DEVELOPMENT OF HIGH PRESSURE SPRAY TRIGGERING

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DEVELOPMENT OF HIGH PRESSURE SPRAY TRIGGERING

WAN MOHD RASHDAN BIN WAN MANSOR

Report submitted in partial of the requirements
for the award of the degree of
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FACULTY OF MECHANICAL ENGINEERING

We certify that the project entitled "Development of high pressure spray triggering" is written by Wan Mohd Rashdan Bin Wan Mansor. 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 fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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

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Dedicated to my parents

ABSTRACT

This project presents the study about development of high pressure spray triggering and control in a direct injection gasoline injector of a gasoline engine. The objectives of the study is to develop injection system using a parameters of time and pressure in order to identify the spray characteristics including spray angle, spray tip penetration and spray width. The scopes of this research is choosing control system EFI in type of injection, setup test rig for experimental using high pressure chamber and develop control and triggering system in order to control the timing and delay of the injector. After test rig fabrication is done and all equipment has been setup, experiment is done by supplying pressure from high pressure fuel pump to fuel injector that attach to high pressure chamber. Ambient temperature was set to 300 K and ambient pressure is 10 kpa, 20 kpa, 30 kpa and 40 kpa. Simple triggering and control has been developing using MATLAB Simulink and the DAQ software result was analyzed due to sample of calculation.

ABSTRAK

Projek ini menunjukkan kajian tentang membangunkan system tekanan tinggi kawalan semburan cecair dalam injektor petrol bagi enjin gasoline. Tujuan kajian ini adalah untuk membangunkan sistem kawalan dengan menggunakan parameter masa dan tekanan untuk mengenal pasti ciri-ciri semburan termasuk sudut semburan, penetrasi semburan dan lebar semburan. Ruang lingkup dalam penelitian ini adalah memilih sistem kawalan mengikut jenis injektor, menyediakan rangka ujian bagi melakukan eksperimen dengan menggunakan kebuk bertekanan tinggi dan membina sistem kawalan untuk mengawal masa dan kelewatan Injektor. Setelah fabrikasi rangka ujian dilakukan dan semua peralatan telah disediakan, eksperiman dilakukan dengan membekalkan tekanan dari pam bertekanan tinggi ke injektor yang terletak di kebuk tekanan tinggi. Suhu persekitaran ditetapkan untuk 300K dan tekanan diberi sebanyak 10 kpa ,20 kpa, 30 kpa dan 40 kpa. Sistem kawalan injektor dibina menggunakan aturcara MATLAB Simulink dan perisian DAQ dianalisis keputusan dibandingkan dengan penyelidikan terdahulu dan contoh pengiraan.

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LIST OF SYMBOLS

P	Normal pressure
P_o	Normal pressure constant
P_t	Total resultant load (Tensile)
P_c	Total resultant load (Compression)
E	Young's modulus
$\mathbf{K}$	Stiffness matrix
$\mathbf{u}$	Vector of displacements
$\mathbf{f}$	Vector of applied forces
x	Relative density
ρ	Density
c	Compliance
x	Stiffness
g_e	Design variable

LIST OF ABBREVIATIONS

GDI	Gasoline Direct Injection
ECU	Electronic Control Unit
EFI	Electronic Fuel Injection
Fps	Frames Per Second
DAQ	Data Acquisition Toolbox
FE	Finite element
FEA	Finite Element Analysis
FEM	Finite element modelling
HEXA	Hexahedral
IC	Internal Combustion

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Fuel injection control system directly affects the fuel efficiency and pollution level or substances that can be used as fuels of automotive engines, other than conventional fuels. The benefits of these alternative fuels are that they emit less air pollutants and they are very economical compared to conventional fuels .Since 1970s, the environment pollution and energy consumption has become serious concerns associated with engine control technology. The self-tuning control technique is applied to improve the engine performance by controlling the engine speed and exhaust flow. Most fuel injection systems are for gasoline or diesel applications. With the advent of electronic fuel injection (EFI), the diesel and gasoline hardware has become similar. EFI's programmable firmware has permitted common hardware to be used with different fuels.

For this design, it is necessary to investigate the spray development process, the ignition probability, and the combustion propagation process of Combustion Natural Gasses. In this study, a combustion chamber with a visualization system is designed and built. CNG is injected into the combustion chamber by a gasoline direct injection (GDI) injector and ignited by a spark plug placed near the injector. The close arrangement of the injector and spark plug provides a stratified charge of CNG around the spark discharge position. Images of the CNG spray development and combustion propagation processes were digitally recorded. The results of this study can contribute important data for the design and optimization of spark-ignited direct injection (SIDI) CNG engines.

1.2 PROBLEM STATEMENTS

In most spray applications, spray characteristics, such as droplet size and distribution, are highly dependent on the specific spray nozzle used, control in the system which makes it difficult to alter them without a complete overhaul of the system. The implementation of spray control that could enable manipulation of spray behavior and parameters, as necessary, would enhance the versatility and efficiency of sprays.

1.3 OBJECTIVES OF PROJECT

The objectives of the study are:

i. To study about fuel injection system.
ii. To design and integrate of the programming part to control injector fuel spray.
iii. To develop a triggering and control system based on time and pressure.

1.4 SCOPE OF PROJECT

There are three scopes in this study:

i. Study on fuel injection triggering and control system.
ii. Develop and setup test device use DAQ software for triggering.
iii. Develop simple triggering and control using MATLAB Simulink

1.5 OUTLINE OF REPORT

Chapter 1 introduces the background, problem statement and the scopes of this study. Chapter 2 presents the literature study about injector, Matlab simulink and spray of the injector pressure. Chapter 3 discusses the development of injector pressure modeling, DAQ software and the optimization technique. Chapter 4 discusses the results and analysis of the Matlab , and optimization of the injector pressure. Chapter 5 presents the conclusion and recommendation of the future work.

1.6 SUMMARY

The project background, objective, problem statement, and project scope was very important in order to guide me follow the project cover. While the project flowchart was guide me to complete the work at the time given.

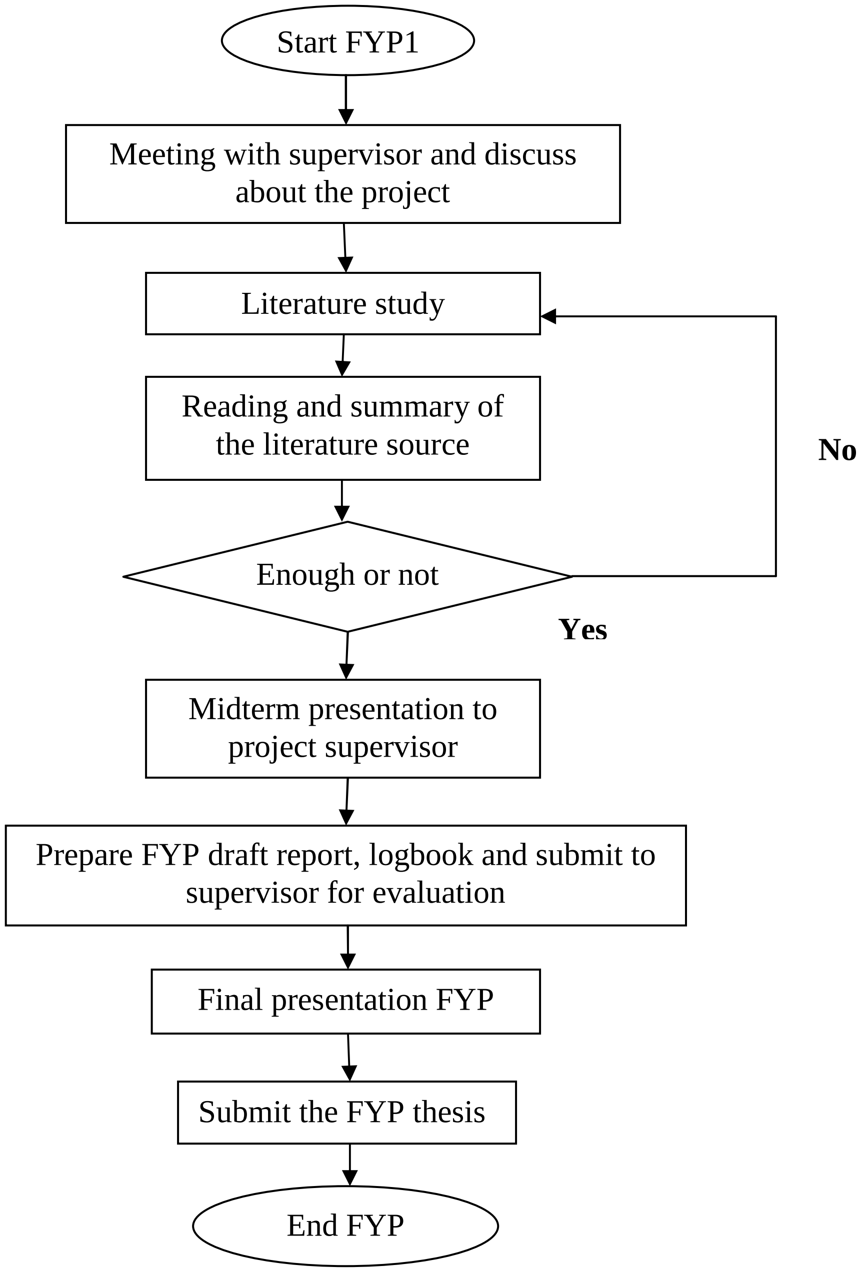

Figure 1.2: Project flowchart

CHAPTER 2

LITERITURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide information which related to the injector pressure, Matlab simulink , DAQ software component and also about Maximum of EFI injector pressure . The research concludes about fuel injection system, control mechanism and spray behaviors.

2.2 FUEL INJECTION

In modern automotive internal combustion engines, the varieties of injection systems have existed. A fuel injection system is designed and calibrated specifically for the types of fuel it will handle. Most fuel injection systems are for gasoline or diesel applications. With the advent of electronic fuel injection (EFI), the diesel and gasoline hardware has become similar. EFI's programmable firmware has permitted common hardware to be used with different fuels.

Basic components in fuel injection system are fuel injector, high speed camera and electronic control unit (ECU) such as injector driver and digital delay generator for the signal line while other components such as fuel tank, fuel filter, high pressure pump and pressure regulator for the fuel line. In the laboratory experiment, high pressure chamber is used as a main character in order to identify spray patterns. Some of the experiment that using high speed camera can trigger with personal computer and ECU. The data gained will show in the personal computer automatically.

