SIMULATION OF GASEOUS FUEL INJECTOR GEOMETRIES OF MULTI HOLES NOZZLE BY USING CNG ENGINE

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We certify that the project entitled " Simulation of Gaseous Fuel Injector Geometries of Multi Holes Nozzle By Using CNG Engine " is written by Muhamad Akbar Osman Bin Md Hashim. We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

Dr. Sugeng Ariyono ....

Examiner Signature

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

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NOVEMBER 2009

SUPERVISOR’S DECLARATION

I hereby declare that I have checked this project 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.

....

Prof. Dr. Rosli Abu Bakar

Supervisor/Dean of Faculty of Mecanical Engineering

Date: 22 November 2009

STUDENT'S DECLARATION

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

....

Muhammad Akbar Osman Bin Md Hashim

MH06052

Date: 22 November 2009

DEDICATION

For my Father and Mother.

Md Hashim Bin Sabar

Rohani Binti Ali

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisor Prof. Dr. Rosli Abu Bakar for his wisdom, endurance and encouragement during his supervison period. Besides the accomplishment of this project, I learn from him how to lead a meaningful life

Special thanks is extended to Mr. Gan Leong Ming, who is so helpful in sharing a lot of information, encouraging me to seek for deeper knowledge in preparing this thesis. As for my friend Mr Mohd Khidhir bin Masteki, I would like to thank him for his kindness in doing me favour in getting additional information regarding this project. Also thanks to all my fellow friends for their cooperation and help.

Not to forget my parents and my brothers who supported me throughout the year. Thanks for their concern, encouragement and understanding.Finally, to those who have contributed directly or indirectly tp the success of this project whom I have not mentioned their name specifically. Without them this project would not be successful

.

ABSTRACT

Compressed natural gas (CNG) is the most preferred for fossil fuel substitution. This project is to study simulation of gaseous fuel injector geometries of multi-hole nozzle by using CNG engine. Three main components are focused on this paper. First, the relation between engine speed and injector pressure in achieving stoichiometric air-fuel mixture is investigated. Second, relation between valve lift and injector pressure in obtaining stoichiometric air-fuel mixture is investigated. Lastly the quality of air-fuel mixture in engine cylinder is investigated. Stoichiometric air-fuel mixture leads to good drivability, high combustion efficiency, and avoid internal damage on engine parts. In order to achieve stoichiometric air-fuel mixture, the different engine speeds and valve lift are considered and investigated. Therefore, Computational Fluid Dynamics (CFD) method using COSMOS FloWork simulation software is used for this purpose. The simulation of gaseous fuel injector geometries of multi-hole nozzle by using CNG engine is conducted in 1.78mm, 3.55mm, 5.33mm and 7.1mm intake valve lift, and also engine speeds at 2000 RPM, 3000 RPM, 4000 RPM and 5000 RPM. The results are shown; by increasing the engine speed, the injector pressure increases at different valve lift. Valve lift increment will increase the injector pressure for different engine speeds but the injector pressure is constant for valve lift increment from 75 percent to 100 percent. In the best trend air-fuel mixing result, the injected gas fuel and intake air has been mixed spread evenly in combustion chamber

ABSTRAK

Gas Asli Mampat (CNG) adalah bahan yang popular sebagai penganti untuk bahan bakar fosil. Projek ini bertujuan untuk mengkaji simulasi geometri nozel injektor bahan bakar gas pelbagai-lubang dengan menggunakan enjin CNG. Tiga komponen utama difokuskan dalam kertas ini. Pertama, hubungan antara kelajuan enjin dan tekanan injektor dalam mencapai campuran stoikiometrik antara udara dengan bahan api diselidiki. Kedua, hubungan antara bukaan injap masuk dan tekanan injektor bagi memperolehi campuran stoikiometrik ini dikaji. Akhir sekali, kualiti campuran antara udara dan bahan api dalam kebuk enjin dikaji. Campuran udara dan bahan api yang stoikiometrik adalah terbaik dalam mencapai kebolehpanduan yang bagus, kecekapan pembakaran yang tinggi, dan juga mengelakkan kerosakan pada bahagian dalam enjin. Dalam rangka mencapai campuran antara udara dan bahan api yang stoikiometrik, kelajuan enjin dan bukaan injap masuk yang berbeza perlu depertimbangkan. Oleh itu, kaedah simulasi Computational Fluid Dynamics (CFD) FloWork COSMOS digunakan untuk tujuan ini. Simulasi injektor bahan api gas pelbagai lubang nozel dengan menggunakan enjin CNG dilakukan ketika bukaan injap masuk enjin pada 1.78mm, 3.55mm, 5.33mm dan 7.1mm dan kelajuan enjin pada 2000 RPM, 3000 RPM, 4000 RPM dan 5000 RPM. Hasil simulasi menunjukkan; peningkatkan kelajuan enjin akan menyebakan tekanan injektor meningkat pada bukaan injap masuk yang berbeza. Penambahan saiz bukaan injap masuk akan memerlukan tekanan injektor yang lebih tinggi pada kelajuan enjin yang berbeza namun tekanan injektor adalah malar pada bukaan injap masuk semasa kenaikan dari bukaan 75 peratus sehingga 100 peratus keputusan trend terbaik campuran udara dan bahan api, menunjukkan bahan api gas yang disuntikkan dan asupan udara telah tercampur secara sekata di ruangan pembakaran.

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LIST OF SYMBOLS

AF	Air-Fuel Ratio
m_a	Mass of Air
m_f	Mass of Fuel
$\dot{m}_a$	Mass Flow Rate of Air
$\dot{m}_f$	Mass Flow Rate of fuel
Up	Piston Mean Speed
S	Stroke
N	Engine Speed

LIST OF ABBREVIATIONS

CNG	Compressed Natural Gas
PFI	Port Fuel Injection
MPFI	Multi Point Fuel Injection
CAD	Computer-aided design
CFD	Computational Fluid Dynamics
CH_4	Methane
CO	Carbon Monoxide
NO_x	Nitrogen Oxide
SO_x	Sulphur Oxide
HC	Hidrocarbon
PM	Particulate Matter
AF	Air-Fuel Ratio
RPM	Revolution Per Minute

CHAPTER 1

INTRODUCTION

1.1 RESEARCH INTRODUCTION

Fuel injection is a system for mixing fuel with air in an internal combustion engine. It has become the primary fuel delivery system used in gasoline automotive engines, having almost completely replaced carburetors in the late 1980s. The primary functional difference between carburetors and fuel injection is that fuel injection atomizes the fuel by forcibly pumping it through a small nozzle under high pressure, while a carburetor relies on low pressure created by intake air rushing through it to add the fuel to the air stream. The fuel injector is only a nozzle and a valve, the power to inject the fuel comes from farther back in the fuel supply system. With the emerging of alternative fuel vehicles in the automotive market, impact from the increasing regulation concerning emission and the need of less dependent on crude oil. One of the alternative fuels which got special attention is compressed natural gas (CNG).

The most efficient and energy saving combustion is with stoichiometric (perfect) air fuel mixture ratios where all fuel is consumed. The correct air-fuel ratio is required for an engine to provide good drive ability, reduce vehicle emission and prevent internal damage to engine parts. The ideal fuel injection system requires pre-determined local air-fuel ratio distribution for maximum combustion and energy efficiency and minimum generation of pollutants.Spray characteristics and is the most important factors for achieving the required local air-fuel ratio distributions

Optimum fuel preparation and mixture formation are core issues in development of CNG engines, as these are crucial for defining the border conditions for the subsequent combustion and pollutant formation process. The local air-fuel ratio can be seen as one of the key parameters for this optimization process, as it allows the characterization and comparison of the mixture formation quality.

In general, complex apparatus such as laser colour sheet method, high-speed video camera, high-speed optical multi-channel analyzer and linear Raman spectroscopy been used to determine the mixture formation in the cylinder. However, in rapid development of computational aided of flow analysis, Computational fluid dynamic (CFD) can perform the same task. By using CFD, analysis of the mixture formation process for a multi-hole fuel injector nozzles under varying engine speed and engine conditions. By using CFD, the cost can be saved and less time taken.

This project will be developed the port injection CNG engine using different injector nozzle holes geometries. The objectives on the gas fuel spray simulation of port injection CNG engine using different type of injector nozzle holes is to simulate the injected gas fuel spray effect in combustion chamber of port injection dedicated CNG engine based on variation intake valve lift and engine speed.

1.2 PROBLEM STATEMENT

The stoichiometric ratio of the air-fuel mixture leads good drivability, high combustion efficiency, reduce of emission and avoiding the internal damage of the engine parts. To achieve this stoichiometric ratio, several parameters need to be juggled such as the engine speed, valve opening and the type of the injector nozzle.

The engine speeds influence the sucking of air into combustion chamber where it directly proportional to the fuel requirement in order to perform good mixture. The excessive air of will produce lean mixture while reluctant of air will produce rich mixture. Inappropriate mixture of air and the fuel is not good for engine combustion, even more the engine would not be able to start. To make sure the mixture at the correct ratio or at the stoichiometric ratio, the correct volume of fuel injected by the fuel injector must be mixed with air and the ratio between air and fuel must be around 17.2 for CNG engine.

The intake valve lift also plays the big role in the period of fuel injected and fuel mixing with air. When the valve open , the air volume with the fuel volume will enter to the engine cylinder. Different valve opening will effects the air and the fuel while entering the engine cylinder. The valve opening will also affect the fuel spray trajectory.

Good spray of the fuel is one of the important thing need to figure out and studied. To obtain good spray, the number of hole, hole diameter and the type of injector nozzle need to be correctly chosen.

Homogeneity of mixture is also plays big role in engine performance and emissions. Even though the mixture is at stoichiometric ratio it still can give bad performance emits high emissions unless the mixture is well homogeneous. To study the homogeneity of the mixture the scattering of the mixture inside the engine cylinder need to be observed.

1.3 OBJECTIVES

Generally, the objectives to be achieved in this project are stated below:

i. To investigate the relationship between injector pressure and engine speed in achieving the stoichiometric air-fuel mixing.
ii. To investigate the relationship between injector pressure and valve lift in obtaining the stoichiometric air-fuel mixing.
iii. To observe the mixing quality of air-fuel mixture in the engine cylinder.

1.4 SCOPES

The project is focused on :

i. Literature review
ii. Design the fuel injector with different type of nozzle hole
iii. Simulate the model by using Computational Fluid Dynamic (CFD)
iv. Result comparing with different type injector nozzle

1.5 HYPOTHESIS

As the engine speeds is related to the injector pressure, the increment in engine speed will increase the injector pressure to achieve stoichiometric mixture. As the valve lift is related to the injector pressure, the increment in valve lift will increase the injector pressure to achieve stoichiometric mixture. As higher engine speed creates high turbulence intensity, the higher turbulence intensity will increase the mixing quality of air fuel mixture.

1.6 METHODOLOGY

i. Stage 1 : Literature study

Make review on literature study involving project title

ii. Stage 2 : 3D modeling

3D modeling of the injector and the engine geometry

iii. Stage 3 : Boundary condition setting simulation

Set up boundary condition for simulation analysis

iv. Stage 4 : Simulating analysis by using CFD software

Simulation analysis using COSMOS FloWork

v. Stage 5 : Analysis of simulation result

Analyze result from simulation

1.7 PROJECT FLOW CHART

Progress work of this project is summarized in form of flow chart below. Chart contains work and task of Final Year project 1 and 2.

