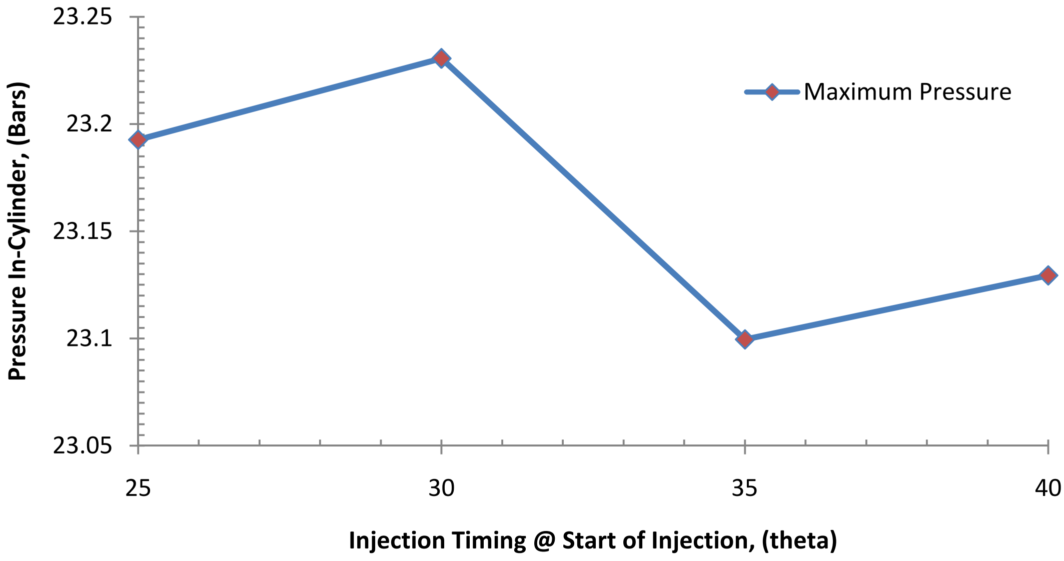


Figure 4.13 : Graph Between Peak (Maximum) Pressure In The Cylinder Versus Different Injection Timing (Start Of Injection) In Injector.

From the figure 4.14, the peaks or maximum value is very close that cannot be seen clearly. In figure 4.15, the peaks or maximum temperature is shown clearly. For temperature case, we get the different value where the higher temperature is on 40 degrees of CA which has been set in injection timing (start of injection). The temperature for injection timing (start of injection) 30 degrees of CA is 1040.71 K lowers than temperature of injection timing (start of injection) 40 degrees of CA which is 1045.5 K.