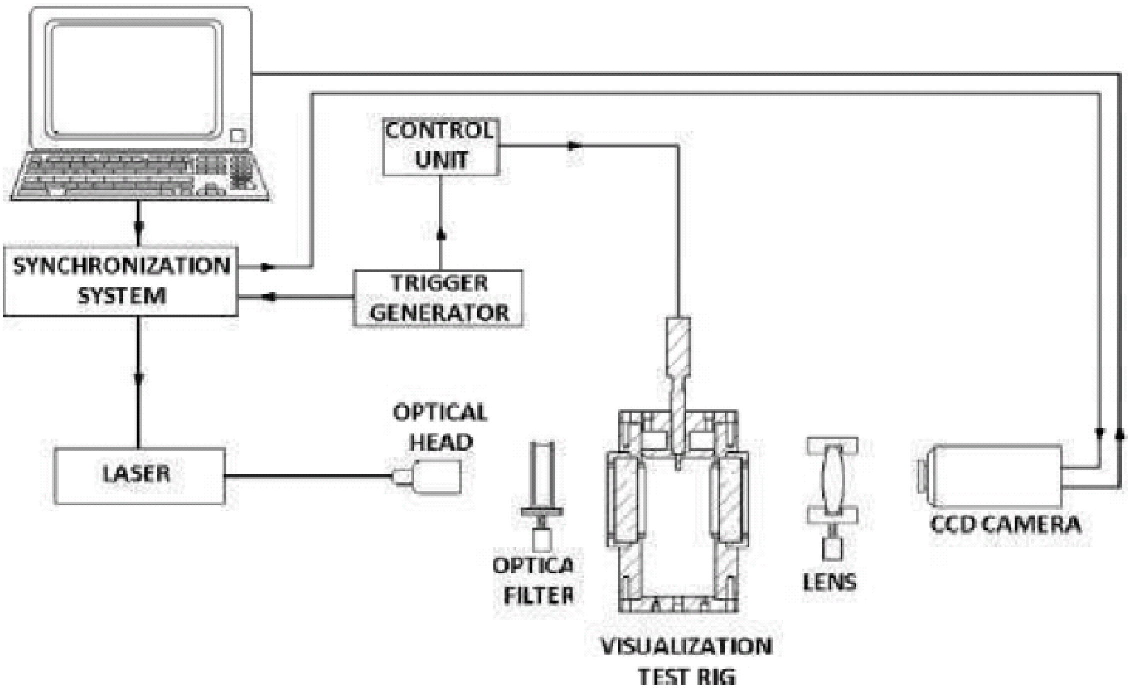

Figure 2.1: Fuel injection system

Source: J.M Desantes, 2009

2.2.1 Fuel Injector

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 operated, also exist. A metered amount of fuel is trapped in the nozzle end of the injector, and a high pressure is applied to it, usually by a mechanical compression process of some kind. At the proper time, the nozzle is opened and fuel is sprayed into the surrounding air. The amount of fuel injected each cycle is controlled by injector pressure and time duration of injection. An electronic fuel injector consists of the following basic components which is valve housing, magnetic plunger, solenoid coil, helical spring, fuel manifold and pintle (needle valve). When not activated, the coil spring holds the plunger against its seat, which blocks the inlet flow of fuel. When activated, the electric solenoid coil is excited, which moves the plunger and connected pintle (needle valve).

This opens the needle valve and allows fluid from the manifold to be injected out the valve orifice. The valve can either be pushed opened by added pressure from the plunger or it can be opened by being connected to the plunger, which then releases the pressurized fuel. Each valve can have one or several orifice openings. In mechanically controlled injectors there is no solenoid coil and the plunger is moved by the action of a camshaft.

Figure 2.2: Fuel spray for combustion system

Source: www.enginebasics.com/Engine Basics Root Folder/Fuel Injectors 2

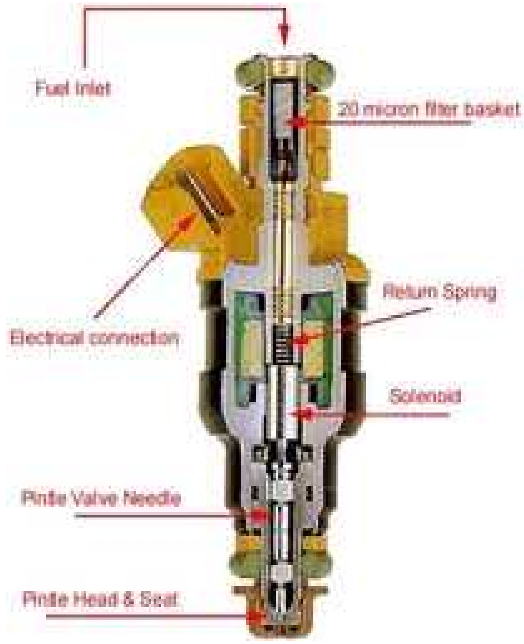

Figure 2.3: Fuel Injector

Source: Lee, C.S 2009

2.2.2 High speed camera

In order to get different spray characteristic in term of different timing and pressure controlled by ECU, it is require a high speed camera. An example of high speed camera that mostly use is Photron, Fastcam-APX-RS. This camera provides full megapixel resolution images at frame rates up to 3,000 frames per second (fps), 512 x 512 pixels resolution at 10,000 fps and at reduced frame rates to an unrivaled frame rate of 250,000 fps. Utilizing Photron's advanced CMOS sensor technology, the APX-RS provides the higher light sensitivity than any other comparable high-speed imaging system. Both color and monochrome models are available, both with excellent anti-blooming capabilities. A user selectable 'Region of Interest' function enables the active image area to be defined in steps of 128 pixels wide by 16 pixels high to allow the most efficient use of frame rate, image resolution and memory capacity for any event. Up to 20 commonly used configurations can be saved to memory for future operation. Available with Gigabit Ethernet, Fire wire and fiber optic communications, this compact camera can provide exposure durations as short as 2 microseconds and is easily operated in the field with or without a computer through use of the supplied remote keypad, enabling full camera setup, operation and image replay.

Figure 2.4: High speed camera

Source: Photron 2010

2.2.3 Injector driver

Injector driver modules work with the central computer system and the fuel injection system in a vehicle. Only vehicles with fuel-injection systems will use an injector driver module. Engines that need high pressure fuel injection rely on injector driver to control the fuel injection system. The main purpose of an injector driver is to control the amount and timing of fuel injection within the vehicle's system.

Figure 2.5: Injector Driver

Source: www.thunderracing.com

2.2.4 Digital delay generator

Digital delay generator is a piece of electronic test equipment that provides precise delays for triggering, syncing, delaying and gating events. It is used in many types of experiments, controls and processes where electronic timing of a single event or multiple events to a common timing reference is needed. Similar to a pulse generator in function but with a digital delay generator the timing resolution is much finer and the delay and width jitter much less.

Figure 2.6: Digital delay generator

Source: www.highlandtechnology.com

2.3 CIRCUIT 555 TIMER IC

The 555 Timer IC is an integrated circuit (chip) implementing a variety of timer and multivibrator applications. The IC was designed by Hans R. Camenzind in 1970 and brought to market in 1971 by Signetics (later acquired by Philips). The original name was the SE555 (metal can)/NE555 (plastic DIP) and the part was described as "The IC Time Machine". It has been claimed that the 555 gets its name from the three 5 kF resistors used in typical early implementations, but Hans Camenzind has stated that the number was arbitrary.

Figure 2.7: NE 555 IC

Source: Lubkin, G.B. 1996.

2.4 SPRAY CHARACTERISTICS

The microscopic spray characteristic including axial spray tip penetration, spray width and spray angle are shown in figure 2.6. The spray tip penetration and spray width were defined as maximum distance from the nozzle tip of the side view spray image and maximum radial distance from the bottom view, respectively. Also the spray cone angle is defined as the interval which is formed by the nozzle tip and two straight lines wrapped with the maximum outer side of the spray. Amirruddin, A.K. (2009) says that the higher ethanol contains the spray spread faster, present longer penetration distance.

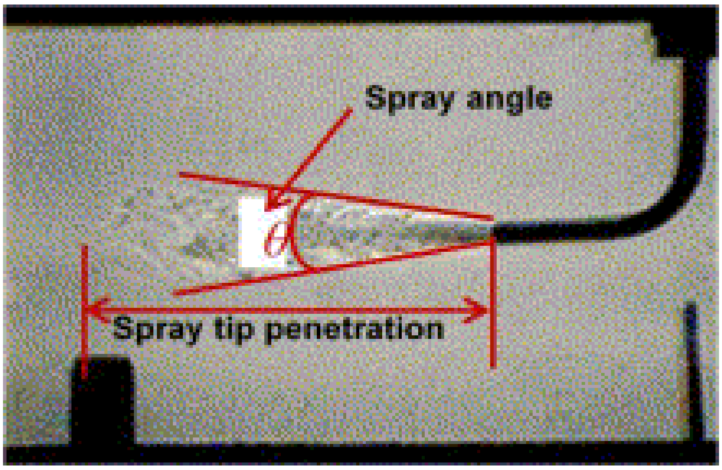

Figure 2.8: Definition of spray characteristic (sprays tip penetration, spray width and spray angle)

Source: Lee, C.S et al. 2009

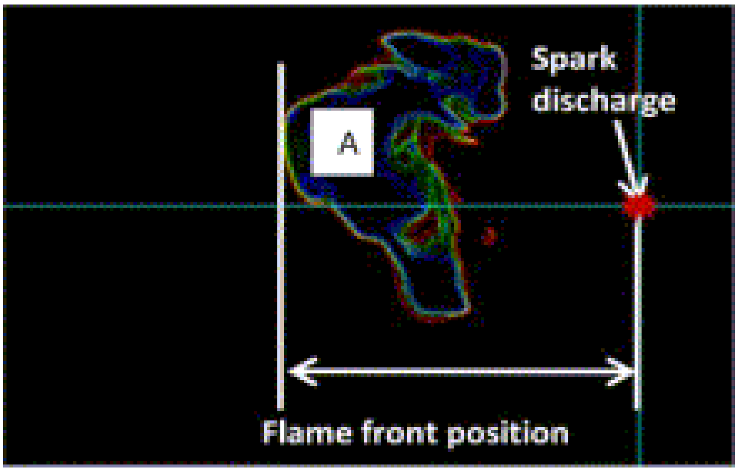

Figure 2.9: Definition of spray characteristic (flame front position)

Source: Lee, C.S et al. 2009

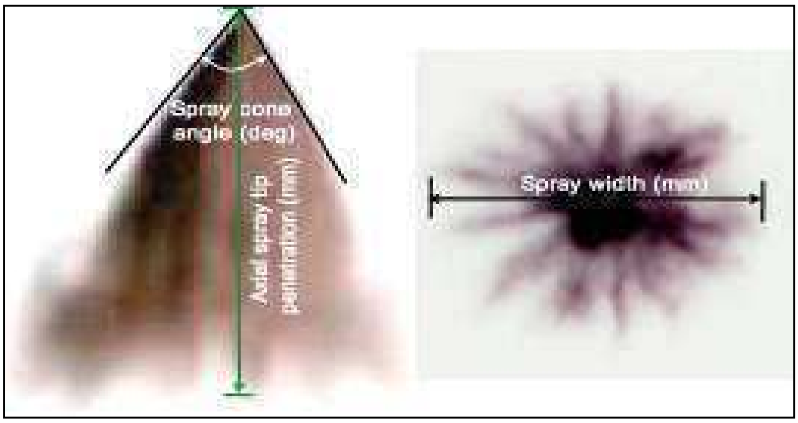

Figure 2.10: Definition of spray characteristic (spray width and spray angle)

Source: Lee, C.S et al. 2009

An evaluation of the correlations between spray tip and function of time, indicated that the formula developed by Dent, best predict the equation:

$$S = 3.07\ (P/\ p)^{1/4}\ (tdn)^{1/2}\ (294/T)^{1/4} \quad (2.1)$$

Where P, pressure across the nozzle, p, density of fuel, t, time after start of the injection, d, diameter of nozzle and T, ambient temperature.

2.5 CONCLUSION

This chapter has been the summary of previous works that related to this project. The works were discussed are about spray triggering, spray penetration and spray characteristic of injector. The next chapter will be discussed about the methodology of this project.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter presents the overall methodology of the optimization based on high pressure spray triggering. The optimization is the most critical combustion process in the automotive industry. It is very important that any production company invested millions of their profits into Research and Development (R&D) the engine. The aim of this chapter is to develop a methodology to improve the injector pressure spray process of high pressure spray triggering.