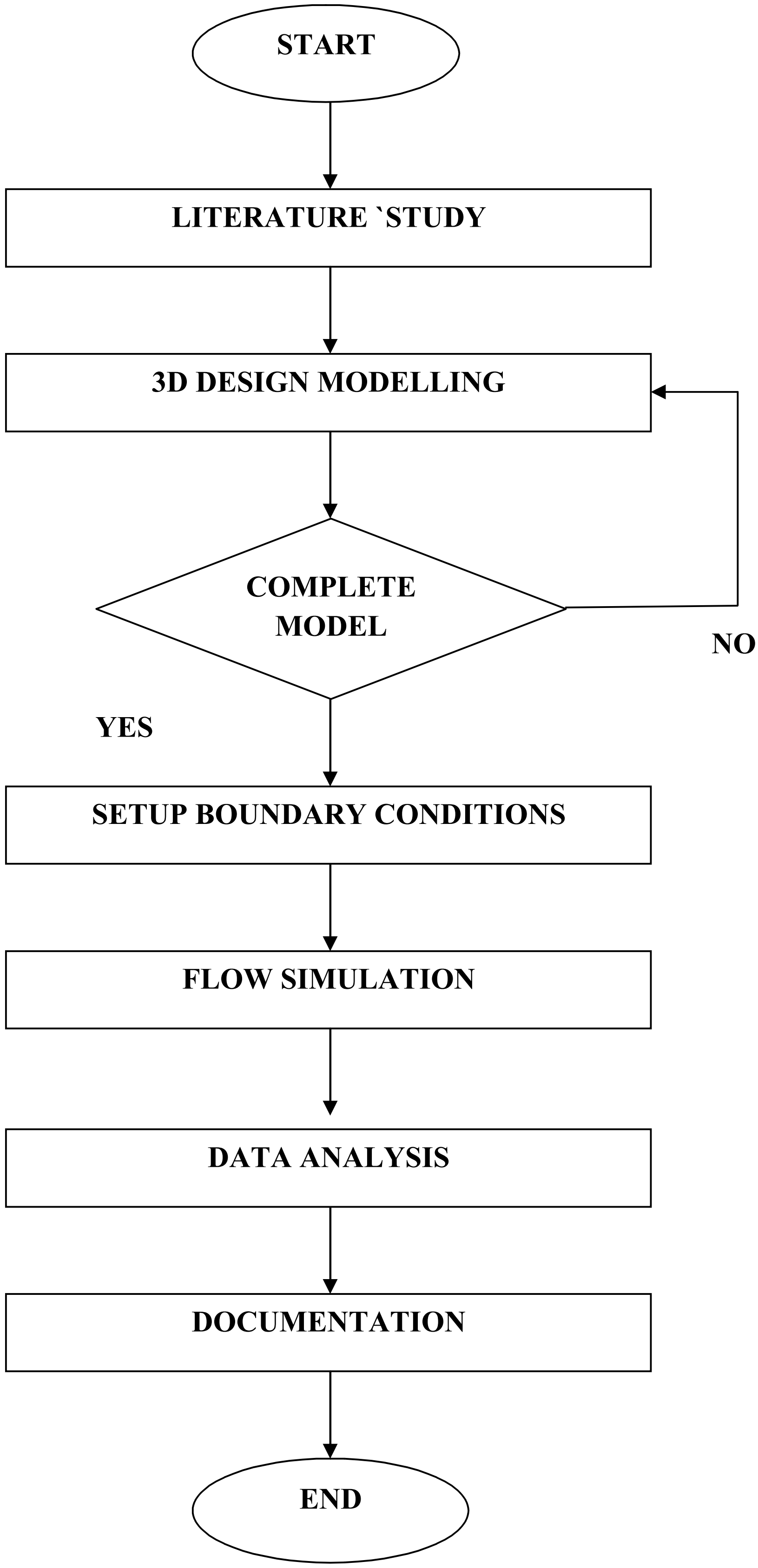

Figure 1.1 Project Flowchart

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

CNG cars available in Europe are bi-fuel vehicles burning one fuel at a time. Their engine is a standard gasoline internal combustion engine. This means that they can indifferently run on either gasoline from a gasoline tank or CNG from a separate cylinder in the trunk. The driver can select what fuel to burn by simply flipping a switch on the dashboard.

Several manufacturers such as Fiat, Opel (General Motors), Peugeot, Volkswagen, Toyota, Honda and others) sell bi-fuel cars. In 2006, Fiat introduced the Siena Tetrafuel in the Brazilian market, equipped with a 1.4L FIRE engine that runs on E100, E25 (Standard Brazilian Gasoline), Gasoline and CNG .

There were several modifications and development due to increase the efficiency of CNG fueling system, one of it is improvement of the injector nozzle (Semin et al., 2009). The effects of the CNG engine injector nozzle holes geometries of the port injection CNG engine can be achieved through increased understanding of the fuel spray process and this effect on engine performance and emissions (Semin et al., 2009).

In the order to discover the effect of multi-hole gaseous fuel injector nozzles on compressed natural gas (CNG) engine simulation tools such as COSMOS FloWork software will done the job. Before that several parameters and condition need to be decided before running the simulation.

The gas type fuel injector is appropriate for the CNG usage. It is also suitable for other type of gas such as hydrogen (Gupta, 2006).The injector will be placed at the intake manifold, therefore port fuel injection system is chosen

2.2 NATURAL GAS

Natural gas is primarily methane chemically known as (CH_4).The methane have simple chemistry bond between carbon and hydrogen .This makes natural gas a very friendly fuel for the environment. Methane is a hydrocarbon which is considered non-reactive (Speigth, 2007). That means hydrocarbon emissions of natural gas do not react with sunlight to create smog. CNG is non-toxic, non-carcinogenic, and non-corrosive. Natural gas is also lighter in weight than air (Vergara, 1990). This provides for an increased safety factor as any leakage will quickly dissipate into the atmosphere reducing the risk of a potential explosion as compared to liquid fuels which pool on the ground, or pollute our ground waters.

The adaption of CNG as the fuel is the turning point of the usage of cleaner fuel. The usage of CNG can reduce dependent of gasoline and diesel as the fuel (Gordon, 1991).

Table 2.1 : Composition of consumers power natural gas after compressed in cylinders (Speigth, 2007).

Component	Mass Percent	Volume Percent
Methane (CH_4)	88.72	94.506
Ethane (C_2H_6)	4.686	26.663
Propane (C_3H_8)	1.607	0.632
i-Butane (C_4H_{10})	0.416	0.127
Butane (C_4H_{10})	0.420	0.128
i-Pentane (C_5H_{12})	0.201	0.047
Pentane (C_5H_{12})	0.133	0.031
Nitrogen (N_2)	1.788	1.091
Carbon Dioxide	2.020	0.784
Total	100.00	100.00

2.2.1 Natural Gas Composition

Natural gas is composed primarily of methane typically, at least 90 percent, but may also contain ethane, propane and heavier hydrocarbons. Usually, compressed natural gas is referred as methane (CH4) because methane occurred abundantly in the composition of natural gas (Speigth, 2007) . Table 2.1 shows Fuel properties between Gasoline, Methane and CNG .

2.2.2 Natural Gas Combustion

In theory, and often but not always in practice, natural gas burns more cleanly than other fossil fuels. It has fewer emissions of sulfur, carbon, and nitrogen than coal or oil, and it has almost no ash particles left after burning. Being a clean fuel is one reason that the use of natural gas, especially for electricity generation, has grown so much and is expected to grow even more in the future.

Natural gas is less chemically complex than other fuels, has fewer impurities, and its combustion accordingly results in less pollution. In the simplest case, complete combustive reaction of a molecule of pure methane (CH_4) with two molecules of pure oxygen produces a molecule of carbon dioxide gas, two molecules of water in vapor form, and heat (Speigth, 2007). The natural gas combustion stated as :

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O + \text{heat}$$

In practice, the combustion process is not always perfect and when the air supply is inadequate, carbon monoxide and particulate matter (soot) are also produced. In fact, because natural gas is never pure methane and small amounts of additional impurities are present, pollutants are also generated during combustion. Thus, the combustion of natural gas also produces undesirable compounds, but in significantly lower quantities compared to the combustion of coal, and petroleum products (Speigth, 2007).

It should be noted that gases especially, methane burn cooler than gasoline. The result of this, at stoichometric conditions methane produces lower levels of NOx (flame temperature of fuel) is one of the parameter in the formation of NOx.

$$CH_4 + 2O_2 + \text{Additional impurities} \longrightarrow CO_2 + 2H_2O + \text{heat} + NO_x + SO_x$$

2.2.3 Natural Gas Emissions

Air-Fuel ratio has the greatest influence on emission. The main components of emission are carbon monoxide, carbon dioxide, nitrogen oxide, hydrocarbons (Speigth, 2007). There are four main parameters which determine the emission in an engine (Gordon , 1991) :

- Chemical composition of the fuel
- Homogeneity of the Air/Fuel mixture
- Air/Fuel ratio
- Ignition timing.

2.2.3.1 CO Emissions

CO formation in the exhaust gas is depends on availability of oxygen during combustion process. In other word Air-Fuel ratio is important in determining CO level.

- Lean mixture, it means there is more oxygen than required to burn all fuel
- Rich mixture, there is less oxygen than necessary to burn all the fuel.
- Stoichiometric, there is just enough air is allowed to burn all the fuel.

Engines powered by gaseous fuels like propane, natural gas have the same or lower CO concentrations in the exhaust for the same Air-Fuel ratio. Because these fuels have higher hydrogen to carbon ratio and they mix better than liquid fuels providing more homogeneous mixtures and can be operated much leaner.

2.2.3.2 Hydrocarbon Emissions

The mechanisms which cause HC emissions can be defined as follows:

- That part of the Air-Fuel mixture not reached by the flame front, such as the charge coming from crevice volume between piston, rings and cylinders
- Flame quenching at the combustion chamber walls, leaving a layer of unburned fuel-air mixture adjacent to wall
- Absorption of fuel vapor into oil layers on the cylinder during intake and compression strokes and desorption of fuel vapor into the cylinder during expansion and exhaust strokes.
- Incomplete combustion because of slow flame front.

2.2.3.3 NOx Emissions

NOx are reactive with hydrocarbons resulting smog formation. It is also toxic itself. Although emission of CO and hydrocarbons is related to incomplete combustion, NOx emission mainly depends on combustion temperature and combustion duration. While NO and NO2 occurs together, NO is the predominant one. NO_x nominally accounts for approximately 90 % of the total NO_X . The rate of formation of NO is primarily dependent on the temperature of the burned gases. It is obvious main parameter in the control of NO_x (Gordon, 1991):

- Compression ratio
- A/F ratio, fuel composition
- Ignition timing
- Combustion mixture diluents such as exhaust gases

Time is the second factor in the occurrence of NO. The contribution of NO formation is more significant if the mixture is burned early. Because the early burned mixture has more time to reach equilibrium. Another appearance of time factor is at different engine speeds. At higher engine speeds contribution of NOx is lower due to the less time required to achieve the engine cycle (Gordon, 1991).

2.2.4 Advantages Of CNG As Transportation Fuel

Natural gas used as a transportation fuel is called compressed natural gas (CNG). That's because the gas is compressed to a pressure of about 3,600 pounds per square inch (psi) and stored in a fuel cylinder aboard the vehicle. CNG flows into the engine's combustion chamber and is ignited to create power to drive the vehicle. The advantages CNG as the Transportation fuel as below (Ingersol, 1996).

i. Less Noise and Air Pollution
ii. Lower Fuel Cost
iii. Reliable Vehicles
iv. Lower Maintenance Costs
v. Performance Advantage
vi. Safety Advantage

2.2.5 CNG Conversion System

There are basically two types of conversion systems available, mechanical (carburetted) and electronic (fuel injected) types (Duret, 2001). Mechanical systems work on the same principles as gasoline carburetor does. The fuel is mixed with the intake air in the air-fuel mixer (carburetor). In electronic systems, injectors or flow control valves are used to meter the fuel into the intake air.

In mechanical conversion system gaseous fuel is introduced into intake manifold. The mixer is placed upstream of the throttle valve in order to respond to manifold pressure to provide the adequate amount of fuel introduced into the manifold for engine load. Some mixers have air valve to control the air flow rate. Needle valve adjustments provide appropriate air-fuel mixture.

The main difference in the application of electronic conversion method with respect to mechanical conversion is the use of solenoid driven injectors or proportional metering valves to supply the fuel into intake manifold instead of fuel air mixture. Fuel injection provides significant advantages over the use of mixer (Duret, 2001). These are:

- Non requirement of second stage regulator.
- Better emission control.
- Easy starting, particularly in cold weather.
- Better Brake Specific Fuel Consumption (BSFC).
- Quick throttle response.
- Accurate fuel control.
- Possibility of flow rate control on deceleration.

2.3 FUEL INJECTOR

A fuel injector is nothing but an electronically controlled valve. It is supplied with pressurized fuel by the fuel pump in your car, and it is capable of opening and closing many times per second. When the injector is energized, an electromagnet moves a plunger that opens the valve, allowing the pressurized fuel to squirt out through a tiny nozzle. The nozzle is designed to atomize the fuel to make as fine a mist as possible so that it can burn easily (Taylor, 1985).

Fuel injectors are nozzles that inject a spray of fuel into the intake air. They are normally controlled electronically, but mechanically controlled injectors which are cam actuated also exist. A metered amount of fuel is trapped in the nozzle end of the injector, and high pressure is applied to it. At the proper time, the nozzle is opened and the fuel is sprayed into surrounding air.

Most modern automobile SI engine has multipoint port fuel injector. In this type of system, one or more injectors are mounted by the intake valve(s) of each cylinder. The fuel spray into the region directly behind the intake valve, sometimes directly onto the back of valve face. Contact with the relatively hot valve surface enhances evaporation of the fuel and helps cool the valve. The injectors are usually timed to spray the fuel into quasi-stationary air just before the intake valve opens. High spray velocity is necessary to assure evaporation and mixing with air (Hollembeak, 2006).

Injection pressure is generally on the order of 8 bar to 15 bar (Podnar et.al., 2000) for direct injection while for in-direct injection the pressure at range of 2 to 7 bar (Hollembeak, 2006). Engine operating conditions and information from sensors in the engine and exhaust system are used to continuously adjust Air-Fuel ratio and injection pressure.