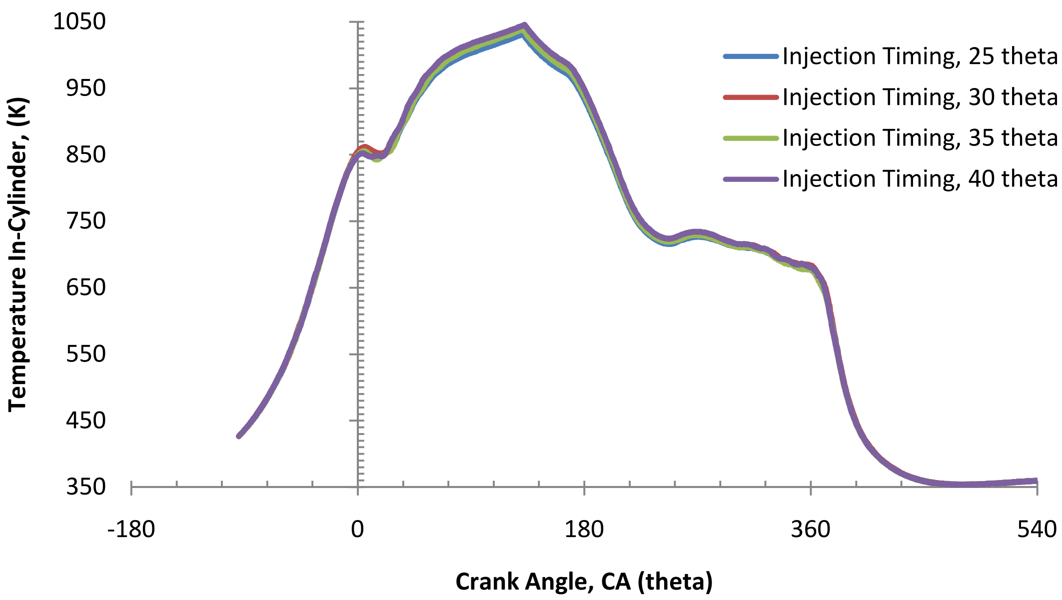


Figure 4.14 : Graph temperature versus crank angle with different injection timing (start of injection) from 25 degrees of CA to 40 degrees of CA.

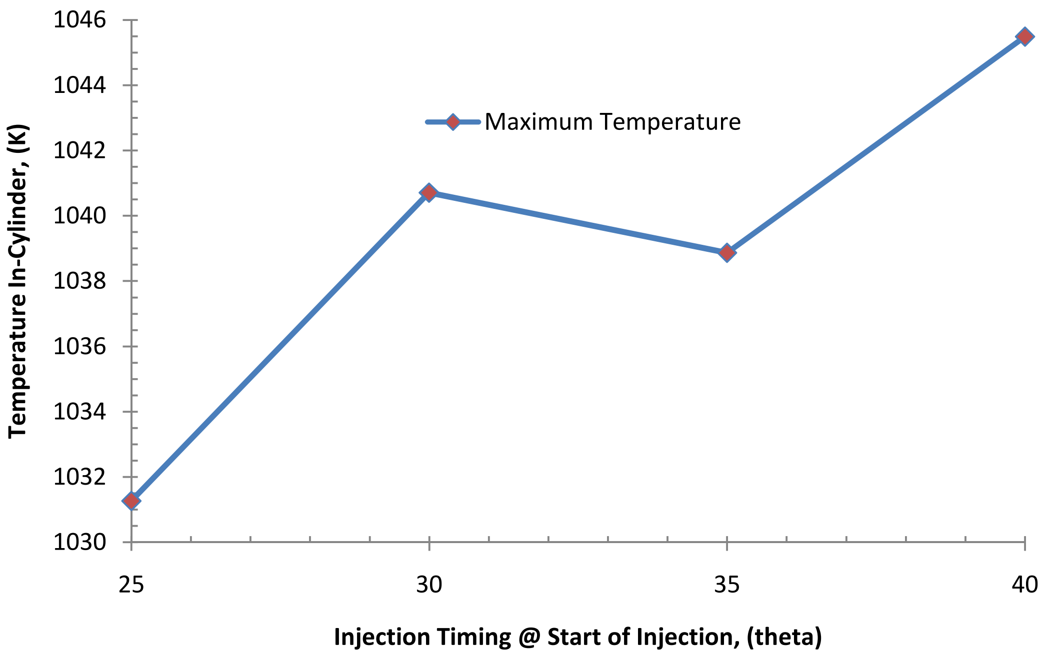


Figure 4.15 : Graph between peak (maximum) temperature in the cylinder versus different injection timing (start of injection) in injector.

4.5 DIFFERENT INJECTION DURATION USING PRE-CHAMBER ENGINE

In this case, the injection timing (start of injection) will be set from 25 degrees of CA to 40 degrees of CA. The comparison pressure and temperature in-cylinder with different injection duration (Crank Angle Array) using CNG fuel with pre-chamber on SI engine is shown. The injection timing (start of injection) 40 degrees crank angle are selected from third case study where the highest temperature in-cylinder and will be set to the constant.