3.2 THEORETICAL BASIS OF INJECTION

The injection system used for this study was a common rail, electronically controlled unit injector system. The system was constructed on a moveable cart and the injector was mounted on a constant volume spray chamber. The injection system included a fuel pumping system, a lubrication system, an injector, and a control system. Figure 3.1 and 3.2 shows the connections between these components. The high pressure fuel pump was a multiplelobe, cam jerk type fuel injection pump which was driven by an electric motor. The pump pressurized the fuel inside an accumulator (common rail) to pressures up to 80 kpa. However, 40 kpa was used as a maximum pressure for the experiments as to ensure the reliability of fuel system components. The injection pump was lubricated by a separate oil lubrication system which contained an oil sump, a hydraulic pump, a flow controller, and a pressure controller. Fuel metering was done with a three way valve at the injector. The function of the three-way valve was to switch the nozzle fuel pressure between the common-rail pressure and atmospheric pressure. Injection timing and quantity were controlled by changing the timing of the pulse and the pulse width applied to the three-way valve. The nozzle tip was a 6-hole, mini-sac type of diesel injector tip. The hole diameter was 0.26 mm and the length was 0.5 mm, which makes the nozzle L/D ratio about 1.923. There were two electronic control units to control this injector, an injector controller and a pump controller. These controlled the injection timing, injection duration, injection quantity, injection rate, and injection pressure of the injector. The injection timing and injection duration for each split injection was adjusted independently using the injector controller. The injection pressure was controlled from the pump controller.

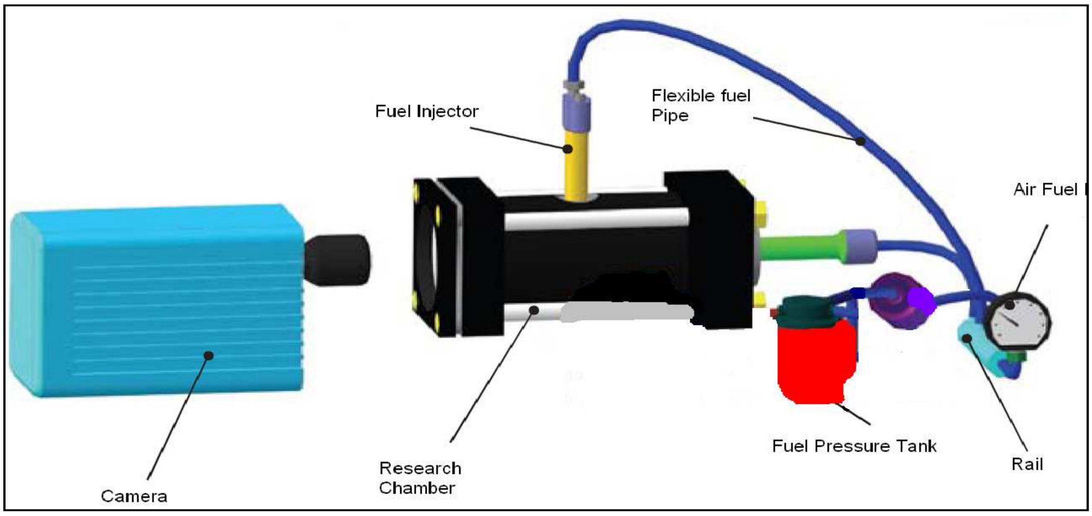

Figure 3.1: Experimental setup

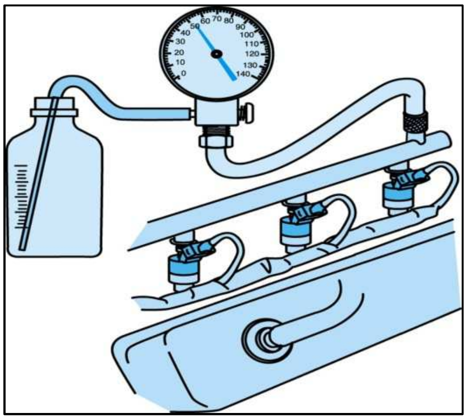

Figure 3.2: Connecting of injector

3.2.1 Fuel Injector

The injector used is a vertical centrally mounted prototype with a six-hole nozzle in a close spacing arrangement with the spark plug. The nozzle holes are 0.5 mm in diameter at the exit and essentially consist of two groups of three nozzle holes. The six nozzle holes have different injection angles producing the spray pattern illustrated in Figures 3.3 and 3.4, where 6 plumes pass around the spark plug. There is an initial delay before fuel is seen at the injector tip, governed by the injector driver used.

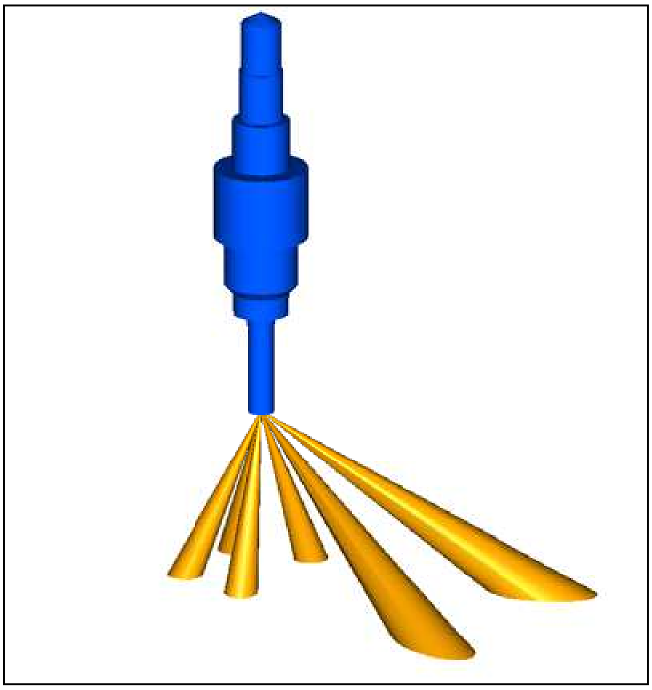

Figure 3.3: 6 plumes pressure injector

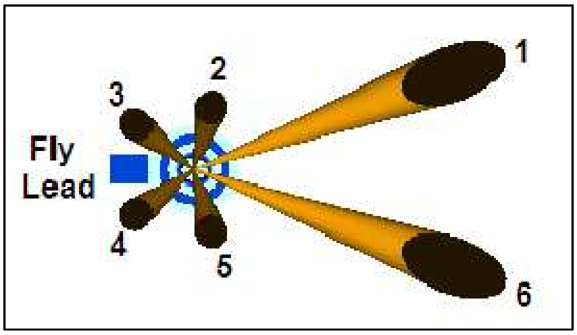

Figure 3.4: Base view of 6 plumes pressure injector

3.2.2 Injection Timing

The Injection timing used for early injection homogeneous mode was set quite early in the intake stroke (SOI 80° CA ATDC) to maximize the time available for evaporation before ignition. This must however be balanced by the need to avoid excessive liquid impingement on in-cylinder surfaces, particularly on the piston crown; therefore 80° CA ATDC was used as a compromise. With initial spray-tip velocities of about 80 m/s however, measured using 150 bar injection pressure, liquid impingement on liner and piston surfaces is difficult to avoid, particularly at low in-cylinder pressures. The injection duration was set to 0.78 ms, corresponding to stoichiometric conditions for the part-load operation point used throughout this study.

3.2.3 Multiple Injections

In order to achieve control over multiple split injections, the AVL ETU was used with an inbuilt function linking two output trigger channels. The spacing between each split injection is ultimately limited by the response time of the particular injector and injector driver system. To be able to perform some form of comparison between single and multiple injections, a split injection strategy was devised to allow stoichiometric operation comprising of three shorter injections to deliver the same amount of fuel as the single injection and maintain the same operating point. In order to keep the time available for evaporation the same before ignition for both injection strategies, the multiple injection strategy was chosen to have an earlier start of injection to accommodate the increased delays in the injection system due to multiple triggering. The first injection was programmed to start at 60° CA ATDC, the second at 70° CA and the third at 80° CA ATDC (*i.e.* dwell time of 10° CA), with pulse durations of 0.25 ms, 0.28 ms and 0.25 ms respectively, such that the last injection pulse starts at the same time in the cycle as the single injection (Figure 6). The decision behind such a strategy is that using a single injection with such an early SOI would result in significant piston impingement due to the high piston position and the increased momentum of the longer single-injection spray plumes. Thus, the case is made that such an injection strategy is one potential method for reducing the levels of direct wall impingement and improving mixture preparation under conditions of homogeneous engine operation.

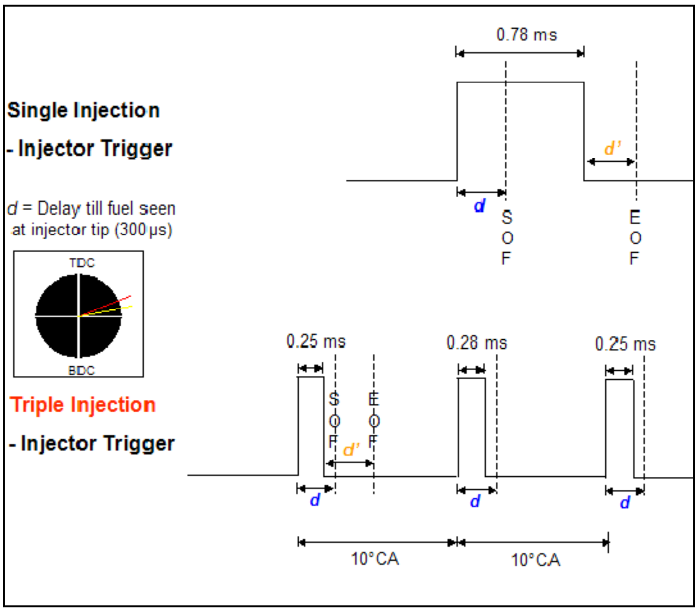

Figure 3.5: Multiple Injections versus Single Injection.

3.3 OPTICAL SYSTEM AND IMAGING PROCESS

An optical system was designed to visualize the intermittent fuel sprays. It consisted of see-through spray chamber, and a high speed camera. This optical set-up was arranged for a light extinction method which was used to measure the overall average droplet size for the entire spray. Figure 3.6 shows a schematic diagram of the optical set-up used in this study. The laser light source is a pulsed copper-vapor laser. The duration of each laser pulse is 10-40 ns and the average energy per pulse is 2 mJ. The spray chamber used was the same as in a previous experiment. The chamber was an aluminum cylinder, 200mm in diameter and about 200mm long, with optical windows on both ends. The chamber provided an environment with high gas pressure at room temperature. One of the end plates was designed to allow the common rail injector to be mounted on the end plate at a 62.5° angle, so that one of the spray plumes from the 125° injection angle multi-hole nozzle was perpendicular to the light beam path. Images were recorded with a high speed 16 mm camera at a framing rate of 5000 frame/sec. The camera was connected to the laser so each frame corresponded to one laser pulse.

