DEVELOPMENT OF A FUEL INJECTOR TRAINING KIT

BY

GUWOR-NIKI WARE-EBI HARRY

17/ENG06/038

SUBMITTED TO

DEPARTMENT OF MECHANICAL AND MECHATRONICS ENGINEERING

COLLEGE OF ENGINEERING

AFE BABALOLA UNIVERSITY ADO-EKITI, EKITI STATE, NIGERIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A BACHELOR OF ENGINEERING (B.ENG.) DEGREE IN MECHANICAL ENGINEERING

JUNE, 2022.

DECLARATION

I hereby declare that this project has been carried out by me, **GUWOR-NIKI Ware-Ebi Harry** with the matriculation number 17/ENG06/038 and submitted to the Department of Mechanical and Mechatronics Engineering, Afe Babalola University, Ado-Ekiti in partial fulfillment of the requirements for the award of Bachelor of Engineering (B.Eng.) degree in Mechanical Engineering.

Guwor-Niki Ware-Ebi Harry **Signature and Date**

Student

CERTIFICATION

This is to certify that this work titled Development of Fuel Injector Training Kit was carried out by **Guwor-Niki, Ware-Ebi Harry** with student matriculation number 17/ENG06/038 with the report prepared, and presented to the Department of Mechanical and Mechatronics Engineering, Afe Babalola University, Ado-Ekiti, Ekiti State, Nigeria in partial fulfillment of the requirements for award of Bachelor of Engineering (B.Eng.) Degree in Mechanical Engineering.

Engr. I. D. Uchegbu **Signature and Date**

Project Supervisor

Engr. Prof. A. O. M. Adeoye **Signature and Date**

Head of Department

Mechanical and Mechatronics Engineering

DEDICATION

This project is dedicated to the Almighty God for His continuous grace and mercies in my life during my five years in Afe Babalola University Ado Ekiti.

ACKNOWLEDGEMENTS

Firstly, I would like to thank God Almighty for giving me this great opportunity to learn and increase in knowledge and grace. My profound gratitude goes to the Provost of the college of Engineering, Engr. Prof. J. O. Dada and the Head of Department, Mechanical and Mechatronics Engineering, Engr. Prof. O. A. M. Adeoye.

Very special appreciation also goes to my supervisor, Engr. I. D. Uchegbu. You have labored day and night to ensure that my work is the best. Thank you. I am forever grateful. I want to also specially thank all academic and non-academic members of staff of the department of Mechanical and Mechatronics Engineering of Afe Babalola University Ado-Ekiti (ABUAD) for your incredible competence, care and commitment. God bless you all.

I would also like to say a big thank you to my family for their love and my friends for their support, time and sacrifices; enough words do not exist to quantify my appreciation. God bless you all.

ABSTRACT

Due to the rising need for improved learning aids, as a result of the challenges of inadequate facilities for teaching, studies must forge on to explore and develop means in which engineering education can be delivered efficiently. As a part of the world energy system, fossil fuels play a huge role and will continue to for the foreseeable future, and as a result, the study of internal combustion engines (ICEs) is highly imperative in the field of mechanical engineering.

This work develops a fuel injector training kit that demonstrates the injection of fuel into the combustion chamber according to a firing order, and it will be used to enhance the study of ICEs in the Afe Babalola University Ado-Ekiti (ABUAD) Department of Mechanical and Mechatronics Engineering.

This kit is designed using Autodesk Solid works and a stainless steel fuel rail was chosen due to its high resistance to chemical corrosion. An Arduino Uno Microcontroller was connected to a flow meter to monitor the flow rate of the developed fuel injector training kit.

A volume of 2L of fuel was made available for this experiment; a volume of 0.4316L was injected across 10 experiments carried out with increasing spit time. From the experiment, the corresponding flow rates were derived, which was used in calculating the volume injected.

This work has been able to lay a foundation for studies on fuel injection using an electronic control unit module. It has also laid a foundation for research work by developing a fuel injector training kit for demonstration and experimental purposes.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

Fuel injection systems have a large impact on the combustion process, and hence play an important role in lowering engine fuel consumption (Latarche, 2021). The injection system's job is to provide fuel to each cylinder in a timely manner depending on the engine's revolution per minute. The electronically controlled injection technology is a method of controlling the quantity, timing, and law of fuel injection in order to achieve a well-organized combustion process and optimum performance in terms of fuel economy, power, and emissions under a variety of operating situations. The Mechanical Engineering practice and profession will be pivotal in the effort to promulgate the study of internal combustion engine systems in higher institutions by creating cost-effective fuel injector training kits for demonstration of the working process of fuel injectors.

1.1 Background to the Study

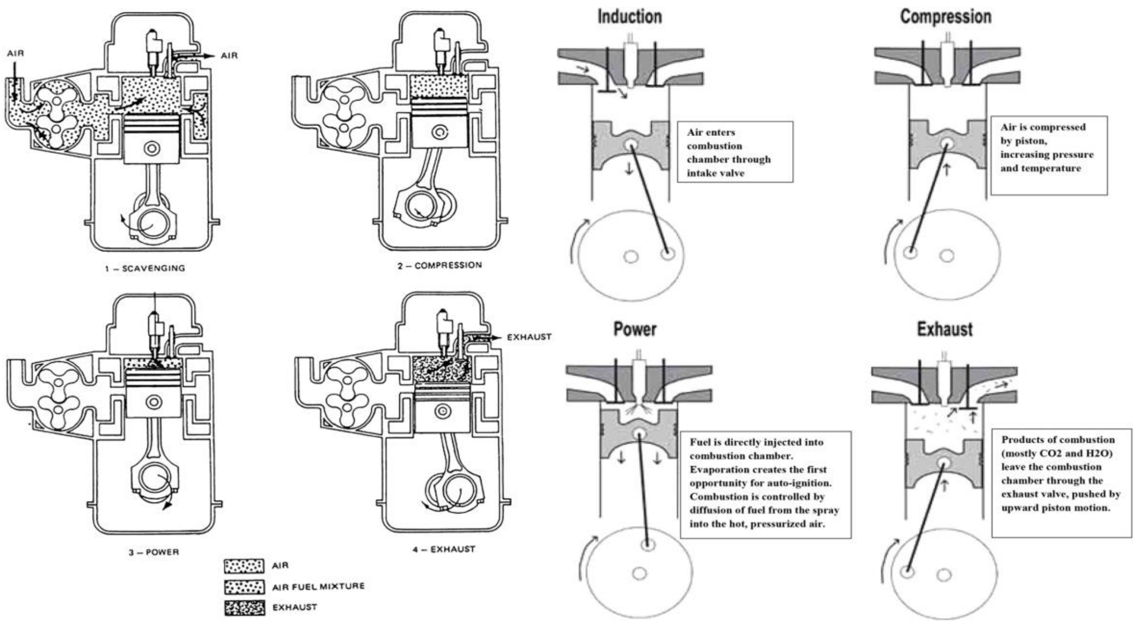
Internal combustion engines (ICEs) currently power 99.8% of global transportation, while petroleum-based liquid fuels provide 95% of transportation energy (Leach et al., 2020). Fossil fuels will be a part of the energy system for the foreseeable future. With this in mind, it is thus imperative on the engineering profession to develop systems that aid the teaching processes of internal combustion engines (Foster & Elzinga, 2013).

This work develops a fuel injector training kit that demonstrates the injection of fuel into the combustion chamber. Fuel injection systems are commonly used in Compression Ignition Engines (CIEs). For Spark Ignition Engines (SIEs), instead of injecting gasoline directly into the cylinder, the fuel and air are expected to mix in the carburetor and enter the combustion chamber. Notwithstanding, due to several major limitations of carburetion, the gasoline injection technology in SIEs has recently gained popularity. However, for the purpose of this study, CIEs would be mainly considered.

In operation, the fuel injector is timed to feed fuel at high pressure in an atomized form into the combustion chamber. The two-stroke and four-stroke architectures are the two main methods to CIEs. Considering the engine speed is limited to low revolutions per minute (RPM), very large CI engines (ships and locomotives in particular) tend to be two-stroke (Ciatti, 2015). Because air is fed into the cylinder via ports in the cylinder liner, two-stroke CI engines require an external source of air, such as a turbocharger or supercharger. The configuration can be seen in Figure 1.1a.

When the piston dips below them in the power stroke, the intake air apertures in the cylinder liner open, allowing pressurized, cool air into the cylinder. As the piston approaches Bottom Dead Center (BDC) in the power stroke, the cylinder head's exhaust valves open, allowing hot exhaust to exit the cylinder through the top-mounted exhaust valves. The intake ports in the cylinder liner open as the piston approaches BDC, enabling fresh air into the cylinder and forcing the last of the exhaust out the top exhaust valves. Until the exhaust valves close, the scavenging action continues (Ciatti, 2015). Because the intake ports are still open, new air from the blower continues to flow into the cylinder until the piston passes over the top of the intake ports on the liner, trapping the air inside. The air is then heated and pressed until the piston is close to Top Dead Center (TDC). The fuel injector sprays a high-pressure stream of fuel into the hot, compressed air, which causes auto-ignition and combustion. The cycle then repeats itself. The schematic of a four-stroke compression engine can be seen in Figure 1.1b.

In the four stroke system, during the intake stroke, TDC to BDC, air from the intake manifold is inducted into the cylinder, the intake valves close, and the piston advances back toward TDC while compressing the air to elevated temperature and pressure.



(a) **(b)**

Figure 1.1a-b: Schematic of Two-Stroke (a) and Four-Stroke (b) Compression Ignition Engine

(Ciatti, 2015)

Finally, in the exhaust stroke, the exhaust valves open and the piston returns to TDC, forcing the exhaust combustion products out. From here, the cycle repeats again. With the above processes, it becomes evident that fuel injection is a fairly complex process. Thus, the fuel injector training kit will be incorporated with an electronic control unit consisting of a microcontroller to continuously monitor the injection speed and a flow meter to measure the flow rate accordingly.

1.2 Statement of the Problem

Since most conventional fuel injection demonstration systems are often mechanized, they are plagued with various challenges including the unavailability of an electronic control unit to which the rate of injection is monitored across varying time intervals. Automated variation in injection rate helps to accurately determine the amount of fuel injected in a stipulated time and also to study the corresponding flow rates. Another considerable challenge that results from the lack of a control unit is inability to study the fuel economy resulting from varied injection rates. Retarding the fuel injection timing increases the fuel economy penalty (Fayad, 2019).

1.3 Aim and Objectives of the Study

This aim of this study is to develop a cost effective fuel injector training kit that can be used for student training in automobile workshops. The specific objectives of this project are to:

i. develop an injection system that can be used for studying effects of acceleration on flow rate and fuel economy;
ii. incorporate the electronic control unit and
iii. evaluate the developed fuel injector training kit.

1.4 Justification of the Study

Student training is a very important phase of learning in engineering. It is pivotal to the development of students and is a major requirement in the fulfillment of a B.Eng. degree. In Nigeria, one of the major issues facing the engineering education is inadequate facility for teaching. According to a survey by Oloyede *et* al., 95% and 90% of students and lecturers respectively, who participated in the questionnaire complained about the level of available equipment in their engineering departments (Oloyede et al., 2018). Hence, the development of this system will help improve the available learning apparatuses in automobile workshops in universities and other stations of learning.