From the figure 4.16, the graph pressure versus crank angle with different injection timing (start of injection) from 25 degrees of CA to 40 degrees of CA shows the result different injection duration produced comparable maximum cylinder pressure for each case. In figure 4.17, the graph between peak (maximum) pressure in the cylinder versus different injection duration (crank angle array) in injector has shows that the higher pressure in the cylinder SI engine with pre-chamber is on 25 degrees of CA injection duration (crank angle array) is 24.2 bar. When the injection duration (crank angle array) is set to 40 degrees of CA, the pressure is dropped to 23.12 bars in the cylinder.

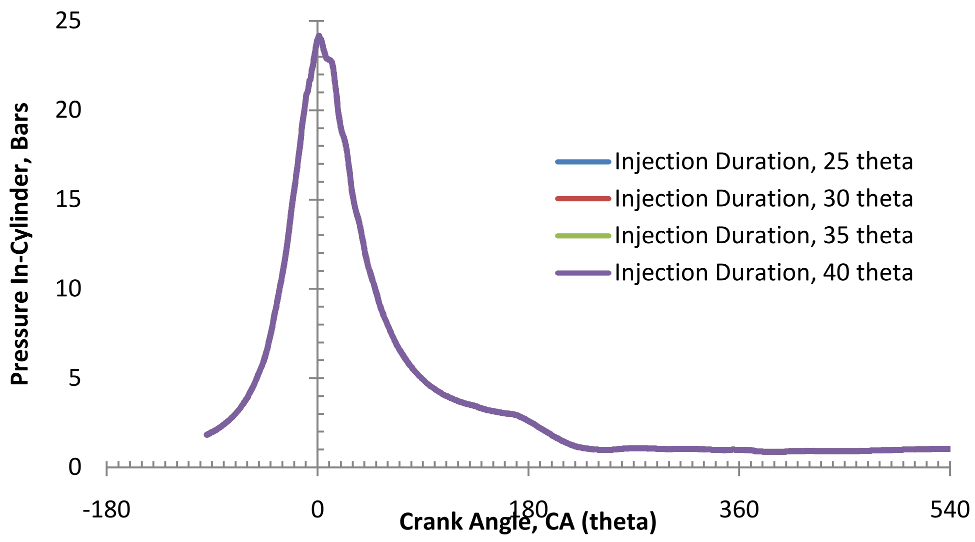


Figure 4.16 : Graph Pressure Versus Crank Angle With Different Injection Duration (Crank Angle Array) From 25 Degrees of CA to 40 Degrees of CA.

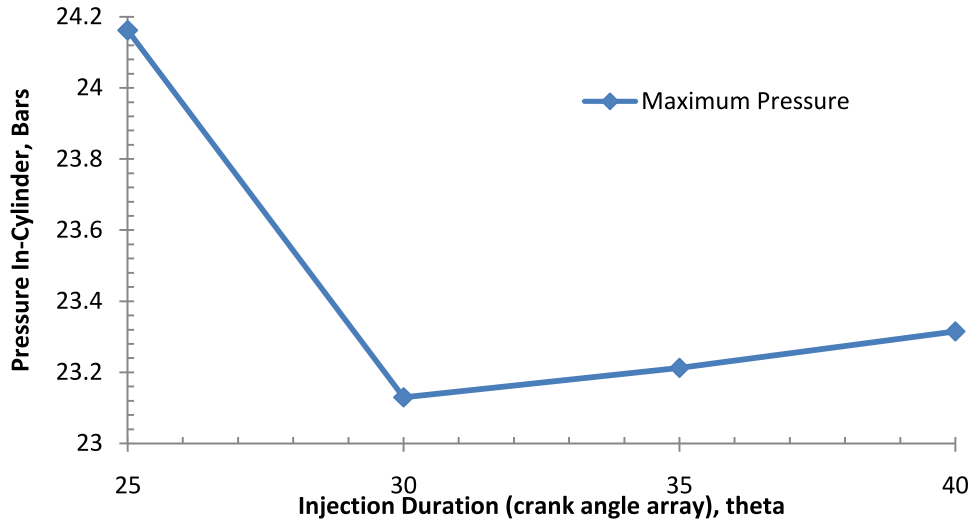


Figure 4.17 : Graph between peak (maximum) pressure in the cylinder versus different injection duration (crank angle array) in injector.