The duration and pressure of injection is determined by feedback from engine and exhaust sensors. Sensing the amount of oxygen in the exhaust is one of the more important feedbacks in adjusting injection duration for proper Air-Fuel ratio. This is done by measuring the partial pressure of the oxygen in the exhaust manifold. Other feedback parameters include engine speed, temperatures, air flow rate, and throttle position.

Engine start up when a richer mixture is needed is determined by coolant temperature and the starter switch. Various ways of determining intake air flow rate include pressure drop measurement and hot-wire flow sensors. Hot-wire sensors determine air flow rate by the cooling effect on hot electrical resistors.

Some SI and all CI engine fuel injection systems have the injectors mounted in the cylinder head and inject directly into the combustion chamber. This gives very constant fuel input cycle-to-cycle and cylinder-to-cylinder. Modern experimental two-stroke cycle automobile engines use this system to avoid losing fuel out of the exhaust system during scavenging and valve overlap. This type of system requires very precise injectors giving extremely fine droplets of fuel. Fuel is added during the compression stroke, which allows an extremely short period of time for evaporation and mixing, less than 0.008 second at 3000 RPM.

High turbulence and swirl are also important. Injectors that spray directly into the combustion chamber must operate with much higher pressures than injectors that spray into the intake system and some as high as 10 MPa. The air into which the fuel must be injected is at much higher pressures.

2.3.1 Injector Nozzle

The most important part of the injection system is the nozzle. The fuel is injected through the nozzle holes into the combustion chamber. The number and size of the holes depends on the amount of fuel that has to be injected, the combustion chamber geometry, and the air motion inside the cylinder (Baumgarten, 2005).

Nozzle is that part of an injector through which the liquid or gaseous fuel is sprayed into the combustion chamber. The nozzle should fulfill the following function:

i) Atomization: This is very important function since it is the first phase in obtaining proper mixing of the fuel and air the combustion chamber.

ii) Distribution of fuel: Distribution of fuel to the required areas within the combustion chamber.

iii) Prevention of impingement on walls: Prevention of fuel from impinging directly on the walls of combustion chamber or piston. This is necessary because fuel striking the walls decomposes and produces carbon deposits. This causes smoky exhaust as well as increase in fuel consumption.

iv) Mixing: Mixing the fuel and air in case of non-turbulent type of combustion chamber should be taken care of by the nozzle.

Factors affecting this are :

- Injection pressure: Higher the injection pressure betters the dispersion and penetration of the fuel into all the desired locations in combustion chamber.
- Destiny of air in the cylinder: If the density of compressed air in the combustion chamber is high then the resistance to the movement of the droplets is higher and dispersion of the fuel is better.

- Physical properties of fuel: The properties like self-ignition temperature, vapor pressure, viscosity, etc. play an important role in the distribution of fuel.

2.3.2 Types of Nozzle

The design of the nozzle must be such that the liquid fuel forced through the nozzle will be broken up into fine droplets, or atomized, as it passes into combustion chamber (Taylor, 1985). This is the first phase in obtaining proper mixing of the fuel and air in the combustion chamber. Various types of nozzle are use in SI engines. The most common types are:

i) The pintle nozzle,
ii) The single-hole nozzle,
iii) The multi-hole nozzle,
iv) Pintaux nozzle

2.3.3 Multi-hole Injector Nozzle

Multi-hole injector nozzle has a plurality of orifices where fuel injected through the nozzle is atomized or reduces to small particle because the orifices hole is smaller in size where the number of orifices is large. The spray angle of this fuel injector has a higher degree of angle due to the arrangement of the holes causing the fuel be able to mix well with air.

A multi-hole fuel injector nozzle is has a plurality of orifices or nozzle holes are formed through a nozzle head in such a way that the angles of spray are increased stepwise as the orifices are farther located from the center of the nozzle tip. The orifices may be arrayed in row or column or along one or a plurality of coaxial circles.

A nozzle of this type would be expected to provide less penetration and more mixing than a single large hole nozzle. These nozzles were expected to provide a greater level of mixing, and the hole pattern was designed to fit the combustion chamber geometry (Podnar et.al., 2000). The Figure 2.1 shows the cross-section of multi-hole fuel injector.

The orifice of gaseous fuel injector has larger hole diameter than liquid fuel injector due to gas fuel does not need to atomized where particle in gaseous state are not linked with the other particles. Recommended by Semin et.al., the diameter of holes should be 3.5 mm for single-hole injector, 1.5 mm for two-hole injector, 1.35 mm for three-hole injector, 1.25 mm for four-hole injector and 1 mm for five-hole injector.

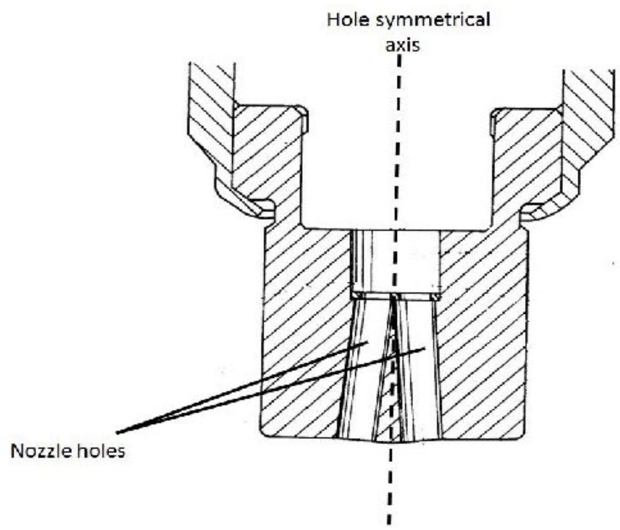

Figure 2.1 : 2D diagram of multi-hole fuel injector

2.3.4 Injector Angle

Basically, there are three factors that have to be juggled: which are idle quality at which would also include emissions in an OEM smog-legal application, proper fuel/air atomization, and the physical constraints of the engine and intake-manifold configuration. These factors combine to determine injector location and angle within the intake manifold's inlet runner.

In a perfect world, nozzle location should be as parallel to the airflow stream as possible. The nozzle angle in relation to the airflow stream is termed the "intercept angle. The intercept angle should not be more than 45 degrees (Starder, 2004), although it can be less. Maintaining the proper intercept angle generally helps low-speed drivability and may also improve performance throughout the engine's operating band.

2.4 INJECTOR ARRANGEMENT

The port injection most probably can divided into two popular type, which are :

a) Single point Fuel Injection (Figure 2.2 a)
b) Multi Point Fuel Injection (Figure 2.2 b)

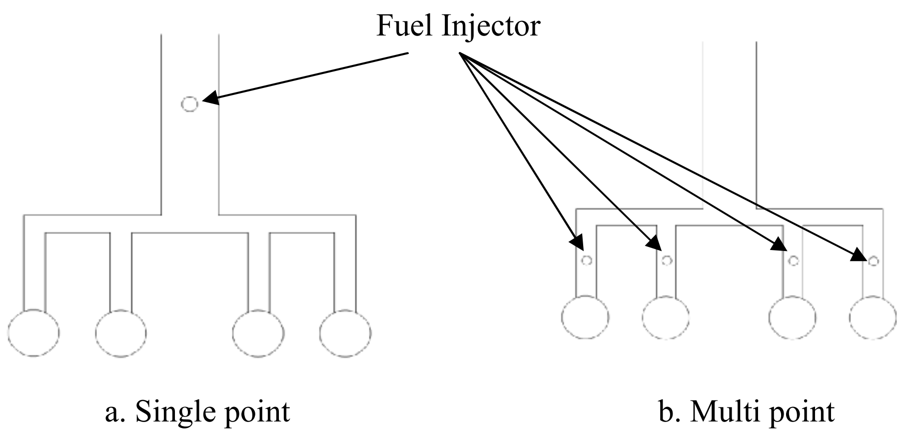

Figure 2.2: Schematic diagram of different type of port injection system

2.4.1 Multi-Point Fuel Injection (MPFI)

In the multi point fuel injection system an injector is located in the intake manifold passage. The fuel is supplied to the injectors via a fuel rail in the case of top fed fuel injectors and via a fuel galley in the intake manifold in the case of bottom fed fuel injectors. Multi Point Fuel Injection systems provide better performance and fuel economy as compared to Single Point Fuel Injection (Hollembeak, 2006). Most of the MPFI systems use one injector per cylinder but in certain applications up to two injectors per cylinder was used to supply the required fuel for the engine. Multipoint port injector systems are better systems at giving consistent air-fuel delivery. Some multipoint systems have an additional auxiliary injector or injectors mounted upstream in the intake manifold to give added fuel when rich mixtures are needed for start up, idling, or high RPM operation.

Because there is such a short duration of time and length after fuel injection for evaporation and mixing to occur, it is essential that port injectors spray very tiny droplets of fuel. Ideally, droplet size could be varied with engine speed, smaller at higher speeds, when real time is shorter (Farnell, 2006).

Intake systems with multipoint injectors can be built with improved volumetric efficiency (Hollembeak, 2006). There is no venturi throat to create a pressure drop as with a carburetor. Because little or no air-fuel mixing occurs in most of the intake manifold, high velocity is not as important, and larger diameter runners with less pressure loss can be used. There is also no displacement of incoming air with fuel vapour in the manifold.

2.5 TYPES OF FUEL SPRAY

The fuel sprays may be classified under two heading; hard sprays and soft sprays (Taylor, 1985). The former as the name implies, have a relatively large amount of energy in the spray while the later exhibit the opposite characteristics. Whether the spray is hard or soft does not basically depend upon whether the spray is composed of large or small particles or is produced by high or low pressure.

The difference is in the dissipation of fuel as it leaves the nozzle. The fuel is issued from the nozzle as a solid stream; this is torn apart by the friction between the air and the fuel stream. A nozzle which allows the fuel to issue as a solid cylinder or several solid cylinders of the fuel will produce a concentrated and compact spray and at the same time will have a solid core of fuel extending for some distance away from the nozzle.

The energy of the spray will therefore, be concentrated over a relatively small area around its axis and the spray will be hard. On the other hand, if the fuel issues in the form of thin hollow cone or will be the case with the outward opening spraying loaded valve, the dissipation of fuel will increase rapidly with the distance from the nozzle and except for the vicinity of the nozzle itself, the energy will be dissipated over a wide area of the spray and it will be soft. The degree of hardness or softness depends upon the pressure across the nozzle, which is not necessarily the same as the difference in pressure between fuel pipe and engine chamber.

2.6 AIR-FUEL RATIO

Air is to supply the oxygen needed for the chemical reaction in the combustion chamber of the internal combustion engine. For combustion reaction to occur, the proper relative amounts of air (oxygen) and fuel must be present. Air-fuel ratio is the parameters to describe the mixture ratio (Heywood, 1988). In order to determine the air-fuel ratio the mass or mass flow rate of air is divided with the mass or mass flow rate of the fuel. The equation below describes the air how to calculate an air-fuel ratio (Pulrabek, 2004).

$$AF = m_a / m_f \tag{2.1}$$

Where : m_a = mass of air
m_f = mass of fuel

In order to have complete combustion, four things must be present, the correct amount of air :

i. must be mixed with the correct amount of fuel
ii. in a sealed container
iii. this mixture must be shocked by the correct amount of heat at the correct time
iv. Although other factors can be affect combustion, these are the most important ones.

An engine is generally operated at different loads and speeds. For this, proper air-fuel mixture should be supplied to the engine's cylinder. Fuel and air are mixed to form 3 different types of mixtures (Heywood, 1988):

i) Chemically correct mixture

ii) Rich mixture

iii) Lean mixture

The mixture should provide be at the suitable air-fuel ratio in accordance with engine operating requirements and this ratio must be within the combustible range (Azeman, 2001).

2.6.1 THE STOICHIOMETRIC RATIO

At this point it is obvious that there must be an optimum air-fuel mixture. The optimum Air-Fuel ratio is called the stoichiometric ratio (Heywood, 1988).When the Air-fuel Ratio is at the stoichiometric ratio, every fuel molecule combines with oxygen molecule with nothing left over .In a CNG fuel system, chemically correct air-fuel ratio is 17.2 : 1(Hollembeak, 2006). The mixture should provide be at the suitable air-fuel ratio in accordance with engine operating requirements and this ratio must be within the combustible range. The stoichiometric Air-Fuel ratio is required for an engine to provide good drive ability, reduce vehicle emissions, and to prevent internal damage to engine parts (Annamalai, 2002).

2.7 IN-CYLINDER MIXTURE PHENOMENA

Distribution of fuel-air mixture has a strong influence on performance and emission of internal combustion engine. The fuel-air mixture change with respect to injection timing, cycle equivalence ratio and engine speed. With open-valve injection intensive mixing during intake and compression stroke results in relatively homogeneous mixture in the cylinder. Sequential induction of fuel-air mixture and fresh air results in stratification in the cylinder among the test cases at closed-valve injection.