Since combustion engines are a major area of mechanical engineering at undergraduate level, the system becomes desirable in the demonstration of fuel injection into the combustion chamber with the use of a common rail system. The control unit can be used to vary the rate of injection, and the flow meter to measure the flow rate according to a varied acceleration.

1.5 Scope of the Study

This research is limited to development of a fuel injector training kit for student’s training in automobile workshops. The system is incorporated with an electronic control unit that is limited to data inputting, acquisition and display.

CHAPTER TWO

LITERATURE REVIEW

Fuel is delivered at very high pressure to the injection system to ensure that the fuel injection rate is sufficient (Latarche, 2021). This ensures that the fuel is well atomized to distribute the exact required amount to the combustion chamber. Atomization in fuel injection is a process in which fuel at high pressure passes through a nozzle opening and breaks into a misted spray. Going into the combustion chamber, the mist then combines with air before being vaporized into a state suitable for combustion. For a satisfactory spray formation and air–fuel combination, injection pressures should be above 1000–1200 bar (Latarche, 2021). Also, in terms of fuel economy, pollution, and the ability to tolerate inferior fuel, high injection pressures at full load are helpful. For car engines, modern injection systems now produce full-load peak pressures of 1,000-2,050 bar, and for commercial vehicles, 1,000-2,200 bar (Grieshabe & Stein, 2014). However, injection pressure should be kept at appropriate levels to avoid engine over fueling, which can result in poor fuel economy. Increasing the injection pressure results in increase in the structural noise due to growing the pressure rise speed (Shatrov et al., 2015).

According to Latarche, injection has variances, reflecting the fact that, despite significant investment in study into its mechanism, the complexity of how combustion evolves after ignition is still mostly empirical (Latarche, 2021). Notwithstanding, some of the essentials are as follows:

i. At least portion of the fuel injected is finely atomized enough to start combustion. It is not possible to ignite a droplet of fuel until it has attained the temperature required for spontaneous ignition and only a small number of fine droplets are required.

ii. To burn, the fuel must be mixed with the air. Because most of the air in a roughly cylindrical region is near the perimeter, most of the fuel must penetrate there, and large droplets make this simpler; thus, the use of broad core angles and many spray holes.

iii. Fuel must never reach the liner walls, unless it will pollute the lubricating oil. The walls of the chamber offer a safe target at which spray can be directed, which is an advantage of combustion areas formed in piston crowns. The design of this combustion area allows for air to be drawn above the piston for combustion as the piston descends.

iv. The injection period should be short and must come to a close quickly. Dribble and secondary injection are common sources of smoke, as well as lubricating oil that has been diluted with fuel or has become clogged with insoluble particles. Dribble is a condition caused by faulty seating faces or sluggish closure, in which fuel continues to come from the nozzle at pressures too low to atomize effectively. Secondary injection occurs when the pressure wave induced by the conclusion of the primary injection is cast back to the pump and then back to the injector, reaching it with enough pressure to reopen the injector at a relatively late stage in the combustion process (Latarche, 2021).

2.1 Basic Fuel Injection System

Fuel injection systems can be divided into two basic component groups.

i. Low-pressure side and;

ii. High-pressure side.

2.1.1 Low-pressure side components

With the aid of these parts, fuel is drawn from the fuel taken, safely to the fuel injection system. They are called low-pressure side components because the pressure on this side of the fuel system is minimal. The low-pressure pump supplies the pressure. They are: low-pressure pump, fuel tank, fuel supply lines, and fuel filter.

i. Fuel Tank: The fuel is stored in the fuel tank. The fuel tank is often made of stainless steel, a material that cannot corrode due to the corrosive nature of the fuel. To prevent fire due to ignition of fuel, the fuel tank is kept far from the engine.

ii. Fuel lines: Often flexible and fire-retardant, these fuel lines are connected from the low-pressure pump and they carry fuel from the tank to the high-pressure pump.
iii. Low-pressure pump: The low-pressure pump draws fuel from the tank and supplies it to the high-pressure pump.
iv. Fuel filter: It serves as a protection for the fuel pump against impurities. It guides the pick up tube of the fuel pump. It prevents dirty fuel from entering the fuel pump, which can cause eventual failure of the pump.

2.1.2 High-pressure side components

These components generate high-pressures, as well as measure and distribute fuel to the combustion chamber. They are: high-pressure pump (also known as supply pump), fuel injector and injection nozzle.

i. High-pressure pump: This is considered as the heart of the fuel injection system. Its primary purpose is to provide the correct amount of fuel to the injector at a high pressure.
ii. Fuel injector: The rate of combustion is depends heavily on the fuel injector. The injector atomizes the fuel into fine droplets, increasing their surface area and assisting with subsequent combustion mixing. The needle valve, compression spring, nozzle, and injector body are all part of it.
iii. Fuel injection nozzle: The nozzle is the part of the injector, having needle like holes, through which fuel is injected into the combustion chamber in fine-misted sprays.

A nozzle should fulfill the following requirements:

i. Proper atomization of fuel;
ii. Proper fuel mixing;
iii. Spraying of fuel in such a way that there is no direct contact with the chamber walls;
iv. Distributing fuel in the cylinder against the cylinder pressure.

Figure 2.1 shows a representation of a basic fuel injection system.

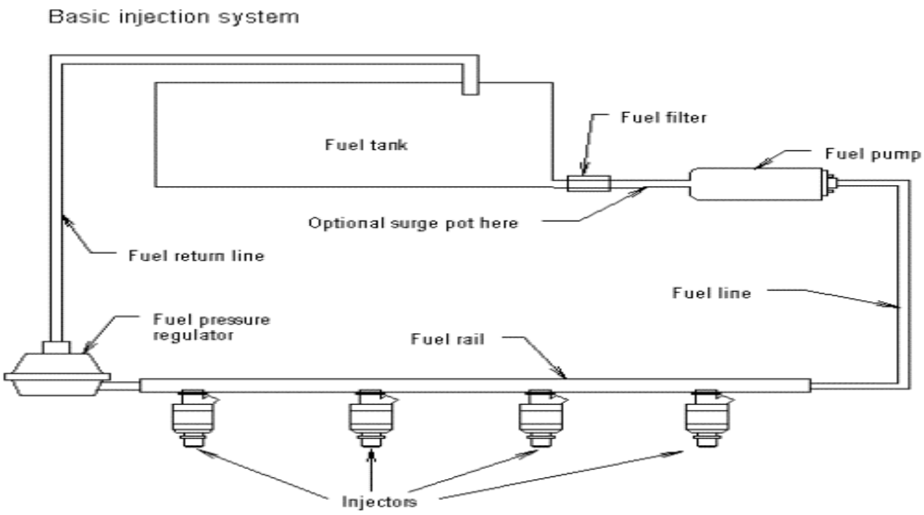


Figure 2.1: Schematic Representation of a Basic Fuel Injection System (Emerald, 2016)

2.2 Fuel Injection Parameters

According to Grieshabe & Stein, the following are key parameters to be considered in the fuel injection process (Grieshabe & Stein, 2014):

i. Start of Injection and Delivery
ii. Injected Fuel Quantity
iii. Injection Duration
iv. Rate of Discharge Curve
v. Injection Pressure

2.2.1 Start of injection and delivery

Fuel economy, the emission levels and combustion noise are all factors of fuel injection. The time in which injection takes place affects the air-fuel mixture time. As a result, to maximize the injection system's performance, the start of injection must be taken as important. The position in degrees of crankshaft rotation relative to crankshaft Top Dead Center (TDC) at which the injection nozzle opens and fuel is delivered into the engine combustion chamber is known as the start of injection (Grieshabe & Stein, 2014). At that time, the piston's position has an impact on the flow of air inside the combustion chamber. It also affects the density and temperature of the air. As a result, the degree of mixing of air and fuel is also determined by the injection start.

The standard values for direct injection are (Grieshabe & Stein, 2014):

i. No load: 2° crankshaft angle before TDC to 4° crankshaft angle after TDC;

ii. Part load: 6° crankshaft angle before TDC to 4° crankshaft angle after TDC;

iii. Full load: 6 to 15° crankshaft angle before TDC, for direct engine car engines, and

For direct-injection commercial-vehicle engines:

i. No load: 4 to 12° crankshaft angle before TDC;

ii. Full load: 3 to 6° crankshaft angle before TDC to 2° crankshaft angle after TDC.

Aside from the start of injection, the start of delivery is another factor to consider. It has to do with when the fuel-injection pump begins to supply fuel to the injector. At the start of delivery, the relative time between the pump and the engine is set. Because there is a clear relationship between the start of delivery and the start of injection (injection lag), this is conceivable. Injection lag is the time it takes for the pressure wave to travel from the high-pressure pump to the injection nozzle. As a result, the length of the line determines it.

2.2.2 Injected fuel quantity

The required fuel mass, m_e, for an engine cylinder per power stroke is calculated using equation 2.1 (Grieshabe & Stein, 2014):

$$m_e = \frac{P \cdot b_e \cdot 33.33}{n \cdot z} \text{ [mg/stroke]} \qquad (2.1)$$

Where:

P is the engine power in kilowatts

b_e is the engine specific fuel consumption in g/kWh

n is the engine speed in rpm

z is the number of engine cylinders

The fuel mass injected by the fuel-injection system depends on the following variables:

i. The injection duration
ii. The variation over time of the difference between the injection pressure and the pressure in the combustion chamber
iii. The density of the fuel

Diesel fuel is compressible, which means it may be compressed under high pressure. This increases the amount of fuel injected.

2.2.3 Injection duration

The injection nozzle is open at this time, and fuel pours into the combustion chamber. This parameter can be provided in milliseconds or degrees of crankshaft or camshaft angle. Various diesel combustion processes necessitate varying injection durations. A crankshaft angle of 30° during injection duration is equivalent to a camshaft angle of 15°which results in an injection pump speed of 2,000 rpm, equivalent to an injection duration of 1.25 ms (Grieshabe & Stein, 2014).

2.2.4 Rate of discharge curve

During the injection duration, the rate of discharge curve depicts the fuel-mass flow plotted against time when injected into the combustion chamber. The fuel-injection pump in cam-controlled fuel-injection systems builds pressure constantly throughout the injection operation. As a result, the pump's speed has a direct impact on the rate of fuel delivery and, as a result, the injection pressure. According to Grieshabe & Stein, in cam-controlled systems, the cam and the injection pump work together to generate pressure and deliver the injected fuel quantity (Grieshabe & Stein, 2014). This causes the following effects on injection properties:

i. As engine speed and injected fuel quantity increase, injection pressure rises until maximum pressure is attained.
ii. The injection pressure rises at the start, but falls to nozzle-closing pressure before the injection is completed.

2.2.5 Injection pressure

Fuel injection is a procedure that employs pressure in the fuel system to cause fuel to flow through injector jets. A high fuel system pressure causes a high rate of fuel outflow at the injection nozzle. The interaction of the turbulent jet of fuel with the air inside the combustion chamber causes fuel atomization. As a result, the finer the fuel is atomized, the higher the relative velocity between the fuel and the air, as well as the density of the air. Because of the length of the high-pressure fuel line, which is matched to the reflected pressure wave, the injection pressure at the nozzle may be higher than in the fuel-injection pump.