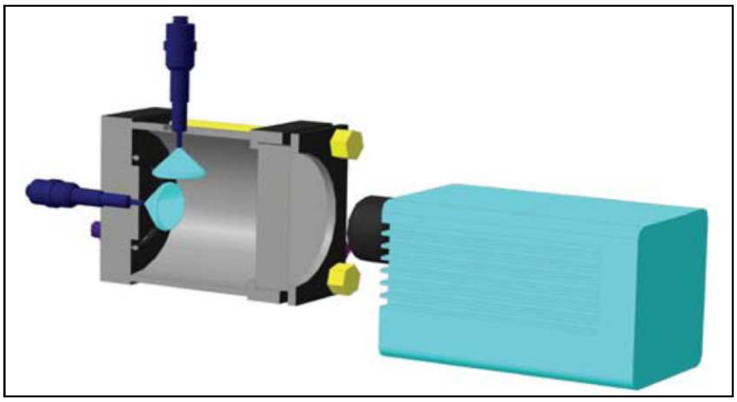

Figure 3.6: Optical system set-up

A digital imaging analysis system was used to process the images taken on the film. The components of the system were on a common base, which fixed the relative position of the film to the image capturing device. The film was loaded on a projector and each frame was back lit by a uniform diffusing light source. The image on the film was snapped by a CCD camera and sent to a frame grabber board inside the host computer. The digital format of the image contained 512´480 pixels with a 8-bit gray scale resolution. The gray level of a pixel was proportional to the transmitted light intensity, so information about light extinction through the spray could be obtained. With this information, we will be able to estimate the overall spray Sauter Mean Diameter (SMD). The spray tip penetration length and spray angle were measured directly from the spray images. The method we used to estimate the overall spray SMD, a light extinction method, has been developed and used to investigate diesel sprays by several researchers [10,11]. Basic assumptions employed included: an axisymmetric spray pattern, a fixed, known spray droplet size distribution function, spherical droplets, constant index of refraction, no multiple scattering when light passes through the spray field, and no light absorbed by the spray droplets. The equation used to calculate the spray overall SMD was written as:

$$D_{32}(all) = \frac{3}{2} \frac{\overline{R}(\overline{\alpha}_{32}\theta_d)\overline{Q}_{ext}(\overline{\alpha}_{32})}{\rho_f} \frac{M_f(all)}{a_p \sum_{j=1}^{p} \left(-\ln \tau_j\right)} \tag{3.1}$$

Where *D*32 (*all*) is the spray overall average SMD, *R* (*a* 32 q*d) 1ext* (*a* 32) is as average corrected extinction coefficient, r*f* is the fuel density, *M f* (*all*) is the total mass of the spray, *ap* is image pixel area, t *j* is the local transmittance of the jth optical path, *P* is the total number of pixels and the summation is done over all pixels contained inside a spray plume.

3.4 DATA ACQUISITION

Both the dynamometer and the engine were equipped with optical encoders. Two encoders were used on the engine, one of the encoders was mounted on the intake camshaft and the other on the crankshaft, both of type Leine-Linde 503, giving 0.2° CA resolution. The cycle marker (TDC) and crank-angle marker or ‘clock’ signals were both connected to an AVL 427 Engine Timing Unit (ETU) to synchronize the various trigger signals to the camera, laser and LABVIEW®1 data acquisition systems. The amplifier’s voltage signal was digitised using a LABVIEW®- based system with a sampling rate equivalent to the clock source of the crankshaft encoder *i.e.* 45 kHz, or once every 22.2 μs (0.2° CA/sample) at 1500 RPM. For each test condition 200 consecutive cycles of data was recorded for four channels, cylinder pressure, a cycle TTL marker, the HFS signal and the RTS signal. To process the large amounts of data generated by such a large test matrix, a processing routine was written in MATLAB to batch process multiple files and perform read/write operations to simultaneously (a) correct the in-cylinder pressure signal with intake BDC pressure as the pegging pressure, (b) take the raw data and apply the necessary corrections using equations 1–3 and (c) calculate the following cycle statistics: mean, standard deviation (or Root Mean Square, RMS), as well as the Coefficient Of Variation, COV = RMS/Mean. Other routines were written as necessary in order to process the corrected data to extract detailed information for particular locations in the cycle, for example the maximum and minimum heat fluxes produced on a cycle-by-cycle basis and the corresponding statistics for these as well as the timings of peak heat flux during the cycle and corresponding statistics.

3.5 IMAGE ACQUISITION

The following section outlines the imaging methodology used to obtain the in cylinder spray imaging results. This was carried out using a high-speed camera with synchronised laser system to obtain crank-degree resolved information of spray formation and development. Using a modified piston which allowed imaging of the full cylinder bore - rather than that usually captured, corresponding to the piston crown window dimensions (~70% bore) - and which is discussed later in this paper, the arrangement also allowed spray impingement on the cylinder liner walls to be confirmed.

3.5.1 High-Speed Camera

The fuel spray was imaged using a high-speed CMOS camera (Photron APX-RS) at a frame rate of 9 kHz under most conditions, corresponding to 1º CA between frames at 1500 RPM. This was possible with an image resolution of 640×480 pixels, giving an optical resolution of ~160 μm per pixel. The camera has an internal memory of 2.15 GB which allowed up to 100 cycles to be captured in a single acquisition run with an imaging sequence of ~68 frames per cycle. It was possible to reduce the number of images acquired per cycle in order to increase the number of consecutively recorded cycles. The limit using one crank-angle degree resolution was found to be ~30–40 images per injection to allow enough detail of the injection and post-injection event to be captured, giving a total of ~150 cycles per acquisition run. The duration of downloading the camera memory was of approximately 5 minutes. Due to memory and processing time considerations it was finally decided to acquire 100 cycles for each test condition. The camera was coupled to a 60 mm Nikon lens with f2.8. The imaging set-up was optimized so that the camera and lens settings would suit imaging of the liquid spray using laser-sheet Mie Scattering.

For the full quartz cylinder liner configuration it was necessary to set the image resolution to a 512×1024 pixel so that piston stroke could be imaged nearly in its entirety and potential piston impingement recorded. To do this the camera frame rate had to be reduced to 5 kHz which at 1500 RPM resulted in a temporal resolution of 1.8° CA per imaged frame.

3.6 STEPS OF ANALYSIS ACCESSING SUBSYSTEMS OF A DAQ DEVICE

3.6.1 Geometry

The design of high pressure chamber and injection was design in 2D by ANSYS - fluent software. Figure 3.6 show the design of high pressure chamber injector. The high pressure chamber was designed with rectangular shape with 60mm x 100mm of dimension. This model was generated to geometry in ANSYS Workbench. The material of model was set to fluid. Figure below show the model consist with 4 main surfaces, such as pressure inlet, pressure outlet, wall and axis. The straight yellow line was set as pressure outlet and the blue line was set as pressure inlet. The axis for half design was set as green line and the wall on red line. The 2D design in half is used to easy and quick process in running of simulation.

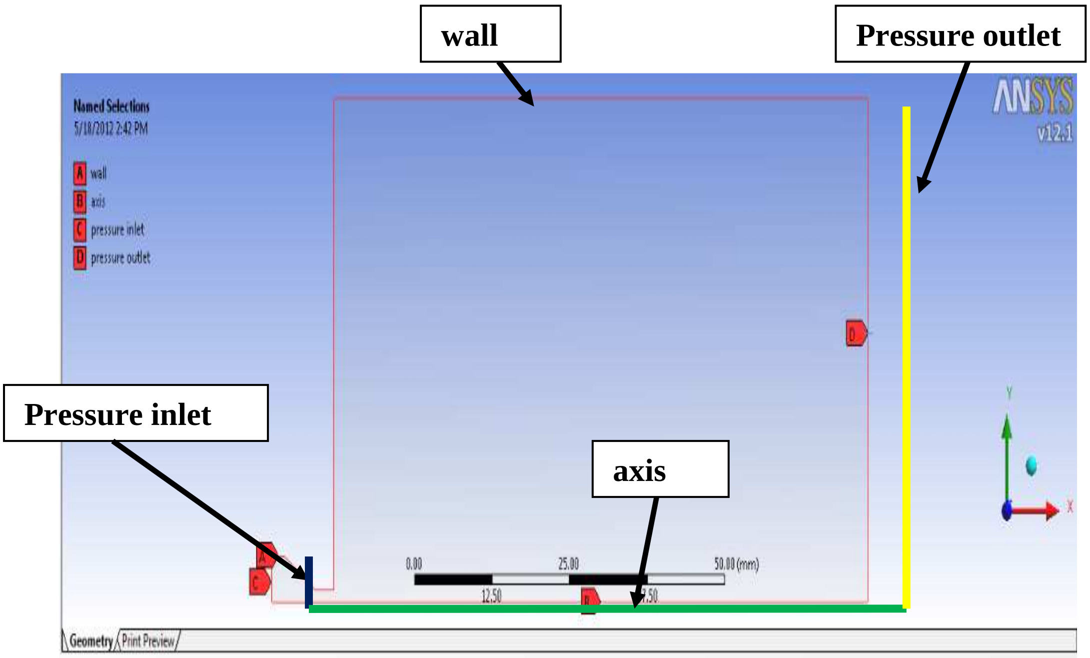

Figure 3.7: Spray model and geometry.

3.6.2 Meshing

The Figure 3.4 shows the mesh of model. The model was meshing with automatic mesh in ANSYS CFD. The enlarged nozzle region is shown below the mesh showing the entire flow domain. Grid sensitivity computations by Li *et al.* (2004) indicated that at least 10 cells across the nozzle orifice were needed for grid independence. This was consistent with the grid recommendations of Abraham (1997).

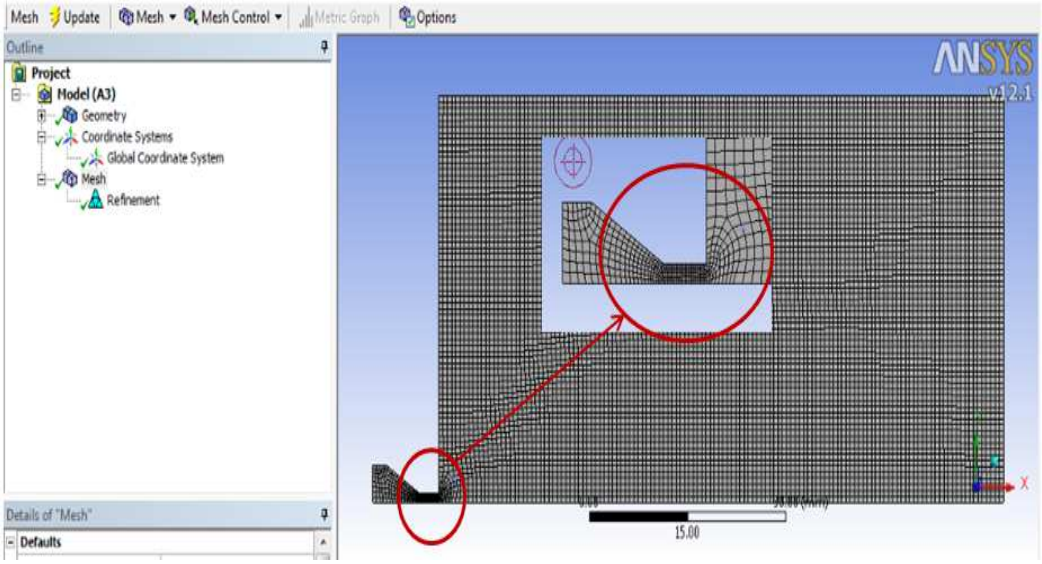

Figure 3.8: Meshing.

3.6.3 Setup

After mesh, Setup was used to launch the appropriate application in ANSYS Fluent. All parameters like load, boundary condition, type of material, and otherwise were insert in this setup.

General

Check the mesh. ANSYS Fluent was performed various checks on the mesh and report the progress in the console. Ensure that the reported minimum volume was a positive number.