As understanding of the phenomena deepens, ideas for controlling combustion and measures to bring these ideas to reality are being contemplated. However, even it is admitted that once combustion has started, it is difficult to control. The alternative is to control the phenomena before combustion starts, such as flows, atomization or mixing. Thus, depending on a purpose of combustion control, an approach called “phenomena design” is being examined, in which the phenomena occurring before combustion is controlled for optimization (kuwahara, 2002).

With open-valve injection intensive mixing occurs during the intake and compression strokes to result in relatively homogeneous mixture at the ignition timing. With closed-valve injection, on the other hand, rich mixture in the port is first drawn into the cylinder and subsequently fresh air follows. Mixing during the compression stroke is not enough to produce homogeneous mixture in the cylinder.

The different engine speeds show close similarity in the mixture distribution of the cylinder. It means that the turbulent mixing process is scaled by the mean piston speed or the engine speed for the same engine. Enhanced mixing by higher turbulent intensity is balanced by the faster time scale at a higher engine speed. (seok y. lee, 2001).

In-cylinder mixture analysis designers to clarify the factors underlying the phenomena such as airflow, air-fuel mixing, and ignition and combustion of the mixture (kuwahara, 2002). Such information helps designers to develop and implement methods for optimally designing and controlling the factors. Proper combustion control has been achieved through optimum turbulence control for premixed lean burn gasoline engines and through optimum mixing control for direct injection gasoline engines. For the purpose of even more sophisticated combustion control, it is necessary for designers to keep sophisticating their eyes and insights into in cylinder phenomena and updating the information (kuwahara, 2002). Typical diagnostic technology in-cylinder mixture analysis such as:

- Laser color sheet method
- High-speed video camera
- High-speed optical multi-channel analyzer

2.8 MIXTURE HOMOGENEITY

As the combustion efficiency is directly proportional to the degree of homogeneous mixing, it is important to make sure that the air and CNG are homogeneously Port-fuel injection takes advantage of turbulence generated by the intake charge as it flows across the intake valves to achieve very well mixed charge within the cylinder. Direct injection typically also produces a well-mixed charge, provided that the in-cylinder charge motion is designed to disperse the injected fuel. On the other hands, DI can result in a highly inhomogeneity of the mixture at the time of combustion depends on how quickly the fuel can be injected ,vaporized and mixed with the surrounding air charge in the short time between the start of injection and beginning of combustion.

The fuel-air mixture from liquid fuel is largely dependent on atomization and evaporation of the injected fuel droplets, while gaseous injection does not involve the complex phenomena. Mixing of gaseous fuel with ambient air is usually slower than that of liquid fuel due to the lower mass and momentum (Abraham et.al., 1994). The mixture formation process in a CNG engine is influenced by several factors such as fuel composition, chamber shape, injection timing and ignition timing, compression ratio and engine speed (S.Y. Lee et.al., 2001).

Mixture homogeneity can have a significant impact on the emissions characteristic. The low NO_x emissions obtained through not homogeneous combustion as the result of distributed low temperature reactions that occur when the fuel-lean mixture is auto-ignited. As the homogeneity of the mixture is decreased, and the air-fuel ratio at some regions becomes significantly lower than the global air-fuel ratio, the NO_x emission is increase.

Two important mechanisms for HC emissions from are the crevices and liquid fuel effects. HC emissions are generated when the fuel is not fully oxidized during intake stroke. Port fuel injected and direct injection engine are probably destine to have relatively high engine out HC emission due lack of time the fuel to be oxidize.

Soot and particulate matter (PM) are generated in the regions where overly rich mixture are combusted. In heterogeneous mixing the distribution of fuel and air is non uniform and this will cause the occur of soot and particulate matter. Port fuel injected engine generally achieve full vaporization of the fuel and thorough mixing.

At the non homogeneous of fuel and air mixing the heat release rate are very high at some regions and also increase as the air fuel ratio is decrease. This phenomenon can lead to detonation or knock, and ultimately limits the power obtainable from the combustion.

In practice, it is not possible to obtain a perfect homogeneous mixture of fuel, air and residual gases in the cylinder before ignition take place, sufficient turbulence promote to better mixing of air and fuel. In one part of the cylinder, they must be excess and in another part fuel may be present. The excess fuel may not find enough oxygen for complete combustion, which may result in the emission and unburned fuel in exhaust (Gupta, 1999).

2.9 INTAKE MANIFOLD

An intake manifold or inlet manifold is the part of an engine that supplies the air to the cylinders (Hilier et.al., 2004) . The primary function of the intake manifold is to evenly distribute the combustion mixture or just air in a direct injection engine to each intake port in the cylinder heads (pulkrabek, 2004). Even distribution is important to optimize the efficiency and performance of the engine. It may also serve as a mount for the carburetor, throttle body, fuel injectors and other components of the engine.

Due to the downward movement of the pistons and the restriction caused by the throttle valve, in a reciprocating spark ignition piston engine, a partial vacuum which is lower than atmospheric pressure exists in the intake manifold (Hilier et.al., 2004). This manifold vacuum can be substantial, and can be used as a source of automobile ancillary power to drive auxiliary systems: ignition advance, power assisted brakes, cruise control, windshield wipers, power windows, and ventilation system valves.

2.10 COMPUTATIONAL FLUID DYNAMICS (CFD)

Computational fluid dynamics, known today as CFD, is defined as the set of methodologies that enable the computer to provide numerical simulation of fluid flows. Computational Fluid dynamics is a technology that is used to analyze the dynamics of anything that can flow regardless in liquid or gaseous state. It is also a software tool that can model or simulate a flow or phenomena of any system or device under analysis (Hirsh, 2007).

CFD is computed using a set of partial different equations to predict the flow behaviour. Besides that, it is also used for analyzing heat transfer model, mass flow rate, phase change, chemical reaction such as combustion, turbulence model, mechanical movement, mechanical movement, deformation of solid structure and many more.

The word simulation is to indicate that the usage of computer in solving numerically the laws that govern the movement of fluids, in or around a material system, where its geometry is also modeled on the computer. Hence, the whole system is transformed into a virtual environment or virtual product. This can be opposed to an experimental investigation, characterized by a material model or prototype of a system in measuring the flow properties in a prototype of an engine.

Simulations used nowadays are mostly 3D simulation and 2D simulation. Both simulations differ a lot in generating data and analysis of material. 3D simulation gives the higher ability in drawing the geometrical complexity by offering un-uniform surfaces of a material to be simulated. This ability gives a more real-time data by creating a near real-time scenario (Hirsch, 2007). The data generated are more reliable for analysis. In contrast, 2D simulation which offers less geometrical complexities are mostly used to simulate a general overview of the scenario.

The creation of the product is the definition phase, which covers the specification and geometrical definition. It is based on CAD software, which allows creating, and defining the geometry of the system, in or its details. The CAD definition of the geometry is the required an unavoidable input to the CFD simulation task.

CFD always a preferred method over the conventional design method because it is cheaper and save a lot of time. before there is such technology, usually engineers need to build a real model for testing and redo the model again until the optimum result is obtained. Such a long procedure would consume more money and time. With the aid of CFD software, engineer can simulate different set of parameters for testing to get the optimum result before working on the real prototype without any additional cost (Lim, 2004).

In automotive industry for instance the time required for the design and production of new car and engine model has been reduce from 6 to 8 years in the 1970"s to roughly 36 month in 2005,with the announced objective of 24 to 18 months in the new future. This is driven by the method known as CFD with the help of fast growing computer hardware performance (Hirsch, 2007)

Several researcher have been doing their research regarding to engine air flow and also multi-hole fuel injector by using CFD,.They are Mr semin (2009) and Chris DeMinco (2007). Mr Semin had doing research on soray characteristic difference of CNG fuel injector nozzle. He was using 2, 3, 4 and 5 nozzle holes and the injection was a port injection system. While Mr DeMinco has researched about analyzing fuel–air mixing in modern gasoline engines. From his research, discovered that the spray wall impingement is an important factor in resolving accuracy in predictions of mixture quality and CFD models have provided a helpful tool for studying this phenomenon. The models also are proving to be an important asset in the advancement of GDI technology.

Figure 2.3 illustrate the spray characteristic of different injector holes for 2holes(2H), 3holes (3H), 4holes (4H) and 5 holes (5H). In Figure 2.4, an isosurface colored by local liquid concentration (left) is plotted with the flow path lines colored by the air velocity. The drop size distribution (right) is plotted with velocity vectors of air on a plane cutting through the centers of the spark plug and the injector. Both plots show that the spray strongly changes the direction of the air flow.

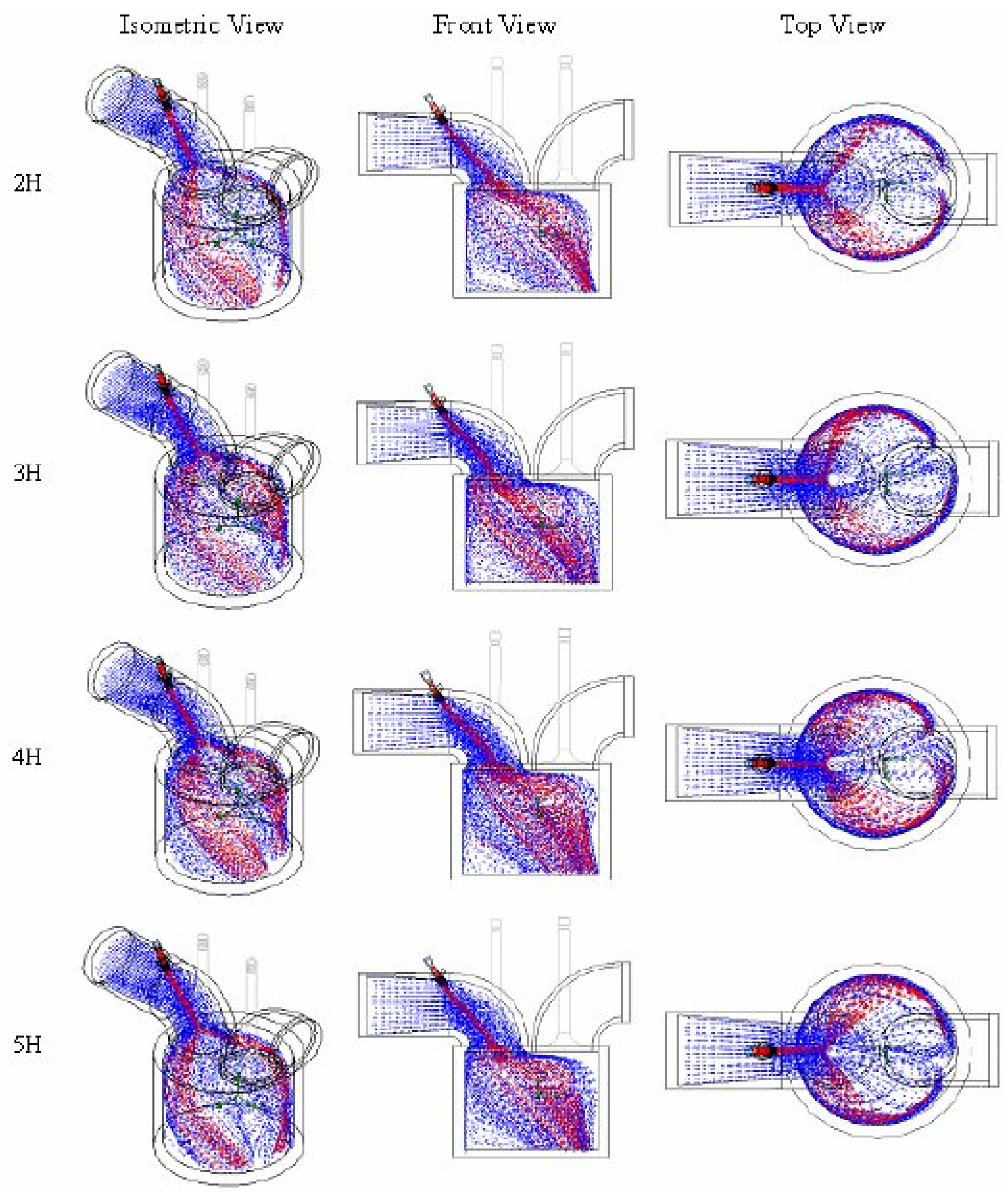

Figure 2.3: Spray patterns from different number of injector nozzle

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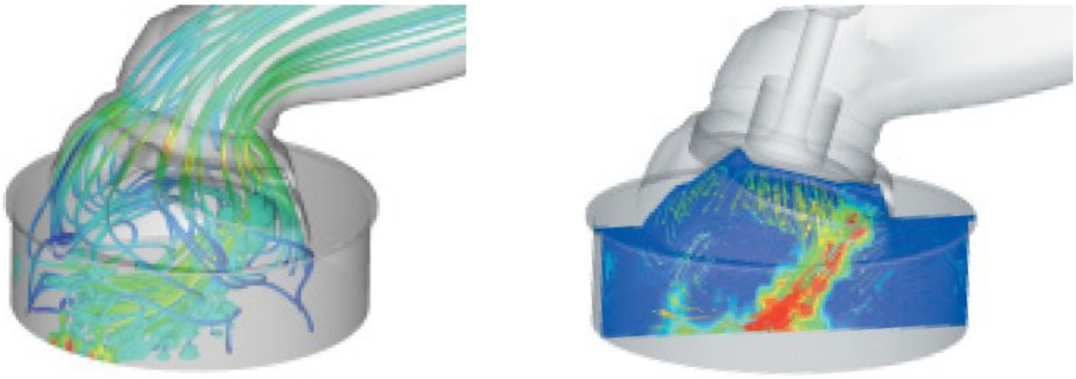