2.3 Classification of Fuel Injection Systems

In the injection process, the basic functions are implemented based on the type of the injection system. These types are classified as either conventionally designed systems and systems with high-pressure accumulators. Injection systems without accumulators always feature high-pressure pump plungers operated directly by a cam, which creates a pressure wave in the high-pressure system, which is then used to open the injection nozzle and inject the fuel cylinder selectively according to the firing sequence (Egler et al., 2010). Another level of classifying these systems includes systems with a “central injection pump” delivering fuel to each cylinder. In this category are inline and distributor pumps, which utilize radial and axial elements for pumping. According to Egler *et al.*, accumulator systems have a high central pump that delivers fuel at extremely high pressure to the accumulator (Egler et al., 2010). In the accumulator, the fuel is metered by injectors, which are controlled by solenoid or piezoelectric valves. Figure 2.2 shows the classification of injection system and their designs.

2.4 Challenges of Fuel Injectors and Injection Systems

Despite the usefulness of high-pressure fuel injection systems, there are also a number of conditions which could make the implementation of this technology would be difficult. They include:

i. In high-pressure systems, flush-wall injection is often employed due to its technical simplicity and conceptual scalability. As a result, there is complexity in developing strategies required to shield the injector structure from hostile thermal environment (Lee et al., 2015).

ii. Fuel leakage on the injector has proven to be a significant downside of the common rail injection method now in use. Sources of leakage include; the leakage on the needle guides and control piston, and the servo valves leakage (Jorg et al., 2011).

iii. When the pressure approaches the vapor pressure locally, cavitation (the formation of vapor pockets) happens. For example, a throttle before the solenoid valve in an injector is purposefully engineered to cause cavitation during injection, making the flow independent of backpressure and solenoid valve lift. However, developing cavitation models necessitates a significant amount of effort in order to ensure the accuracy of component damage forecasts (Egler et al., 2010).

iv. Pressure sensors require a high level of sensitivity to mechanical, environmental, chemical, and electromagnetic stimuli in order to function. Excellent precision is required in addition to high dependability and long service life (Projahn et al., 2010).

v. Injector deposits in the spray-hole have been observed to restrict fuel flow through the injector, resulting in a loss of power. Deposits have recently been observed inside the injector body, such as on the piston, nozzle needle, and armature plate. These deposits might influence the injector's dynamic response, leading in rough idle, and startability issues (Caprotti et al., 2011). To maintain the finest driveability and the lowest possible fuel usage, it's vital to keep control of all of these deposits.

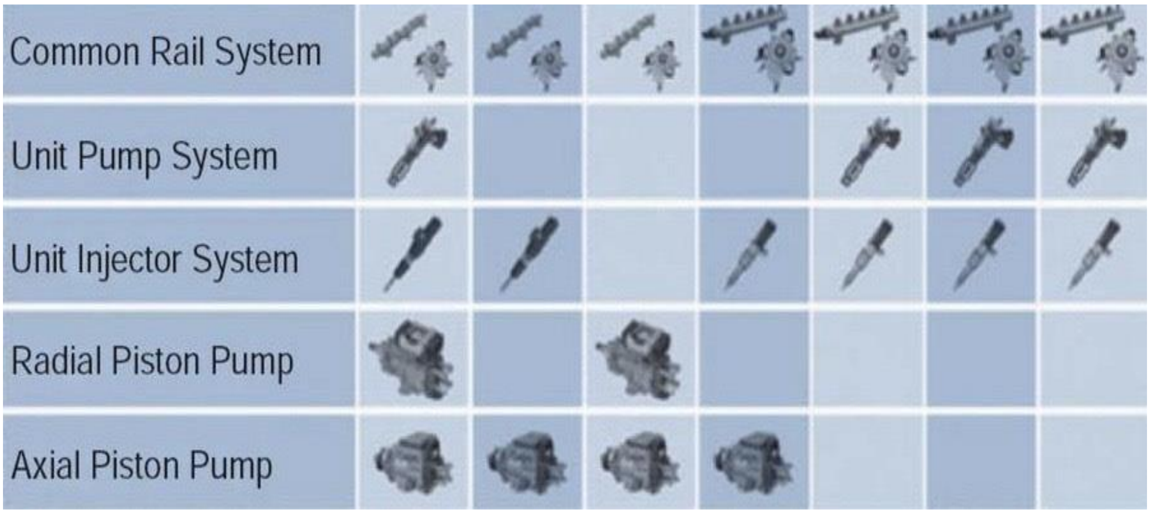


Figure 2.2: Present Injection System Designs

(Egler *et al*., 2010)

Deposits can be found in two places in the injector:

i. In the body of the injector, such as on plungers and internal valves, also known as Internal Injector Deposits (IID);

ii. At the spray hole, where the fuel is atomized for combustion, also known as Spray Hole Deposits (SHD) (Caprotti et al., 2011).

2.5 Development of Fuel Injection Systems

According to Ouyang & An (2019), electronic control fuel injection system has progressed through three stages, namely:

(i.) Position type control

(ii.) Time control

(iii.) Pressure time control

2.5.1 Position type Control

A position type electronic control fuel injection system keeps the structure of a typical injection system, but replaces the mechanical control mechanism with electronic components. A position type electronic control injection system uses electronic control components to replace the original mechanical adjusting mechanism, while electronic control mechanical actuators are used to control the injection process indirectly; as a result, control accuracy and response time are lower than in other electronic control systems (Ouyang & An, 2019).

2.5.2 Time control

As the requirements on fuel injection systems increased over time, the position type control could not meet up with the demands and as a result, another generation of fuel injection systems emerged utilizing the electronic control unit (ECU) to directly regulate the injection start and end point. It completely changed the traditional systems of using mechanical structures, switching from the previously used mechanical injectors to solenoid valve controlled high-pressure injectors. With it came high response and stable control precision.

2.5.3 Pressure-time control

To fulfill rising pollution and fuel economy demands, injector timing precision, fuel injection rate, and injection quantity all had to be improved. This necessitated the development of the third generation of electronic fuel injection systems, which birthed the common rail system. Some characteristics of the common rail system include:

i. Independent generation of injection pressure within the scope of 130-160MPa (Ouyang & An, 2019)

ii. Injection control

iii. Pressurization of the fuel in the common rail utilizing a high-pressure supply pump.

2.5.3.1 Medium-pressure common rail system

The characteristics of this system are:

i. The system's fuel rail has a pressure of 525 MPa (Ouyang & An, 2019).

ii. It does not require a high-pressure oil pump.

iii. It requires fuel valve plunger parts with high precision.

2.5.3.2 High-pressure common rail system

The characteristics of this system are:

i. The pressure of the system can be adjusted.

ii. By computing an appropriate injection time and regulating the opening and closing of the injector with it, the injection time can be varied according to engine speed and load.

iii. It requires a high-pressure fuel pump.

The configuration can be seen in Figure 2.3.

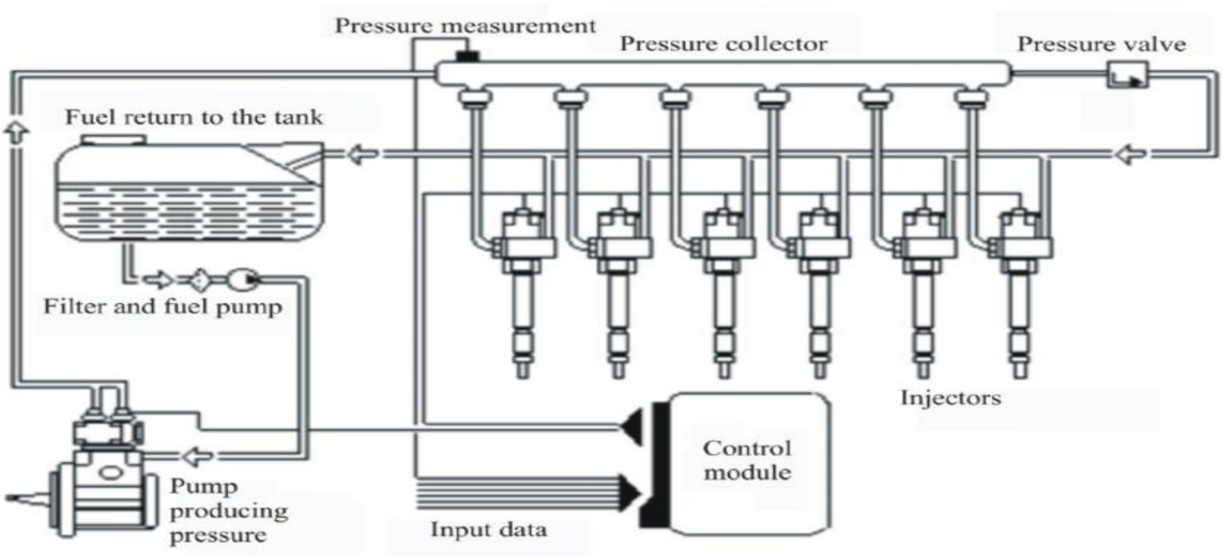


Figure 2.3: Schematic of the High-Pressure Common Rail System

(Jankowski & Kowalski, 2019)

2.6 Safety Measures in Fuel Injection Systems

Corrosiveness and flammability are both risks associated with liquid fuel. Fuel safety precautions are generally common for all injection systems and can be broken down into three categories:

i. Exposure: All fuels corrode our skin and are hazardous to inhale or swallow. When operating with a high-pressure fuel system, it is extremely crucial to keep fuel away from our skin, eyes, and mouth. Before working on the fuel system, including the fuel lines, fuel pump, and fuel injectors, relieve the pressure in the fuel lines. The systems' fuel pressure can be high enough for the fuel to permeate our skin.

ii. Leaking: Leaks can increase the likelihood of a fire and fuel exposure. Before loosening a fuel line fitting, a small cloth should be wrapped around it to absorb any leaking fuel.

iii. Storage: Procedures like easing fuel pressure or draining the fuel tank frequently necessitate temporarily storing surplus fuel and replacing it after the procedure is completed. Fuel must be stored in an airtight container that will not react chemically with it.