From the figure 4.18, the graph temperature versus crank angle with different injection timing (start of injection) from 25 degrees of CA to 40 degrees of CA shows the result with very close value that cannot be seen clearly. In the figure 4.19, we can see clearly that graph between peak (maximum) temperature in-cylinder versus different injection duration (crank angle array) in injector. The maximum temperature in-cylinder is 1066.05 K which on 25 degrees of CA in injection duration (crank angle array). When the injection duration (crank angle array) is set to 40 degrees of CA, the temperature is dropped to 1045.5 K which means the 25 degrees of CA in injection duration (crank angle array) is more suitable for this case.

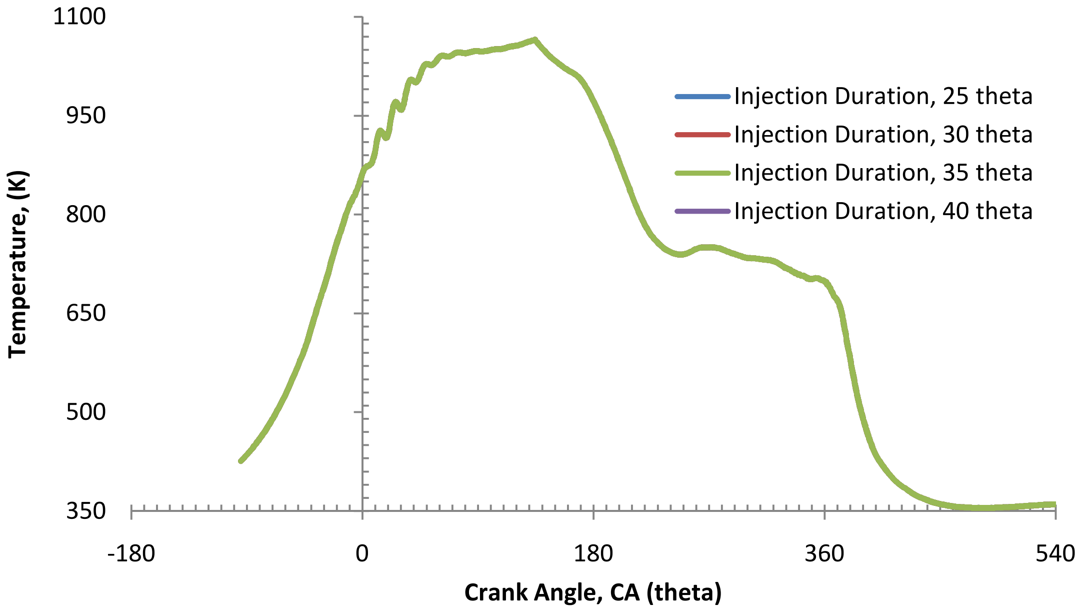


Figure 4.18 : Graph temperature in the cylinder versus crank angle with different injection duration (crank angle array) in injector from 25 degrees of CA to 40 degrees of CA.