Figure 2.4 : Air flow analysis in the intake manifold

CHAPTER 3

METHODOLOGY

3.1 GENERAL METHODOLOGY

This chapter presents the methodology of this project. It describes on how the project is organized and steps in order to complete this project. The methodology is diverged in six parts, which are:

i. Literature study
ii. 3D design modeling
iii. boundary condition setting simulation
iv. meshes refinement
v. air and fuel flow simulation
vi. analysis of simulation result

3.2 LITERATURE STUDY

Before entering the simulation and the analysis stage, the study on the literature review is very important. The study will improves understanding of the project and gives the general idea of the project. This study will be the driven-key for the success of this project. Information from the literature study are gathered and structured into four main components below:

i. Geometry of intake system of CNG engine
ii. Shape of the different type of fuel injector nozzle
iii. Condition of the air and fuel flow in the engine

iv. The homogeneity of the mixture

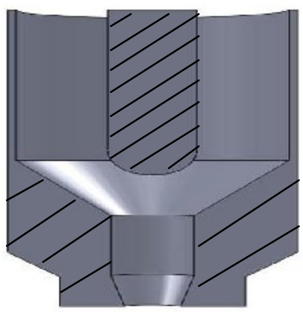
3.3 3D DESIGN MODELING

The crucial part of the project lies in this stage, the models modeled is used for the simulation. The simulation that been done happened inside the 3D model from this stage. Therefore, special attention is given in this stage for the project as stage is vital for the stages follows after this.

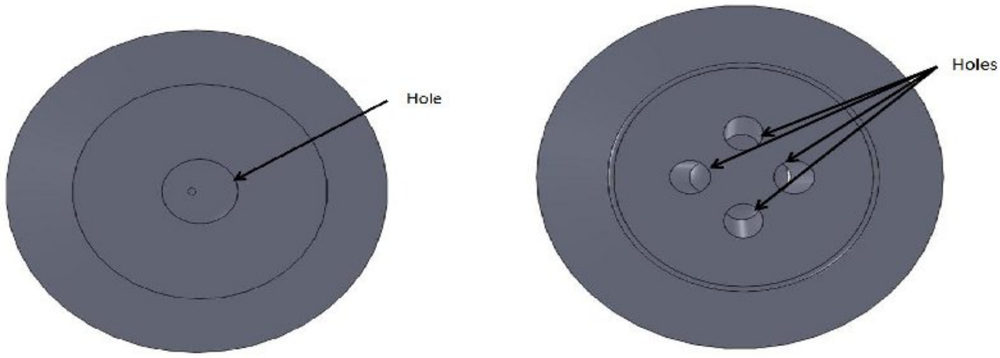
In this stage the 3D modeling is categorized in two parts. The first part is the design of the fuel injector and the second part is the design of the engine intake system. In the design of fuel injector, there are two type of injector that been modeled which are single-hole injector and 4-hole fuel injector (multi-hole injector). For the engine intake system part, the intake manifold, intake valve, combustion cylinder and the spark plug are modeled.

3.3.1 Fuel Injector Design

There are two types of fuel injector that were used in this project which were single-hole injector and 4-hole fuel injector (multi-holes injector). Figure 3.1 (a) and (b) show the cross section view of both single-hole injector and multi-holes injector designed respectively. Figure 3.1 (c) and (d) show the bottom view of the single-hole injector and multi-holes injector designed respectively, these figures show the number of hole of each injector. For single-hole injector the diameter of the hole is 3.5 mm. While, diameter for the multi-holes injector is 1.0 mm for each holes.



a. cross section of single hole nozzle **b.** cross section of multi-hole nozzle



c. bottom view of single-hole nozzle **d.** bottom view of multi-hole nozzle

Figure 3.1 : Design of fuel injector

3.3.2 Intake System Design

The intake system is the domain for the flow simulation process take place. The geometry of the intake system 3D modeling is described in Figure 3.2 and the Table 3.1. The design of the intake system is based on actual engine geometry; engine specification data for the engine is in the table 3.2.

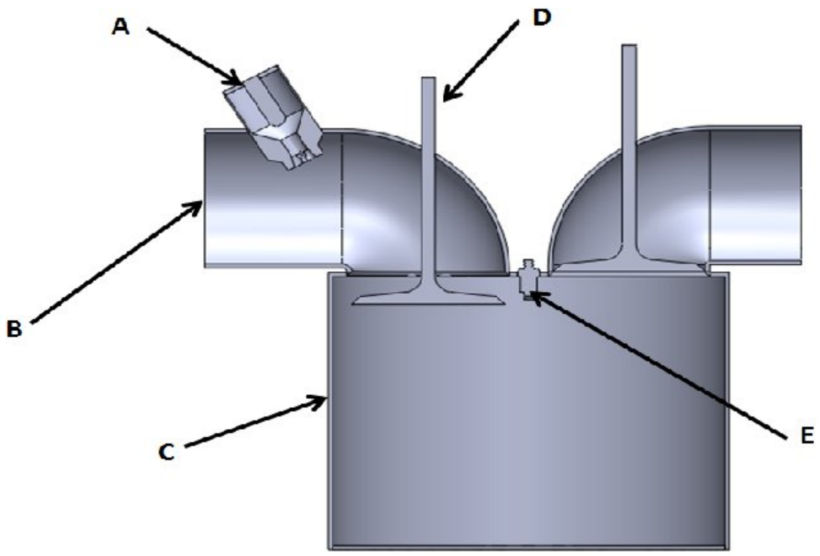


Figure 3.2: Cross section view of the 3D design of the engine

Table 3.1: Design parts and parameters

	Name of part	Description
A	Fuel injector	Using two type of fuel injector: i. Single-hole ii. Multi-holes
B	Intake manifold	Diameter inlet : 40.69
C	Engine cylinder	Bore : 86 mm Stroke : 70 mm
D	Intake valve	Diameter : 35.54 Valve stem diameter : 7.00 mm
E	Spark plug	Spark plug is located at the middle of the engine cylinder

Table 3.2: The engine Specification

Engine parameters	Value
Displacement (cc)	407.00
Bore (mm)	86.00
Stroke (mm)	70.00
Number of cylinder	1.00
Maximum intake valve open (mm)	7.095
Intake valve diameter (mm)	35.54
Intake valve stem (mm)	7.00
Number of cylinder	1
Connecting rod length (mm)	118.1
Intake port diameter inlet (mm)	40.69
Intake Valve Open (IVO) (°CA)	395
Intake Valve Close (IVC) (°CA)	530
Number of nozzle injector	1

In order to achieve one of the objectives in this project, the valve lift was varied to create different valve opening for observation on the effect of air-fuel mixture. The piston displacement changed accordingly with valve lift. The relationship between the valve lift and the piston displacement is stated in table 3.3 below. The bottom surface of the cylinder was assumed as the piston surface therefore the cylinder height will change with the piston displacement.

Table 3.3 : Relationship between Valve lift and the piston displacement

Percentage of Valve Lift (%)	**Valve Lift (mm)**	**Piston Displacement (mm)**
25	1.78	17.50
50	3.55	35.00
75	5.33	52.50
100	7.10	70.00

3.4 BOUNDARY CONDITION SETTING SIMULATION

To identify the flow of air and the fuel mixture, simulation tools was used. The most common educational purpose CFD COSMOS FloWork was selected for this project as the simulation tools The COSMOS FloWork's simulation simulates the flow of the methane and air in a single cylinder engine to obtain the optimum injector pressure in achieving stoichiometric ratio between air and methane. The tools were also used to investigate the quality of air-fuel mixing in the combustion chamber.

During this stage, several settings need to be configure before the simulation could be initiated. The settings can be referred to SolidWorks Flow Simulation 2009 tutorials. The tutorials are provided with the software for convenient.

Before entering the simulation part, the boundary conditions at the design domain are established. The variable of the boundary conditions setting were clearly studied and defined beforehand. Determining the boundary conditions is crucial because the variable setting follows will influence the result of the analysis. Errors in defining the boundary conditions may cause invalid simulation results.

In this project, there were 3 boundary conditions that need to be defined. The boundary conditions are stated as below

i. Inlet pressure for methane setting boundary ,
ii. Inlet pressure for air setting boundary and ,
iii. Outlet velocity boundary.

3.4.1 Inlet Pressure For Methane Setting Boundary

Compressed Natural Gas used in internal combustion engine can be simplified as methane in gaseous state. Methane enters the engine through the fuel injector. The inlet pressure of the injector was varied systematically to indentify the exact optimum injector pressure in order for the air-fuel mixture to reach stoichiometric. The inlet of the fuel injector was defined as the injector pressure inlet.

The inlet pressure was set at the range of 200 kPa to 550 kPa. The total pressure is selected as the type of the inlet pressure inducing the flow through the fuel injector. The temperature of the methane that enters the injector from common rail is approximately 285 K. The substance concentration defined as methane with 1 and air with 0 it is because 100 percent methane and 0 percent air enter the fuel injector. The setup of boundary condition for inlet pressure of methane gas entering the fuel injector was shown in Appendix C.

3.4.2 Inlet Pressure For Air Setting Boundary

At the intake manifold inlet, the environment pressure was selected as the boundary condition. The environment pressure is defined as 101.325 kPa since the condition of intake manifold inlet can be assumed at atmospheric pressure P_{atm} . The temperature of air at the intake manifold is defined as 293.2 K or 20 °C. As only air and no methane assumed enter the intake manifold, the substance concentration will probably enter by 1 for air and 0 for methane gas. The configuration of the boundary condition for inlet pressure of air entering intake manifold is shown in Appendix C.

3.4.3 Outlet Velocity Setting Boundary

The piston speed was assumed as the outlet velocity of air-fuel mixture. This assumption was based on there is no exit for the air-fuel mixture since the exhaust valve was closed due to the process occur during the intake stroke. Another assumption is that the piston surface is the bottom surface of engine cylinder. Based on these assumptions, the outlet velocity boundary condition was set at the bottom surface of the engine cylinder.

The piston speed or outlet velocity was calculated based on the engine speed by using equation (3.1). Equation (3.1) was referred from pulkrabek book, Engineering Fundamentals of The Internal Combustion Engine. From equation (3.1), the value of S is the length of the stroke which is 70 mm while the value of N correspond to engine speed. The engine speed varies from 2000 RPM to 5000 RPM. The Table 3.4 below shows the outlet velocity from engine speed range from 2000 RPM to 5000 RPM. The step to define the boundary condition parameters for inlet outlet velocity can be refer to Appendix C.

$$Up = 2SN \tag{3.1}$$

Table 3.4 Outlet velocity due to engine speed

RPM	**Outlet velocity (m/s)**
2000	4.67
3000	7.00
4000	9.33
5000	11.67

3.5 COMPUTATIONAL MESH GENERATION SETTING

Computational mesh generation represents an important procedure in numerical analysis of complex processes. With the aid of simulation tools, one can analyze intricate flow problems. The accuracy of the numerical results is strongly influenced by the mesh mapping and the boundary conditions.

The mesh generation in simulation tools is done automatically in solid and fluid regions eliminating the need to manually identify an optimum mesh. Automatic mesh refinement is needed in small geometric features. At first, the meshing automatically generates level three of initial mesh. Then, several identified surfaces need to have local initial mesh done due to the small gap size. If the local initial mesh is not done, the calculation on particular surfaces will be omitted and this will affect the simulation results a lot.

3.6 MESHES REFINEMENT

In order to get reliable and high accuracy results, the mesh refinement method need to be applied. Mesh refinement operation also known as volume smooth command was used to smoothes the spacing of mesh nodes throughout one or more volumes. It was applied by using smooth volume mesh form as in. While smoothing the volume mesh, simulation tool automatically adjusts mesh node locations in order to improve the uniformity of spacing between nodes throughout the mesh. To smooth the volume mesh, the following parameters were specified:

- The surfaces for which the mesh is to be smoothed.
- The refinement level

Refinement is not only done on region with small gaps. Refinement is also done on surfaces like valve face and bottom surface of the cylinder to have smooth and small size of meshing on the surface. These surfaces needed refinement because these part were impinged by fuel spray. Inappropriate mesh on this parts will emit low-accuracy result.