2.7 Review of Previous Studies on Fuel Injection Systems

A wide array of research work has been carried out on fuel injection systems in other parts of the world. The science of fuel injection has steadily progressed over the last four decades, however there is much room for innovation and creative thinking. Agarwal *et al.* (2013) developed a mechanical fuel injector-cleaning machine using an air compressor as the central power source. The main aim of their work was to develop a fuel injection system that cost ten times less than the existing electronic type fuel injection systems. Kusada *et al*. (2017) designed and developed a fuel injector tester using a 12 volts automotive SLI (starting, lighting, and ignition) battery to power the system. They highlighted lack of equipment and secondary plans for recharging the battery when due as a limitation in their work. Punov (2014) studied the fuel injection characteristics of a common-rail solenoid injector to be used in 2.0 liters diesel engine for lightduty vehicle application. According to his work, the rate of injection was calculated as a function of crank angle at various engine operating points, as well as the impact of some geometric parameters on the injection process. Aburass (2016) gave an insightful overview into fuel injection systems fuelled with biodiesel. In comparison to the pressure of the plunger, fuel delivery valve, and pipeline fuel, he noted that the pressure in the fuel injector is higher and delayed. Crescenzo (2015) worked on pressure measurement in the high-pressure fuel system. His work gave a complete understanding of the primary elements involved in the injection process, such as rail pressure, injection on-time, and injector temperature, backed up by pertinent data. His research focused on rail pressure in particular, and his findings revealed that fuel temperature and fuel characteristics have significant effects on system dynamics. Considerable inaccuracies in the detection of the exact start and finish times of injection were found to be a limitation in his study. Nouraei (2012) designed and developed a direct-acting piezoelectric injector for a fuel injection system. He included off power holding of the injection nozzle and improved rate of rejection, compared to that of the commercial injectors. Senthilkumar and Sreejyoth (2019) worked on fuel injection testing through development of an external rig, by increasing the injector plunger diameter from 9.5mm to 11mm. This led to an increase in fuel injection rate. Since the fuel injection rate increased, cylinder head temperature and peak cylinder pressure measurement was to be done. And that led to a possibility of plunger scoffing and oil dilution.

CHAPTER THREE

MATERIALS AND METHODS

The fuel injection system chosen was a common rail direct injection type (CRDI) due to its ease of use, better fuel efficiency and improved overall injection performance. An arduino microcontroller was used in the electronic control unit to send output to the injectors and feed pump, and also to receive input from the flow meter. It was chosen due to its simple and user-friendly experience. A low-pressure pump was used to send fuel from the tank into the fuel rail. A four-to-one junction was added to direct the fuel from the spit unit, acting as the combustion chamber to a reservoir tank. The flow meter was added to measure the flow rate of the fuel.

The methodology employed for the development is elucidated subsequently.

3.1 Materials

The following materials were used for the development of a fuel injector training kit:

i. Fuel injector rail
ii. Arduino Uno Microcontroller
iii. Low-pressure pump
iv. PLA plastic
v. Flow meter
vi. Fuel filter
vii. Fuel supply
viii. Power supply
ix. Acrylic plastic
x. Mild steel

The part list of the developed fuel injector training kit is presented in Table 3.1

Table 3.1: Part List

S/N	Description	Quantity	Materials	Remarks
1	Fuel injector rail	1	Bought-out	Stainless steel, 12V
2	Arduino Uno	1	Bought-out	
3	Low-pressure pump	1	Bought-out	12V, 11bar
4	Spit chamber	4	PLA plastic	
5	Injector holder	2	Mild steel	
6	4 to 1 junction	1	PLA plastic	
7	Flow meter	1	Bought-out	15mA, 5 – 12V
8	Fuel filter	1	Bought-out	
9	Fuel supply line	2	Bought-out	PVC pipe
10	Power supply	1	Bought-out	12V DC adapter
11	Frame	1	Mild steel	Square pipe
12	Frame cover	3	Acrylic plastic	

3.1.1 Filter

As a protection for the fuel pump against impurities, a fuel strainer was used as the filter. It is a mesh filter that guides the pick-up tube of the fuel pump. It prevents dirty fuel from entering the fuel pump, which can cause eventual failure of the pump.

3.1.2 Fuel injector rail

This is the fuel delivery pipe housing a tube, connected to the injectors. Primarily, it serves as a channel of fuel supply from fuel tank through fuel lines to the multiple fuel injectors, which sprays the fuel into intake ports at high pressure (Jadhav et al., 2014). The solenoid valves of the injectors open and close when excited with a 12v DC, which allows for the passage of fuel through needle-like holes designed for atomization. Due to constant opening and closing of injector holes, there is constant vibration in the system and the fuel rail acts as a damper for it. Figure 3.1 shows the fuel injector rail.

The objective for selection of the type of fuel rail, according to its material is as follows:

i. Ability to withstand temperature changes for short and long durations;
ii. Chemical resistance to water, engine oil, alcohol blended and sour gasoline (Jadhav *et al*., 2014);
iii. Ability to dampen vibrations due to opening and closing of the valve.

With all these considered, a stainless steel fuel rail was chosen, as it fulfilled all the objectives.

3.1.3 Flow meter

This is used to gauge the mass flow rate of fluid flowing through it. It consists primarily of sensors, which detect, calculate and convert their respective measurements accordingly. The flow meter used has an operating current of 15mA and a voltage range of 5 – 12V. Its water flow range is 0.1 – 6 L/min and it has a proof water pressure of <1.2 MPa. It was chosen because its voltage requirement is compatible with the Arduino Uno Microcontroller and the maximum proof water pressure is higher than the 11 bar pressure supplied by the pump.

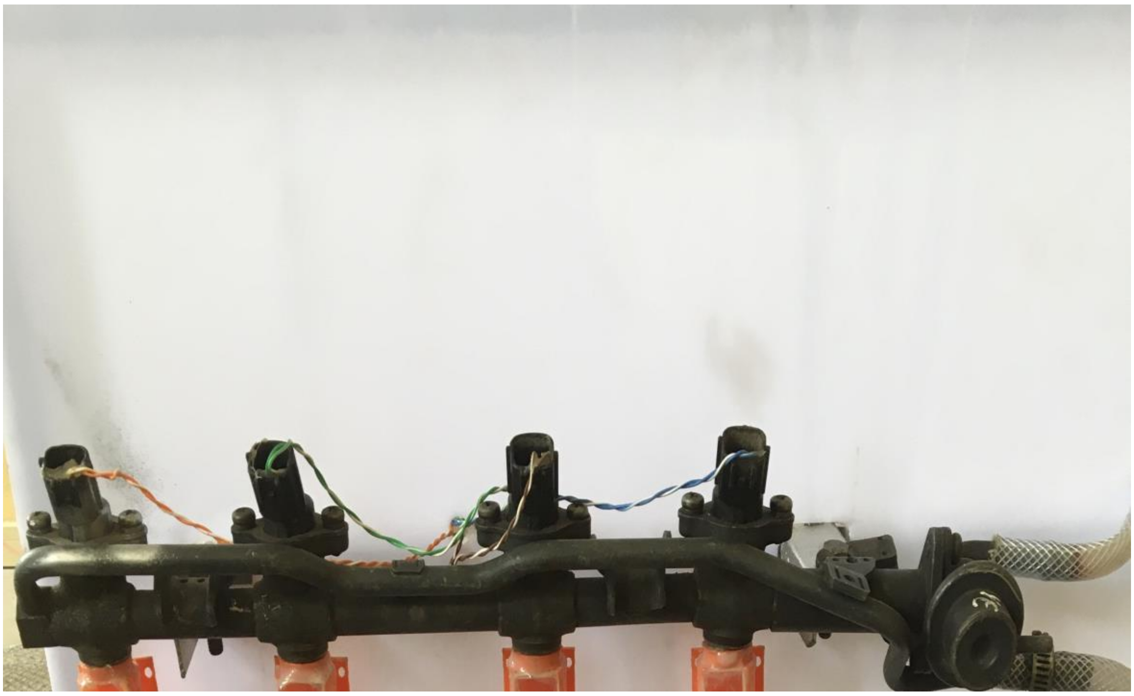


Figure 3.1: Fuel Injector Rail

3.1.4 Arduino uno microcontroller

The Arduino Uno is a microcontroller board that provides a simple and modular way of interfacing the real world with the computer to handle basic processing tasks on a chip while working with hardware sensors. The Arduino Uno uses the ATmega328 chip that supports 14 digital pins that can be configured as either input or output and 6 analog inputs (Goodwin, 2013). Table 3.2 shows the technical features of the Arduino Uno. The Arduino is programmed using the Arduino IDE with source code written in C.

3.1.5 Low-pressure pump

This pumps fuel from the storage tank to the fuel injection system. It has a working pressure of 11bar and operates on 12v DC. The normal working temperature range is -4 – 82^0C and the response time is approximately 2ms. Figure 3.2 shows a low-pressure pump. It consists of an electrical lift pump unit drawing the fuel directly from the fuel tank. In addition to the electric lift pump, the low-pressure feed pump also contains a fuel level indicator, interface device with the fuel tank, eventually pressure regulation or pressure limiting components (Collins *et al*., 2012).

3.1.6 Polyactic plastic

Due to its specific use, and according to the dimensions of the fuel rail exit holes, polylactic plastic (PLA) plastic was used as the raw material for 3D printing the spit chamber. This served as the combustion chamber where fuel is sprayed into by the nozzles. PLA plastic has a melting point of 150^0C and a tensile strength to withstand pressure up to 655 bar. It was chosen for its sustainability, environmental friendliness and its ease when used for 3D printing. Four spit chambers were utilized as the combustion chambers for the four-injector rail. PLA plastic was also used in 3D-printing the 4 to 1 junction that connected the four spit chambers to a single channel, linking the flow meter. Figure 3.3 gives a pictorial view of the 3D-printed spit chamber.

Figure 3.2: Low-Pressure Pump

Figure 3.3: 3D-Printed Spit Chamber

Table 3.2: Technical Specifications of the Arduino Uno

S/N	Item	Value	Remarks
1	Micro-controller	8-bit Amel ATmega328p	1 mm sheet metal
2	Operational voltage	5V	Input range: 7-12V
3	Digital GPIO	14	6 capable of PWM
4	Analog IO	6	10-bit
5	Program memory	Flash 32kb, EEPROM 1kb	SRAM 2kb
6	Clock speed	16MHz	
7	USB	Type B socket	
8	Programmer	In-system firmware	USB-based
9	Serial communications	SPI, 12C	Software UART
10	Other	RTC, watchdog, interrupts	

Source: Norris (2015)

3.1.7 Fuel supply

The fuel supply line used was a PVC pipe with 8mm ID, 11mm OD, thickness of 3mm and a line length of 500mm. Lightweight supply line architecture was chosen because there is little or no pressure/return line (Mule et al., 2013).

3.1.7.1 Pipe dimensions

Internal diameter (ID) = 8mm = 0.008m

Outer diameter (OD) = 11mm = 0.011m

Thickness (t) = 2mm = 0.002m

Line length = 500mm = 0.5m

Drop = 400mm = 0.4m

The radius of the pipe is calculated as:

$$r = \frac{d}{2} \qquad (3.1)$$

$$r = \frac{0.008}{2} = 0.004\text{m}$$

The cross sectional area of the pipe is calculated as:

$A = \pi r^2$ *(3.2)*

$A = 3.142 \times 0.004^2 = 5.027 \times 10^{-5} m^2$

The perimeter of the pipe is calculated as:

$P = 2\pi r$ *(3.3)*

P = 2 x 3.142 x 0.004 = 0.025m

The roughness coefficient of a pipe of PVC material is 150 (Wichowski et al., 2021).

The slope is calculated as:

$S = \frac{y}{L}$ *(3.4)*

Where

y is the drop of the pipe in m

L is the line length in m

From equation (3.4),

$S = \frac{0.4}{0.5} = 0.8$

3.1.7.2 Velocity of fluid flowing through the pipe (V)

According to Hazen-Williams equation, the velocity of fluid flowing through a pipe is:

$V = KCR^{0.68}S^{0.54}$ *(3.5)*

Where:

V is the velocity of fluid flowing through a pipe (m/s)

C is the roughness coefficient dependent on the material

R is radius (m)

S is the frictional head loss

K is the conversion factor

The conversion factor is dependent on the unit system and is 0.849 for metric system (Fred *et al*., 2011).

