A project Report On

EXPERIMENTAL INVESTIGATION ON THE INFLUENCE OF HIGH INJECTION PRESSURES AND RETARDED INJECTION TIMINGS ONA SINGLE CYLINDER CRDI ENGINE

Submitted to

Jawaharlal Nehru Technological University, Anantapur

In partial fulfillment of the

Requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

By

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CERTIFICATE

This is to certify that the project report titled **"EXPERIMENTAL INVESTIGATION ON THE INFLUENCE OF HIGH INJECTION PRESSURES AND RETARDED INJECTION TIMINGS ON A SINGLE CYLINDER CRDI ENGINE"**

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DECLARATION

We hereby declare that the project entitled, **"EXPERIMENTAL INVESTIGATION ON THE INFLUENCE OF HIGH INJECTION PRESSURES AND RETARDED INJECTION TIMINGS ON A SINGLE CYLINDER CRDI ENGINE"** completed and written by us, has not been previously submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

Now-a-days, improved engine exhaust emissions with little or no deterioration in the performance of diesel engine are the main objective of research community. This may be achieved through the use of new technologies and/or modifying the engine hardware. Injection parameters in single cylinder diesel engines can be varied over a wide range using CRDI technology equipped with open ECU.

The Purpose of this study is to investigate the performance and exhaust emissions characteristics by applying retarded injections and varying Fuel Injection Pressures (FIPs) to determine the optimal injection that improves fuel efficiency and reduces exhaust emissions. It is established that retarded injection timing and smaller fuel droplets simultaneously reduce NOx and Smoke emissions of a typical diesel engine. Hence engine testing was carried out using diesel fuel at 1500 rpm, under 50%, 75% and 100% load at various retarded injection timings and injection pressures on a Kirloskar make TV1 type diesel Engine equipped with CRDI pump and open ECU. Reduced Ignition Delay and simultaneous reduction in oxides of nitrogen and smoke emissions with modest deterioration in performance are observed when the engine is operated at 500bar injection pressure and at a injection timing of 19^0 bTDC.

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CHAPTER 1

INTRODUCTION TO DIESEL ENGINE

Diesel engine is any internal combustion engine in which air is compressed to a sufficiently high temperature to ignite diesel fuel injected into the cylinder, where combustion and expansion actuate a piston. It converts the chemical energy stored in the fuel into mechanical energy, which can be used to power many automobiles.

1.1 Origin of Diesel Engine

Fig.1

The invention of the diesel engine goes way back – all the way to the 1890s. Since their introduction, they have remained one of the most common engines used in power generation applications. They have been useful in a variety of industries and functionalities.

In the 1870s, steam was the main supplier of power for factories and trains. Steam powered cars were even being produced alongside those using internal combustion engines. Rudolf Diesel, who invented diesel engines, was a student learning about thermodynamics at the time, and he got the idea for creating an engine that would be highly efficient and convert the heat it generated into power. He got to work developing what would become the diesel engine. He set up his first shop in 1885 to start the development of this new engine and to put his theories into practice. One of his hypotheses was that higher amounts of compression would lead to higher efficiency and power.

Diesel received patents for his designs during the 1890s. The first diesel engine prototype was built in 1893, though the first engine test was unsuccessful, In 1897, Diesel produced successful results after many improvements and tests. In February of that year, he was able to show an efficiency of 26.2% with the engine. Compared with the steam engine popular at the time, the engine Diesel had developed was more efficient by 16.2%.

1.2 Working of Diesel Engine

Diesel engines, like gasoline engines, are considered internal combustion engines. This means fuel is burned inside the main part of the engine where the power is produced. This made diesel engines more efficient than the steam-powered engines at the time, which were external combustion engines that burned fuel outside the cylinders of the engine.

Diesel engines use four-stroke combustion cycles to operate. These include:

- **Intake stroke:** Air comes into the cylinders through the intake valve, and pistons move down.
- **Compression stroke:** The pistons move up, compressing the air.
- **Combustion stroke:** Fuel is injected and ignited at a specific time, forcing the pistons down again.
- **Exhaust stroke:** As the pistons move back toward the top, exhaust created during the combustion process is pushed out.

The heat of the compressed air is what ignites fuel in a diesel engine. Modern diesel engines are up to twice as efficient as gasoline engines which means you can travel farther on the same amount of fuel.

1.3 Diesel Engine vs. Petrol Engine

The Diesel versus Petrol engine comparison has been ongoing since the time of their inception. The primary difference is that petrol engines use spark plugs to ignite the air fuel mixture, while diesel engines rely on heavily compressed air without any spark plugs.

So, in diesel engines, air is very heavily compressed, while in petrol engines, the compression ratio is generally much lower.