The refinement operation and the number of refinement points are closely related in simulation time. Higher level of refinement will take longer simulation time. However, lower refinement level may cause result to be inaccurate. Time is very crucial to this project therefore we need to select appropriate refinement level by taking account the simulation time and the result accuracy. In this project level 3 of refinement level was used and the refinement occurred at three points of iterations which are at 20 iteration, 40 iteration and 60 iteration. The average time taken for each simulation is around 3 to 4 hours.

3.7 AIR AND FUEL FLOW SIMULATION

As the setting requirements are completed, the domain enters the simulation stage. In this stage, the process is focused on simulation tools. By using simulation tools, simple analysis could be done to measure both methane and air flow. Additional and advanced settings are not needed during the simulation. The data is collected when the simulation ended. The period for the simulation depend on the setting of refinement level selected.

Simulation analysis was performed on this stage after all the steps mentioned were followed. In this stage the simulation can be categorized in two condition stated as below:

i. Different engine speed
ii. Different valve lift

In achieving stoichiometric mixture, the correct pressure of injector needs to be applied. The simulation is run several times until the optimum pressure for the air-fuel mixture to be stoichiometric is obtained.

The simulation is done by using two types of fuel injector which is the single-hole injector and the other multi-hole injector. The simulation started with simulating the single-hole injector first, then the multi-hole injector.

3.8 ANALYSIS OF SIMULATION RESULT

After the simulation finished, the data are obtained. The data of the simulation will be divided into three parts for analysis which are :

i. The relationship between engine speed and injector pressure in achieve stoichiometric mixture in the engine cylinder
ii. The relationship between valve lift and injector pressure in achieve stoichiometric mixture in the engine cylinder
iii. The relationship between engine speed and different type of injector in observing the quality of air-fuel mixture in engine cylinder

For the data of the relationship between engine speed and injector pressure in achieve stoichiometric mixture, and data for the relationship between valve lift and injector pressure in achieve stoichiometric mixture, both set of data were collected by using the surface parameter on the piston surface also known as the cylinder bottom surface. Generally, there are two types of set data can be collected at the piston surface which are the air mass fraction and the methane fraction. To determine the air-fuel ratio of the mixture inside the cylinder, value of the air mass fraction is divided with methane mass fraction. Both set data mentioned above are shown in Appendix C. Calculation is made for both set of data by using equation (2.1). Simulation is repeated until the calculated value of ratio is 17.2.

To observe the quality of the mixture, the mixture scattering at the piston surface is determined. In order to obtain the scattering mixture on the piston surface, the surface plot on the piston surface is selected. The steps to determine the surface plot can be refer to Appendix C. Basically, the blue and red colours will appear. Blue colour will determine the methane while red colour will denote the air region. However, the number of colour chosen should be selected properly. At certain number of colours selected, the methane region will not appear. Therefore, the correct number of colours selected is essential. In this project, the colours number selected is 10 and it is applied to every simulation.

CHAPTER 4

RESULT AND DISCUSSION

4.1 THE CORRELATION BETWEEN ENGINE SPEED AND INJECTOR PRESSURE TO ACHIEVE STOICHIOMETRIC MIXTURE

Both figure 4.1 and 4.2 show the effect of engine speed on fuel injector pressure to achieve stoichiometric methane-air mixture. Both figures consist of four lines representing of 25 percent, 50 percent, 75 percent and 100 percent valve lift. Figure 4.1 is for the single-hole fuel injector nozzle meanwhile figure 4.2 for multi-holes fuel injector nozzle.

Analysis on Figure 4.1 gives the relation between engine speed and single-hole injector pressure to achieve stoichiometric mixture in the engine cylinder. The higher the engine speed the higher the injector pressure to achieve stoichiometric mixture. For the 25 percent valve lift, the fuel injector pressure to achieve stoichiometric mixture is minimum while the maximum pressure of fuel injector to achieve stoichiometric mixture is at the 100 percent valve lift.The pressure increment due to the increasing of engine speed for the all scenarios which are from 25 percent to 100 percent valve lift have similar pattern. This happened because of the fuel spray and the different cylinder volume. Different valve lift may have different cylinder volume and the quantity of air inside the cylinder. So, the increasing of cylinder volume and air quantity inside the cylinder need more quantity of methane supplied to get stoichiometric mixture by increasing the injector pressure. The opening of intake valve also affects the situation. For single-hole fuel injector, the spray have small spray angle. The sprayed fuel may impinged the valve face and have tendency to reflect back to the intake manifold. This worsen when intake valve has smaller opening. Therefore higher injector pressure is needed to ensure enough fuel enter to cylinder in order to perform stoichiometric mixture.

Analysis on Figure 4.2 gives the relation between engine speed and multi-hole injector pressure to achieve stoichiometric mixture in the engine cylinder. The higher the engine speed the higher the injector pressure to achieve stoichiometric mixture. For the 25 percent valve lift, the fuel injector pressure to achieve stoichiometric pressure is minimum while for the 50 percent, 75 percent and 100 percent the pressure to achieve stoichiometry mixture are higher than 25 percent valve lift but the pressure are almost the same. The multi-holes fuel injector has larger spray angle than single-hole fuel injector. So, the probabilities of the fuel spray to impinged the intake valve is lower and resulting the lower injector pressure to perform stoichiometric mixture in combustion chamber. At certain valve opening the fuel spray no longer hitting the intake valve, the injector pressure will be constant at any further of the valve opening.

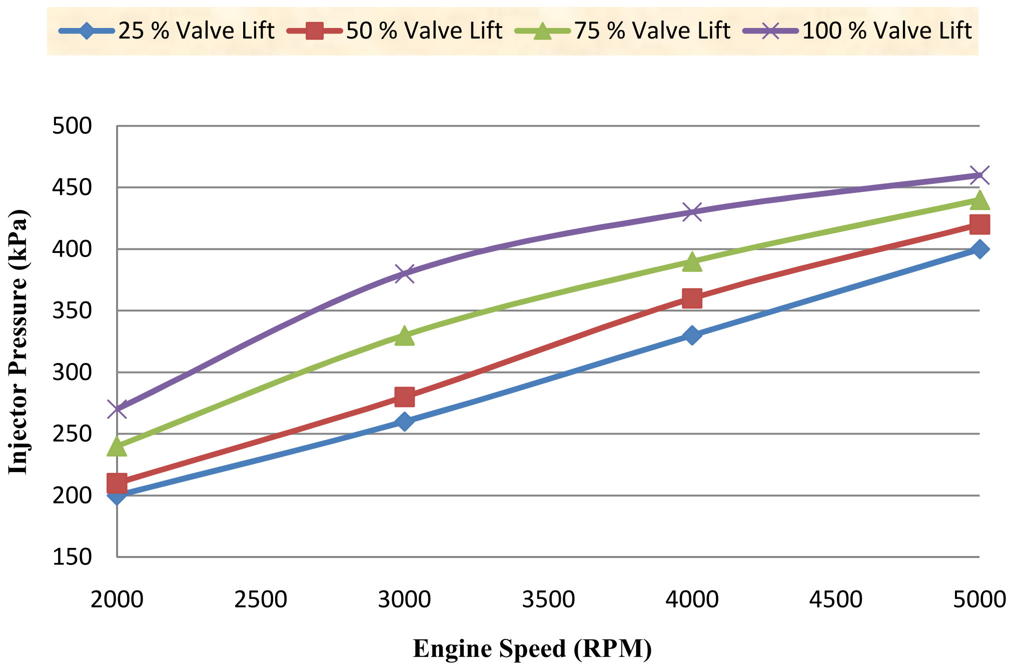


Figure 4.1 : Graph of Injector Pressure Versus Percentage of Valve Lift For Single-hole Fuel Injector

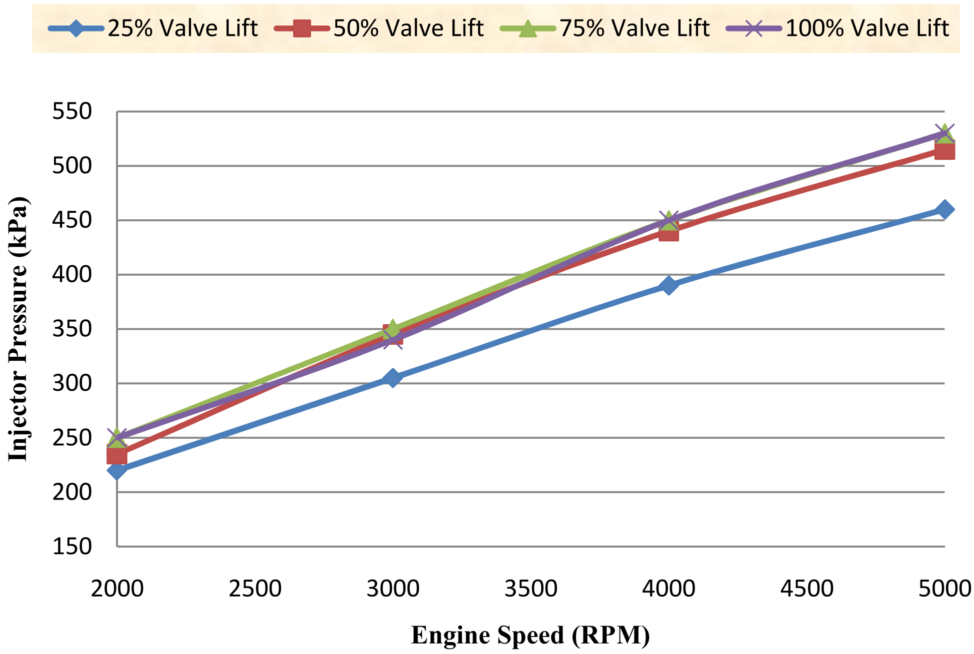


Figure 4.2 : Graph of Injector Pressure Versus Engine Speed For Multi-hole Fuel Injector

4.2 THE RELATIONSHIP BETWEEN VALVE LIFT AND INJECTOR PRESSURE TO ACHIEVE STOICHIOMETRIC MIXTURE

Both figure 4.3 and 4.4 show the effect of valve lift on fuel injector pressure to achieve stoichiometric methane-air mixture. Both figures consist of four lines representing 2000 RPM, 3000 RPM, 4000 RPM and 5000 RPM of engine speeds. Figure 4.3 is for the single-hole fuel injector nozzle meanwhile figure 4.4 for multi-holes fuel injector nozzle.

Analysis on Figure 4.3 gives the relation between valve lift and single-hole injector pressure to achieve stoichiometric mixture in the engine cylinder. Fuel injector increment in valve opening will increase the injector pressure to achieve stoichiometric mixture in engine cylinder. At 2000 RPM the fuel injector pressure to achieve stoichiometric mixture is at the lowest comparing to the other engine speeds manipulated while the maximum pressure of fuel injector to achieve stoichiometric mixture is at the 5000RPM to all valve opening.

Analysis on Figure 4.3 gives the relation between valve lift and multi-hole injector pressure to achieve stoichiometric mixture in the engine cylinder. The fuel injector pressure to achieve stoichiometric mixture is increasing due to the increasing of valve opening from 25 percent valve lift to 75 percent valve lift. At 75 percent valve lift to 100 percent valve lift, the pressure of the injector is constant. At 2000 RPM the fuel injector pressure to achieve stoichiometric mixture is the lowest followed by the 3000 RPM, then 4000 RPM and the highest injector pressure is at 5000RPM. The pattern of the graph from 2000 RPM to 5000 RPM have similar pattern. At the 75 percent to 100 percent valve lift, the injector pressure is constant because the spray of the multi-holes fuel injector will not impinged the intake valve face starting at the 75 percent valve lift. The differences in injector pressure for variety of engine speeds are due the air quantity in the different volume of engine cylinder.