$V = 0.849 \times 150 \times (2.0108\times10^{-3})^{0.63} \times 0.8^{0.54}$ *(...Recall equation 3.5)*

V = 2.2583 m/s

Therefore, the velocity of fluid flowing through the pipe ≈ 2.3 m/s

3.1.7.3 Flow rate (Q)

The flow rate of the fluid flowing through the pipe is calculated as:

$$Q = AV \tag{3.6}$$

Where:

A is the cross sectional area of the pipe in m^2

V is the velocity of the fluid flowing through the pipe in m^3/s

$Q = 5.027\times10^{-5} \times 2.2583 = 0.00011\ m^3/s$

Therefore the flow rate of the fluid flowing through the pipe is 0.00011 m^3/s

3.1.7.4 Burst pressure

The burst pressure for a conduit is given by:

$$P = \frac{T\ (x^2 - y^2)}{y^2\ (1 + \frac{x^2}{y^2})} \tag{3.7}$$

$$x = \frac{OD}{2} \tag{3.8}$$

$$y = \frac{ID}{2} \tag{3.9}$$

Where

P is the burst pressure of the pipe in N/mm^2

T is the tensile strength of the material in MPa

OD is the outside diameter of the pipe in mm

ID is the internal diameter of the pipe in mm

For a PVC pipe, the tensile strength, T = 52Mpa.

$x = \frac{OD}{2} = \frac{1.1}{2} = 0.55mm$

$y = \frac{ID}{2} = \frac{0.8}{2} = 0.4mm$

Substituting x and y and T into equation *(3.7)*

$$P = \frac{52\ (0.55^2 - 0.4^2)}{0.4^2\ (1 + \frac{0.55^2}{0.4^2})} = 16.022\ \text{N/mm}^2 \approx 160.22\ \text{bar}$$

The pressure supplied by the pump is 11 bar, far less than the burst pressure; hence the pipe was suitable for selection.

3.1.8 Power supply

To supply the power required by the ECU, and the system as a whole, a 12V DC power adapter was chosen. This was selected over a battery system, because of reliability, and also to shed off the extra weight the battery would add to the system. Over time, batteries die off and would need to be replaced. Hence, the power adapter was chosen for sustainability and compatibility with the 12V required by the fuel pump and the injector solenoid valves.

3.1.9 Acrylic plastic

Also known as plexiglass, it is a translucent material often used in place of glass. It is easy to shape and fabricate. It was used in fabricating the cover for the fuel training kit system because of its anti-corrosion properties.

3.1.10 Mild steel

For its unparalleled weldability machinability, and availability, mild steel was chosen as the material for the system’s frame. It has high tensile strength, high impact strength and good malleability.

3.2 Methods

In development of the fuel injector kit, the following stages were undergone:

i. Construction of the frame and cover unit;
ii. 3D printing of the spit chambers and the 4-to-1 junction;
iii. Connection of the injector electronic control unit circuit;
iv. Installation of the fuel injector rail;
v. Installation of the low-pressure pump and flow meter;

vi. Installation of the injector ECU on the system.

The first three stages are elucidated in sections 3.2.1, 3.2.2 and 3.2.3.

3.2.1 Construction of the frame and cover unit

The following steps are taken to construct the frame and cover unit:

i. The mild steel square pipe was cut into four sections of length 500mm and two sections of length 550mm.

ii. The four sections of length 500 mm were cut out for the base of the frame and the lengths of 550mm for the body of the frame.

iii. From the four sections, two sections of length 515.40 mm were cut out for vertical axes of the body and 500mm for the horizontal axes.

iv. A section of length 486mm was cut out as a horizontal support guide for the body of the frame.

v. With all the parts cut out, the sections for the body and base were separately welded, before they were welded together.

vi. Two acrylic covers of dimensions 237.3 X 500 mm were cut out using a laser-cutting machine. There were fastened to the base of the frame using adhesive.

vii. Another single cover of dimensions 518.50 X 500 mm was cut out for the frame and fastened to it.

3.2.2 3D printing of the spit chambers and the 4-to-1 junction

The following steps are taken to 3D print the spit chamber and the 4-to-1 junction:

i. The design was drafted on Solid works using the dimensions fully defined

ii. The STL file of the 3D spit chamber design was exported using PLA plastic as the material

iii. The size and placement of the print was decided and the STL file was imported into the longer software.

iv. The slicing software converted the STL file into GCode, which contains the specific instructions for the printer and the spit chambers were printed according to the 3D design

v. The bed was heated to 200^{o}C and the 3D-printing process started.

vi. The process was repeated for the 4 to 1 junction according to its dimensions.

3.2.3 Connection of the injector electronic control unit circuit

The injector electronic control unit was connected on a breadboard for prototyping using the circuit diagram shown in Figure 3.4. Figure 3.4 shows the connection of the ATmega328 chip on the Arduino Uno with the flow sensor and low-pressure pump.

3.2.4 Parts Assembly

The injector rail was mounted on the angle bar connected to the frame, and screwed to fit. This can be seen in figure 3.5. It was connected to the electronic control unit using injector harness. With the injector rail mounted on the frame and acrylic cover connected to the electronic control unit, the fuel pump was connected to the ECU using connecting wires. The fuel supply line of the pump was connected to the supply port of the fuel rail and the return port was connected through a return line back to the plastic tank. With that in place, both the flow meter was also connected to the ECU using connecting wires. The connections can be seen in Figure 3.4. The four spit chambers were fastened on the rail injector exit ports and connected to the four-to-one junction and the supply was connected to the flow meter fixed to the frame, through which a pipe was channeled to the exit tank. The configuration can be seen in figure 3.6.

3.3 Performance Evaluation of the Developed Fuel Injector Kit

This was done to evaluate the performance of the fuel injector training kit in terms of effectiveness of the injector electronic control unit and the consistency of the spray pattern according to the firing order. Data was obtained from the flow meter to determine their accuracy. The spray pattern is monitored and the flow rate is recorded to study the flow according to the spitting time. The flow rate is evaluated against the spitting time with a set duration. The developed fuel injector kit can be seen in Figure 3.7.

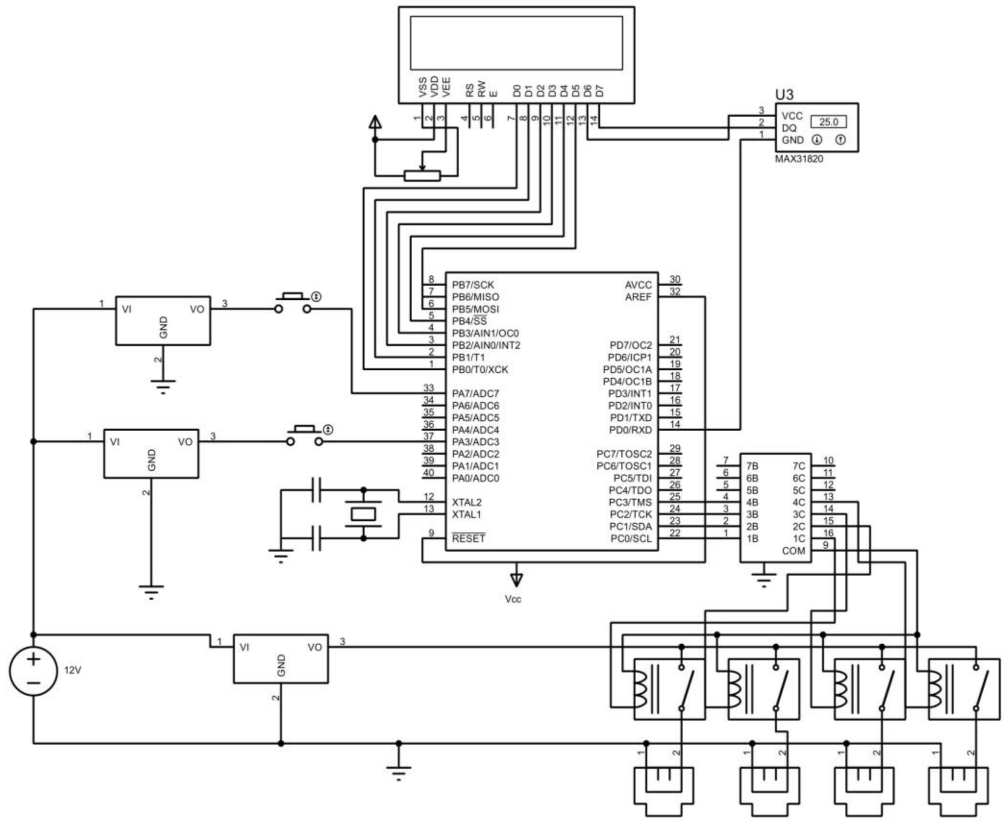


Figure 3.4: Circuit Diagram of the Electronic Circuit Unit

Figure 3.5: Injector Rail Mounted on the Frame

Figure 3.6 Connection of the ECU to the injector rail

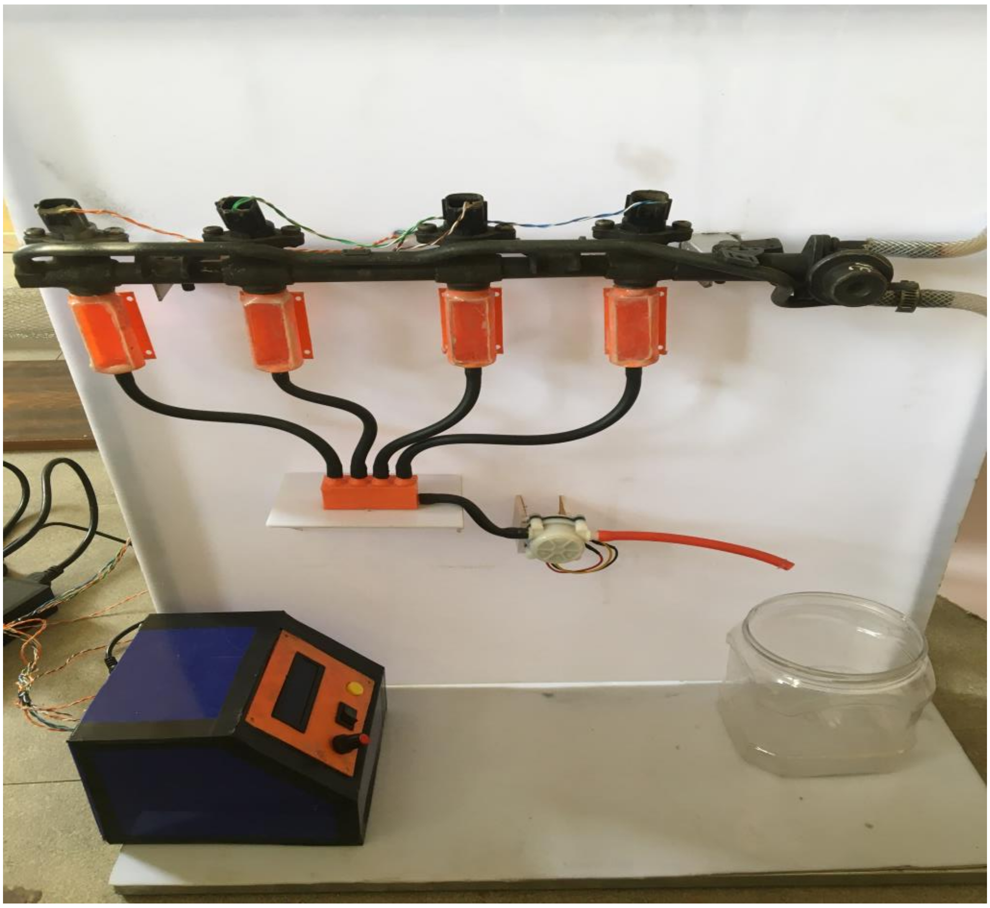


Figure 3.7 Developed Fuel Injector Kit

3.4 Leaks and Integrity Testing

After the injector fuel rail, spit chambers and electronic control unit have been installed, the fuel injector training kit is subjected to leak and integrity test using the following steps:

i. Tighten all hose clips and all fitting joints

ii. Introduce water into the system and inspect all hose clips and fitting joints for leakages.

iii. Mark out leaks if any.

iv. Tighten all hose clips and carry out final inspection on entire system.