Reorder the mesh. To speed up the solution procedure, the mesh should be reordered, which substantially reduce the bandwidth. ANSYS FLUENT was reported the progress in the console.

```
>> Reordering domain using Reverse Cuthill-McKee method:
      zones, cells, faces, done.
   Bandwidth reduction = 32497/697 = 46.62
   Done.

>> Reordering Zones.
   cell zones...done.
   face zones...done.
   Done.
```

Figure 3.9: Reorder report.

Models

Enable heat transfer by enabling the energy equation.

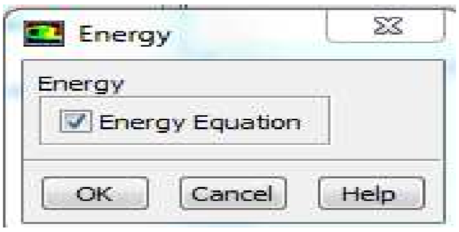

Figure 3.10: Energy dialog box.

Enable the realizable k- ϵturbulence model. Select k-epsilon (2 eqn) in the Model list. Select Realizable in the k-epsilon Model list. The realizable k- ϵmodel gives a more accurate prediction of the spreading rate of both planar and round jets than the standard k- ϵmodel. Retain the default selection of Standard Wall Functions in the Near-Wall Treatment list. Click OK to close the Viscous Model dialog box.

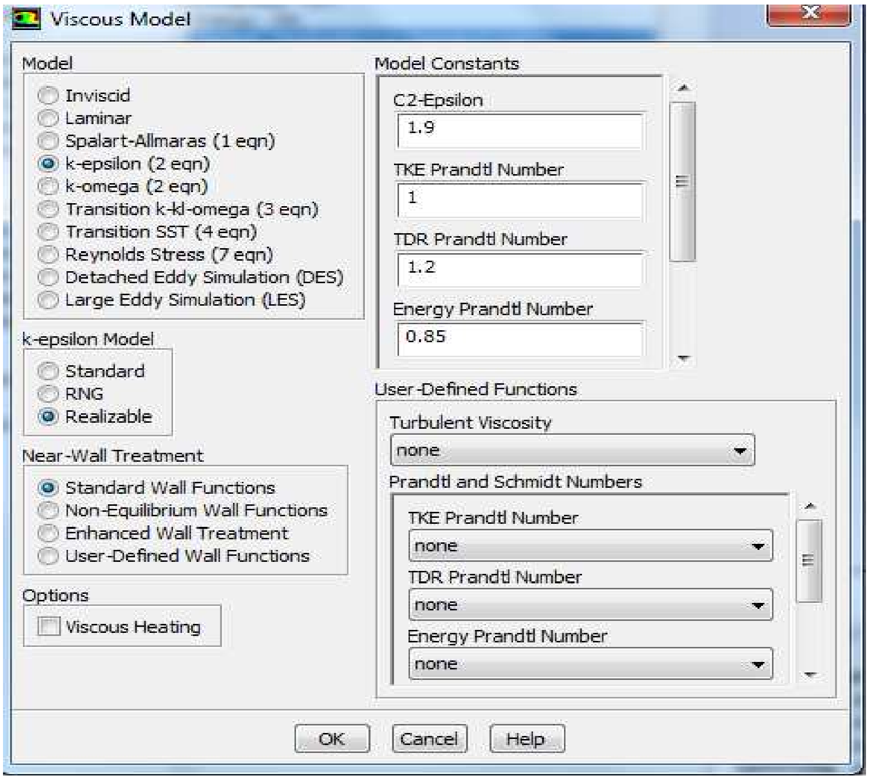

Figure 3.11: Viscous model dialog box.

Enable chemical species transport and reaction. Select Species Transport in the Model list. Select diesel-air from the Mixture Material drop-down list. The Mixture Material list contains the set of chemical mixtures that exist in the ANSYS FLUENT database. The chemical species in the system and their physical and thermodynamic properties were defined by the selection of the mixture material. Click OK to close the Species Model dialog box.

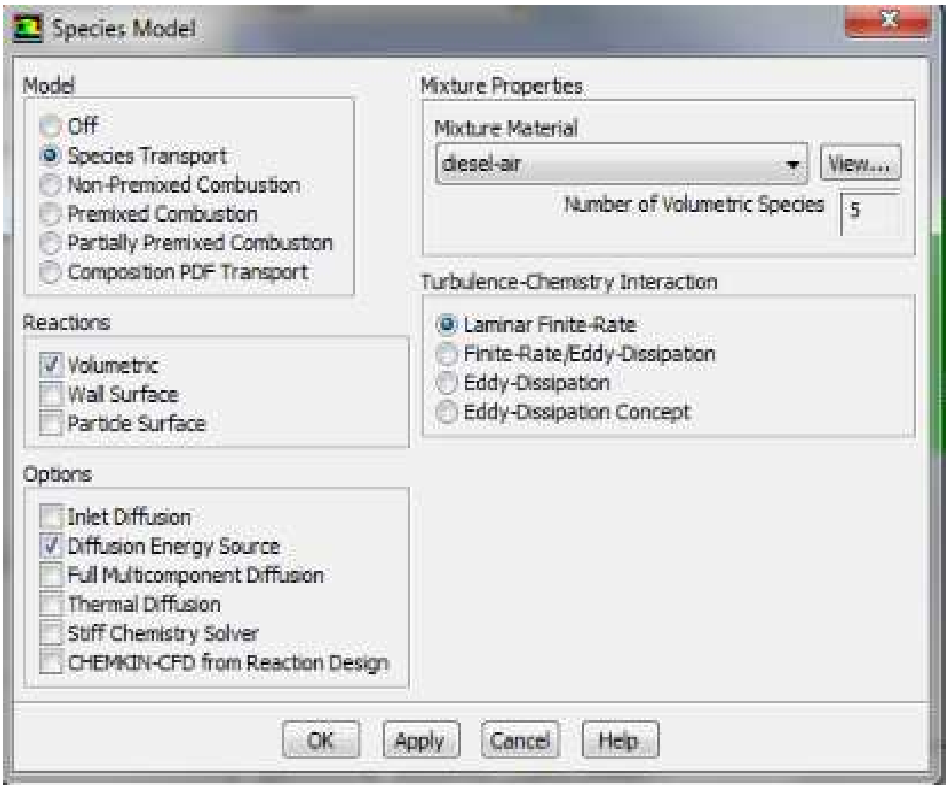

Figure 3.12: Species model dialog box.

Define the discrete phase modeling parameters. Enable Interaction with Continuous Phase in the Interaction group box. This was included the effects of the discrete phase trajectories on the continuous phase. Retain the value of 10 for Number of Continuous Phase Iterations per DPM Iteration. Click the Physical Models tab to enable the physical models. Enable Droplet Collision and Droplet Breakup in the Spray Model group box. Ensure that TAB was enabled in the Breakup Model list. Retain the default value of 0 for y0 and 2 for Breakup Parcels in the Breakup Constants group box.

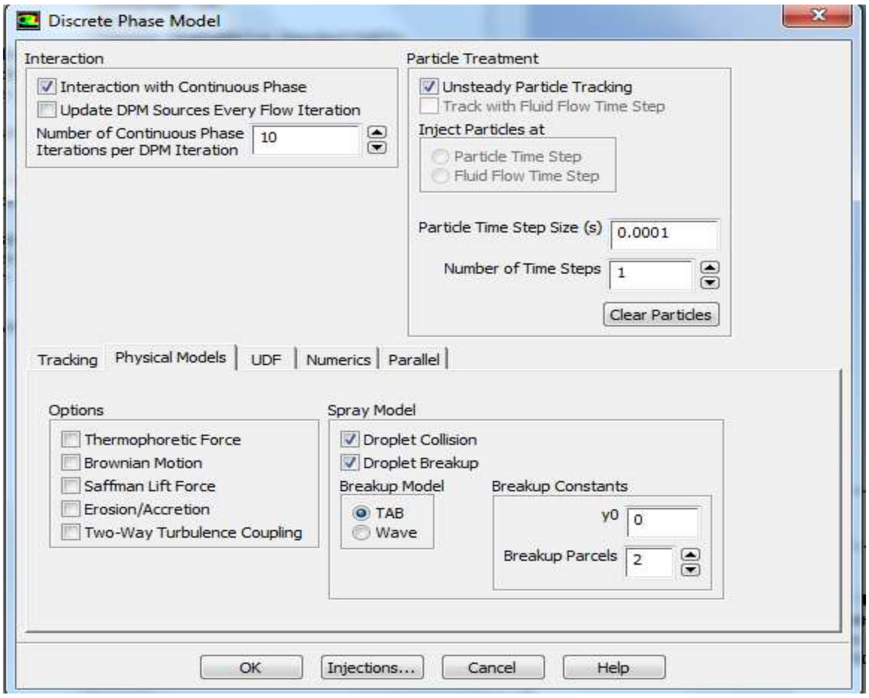

Figure 3.13: Discrete phase model dialog box.

Click the Tracking tab to specify the Tracking Parameters. Retain the default value of 5 for Step Length Factor. Select dynamic-drag from the Drag Law drop-down list in the Drag Parameters group box. The dynamic-drag law was available only when the Droplet Breakup model was used. Retain the Unsteady Particle Tracking option in the Particle Treatment group box. Enter 0.0001 for Particle Time Step Size. Retain the default value of 1 for Number of Time Steps. Click OK to close the Discrete Phase Model dialog box.

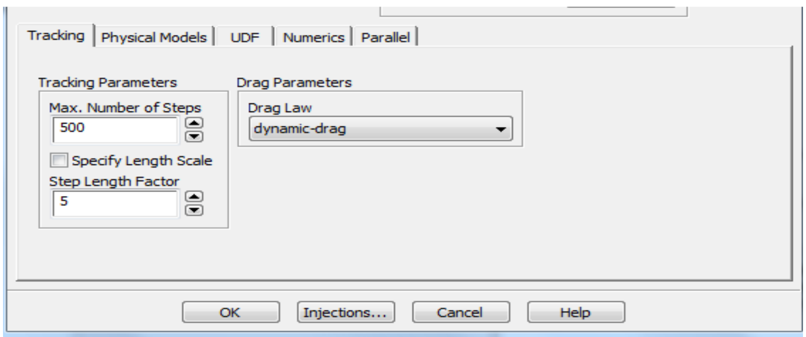

Figure 3.14: Tracking tab dialog box.

Create the spray injection. This step defined the characteristics of the atomizer. Click the Create button to open the Set Injection Properties dialog box. Select single from the Injection Type drop-down list. Select Droplet in the Particle Type group box. Select diesel-liquid from the Material drop-down list. Enter 0, 0, and 0 for X-Velocity, Y-Velocity, and Z-Velocity, respectively, in the Point Properties tab. Enter 263 K for Temperature. Enter 1.785e-3 kg/s for Flow Rate. Retain the default Start Time of 0 s and enter 0.002 s for the Stop Time. For this problem, the injection should begin at $t = 0$ and not stop until long after the time period of interest. A large value for the stop time (e.g., 100 s) ensures that the injection essentially never stops.