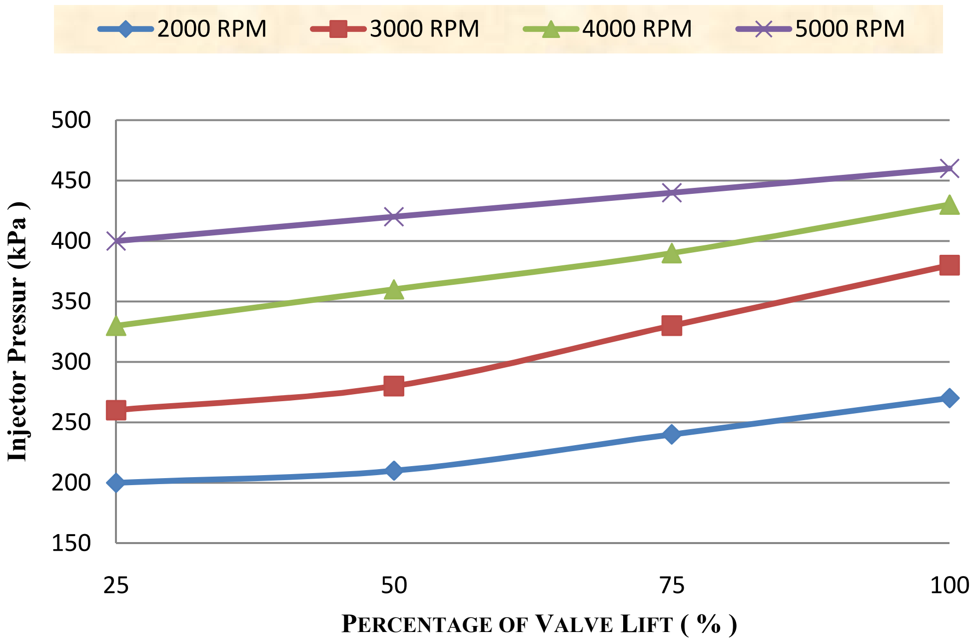


Figure 4.3 : Graph of Injector Pressure Versus Percentage of Valve Lift For Sinle-hole Fuel Injector

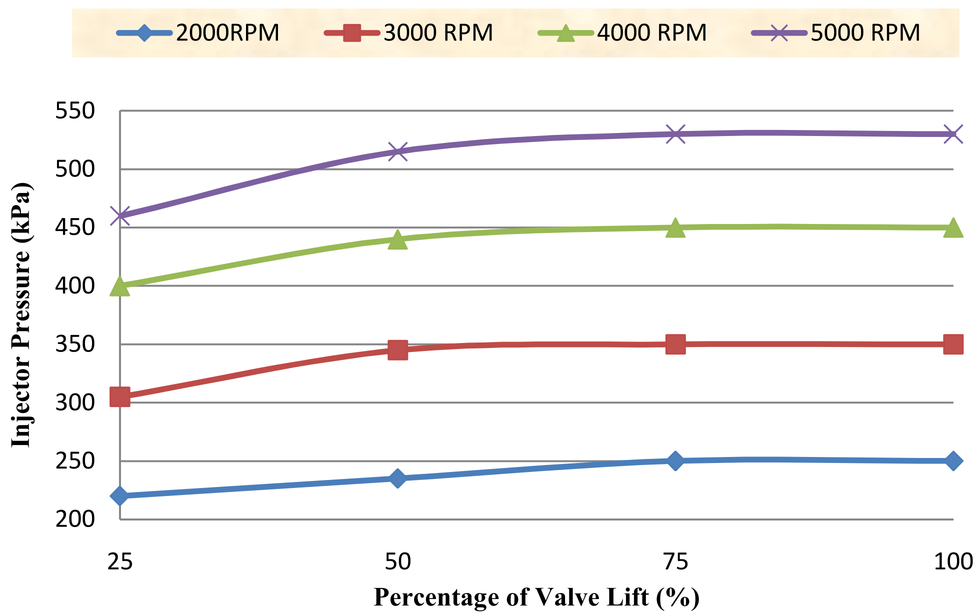


Figure 4.4 : Graph of Injector Pressure Versus Percentage of Valve Lift For Multi-hole Fuel Injector

4.4 IN-CYLINDER MIXTURE FORMATION ANALYSIS

The mixture formation analysis in obtained by observing species volume fraction on the piston surface. The species volume fraction plot on the piston surface indicates the homogeneity of the mixture in the cylinder during intake stroke. This analysis took place at the 100 percent valve lift. The analysis was run using different type of fuel injector nozzle's hole which are:

i. Single-hole fuel injector
ii. Multi-holes fuel injector

4.3.1 Single-hole Fuel Injector Mixture Formation Analysis

Both the figure 4.5 and figure 4.6 shows the air-fuel mixture volume fraction on piston surface. The data shows the quality mixing of mixture in combustion chamber when the intake valve is fully opened.Generally the data generated are labeled in term of the colour plots on the piston surface. In each figures, there are two categories of surface plot which the surface was plot based on air and the other based on methane (CH_4).The surface plot based on air is represented by red while the blue colour is represent surface plot based on methane.

Single-hole fuel injector mixture formation is discussed in Figure 4.5. Generally, the high fraction formation of methane is observed at the right side of the piston surface. In contrast, high fraction of air formation is at the left side of the cylinder. This indicates that, when the valve is fully open, the trajectory of the methane species from the fuel injector is directly to the right side of the piston surface and high density of methane formation is occur at the same side. It is also indicate at the right side of the piston the mixture is at a rich mixture and the opposite side is at the lean mixture. In concerning of the spark plug location, this formation of mixture is not very good indeed for flame propagation and combustion process. To perform a good combustion process and has high flame velocity, the mixture is need to be homogeneous and also rich near to the spark plug location. In this situation, predict that the flame propagation mostly propagate at the right side of the piston surface it is because of the high fraction of the methane. The flame velocity at this side also predicted to be at high speed. However, excess of fuel and reluctant of air (oxygen) may induce the emission of carbon monoxide (CO) due to more fuel is not oxidized.

At the different engine speed, the mixture formation is changing. From the observation, at 2000 RPM to the 4000 RPM the region of high methane concentration is spreading. This occurred due to the time taken for each cycle to form homogenous mixture is lesser. To form homogeneous mixture, a particular period of time is needed. When the engine speed increases, the period of time of mixture before combustion occur in cylinder become lesser, thus homogenous mixture are more difficult to form and causes more non uniform mixture mixing in the cylinder. When the fraction of the methane becomes larger at the right side of the piston surface, it will instigate the other side of the mixture to become leaner. Richer mixture will cause high emission and unburned carbon.

However at 5000 RPM the region of high methane concentration shows a small break up. Methane region size on the right side of piston surface becomes smaller than previous engine speed. This is because of the turbulence effect in the engine due to high spray velocity, high speed air sucked inside the cylinder and the speed of piston moving. As the engine speed increases, the turbulence in the engine become higher, high turbulence is needed to ensure the mixing of the air and fuel rapidly.

4.3.2 Multi-hole Fuel Injector Mixture Formation Analysis

Figure 4.6 shows the mixture formation in the engine cylinder from multi-hole fuel injector. Generally, the air-fuel mixture for the multi-hole fuel injector seem to have better quality of mixing .The mixture shows that small amount of high methane concentration formed in the cylinder. This situation will have better combustion process and flame propagation than the single-hole fuel injector did due to the mixture is better distributed in the engine cylinder. It is predict that, this kind of mixing quality emits low emission bring high efficiency of combustion.

The higher formation concentration of methane in the cylinder observed as the engine speed increasing from 2000 RPM to 3000 RPM. High concentration of methane region is spreading to the middle of the piston surface and formed of slightly rich mixture close to the spark plug location. From figure 4.6, at the 4000 RPM engine speed the size of high methane concentration reduced from the size of lower engine speeds at when the engine speed is approaching higher speed, which is 5000 RPM, the amount of high concentration methane region become the smallest.

At 3000 RPM, the high concentration of methane region size is increased from lower engine speeds due to the period of time of mixture before combustion occur in cylinder become lesser, thus homogenous mixture are more difficult to form. In contrast, at 4000 RPM the high concentration of methane region size reduced from lower engine speeds, it may cause by the effect of the high turbulence intensity. When the engine speed is increase to 5000 RPM, the turbulence intensity also increases and improves the mixture quality. The mixing quality of multi-hole fuel injector is better at lower engine speeds than the single-hole fuel injector at lower engine speeds because of smaller particle of methane spray. Smaller particle of spray (atomized) improve the ability to be mix-welled.

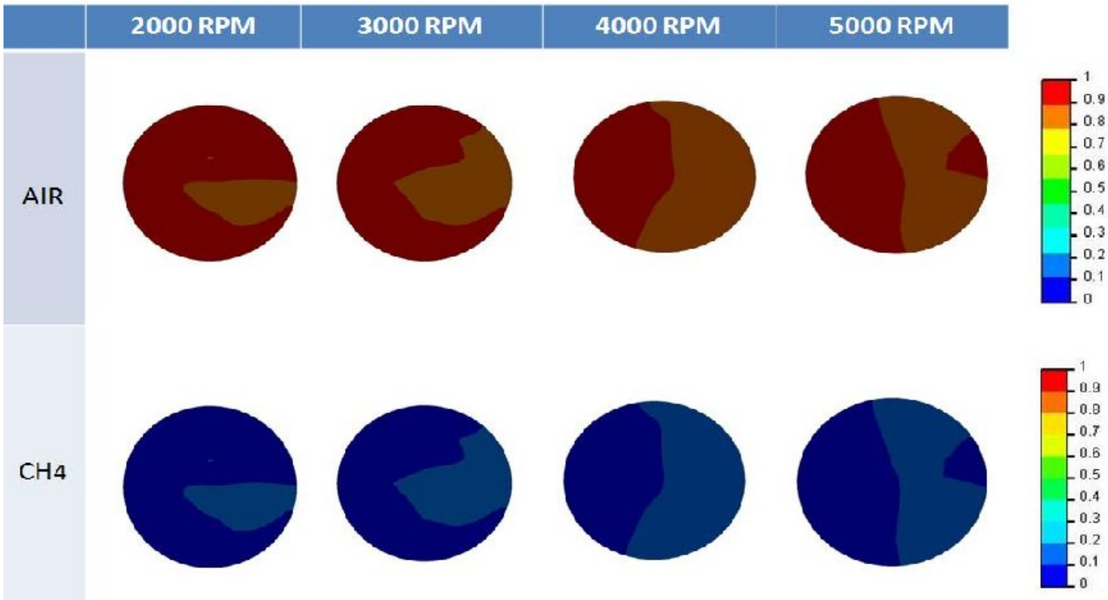


Figure 4.5 : The fuel surface plot for single-hole fuel injector

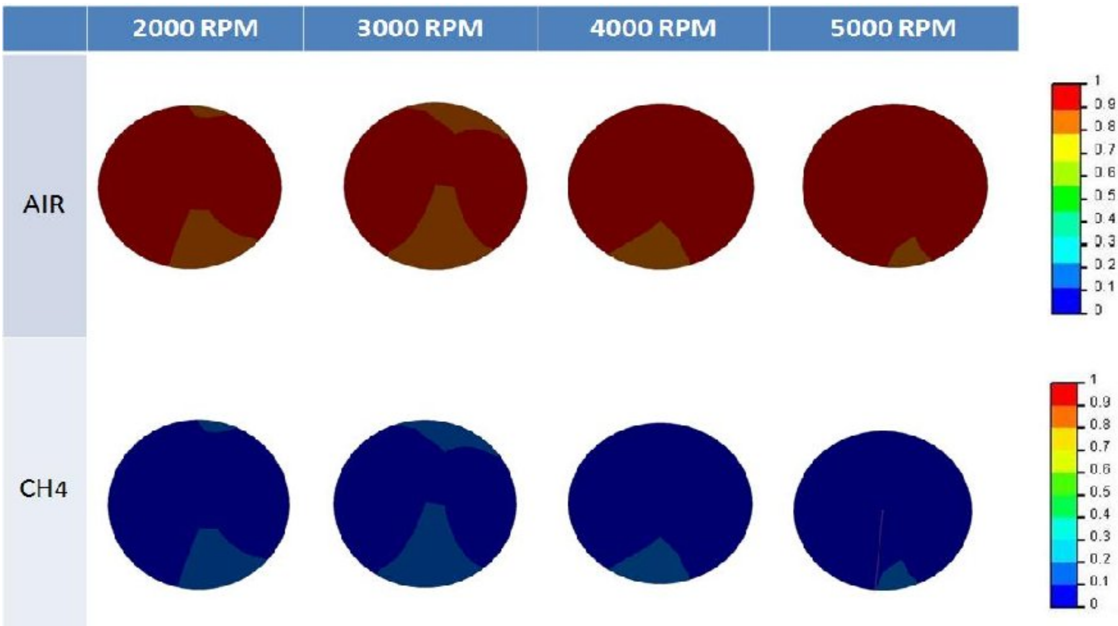


Figure 4.6 : The fuel surface plot for multi-hole fuel injector

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

As the analysis of the project is done, several phenomena can be concluded in this chapter. First, the entire project objectives have been achieved and can be concluded. The conclusion that can be made from the analysis is the multi-holes fuel injector is better than single-hole in term of forming a good air-fuel mixture.

i. **Correlation between engine speed and injector pressure** The engine speed is one of the parameter that will affect the mixture efficiency. At any variation of engine speed, a specific injector pressure is needed to supply a homogeneous stoichiometric ratio. By increasing the engine speed, the injector pressure also increase in correspondence. For single-hole injector, the injector pressure is increased when the engine speed is increased. For comparison on each type of valve lift, 25 percent valve lift has the lowest injector pressure and the highest injector pressure is at 100 percent valve lift. Meanwhile, the multi-hole fuel injector pressure at 50 percent, 75 percent and 100 percent valve lift has almost the same pressure range.

ii. **Correlation between valve lift and injector pressure** Valve opening or valve lift has effect on the air-fuel ratio of the air-fuel mixture. An appropriate fuel injector pressure is used in order to maintain the mixture at the stoichiometric ratio to ensure high combustion efficiency and engine performance. Increment of valve lift increases the pressure of both injectors.