3.5 Determination of System Flow Rate

A known volume of fuel is introduced into the system, through the fuel pump at a constant pressure. A spit time and an operating time period are selected, and the injection process begins, with the flow rate being recorded for each spit time as the process is repeated.

The spit time refers to the time difference in the spray of fuel by each injector. It is a factor of acceleration. Increased spit time between injectors infers reduced acceleration and vice versa. According to the spit times, corresponding flow rates were recorded and from this dataset, the volume of fuel used for injection was determined.

The software employed was Microsoft Excel, which is used for graph plotting. It was used to study the effect of spit time on independent variables such as flow rate (m^3/s), and volume (m^3). The input parameters varied and their ranges include: spitting time (50-500 ms) and injection period (1-10 mins). A run of 10 experiments was generated.

3.7 Bill of Engineering Measurements and Evaluation (BEME) for Fuel Injector Training Kit

This is the engineers' bill of materials showing a developmental analysis of costs associated with materials utilized for the project is detailed in Table 3.3.

Table 3.3: Bill of Engineering Measurements and Evaluation

Item #	Name	Quantity	Description	Source	Unit Price (NGN)	Total Price (NGN)
1	Mild steel pipe	`1/2 length	Square cross section	Bought out	8000	4000
2	Injector rail		12v, 4 cylinder rail	Bought out	13000	21500
3	Storage tank	2	Plastic	Bought out	1000	2000
4	Potentiometer	1	Single turn	Bought out	5000	5000
5	Relay module	4	Single channel, 5V	Bought out	2000	8000
6	Flow meter	1	15mA, 12V	Bought out	5000	5000
7	Current sensor	4		Bought out	2000	8000
8	12v dc power	1	5A, 60W	Bought out	10000	10000
9	Acrylic plastic			Bought out	8000	8000
10	Electrode	1 packet	E020, E6023	Workshop	1000	1000
11	Cutting disc	1		Bought out	1000	1000
12	Grinding disc	1		Bought out	1000	1000
13	Arduino Uno	1	Microcontroller	Bought out	6500	12000
14	Labor				15000	15000
15	Transportation				7500	7500
16	Miscellaneous		5% of total costs			5450
	Total					114,450

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

The flow rate and the effect of increasing spiting time (acceleration) on the system were determined. The injected fuel was then recollected, weighed and compared against the input amount. Table 4.1 shows the summary of the experiment to study the effect of increasing spitting time (acceleration) on fuel consumption obtained from performance evaluation.

4.2 Discussion of Results

From the experiments carried out after the development of the fuel injector training kit, a graph of volume of fuel injected was plotted against the spit time and an inversely proportional relationship was observed. As the spit time increased, the volume of fuel injected into the chamber reduced. A volume of 2L of fuel was used in this experiment; a volume of 0.4316L was injected across 10 experiments carried out with increasing spit time. From the experiment, the corresponding flow rates were derived which was used in calculating the volume injected. The experiments were done using a constant injection time (period) of 1 minute. From the results obtained, the fuel injector kit is functioning according to the design criteria applied. Figure 4.2 shows the relationship between spit time and volume of fuel injected.

Table 4.1: Fuel Injection Values

S/N	Spit Time (ms)	Time (min)	Flow rate (L/min)	Volume Used (L)
1	50	1	0.1333	0.1333
2	100	1	0.1066	0.1066
3	150	1	0.0741	0.0741
4	200	1	0.0593	0.0593
5	250	1	0.0285	0.0285
6	300	1	0.0101	0.0101
7	350	1	0.0082	0.0081
8	400	1	0.0060	0.0060
9	450	1	0.0039	0.0039
10	500	1	0.0012	0.0012

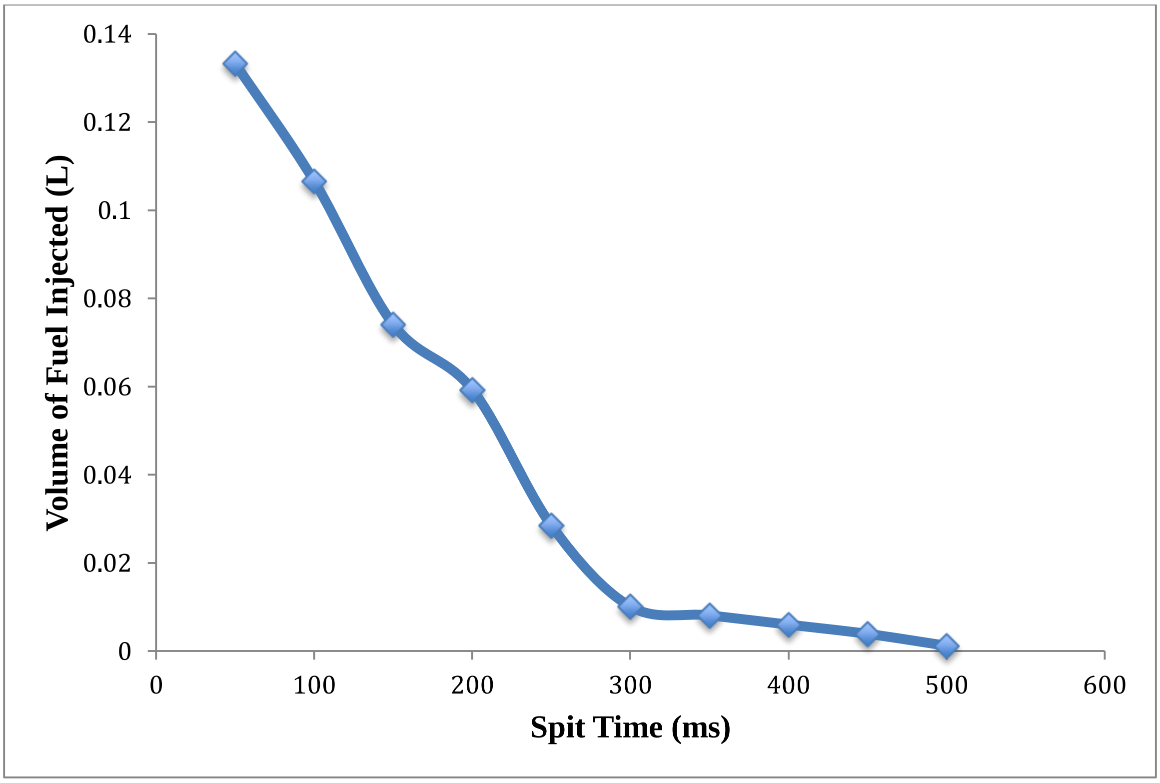


Figure 4.1: Relationship between Spit Time and Volume of Fuel Injected

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

After successful completion of this work, the following conclusions have been reached and recommendations have been made for future work on the Development of a Fuel Injector Training Kit.

5.1 Conclusion

This work has been able to:

i. Design a fuel injector kit for use in universities for studying fuel injection
ii. Develop the designed fuel injector kit
iii. Incorporate a relatively low-cost electronic control unit for the fuel injector kit
iv. Evaluate the developed injector kit.

5.2 Recommendations

The following recommendations will be pivotal to further work on the development of fuel injector training kits:

i. A pressure gauge should be added between the low-pressure pump and the fuel rail to measure the pressure of fuel going into the rail as this would help in monitoring pressure drops.
ii. A wireless module should be added to the system to make the system fully smart and communicate to as an 'Internet of Things' device.
iii. A fuel filter should be added at the four-to-one junction to increase the reusability of the fuel.
iv. Gate valves should be added to the spit chambers so the amount of fuel sprayed by each injector could be compared before release.

5.3 Contribution to Knowledge

This work contributes to knowledge as follows:

i. Improvement in fuel injection demonstration using a microcontroller.

ii. Incorporation of a low-cost electronic control unit for a fuel injector training kit.

iii. Provision of developmental framework for a fuel injector training kit for educational purposes.

REFERENCES

Aburass, A. M. (2016). Diagnostics of Fuel Injection Systems in a CI Engine Fuelled with Bio Diesel Based on Vibration Responses [Masters thesis, University of Huddersfield]. UH Campus Repository.

Agarwal, H., Dubey, K. K., & Kamal, S. (2013). Development of Mechanical Fuel Injector Cleaning Machine in Cost Effective Manner. In International Journal of Engineering and Advanced Technology (IJEAT) (Issue 2). http://i21.geccdn.net/site/images/n-

Caprotti, R., Bhatti, N., & Nobuyuki, I. (2011). Protecting diesel fuel injection systems. SAE Technical Papers. https://doi.org/10.4271/2011-01-1927

Ciatti, S. A. (2015). Compression Ignition Engines – Revolutionary Technology that has Civilized Frontiers all Over the Globe from the Industrial Revolution into the Twenty-First Century. Frontiers in Mechanical Engineering, 1, 5. https://doi.org/10.3389/FMECH.2015.00005/BIBTEX

Collins, D., Frilling, A., Hislaire, I., Iseghem, A. v., Cremer, H., Sanchez, M., Schilling, S., & Bouloc, R. (2012). CO2 savings due to electronically controlled fuel pumps in fuel delivery modules. Institution of Mechanical Engineers - Fuel Systems for IC Engines, 11–19. https://doi.org/10.1533/9780857096043.2.11

Crescenzo, D. (2015). Pressure Measurement in the High Pressure Fuel System.