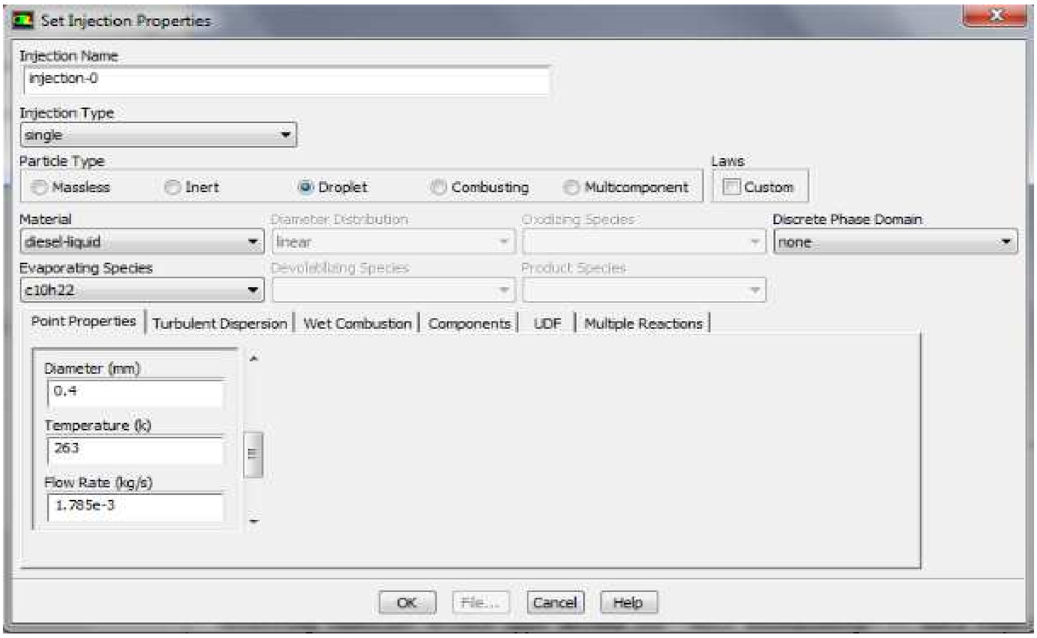

Figure 3.15: Set injection properties dialog box.

Define the turbulent dispersion. Click the Turbulent Dispersion tab. Enable Discrete Random Walk Model and Random Eddy Lifetime in the Stochastic Tracking group box. These models account for the turbulent dispersion of the droplets. Click OK to close the Set Injection Properties dialog box. Click OK in the Information dialog box to enable droplet coalescence. Close the Injection dialog box boundary conditions.

Set the boundary conditions for the inlet. Select Pressure outlet and inlet boundary condition from the Type drop-down list. Enter 40, 70 and 130 kPa in Gauge

Pressure. Select Intensity and Hydraulic Diameter from the Specification Method drop-down list. Enter 2mm for Backflow Hydraulic Diameter and 10% for Backflow Turbulent Intensity. Click the Thermal tab and enter 293 K for Backflow Total Temperature. Click the Species tab and enter 1 for c16h29 in the Species Mass Fractions group box. Click OK to close the Pressure Outlet dialog box.

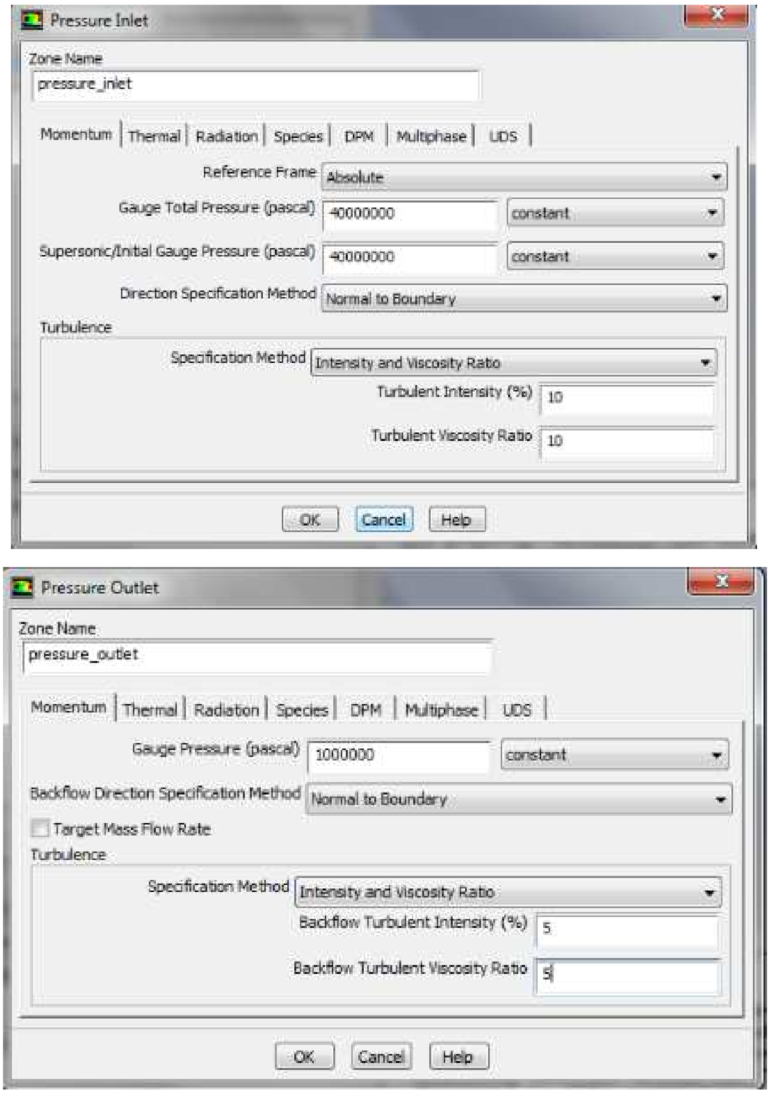

Figure 3.16: Pressure inlet and Outlet dialog box.

Set the boundary conditions for the outer wall. Select Specified Shear in the Shear Condition list. Retain the default values for the remaining parameters. Click OK to close the Wall dialog box.

Figure 3.17: Wall dialog box.

Apply second order upwind at Solution method Select Second Order Upwind from drop-down list for all parameter at Spatial Discretization box except Gradient. Decrease the Under-Relaxation Factor for Discrete Phase Sources to 0.1 at solution control.

Initialize the flow field at Solution Initialization. Select all zones from the Compute from drop-down list. Initialize to initialize the variables. Click Patch button to set c16h29 at 0. At patch dialog box, select X Velocity from Variable list. At Zones to Patch list select Part_1. Enter 0 at Value space. In a similar manner, patch Y Velocity, Z Velocity and c16h29 at 0. Click OK to close the Patch dialog box.

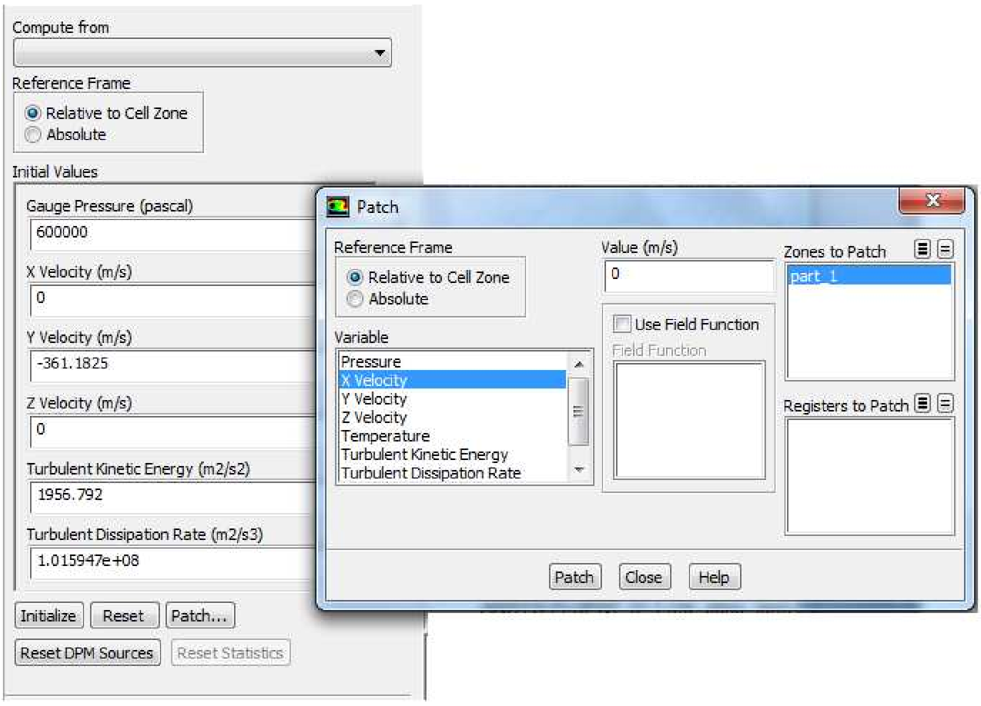

Figure 3.18: Patch dialog box.

Start the calculation by requesting 120 iterations. Enter 120 for Number of Iterations. Click Calculate. The solution converged in approximately 100 iterations.

3.7 PROJECT FLOWCHART & CONCLUSION

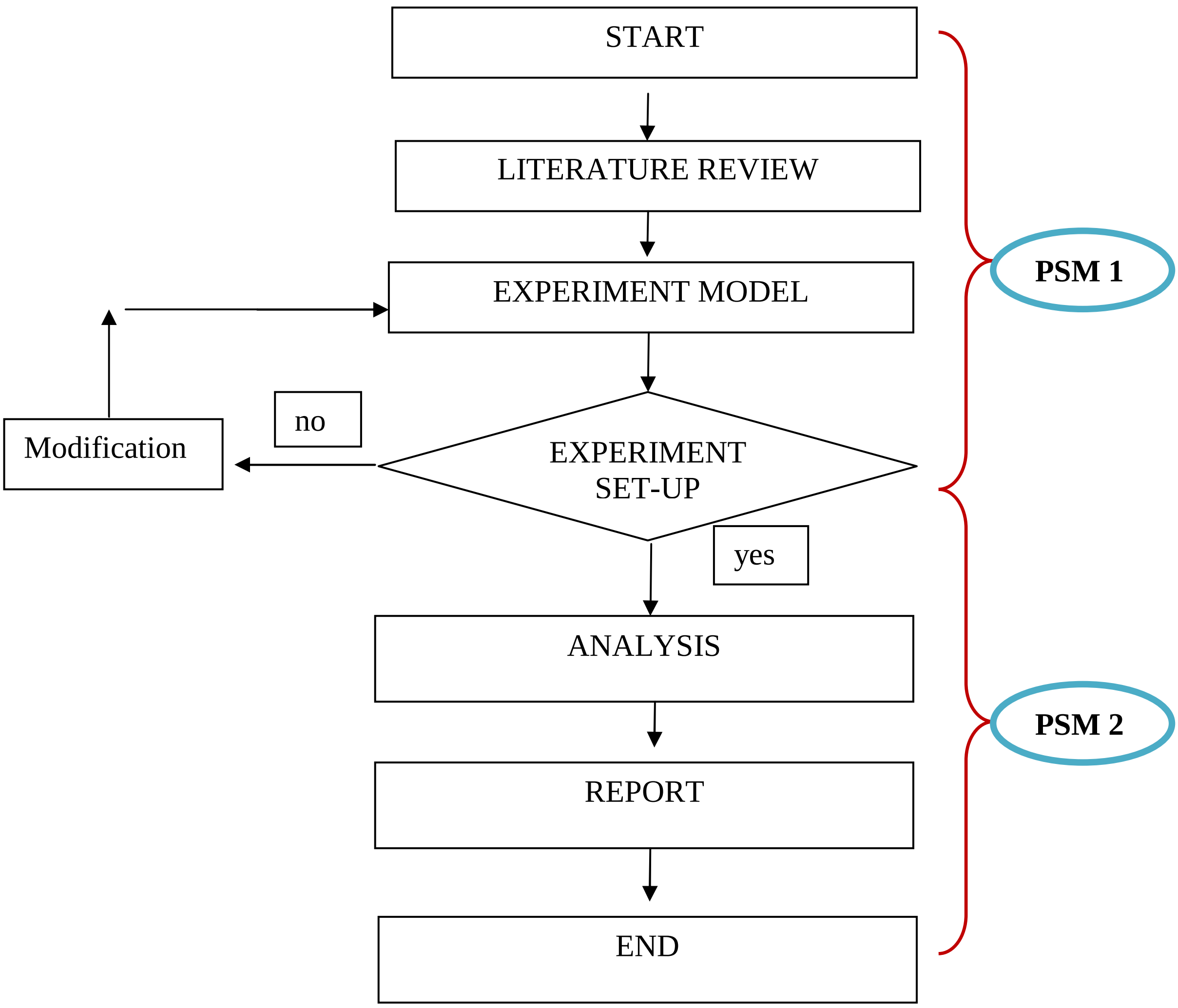

Figure 3.19: Flow chart.