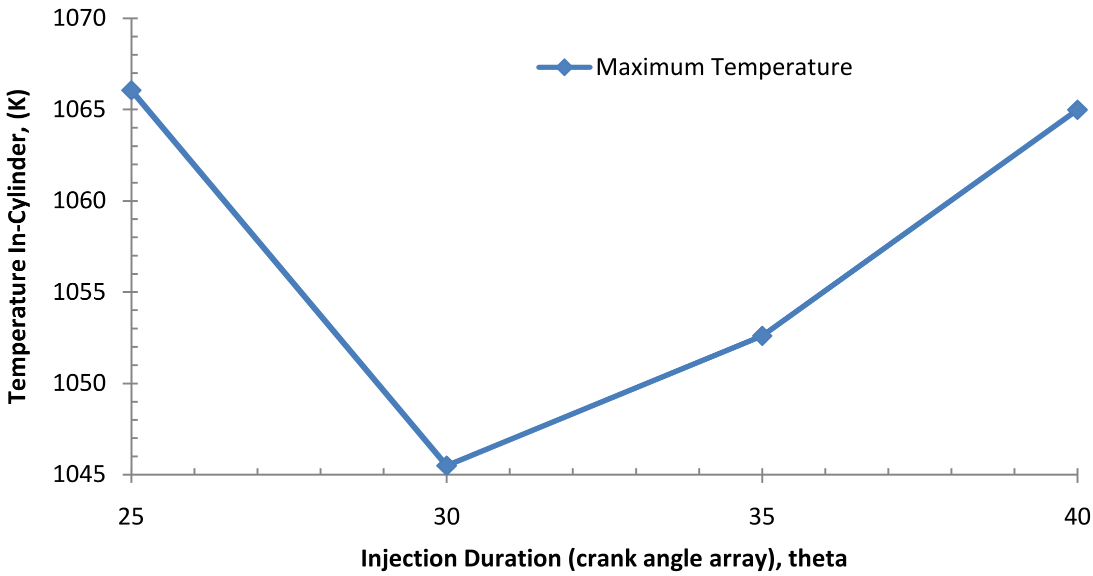


Figure 4.19 : Graph between peak (maximum) temperature in the cylinder versus different injection duration (crank angle array) in injector.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0 INTRODUCTION

This chapter presents the conclusion for the whole project based on objectives as stated in chapter 1. The recommendation for further work such as design improvement also has been discussed in this chapter.

5.1 CONCLUSION

From the results, we can conclude that the emission Nitrogen Oxides (NOx) of CNG fuel is reduced by more than 80% compared with gasoline and the Carbon Dioxides (CO2) reduced by more than 20% compared with gasoline. Based on P-V diagram, maximum pressure and temperature, the pressure performance characteristics in-cylinder of CNG engine is lower than the base gasoline engine. The most suitable injection strategy to get higher pressure and temperature in-cylinder of CNG engine with pre-chamber is using injection pressure (profile array) at 25 bars, injection timing (start of injection) at 40 degrees of crank angle (CA) before TDC and injection duration (crank angle array) at 25 degrees of crank angle (CA). The mixing air and CNG fuel are not achieve perfectly because of the problems within injector or quantity mass flow rate for CNG fuel that must enough to mix with the air in the pre-chamber.

5.2 RECOMMENDATION

Based on current study, it is recommended for future undertaking related to this subject to consider the following suggestions:

a) The simulation need to be validated with the experimental data obtained from the actual pre-chamber engine.
b) For the geometry of engine, do the measurement using scanner machine of three dimensional objects to get the accurate dimension of engine. Do more cases by using different speed, for example from 1000 rpm to 4000 rpm to see more performances characteristics in-cylinder of SI engine and emissions.

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APPENDICES

A Gantt Chart PSM 1

PROJECT ACTIVITIES	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
Briefing of project by supervisor															
Discussion with supervisor															
Find the literature review															
Focus the objective of project															
Engine detach, measurement and dimensional															
Draft of chapter 1 and 2															
Study and Testing simulation on GT-Power software															
Draft of Chapter 3															
Find out the method of analysis															
Discussion and make correction with supervisor															
Finalize draft report															
Prepare for presentation															

B Gantt Chart PSM 2

PROJECT ACTIVITIES	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
Briefing of project by supervisor	■														
Discussion with supervisor	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Find the literature review			■	■	■	■	■	■	■	■	■	■			
Focus and check the objective of project with result											■	■	■	■	
Run simulation testing model engine on GT-Power software			■	■	■	■	■	■	■	■	■	■	■	■	
Analyze the results within the scopes and objective							■	■	■	■	■	■	■	■	
Draft of Chapter 3					■	■	■	■	■	■					
Draft of Chapter 4 & 5										■	■	■	■	■	
Find out the method of analysis	■	■	■	■	■	■	■								
Discussion and make correction with supervisor							■	■	■	■	■	■	■	■	
Finalize draft report											■	■	■		
Prepare for presentation													■	■	
Preparing full report and thesis														■	■