Diesel Fuel Injection (n.d). Retrieved on March 31, 2022 https://dieselnet.com/tech/diesel_fi.php

Egler, W., Giersch, R. J., Boecking, F., Hammer, J., Hlousek, J., Mattes, P., Projahn, U., Urner, W., & Janetzky, B. (2010). Fuel Injection Systems. Handbook of Diesel Engines, 127–174. https://doi.org/10.1007/978-3-540-89083-6_5

Emerald. (2016). [Basic Injection System]. Retrieved April 9, 2022, from https://www.emeraldm3d.com/articles/injection-systems/

Fayad, M. A. (2019). Effect of fuel injection strategy on combustion performance and NOx/smoke trade-off under a range of operating conditions for a heavy-duty DI diesel engine. SN Applied Sciences, 1(9). https://doi.org/10.1007/s42452-019-1083-2

Foster, S., & Elzinga, D. (2013). The role of fossil fuels in a sustainable energy system. UN Chronicle, 52(3), 17–19. https://doi.org/10.18356/1007F69A-EN

Fred, F. F., & H, R. H. (2011). Newly developed friction factor correlation for pipe flow and flow assurance. Journal of Chemical Engineering and Materials Science, 2(6), 83–86. http://www.academicjournals.org/jcems

Goodwin, S. (2013). Smart home automation with Linux and Raspberry Pi. Smart Home Automation with Linux and Raspberry Pi, 9781430258889, 1–304. https://doi.org/10.1007/978-1-4302-5888-9

Grieshabe, H., & Stein, J. O. (2014). Overview of diesel fuel-injection systems. Diesel Engine Management, 72–77. https://doi.org/10.1007/978-3-658-03981-3_7

Jadhav, P., Nanda, A., Tripathi, M., Kumar, A., & Umbarkar, S. (2014). Design considerations for plastic fuel rail and its benefits. SAE Technical Papers, 1. https://doi.org/10.4271/2014-01-1041

Jankowski, A., & Kowalski, M. (2015). Environmental Pollution Caused by a Direct Injection Engine. Journal of Kones. Powertrain and Transport, 22(4), 133–138. https://doi.org/10.5604/12314005.1168461

Kamaltdinov, V. G., Markov, V. A., Lysov, I. O., Zherdev, A. A., & Furman, V. V. (2019). Experimental studies of fuel injection in a diesel engine with an inclined injector. Energies, 12(14). https://doi.org/10.3390/en12142643

Khalid, A., Jaat, N., Sapit, A., Razali, A., Manshoor, B., Zaman, I., & Abdullah, A. A. (2015). Performance and emissions characteristics of crude jatropha oil biodiesel blends in a diesel engine. International Journal of Automotive and Mechanical Engineering, 11(1), 2447–2457. https://doi.org/10.15282/IJAME.11.2015.25.0206

Kusada, A. I., Hassani, C. A., Ali, H., Khan, M. U. (2019) Fuel Injector Tester [Masters Thesis for Islamic University of Technology]. IUT Campus Repository.

Latarche, M. (2021). Fuel injection. Pounder's Marine Diesel Engines and Gas Turbines, 319–357. https://doi.org/10.1016/B978-0-08-102748-6.00011-6

Leach, F., Kalghatgi, G., Stone, R., & Miles, P. (2020). The scope for improving the efficiency and environmental impact of internal combustion engines. In Transportation Engineering (Vol. 1). Elsevier Ltd. https://doi.org/10.1016/j.treng.2020.100005

Lee, J., Lin, K. C., & Eklund, D. (2015). Challenges in fuel injection for high-speed propulsion systems. AIAA Journal, 53(6), 1405–1423. https://doi.org/10.2514/1.J053280

Mule, A., Deshmukh, S., & Shilwant, S. C. (2013). Reliable Fuel Lines Design Considerations and Validation in a Passenger Car. International Journal of Engineering Research and Technology, 2(7). www.ijert.org

Norris, D. (2015). The Internet of Things : Do-It-Yourself at Home Projects for Arduino , Raspberry Pi and BeagleBone Black Build and program projects that tap into the Internet of Things (IoT) using Arduino , Raspberry Pi , and BeagleBone Black.

Oloyede, A. A., Ajimotokan, H. A., & Faruk, N. (2018). Embracing the future of engineering education in Nigeria: teaching and learning challenges. Nigerian Journal of Technology, 36(4), 991. https://doi.org/10.4314/njt.v36i4.1

Ouyang, G., & An, S. (2019). Common rail fuel injection technology in diesel engines

Projahn, U., Randoll, H., Biermann, E., Brückner, J., Funk, K., Küttner, T., Lehle, W., & Zuern, J. (2010). Fuel Injection System Control Systems. Handbook of Diesel Engines, 175–191. https://doi.org/10.1007/978-3-540-89083-6_6

Reif Ed, K. (2014). Diesel Engine Management Systems and Components Bosch Professional

Automotive Information.

Shatrov, M. G., Golubkov, L. N., Dunin, A. U., Yakovenko, A. L., & Dushkin, P. v. (2015). Influence of High Injection Pressure on Fuel Injection Perfomances and Diesel Engine Worcking Process. https://doi.org/10.2298/TSCI151109192S

Theobald Jorg, Schintzel Kay, Andreas Krause, & Ulrich Doerges. (2011, April). Fuel Injection System | Request PDF. MTZ Worldwide. https://www.researchgate.net/publication/270525272_Fuel_Injection_System

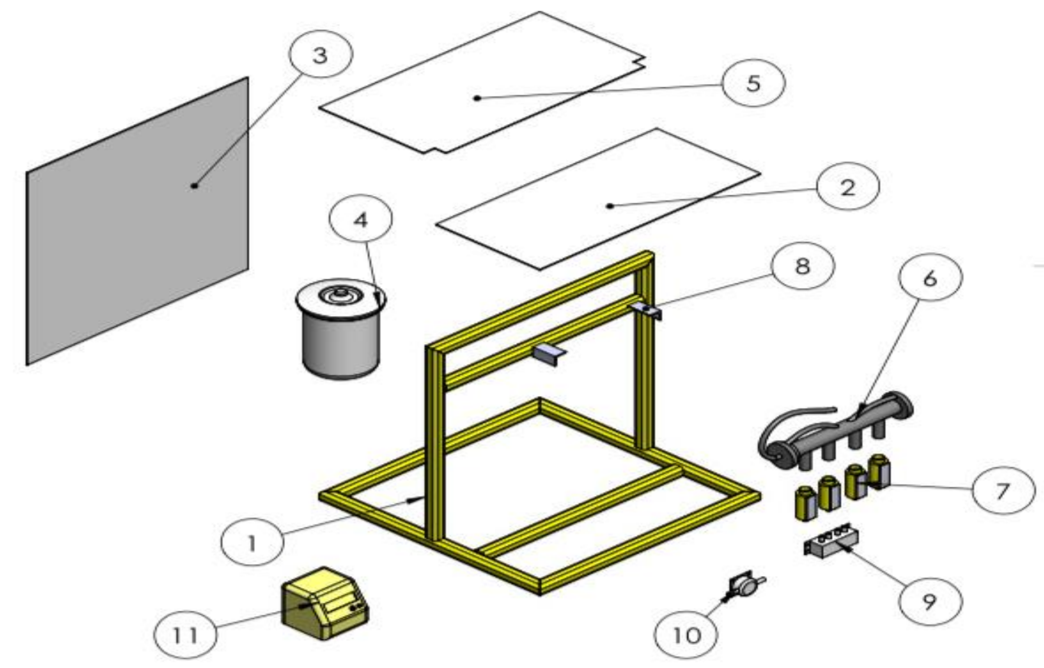
Wichowski, P., Kalenik, M., Lal, A., Morawski, D., & Chalecki, M. (2021). Hydraulic and Technological Investigations of a Phenomenon Responsible for Increase of Major Head Losses in Exploited Cast-Iron Water Supply Pipes. Water 2021, Vol. 13, Page 1604, 13(11), 1604. https://doi.org/10.3390/W13111604

Xia, H. (2021). Research on the internal flow and macroscopic characteristics of a diesel fuel injection process. Plos One, 16(9). https://doi.org/10.1371/journal.pone.0255874

Xia, H., Luo, F., & Wang, Z. (2021). Experimental Research on the Measurement of High Pressure Microflow Based on Momentum Principle. Mathematical Problems in Engineering. https://doi.org/10.1155/2021/2393799

APPENDIX A

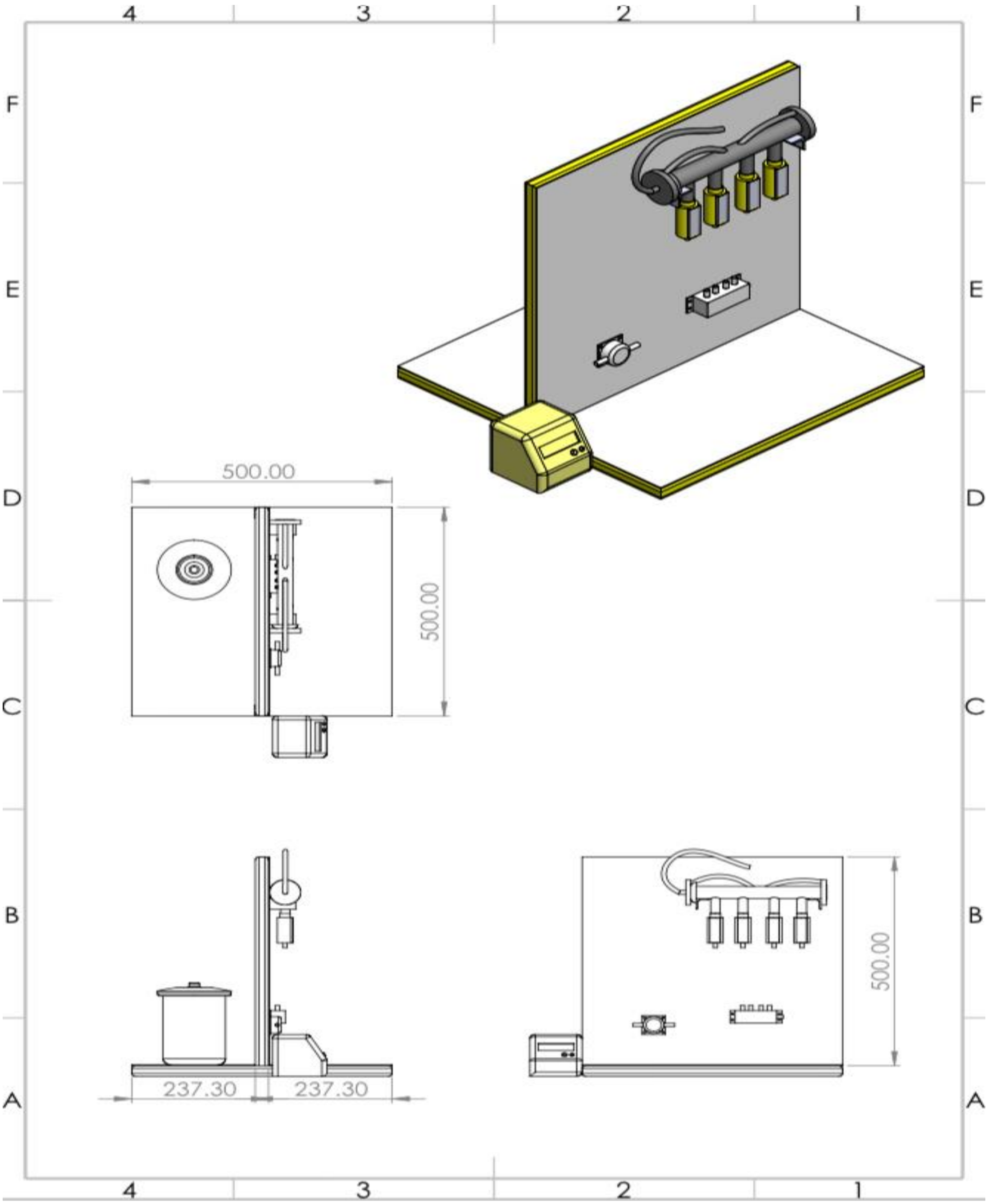
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame	Mild steel square pipe	1
2	Cover 1	Acrylic plastic	1
3	Cover 2	Acrylic plastic	1
4	Storage tank	Plastic tank	1
5	Cover 3	Acrylic plastic	1
6	Injector	Car injector	1
7	Spilt chamber	PLA plastic	4
8	Injector holder	Mild steel angle iron	2
9	4 to 1 junction	PLA plastic	1
10	Flow meter	Digital flow meter	1
11	Control	Control box	1