After gathering all relevant information, the project undergoes to experiment model. In this step, from the knowledge gather from the review is use to design the nozzle injector into chamber, and other to complete the system. After completing the experiment model, the system will be running using DAQ software. All result will be record. If something errors or problems on this step, the experiment model will modified until no error or problems.

The next step is analysis result. Result from simulation will be measure and analyze. The result of simulation includes the liquid atomization, and characteristic of different injection pressure and sac nozzle size like spray angle and spray penetration. The different injection pressure use is 10 kPa and 40 kPa, and the sac nozzle sizes are 0.2mm.

All the above information will be made into the report, where all materials from beginning will be. The report writing process will be guided by the UMP final year project report writing. This process also included the preparation of slide for the final presentation. The project ended after the submission of the report and the slide presentation has been presented.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the details of experiment modeling, selection of the injector type and the pressure develop for the type, identification minimum and maximum of the injector pressure.

4.2 SPRAY CHARACTERISTICS

The spray characteristics presented in this project paper are the spray tip penetration, spray cone angle, and overall spray Sauter Mean Diameter (SMD) of each spray image taken during the injection trigger event. The SMD was calculated with a light extinction method and the measurement error for SMD values was estimated to be 8 % - 10 %. The spray tip penetration and spray cone angle were measured directly from the spray model images. The accuracy of measurements of spray tip penetrations and spray angles were ±0.5 mm and ±0.5º respectively. The measurements on the sprays and the data shown in the following figures were from one injection event. The repeatability of spray was examined by inspecting the rate of injection system and needle lift profiles with flow bench measurements and both transient profiles were consistent. Figure 4.1 shows a typical spray pulse and the way we measured the spray angles pulse. The spray angles pulse were obtained by measuring the angle formed by two straight lines draws from the nozzle tip to the outer periphery of the spray. The spray angle pulse is expected to vary during the spray injection interval due to the transient nature of the spray. In order to better understand the change of spray angles pulse in different areas with respect to time, we measured the spray cone angle pulse at two different regions. One is within 10 mm to 20 mm from the nozzle tip and the other is from 20 mm from the nozzle tip to far downstream injector. As a result, we have two kinds of spray angles pulse, one is called a near spray angle pulse and the other one is called a far spray angle pulse.

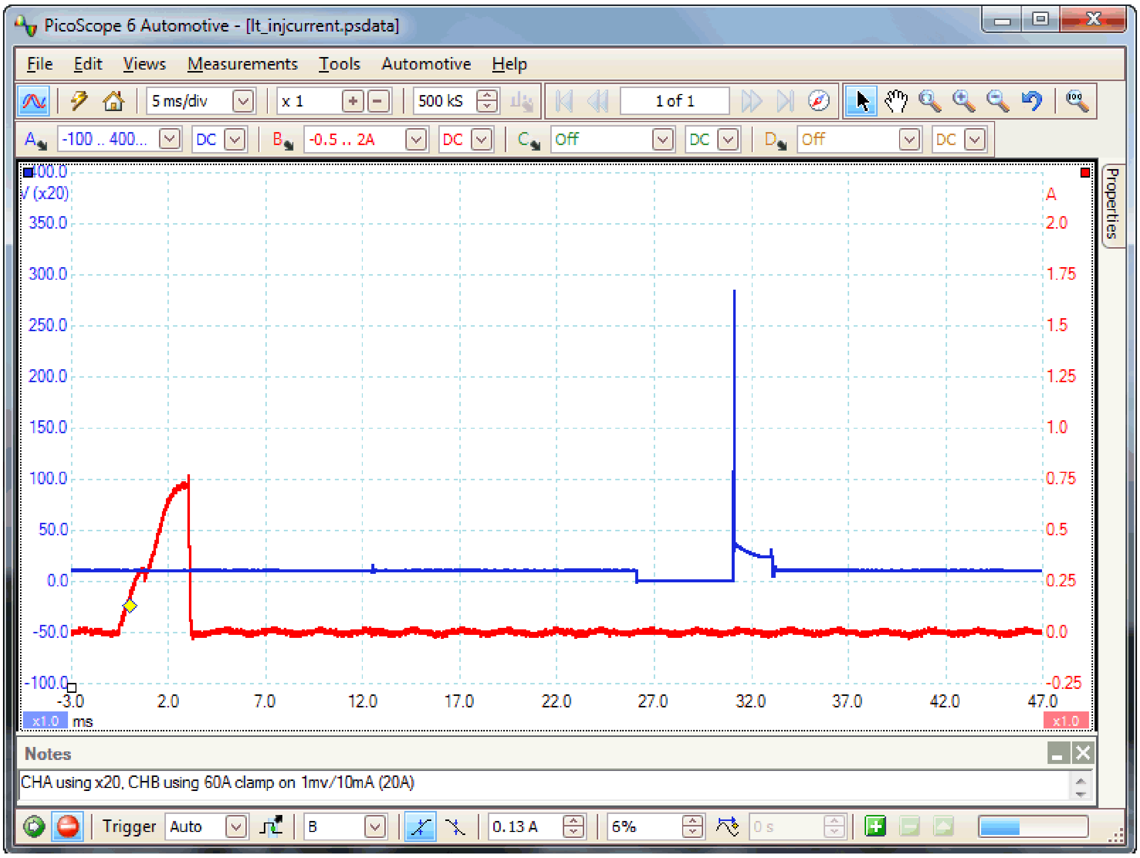

Figure 4.1: Injector spray pulse

4.3 SPRAY PRESSURE PENETRATION

Figure 4.2 shows the spray pressure penetration voltage of a single and multiple injection with different back pressures and different injection pressures time. The solid symbols represent 40 kpa injection pressure cases open. The open marks represent 10 kpa injection pressure cases open. The sprays pressure with lower back pressure and higher injection pressure penetrated faster than the sprays with higher back pressure and lower injection pressure did. A spray with a larger pressure difference between injection pressure and back pressure penetrates faster than a Figure 4.3. Toshiba needle lift and rate of injection profiles spray pressure with a smaller pressure difference does. The pressure difference between the injection pressure pulse and the back pressure pulse determines how fast the spray can penetrate. Higher back pressures pulse made the ambient density higher in our constant volume chamber. The spray tip penetration was less sensitive to the change of back pressure pulse under higher injection pressure (40 kpa) than it was under lower injection pressure (10 kpa).

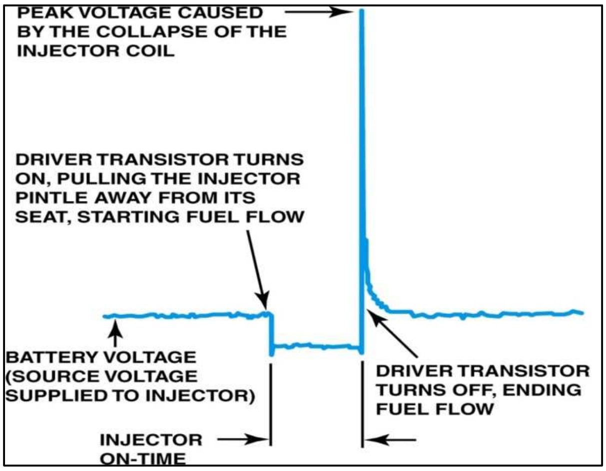

Figure 4.2: Injector voltage pulse

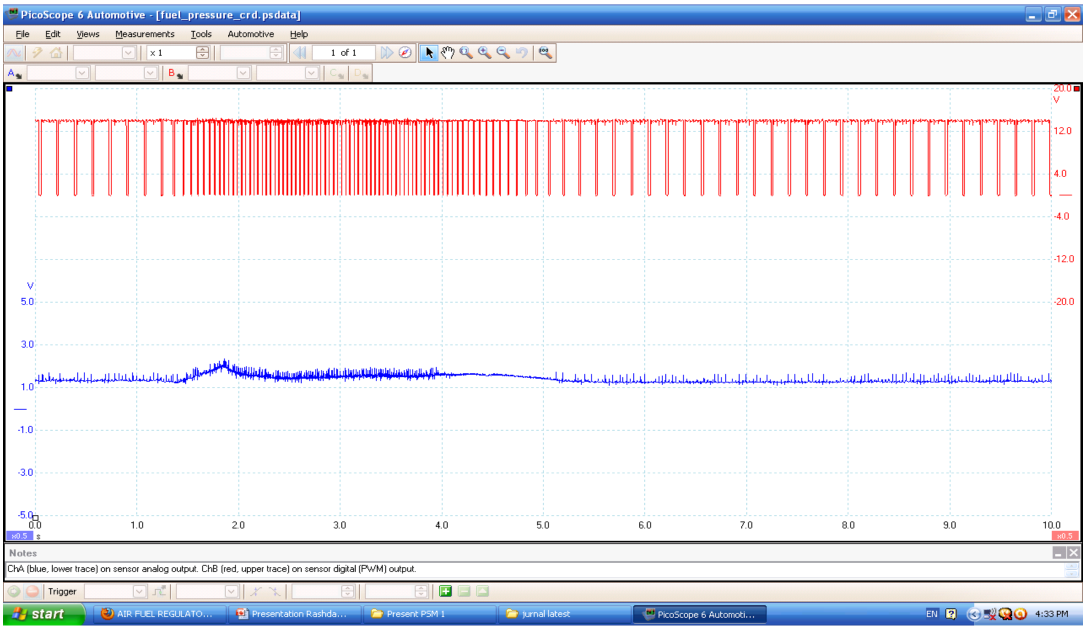

Figure 4.3: Injector pulse

```
% Create an analog input object to communicate with the
% data acquisition device
ai = analoginput ('winsound');
addchannel(ai, 1);

% Configure the object to acquire 2 seconds of data.
Fs = 16000;
duration = 2;
set(ai, 'SampleRate', Fs);
set(ai, 'SamplesPerTrigger', duration*Fs);

% Start the acquisition and retrieve the data.
start(ai)
data = getdata(ai);

% Determine the frequency components of the data
xfft = abs(fft(data));
mag = 20*log10(xfft);
mag = mag(1:end/2);
plot(mag);

% Clean up.
delete(ai);
clear ai

grid on
xlim([0 8000]);
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
```

Figure 4.4: Mathlab coding

4.4 DAQ SOFTWARE SYSTEM CODING

The spray angle is expected to vary during the spray injection interval due to the transient nature of the spray. Figures 4.5 show the mathlab coding for daq software to trigger two kinds of spray angles pulse for single injection sprays with different back pressures at high injection pressure (40 kpa). The higher back pressure cases show a larger near spray angle pulse. The near spray angle pulse decreased during the injection interval, with a change of about 8º. After the end of injection, the near spray angle pulse increased for all back pressures and the increases were larger than 8º the change of the far spray angle for each different back pressure spray was less than 50 over the injection time interval. The far spray angles pulse have the same trend as the near spray angles during the early part of injection, but they did not increase after the end of injection trigger. The effects of back pressure pulse on the spray angle for high injection pressure sprays. The near spray angle pulse values changed, during the injection duration (1.93msec), by about 9º for back pressures from 0.87 MPa to 1.65 MPa. The results of the near spray angle pulse measurements suggest an air entrainment effect which confined the spray and made the spray angle smaller in the near nozzle tip region.