But in multi-hole fuel injector pressure, at 75 percent valve lift to 100 percent valve lift the injector pressure will be constant.

iii. **In-Cylinder air-fuel mixture formation**. Generaaly, the mixture produced by using multi-holes fuel injector is better than single-hole fuel injector in term of the quality of the mixing. The quality mixture best at 5000 RPM by using multi-holes fuel injector which is almost perform a homogeneous mixture. The homogeneity of mixture in the cylinder influence by the spray produced in different type of injector. In additional, the increasing of engine speed changes the distribution of both mixture on the piston surface. At a lower RPM, both mixture of each injector produced small amount of high concentration of methane region showing that both the mixture is slightly rich at certain area. The engine speed effect the time of the mixture to become homogeneous, the higher the engine speed the more the mixture tends to be non homogeneous. However, at 5000 RPM engine speed the homogeneous mixture tends to be easier to form because of high turbulence intensity which make the mixture tends to be well-mixed.

5.2 RECOMMENDATION

Since the CNG having a lot of advantages, it is recommended that the study of the CNG to be an alternative fuel and development of the CNG fuel injector should be carried on to produce a high efficiency automotive equipment.

To further develop the fuel injector, a fuel injector should be fabricated suitable with the vehicle, which can run on the road to get real testing. The performance should be compared with other type of fuel injector available in the market to improve the CNG engine performance.

The use of computational Fluid Dynamics (CFD) of CNG-air fuel injector should be applied on the new design of CNG fuel injector. CFD based on numerical solutions of the fundamental governing equations of fluid dynamics namely the continuity, momentum, and energy equation. Through a CFD,the problem liks involving fluid flow, heat transfer, turbulence, mixer of chemical species, multi step chemistry, two phase flows, moving/rotating bodies and other complex physics can be solve with else.

The design of a new and efficient CNG fuel injector will be improved in the future because the future technology and limited source of oil supply on earth will made a person who concern to do that project.

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APPENDIX

APPENDIX C

BOUNDARY CONDITION SETTINGS

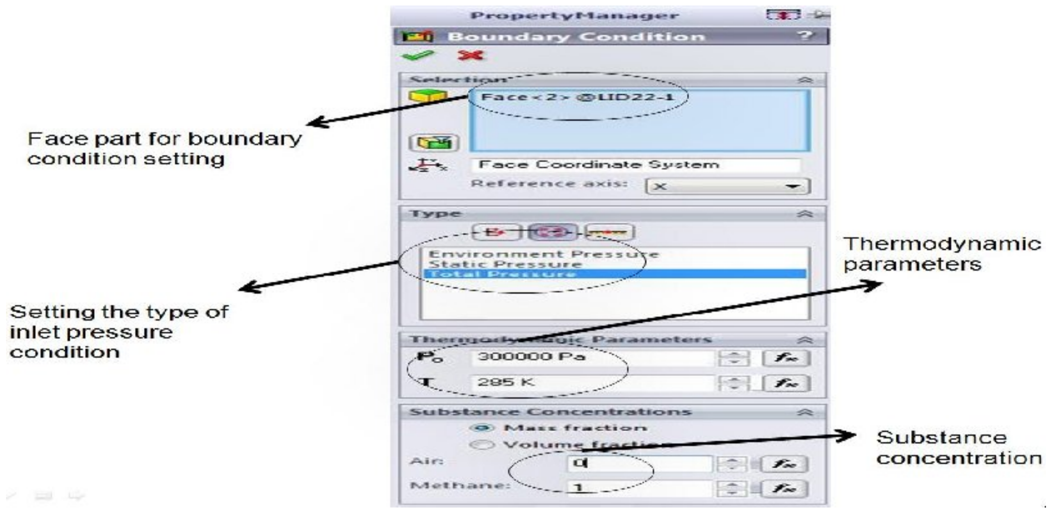

Figure C1: Methane Inlet pressure boundary condition setting

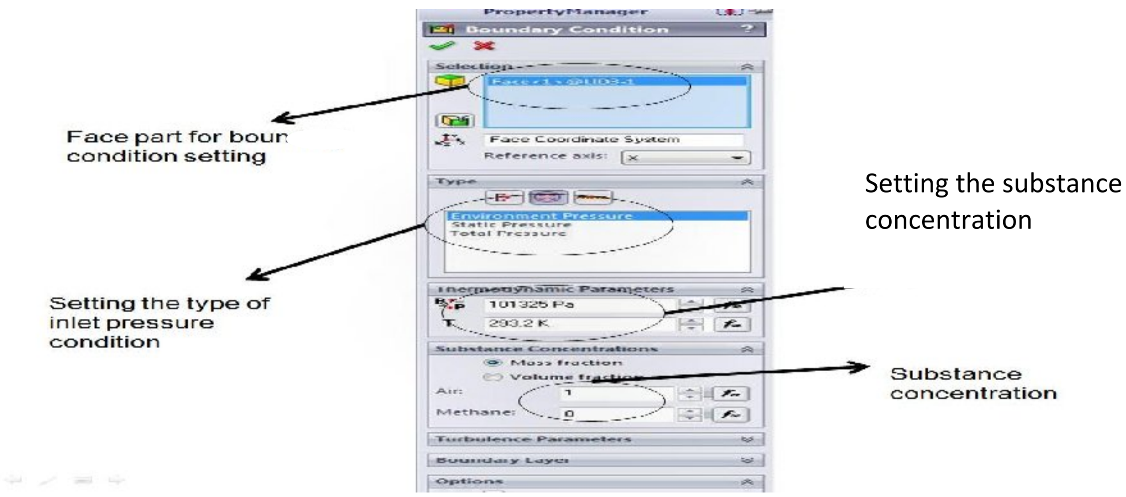

Figure C2: Selecting air Inlet pressure boundary condition

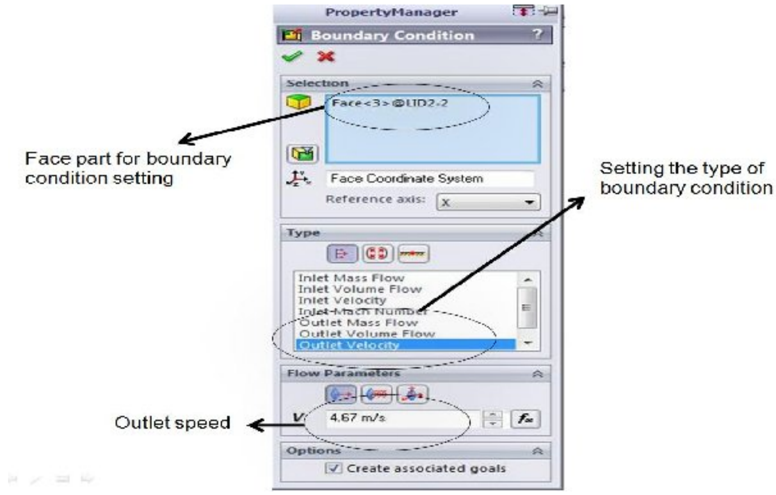

Figure C3: Selecting outlet velocity boundary condition

Local parameters

Parameter	Minimum	Maximum	Average	Bulk Average	Surface area [m^2]
Pressure [Pa]	91791.9	94663.2	93251.3	93254.5	0.00594025
Temperature [K]	292.879	294.296	293.701	293.703	0.00594025
Density [kg/m^3]	1.04258	1.07816	1.061	1.06107	0.00594025
Velocity [m/s]	11.6805	49.3085	27.7879	27.7649	0.00594025
X-component of Velocity [m/s]	-40.2096	23.6076	-7.64525	-7.55631	0.00594025
Y-component of Velocity [m/s]	-11.6938	-11.6296	-11.668	-11.668	0.00594025
Z-component of Velocity [m/s]	-35.1008	37.0471	0.265655	0.261729	0.00594025
Mach Number [ ]	0.0333744	0.140979	0.0795747	0.0795099	0.00594025
Air Mass Fraction [ ]	0.926801	0.963111	0.948136	0.948183	0.00594025
Methane Mass Fraction [ ]	0.0368894	0.0731991	0.0518651	0.051818	0.00594025
Air Volume Fraction [ ]	0.875212	0.935326	0.91024	0.910318	0.00594025
Methane Volume Fraction [ ]	0.0646737	0.124788	0.0897605	0.0896819	0.00594025
Fluid Temperature [K]	292.879	294.296	293.701	293.703	0.00594025

Figure C4: Surface parameter result

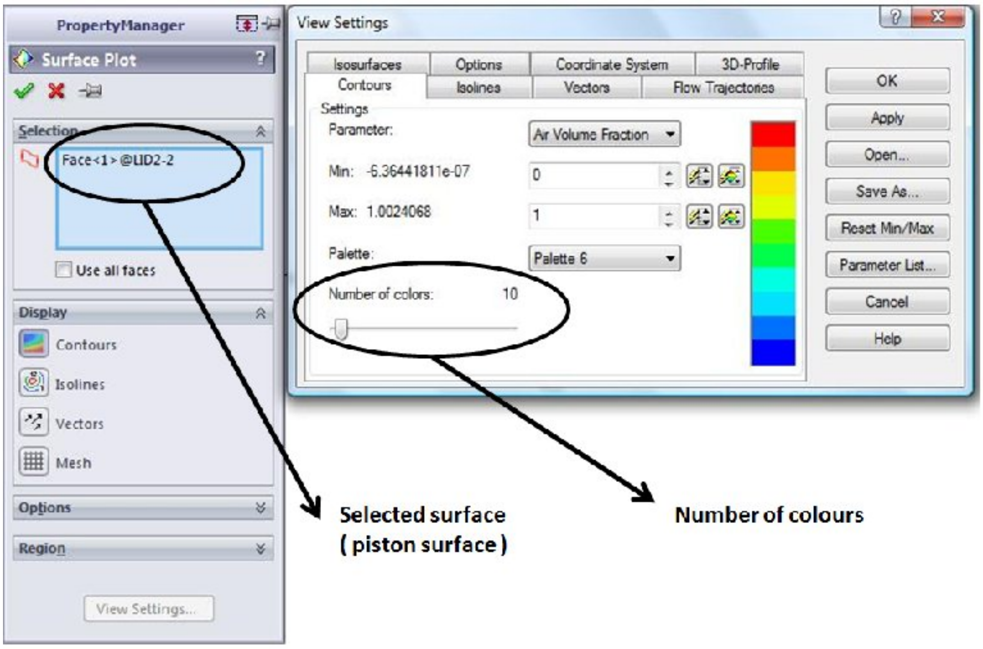

Figure C5: Surface plot setting

APPENDIX D

DATA COLLECTION FROM SIMULATION OF SINGLE-HOLE FUEL INJECTOR

Table D1: Data obtain from different engine speed

Engine speed (RPM)	Valve lift (%)	Injector Pressure (Pa)
2000	25	200000
	50	210000
	75	240000
	100	270000
3000	25	260000
	50	280000
	75	330000
	100	380000
4000	25	330000
	50	360000
	75	390000
	100	430000
5000	25	400000
	50	420000
	75	440000
	100	460000

Table D2: Data obtain from different valve lift

Valve lift (%)	Engine speed (RPM)	Injector pressure (Pa)
25	2000	200000
	3000	260000
	4000	330000
	5000	400000
50	2000	210000
	3000	280000
	4000	360000
	5000	420000
75	2000	240000
	3000	330000

	4000	390000
	5000	440000
100	2000	270000
	3000	380000
	4000	430000
	5000	460000

APPENDIX E

DATA COLLECTION FROM SIMULATION OF MULTI-HOLE FUEL INJECTOR

Table E1: Data obtain from different engine speed

Engine speed (RPM)	Valve lift (%)	Injector Pressure (Pa)
2000	25	220000
	50	235000
	75	250000
	100	250000
3000	25	305000
	50	345000
	75	350000
	100	350000
4000	25	400000
	50	440000
	75	450000
	100	450000
5000	25	460000
	50	515000
	75	530000
	100	530000

Table E2: Data obtain from different valve lift

Valve lift (%)	Engine speed (RPM)	Injector Pressure (Pa)
25	2000	220000
	3000	305000
	4000	390000
	5000	460000
50	2000	235000
	3000	345000
	4000	440000
	5000	515000
75	2000	250000
	3000	350000

	4000	450000
	5000	530000
100	2000	250000
	3000	340000
	4000	450000
	5000	530000