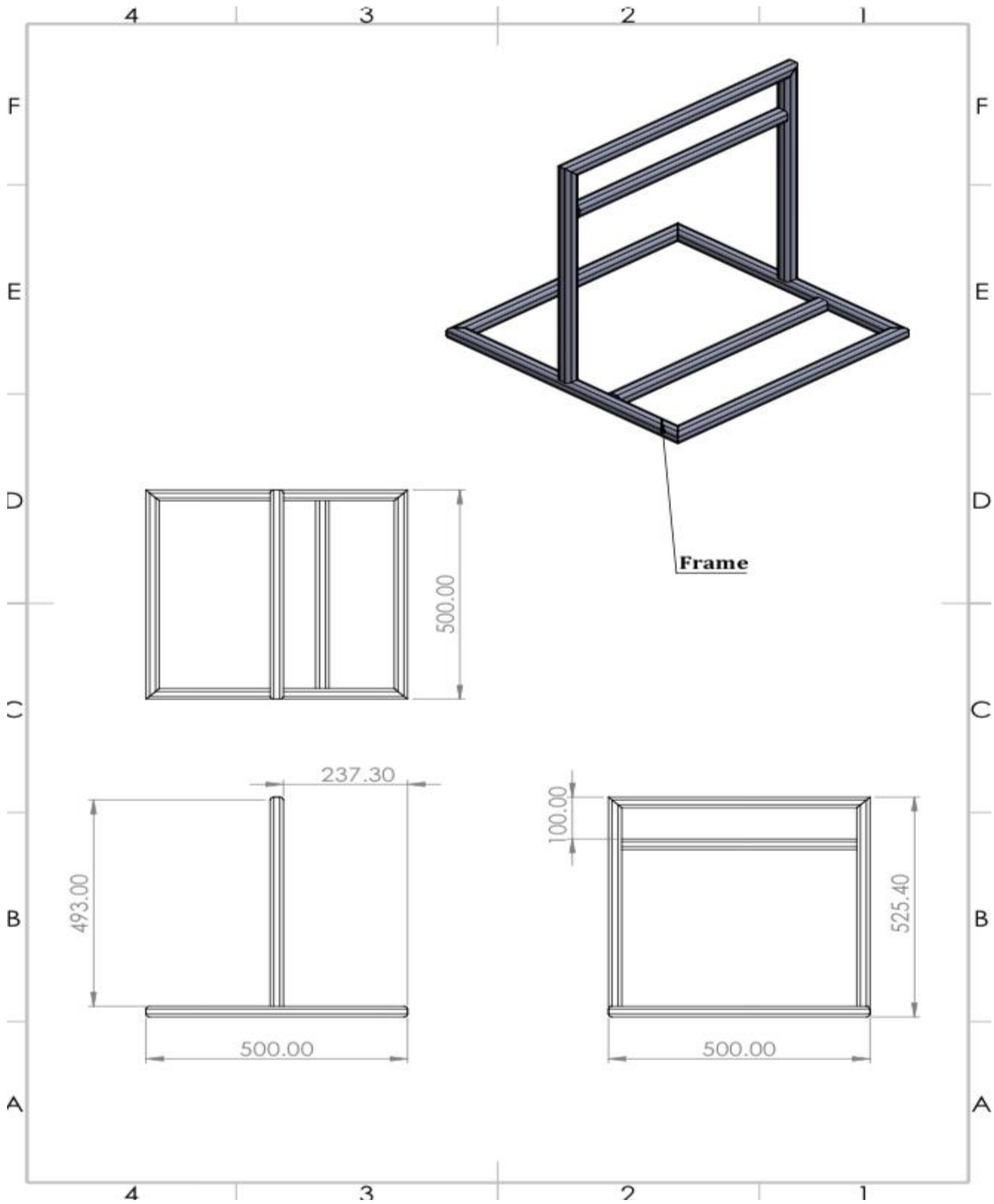
AFE BABALOLA UNIVERSITY, ADO EKITI (ABUAD)

PROJECT TITLE	
DEVELOPMENT OF CAR INJECTOR DEMONSTRATION SYSTEM	
DRAWN BY	WAREEBI GUWOR
MATRIC NO	17/ENG06/038
CHECKED BY	ENGR. I. D. UCHEGBU
APPROVED BY	ENGR. I. D. UCHEGBU
SCALE	1:10
DATE	JANUARY, 2022
ALL DIMENSION IN MILLIMETERS	

Appendix 1: CAD Exploded View of the Fuel Injector Kit



Appendix 2: Orthogonal View of the Fuel Injector



Appendix 3: Orthogonal View of the Frame

APPENDIX B

Microcontroller

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27,16,2);
int INJ1 = 3;
int INJ2 = 4;
int INJ3 = 5;
int INJ4 = 6;
int pump = 10;
intbut1=9 ; int butState1 = 0; int butState2 = 0; int butState3 = 0;

const int potM = A3;
const int potM1 = A2;
float accel = 0;
int accel2 = 0;
float dVolt = 0;
int startUp = 0;
int command = 0;
float flowData;
volatile int flow_frequency; // Measures flow sensor pulses
float  l_hour; // Calculated litres/hour
float  l_min; //new add
unsigned char flowsensor = 2; // Sensor Input
unsigned long currentTime;
unsigned long cloopTime;
unsigned long Time;
int Count = 1;
int counter;
long interval = 0;
unsigned long previousMillis = 0;
unsigned long Start, finished, elapsed;
```

```
float h, m, s, ms;
unsigned long over;
unsigned long startMillis;
unsigned long currentMillis;
unsigned long elapsedMillis;
int DELAY;

void flow () // Interrupt function
{
   flow_frequency++;
}
void setup() {
  Serial.begin(9600);
  lcd.init();
  lcd.init();
  lcd.backlight();
  lcd.setCursor(0,0);
  lcd.print("INJECTOR SYSTEM");
  lcd.setCursor(1,1);
  lcd.print("DEMONSTRATION");
  attachInterrupt(0, flow, RISING); // Setup Interrupt
   sei(); // Enable interrupts
   currentTime = millis();
   cloopTime = currentTime;
  digitalWrite( INJ1, LOW);
  digitalWrite( INJ2, LOW);
  digitalWrite( INJ3, LOW);
  digitalWrite( INJ4, LOW);
 pinMode(INJ1, OUTPUT);
 pinMode(INJ2, OUTPUT);
 pinMode(INJ3, OUTPUT);
 pinMode(INJ4, OUTPUT);
 pinMode(pump, OUTPUT);
 delay(5000);
```

```
startUp = 1; }

void loop() {
  butState1 = digitalRead(but1);
  accel = analogRead(potM1);
  dVolt = (accel/1022.0)*12; //219
  if (dVolt > 12) {
dVolt = 12; }

  Serial.println(elapsedMillis);
   if( startUp == 1 ) {
    lcd.clear();
  lcd.setCursor(1,0);
  lcd.print("PRESS KEY A");
  lcd.setCursor(2,1);
  lcd.print("FOR TESTING");
  delay(200);
}

  if (butState1 == HIGH) {
  counter = Count++;
  startUp = 2;
  delay(400);
}

 if (counter > 3) {
    Count = 0;
}

  if (counter == 1 && startUp == 2) {
 accel2 = map (analogRead(potM),0, 1021, 50, 500 ); //219
 lcd.clear();
//

lcd.setCursor(1,0);
lcd.print("Select S Time");
```

```
lcd.setCursor(5,1);
lcd.print(accel2);
lcd.setCursor(11,1);
lcd.print("ms");
delay(200);
}

 if (counter == 2 && startUp == 2) {
 Time = map(analogRead(potM), 0, 1021, 1, 10);
 interval = Time * 60000;
lcd.clear();
lcd.setCursor(1,0);
lcd.print("Select period");
lcd.setCursor(5,1);
lcd.print(Time);
  lcd.setCursor(9,1);
lcd.print("min");
delay(200);
}

 if (counter == 3 && startUp == 2) {
   unsigned long currentMillis = millis();
    currentTime = millis();
      Start = millis();
  // Every second, calculate and print litres/hour
  if(currentTime >= (cloopTime + 1000))
  {
     cloopTime = currentTime; // Updates cloopTime
     // Pulse frequency (Hz) = 7.5Q, Q is flow rate in L/min.
     l_hour = (flow_frequency * 60 / 7.5); // (Pulse frequency x
60 min) / 7.5Q = flowrate in L/hour
      l_min = (flow_frequency / 7.5);// new add
      flow_frequency = 0; // Reset Counter
}
```

```
  lcd.clear();
  lcd.setCursor(0,0);
  lcd.print("Volt=");
  lcd.setCursor(6,0);
  lcd.print(dVolt);
  lcd.setCursor(10,0);
  lcd.print("v");
  lcd.setCursor(0,1);
  lcd.print("S-T=");
  lcd.setCursor(4,1);
  lcd.print(accel2);
  lcd.setCursor(7,1);
  lcd.print("ms");
  lcd.setCursor(11,1);
  lcd.print("P=");
  lcd.setCursor(13,1);
  lcd.print(Time);
  lcd.setCursor(15,1);
  lcd.print("M");
  if (currentMillis - previousMillis > interval) {
      startUp = 3;
      previousMillis = currentMillis;
      finished = Start;
  }
}

if ( counter == 3 && startUp == 2) {
    digitalWrite(pump, HIGH);
    digitalWrite( INJ1, HIGH);
    delay(accel2);
    digitalWrite( INJ1, LOW);
    delay(accel2);
    digitalWrite( INJ3, HIGH);
    delay(accel2);
```

```
    digitalWrite( INJ3, LOW);
    delay(accel2);
    digitalWrite( INJ4, HIGH);
    delay(accel2);
    digitalWrite( INJ4, LOW);
    delay(accel2);
    digitalWrite( INJ2, HIGH);
    delay(accel2);
    digitalWrite( INJ2, LOW);
    delay(accel2);
}

  if (counter == 3 && startUp == 3) {
  digitalWrite(pump, LOW);
  digitalWrite( INJ1, LOW);
  digitalWrite( INJ3, LOW);
  digitalWrite( INJ2, LOW);
  digitalWrite( INJ4, LOW);
  lcd.clear();
  lcd.setCursor(2,0);
  lcd.print("Completed");
  lcd.setCursor(0,1);
  lcd.print("F R=");
  lcd.setCursor(4,1);
  lcd.print(l_min,4);
  lcd.setCursor(10,3);
  lcd.print("L/Min");
  delay(2500);
 startUp = 1;
 counter = 0;
} }
```