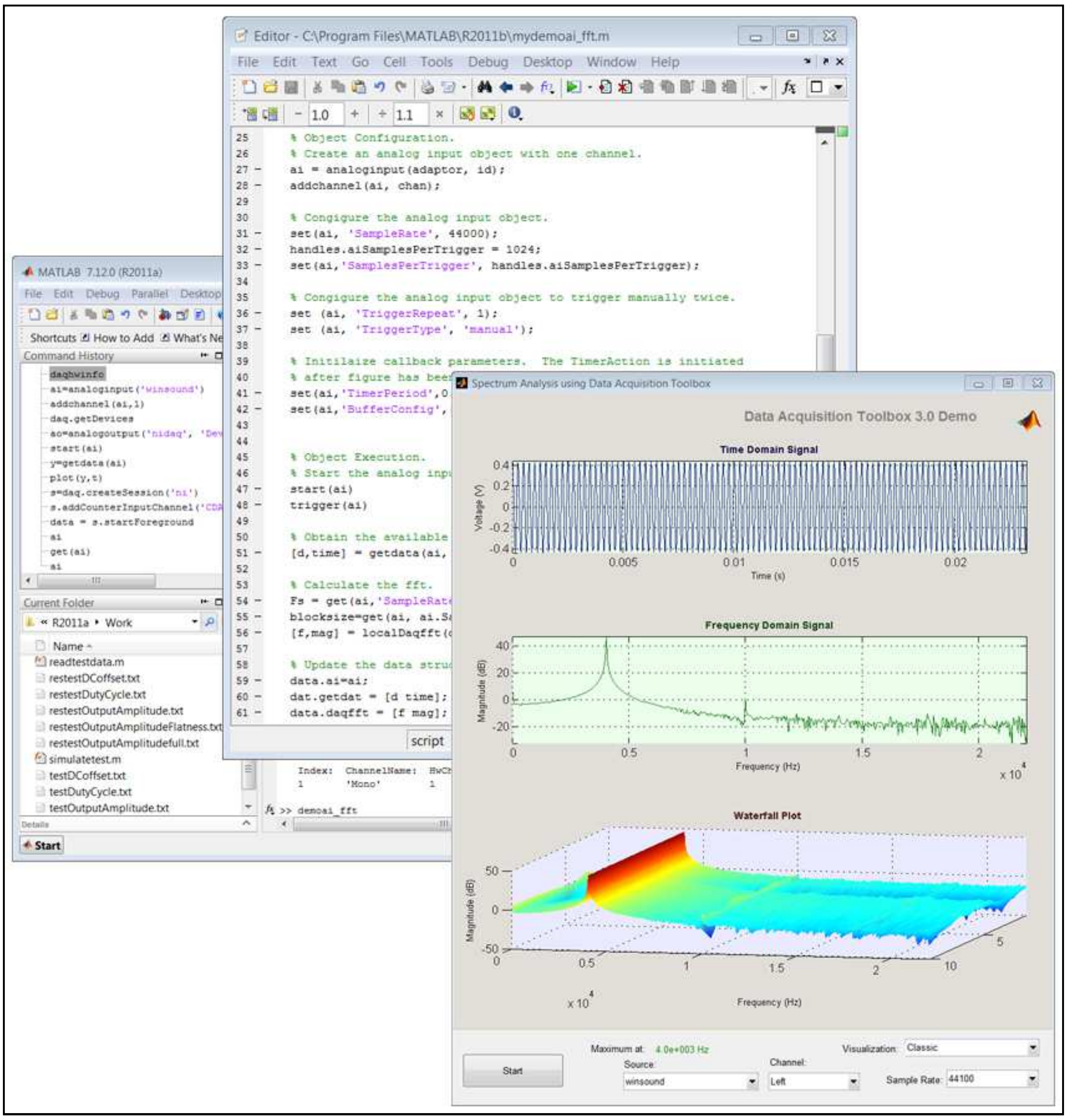

Figure 4.5: Data acquisition toolbox software

4.5 SPRAY TRIGGERING PRESSURE

Figure 4.5 presents the dwell effect on the double injection triggering spray SMD. The SMD increased from the start of injection and started to decrease before the end of the first split injection interval. It decreased further during the time between two split injections. The longer the dwell between two split trigger injections, the smaller the SMD of the spray pulse was before the second injection started the trigger. After the start of the second split injection trigger, the SMD increased until the end of the second split injection. Again, it decreased after the end of second split injection trigger. We compared the SMD's of a single injection trigger to those of two double injections and one triple triggering injection. All these cases were under the same injection pressure pulse and similar back pressure and have similar fuel deliveries. The dwells for double injections pulse and triple injections were the same (9º crank angle @ 0.63 msec at 1600 RPM). The SMD's for the single injection spray pulse and the double injections sprays have the same trend; they increased during the injection interval. A longer injection trigger the interval produced larger SMDs. After the end of injection triggering, the SMD's became smaller.

4.6 CONCLUSION

The develop of high pressure spray triggering modeling and analysis of injection system has been presented. The analysis was performed to determine the best maximum pressure to use in DAQ. The experiment model was done to get the mode shapes. The maximum and minimum of the injector was successfully performed and the pressure of the injector can press 40 kpa in maximum pressure. The summary of the finding will be present in the next chapter.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter summarized the conclusion and recommendations for the overall objective of the project based on Data Acquisition Toolbox software and test analysis of spray characteristic.

5.2 CONCLUSION

The objectives of this work were to study the effects of multiple triggering injections on spray pressure. From the data obtained in this study, we make the following summary:
Under high injection pressure (40 kpa), the back pressure high (ambient density) has less effect on the spray tip penetration than it has on the spray tip penetration length of low injection pressure (10 kpa).

i For multiple injection pressure sprays, the second or third injections penetrate faster than the first split spray. The shorter the time spacing between the two split sprays, the faster the following split spray can penetrate.

ii Higher back pressure (ambient density) causes the sprays to have larger spray angles.

iii Under high injection pressure (40 kpa), the back pressure (ambient density) has less effect on the far spray angle than it has on the high spray angle of low injection pressure (10 kpa) sprays.

iv Spray angles measured within different regions (near and far spray angles) provide more information on the spray transient characteristics than a single multiple spray angle does.

v The near spray angles decreased from the start of injection to the end of throttle injection, and after the end of injection the near spray angle increased.

vi Multiple injections produced more variation in near spray angle during an entire throttle injection event and they generated larger far spray angles than a single injection. Specifically, the near spray angles for the multiple injections decreased within every split injection interval and increased during each time spacing between pulse injection intervals and also after the end of injection pulse. This may be good for the fuel spray and ambient air mixing, indicating the reason why high injection pressure coupled with selected multiple injections strategies can reduce the high emissions and particulate for engine combustion.

vii During an throttle injection interval, the overall spray SMD increased. After or between injection intervals, the overall spray SMD decreased the spray.

5.3 RECOMMENDATION

There is still scope for further study to improve the maximum and minimum pressure. The recommendations are as follows:

i When using this simulator, creating and changing an experiment is easy, and the correspondence between the actual parts of the model is clear because the simulator is a block element assembly the model.

ii Analytical results corresponded well to the actual measurements. The simulator can be used to reduce drastically the number of experiments and the model, this is effective for speeding up development the process.

iii Flow rate has been improved, especially at high engine speeds running, by improving the outlet check valve and the cam profile check.

iv The fuel piping system for a V6 cylinder engine was optimized, the pressure pulsation and the deviation of injection rate were decreased and increased, and in addition, the design value of the common rail injector volume was clarified.

v Using this simulator, we developed an excellent model single plunger pump and fuel piping injector system that has a large flow rate and small pressure pulsation.

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APPENDIX A

Project Activities	Week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.Meeting and briefing with supervisor	■	■													
2.Do literature review	■	■	■	■	■	■	■								
3. Gathering all relevant information		■	■	■	■	■	■	■							
4.Make injector sketch in 2D and 3D					■	■	■	■							
5.Search suitable parameter								■	■						
6. Design the nozzle injector and chamber in 2D										■	■				
7.Prepare a report												■	■		
8.Prepare for presentation													■		
9.Presentation														■	

Figure A.1: Gantt chart for PSM 1

No	Project Activities	Week														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.	Briefing with supervisor for FYP 2	■														
2.	Discuss the suitable parameter for simulation		■	■	■	■	■									
3.	Find more journal about simulation ANSYS fluent				■	■	■	■	■	■	■					
4.	Modify and rebuild the spray model				■	■	■	■	■	■						
5.	Meshing and simulation the model								■	■	■	■				
6.	Analyze the results										■	■	■			
7.	Collect the data and conclusion											■	■	■		
8.	Prepare a full report										■	■	■	■		
9.	Prepare presentation slide													■		
10.	Presentation for FYP 2														■	
11.	Submit the thesis														■	

Figure A.2: Gantt chart for PSM 2

APPENDIX B

Figure 6.1: Set-up the common rail

Figure 6.2: Test the injector maximum pressure

Figure 6.3: Test the injector pressure

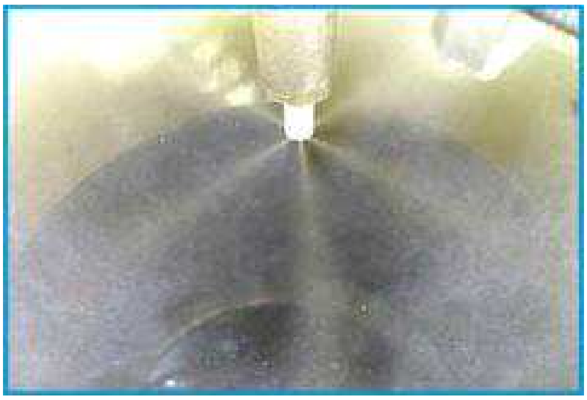

Figure 6.4: Test the injector characteristic

Figure 6.5: Test high pressure of the injector

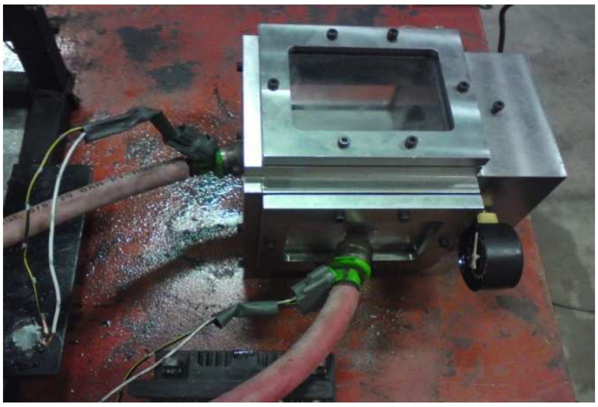

Figure 6.6: Set-up the chamber

Figure 6.7: Set the fuel pump pressure with fuel regulator

Figure 6.8: Chambering test