Diesel engines have lower specific fuel consumption than gasoline engines, so they are more economical, they have a better operating characteristic, i.e. they change the number of revolutions very little with the change of load.

Diesel engines provide more efficiency by using 15-20% less fuel compared to petrol engines. The low-end torque of diesel engines provides a much better highway driving experience.

Diesel engines have always been more fuel efficient, durable and delivered more torque than petrol engine. Typically, they contain less toxic pollutants but they did have higher quantities of carbon (soot) in their exhaust than gasoline engines.

1.4 Emissions from diesel engine

Diesel engines are more widely used than petrol engines due to their low maintenance cost, energy efficiency, high durability and reliability. Although they have many benefits, they have a significant impact on environmental pollution issues worldwide which can cause serious environmental and health problems.

For ideal thermodynamic equilibrium, full combustion of diesel fuel produces only CO2 and H2O in the combustion chambers of the engine. However, many factors such as air-fuel ratio, ignition time, combustion chamber turbulence, combustion form, air-fuel density, combustion temperature, etc. put it out of question and many harmful products are produced during combustion. The most important harmful products are CO, HC, NOx and PM.

Carbon monoxide (CO):

Carbon monoxide is formed as a result of incomplete combustion in which the oxidation process does not take place completely. This concentration is largely dependent on the air / fuel mixture and is classified as a rich mixture where the excess-air factor (λ) is less than 1.0. This is especially true during engine start and instantaneous acceleration, which requires rich mixing. In enriched compounds, due to the absence of air and reactant concentrations, not all carbon is converted to CO and CO is not converted to concentration. Although CO is produced during operation in rich mixes, even a small fraction of CO is released under lean conditions due to chemical kinetic effects.

Diesel engines are lean combustion engines with a consistently high air-fuel ratio. Therefore, CO formation in diesel engines is very low. However, if the droplets in the diesel engine are too large or there is enough turbulence or swirl in the combustion chamber, CO will be produced.

Carbon monoxide is an odorless and colorless gas. In humans, the CO in the air is absorbed by the lungs and circulated in the bloodstream. It binds to hemoglobin and inhibits its ability to transfer oxygen. Depending on the concentration of CO in the air, it can lead to asphyxia, which affects the function of various organs, resulting in impaired concentration, slow reactions and confusion.

Hydrocarbons (HC):

Hydrocarbon emissions are composed of unburned fuels as a result of insufficient temperature which occurs near the cylinder wall. At this point, the air-fuel mixture temperature is significantly less than the center of the cylinder. Hydrocarbons consist of thousands of species, such as alkanes, alkenes, and aromatics. They are normally stated in terms of equivalent CH4 content.

Diesel engines normally emit low levels of hydrocarbons. Diesel hydrocarbon emissions occur principally at light loads. The major source of light-load hydrocarbon emissions is lean air-fuel mixing. In lean mixtures, flame speeds may be too low for combustion to be completed during the power stroke, or combustion may not occur, and these conditions cause high hydrocarbon emissions.

In Diesel engines, the fuel type, engine adjustment, and design affect the content of hydrocarbons. Besides, HC emissions in the exhaust gas depend on irregular operating conditions. High levels of the instantaneous change in engine speed, untidy injection, excessive nozzle cavity volumes, and injector needle bounce can cause significant quantities of unburned fuel to pass into the exhaust.

Unburned hydrocarbons continue to react in the exhaust if the temperature is above 600°C and oxygen present, so hydrocarbon emissions from the tailpipe may be significantly lower than the hydrocarbons leaving the cylinder. Hydrocarbons have harmful effects on the environment and human health. With other pollutant emissions, they play a significant role in the formation of ground-level ozone. Vehicles are responsible for about 50% of the emissions that form ozone. Hydrocarbons are toxic with the potential to respiratory tract irritation and cause cancer.

Retarding SOI timings lowers the in-cylinder pressure and temperature during combustion, which in turn increases the unburnt hydrocarbon emissions. At higher FIPs, BSHC emissions increased sharply, when the SOI timings were close to TDC. This was possibly due to piston wall impingement of the fuel sprays because, during the fuel injection, the piston remains very close to the injector tip.

Nitrogen oxides (NOx):

It refers to oxides of nitrogen. The purists would say that it refers to nitric oxide (NO) and nitrogen dioxide (NO2). Nitrogen oxides are produced due to High temperature combustion of fuels where the temperature is hot enough to oxidize some of the nitrogen in air to NOx gases. This includes burning hydrogen, as it burns at a very high temperature. As the diesel engines operate at a higher temperature and pressure than petrol engines. These conditions favor the production of NOx gases. The quantity depends on the volume and duration of the hottest part of the flame.

NOx has direct and indirect effects on human health. It can cause breathing problems, headaches, chronically reduced lung function, eye irritation, loss of appetite and corroded teeth. Indirectly, it can affect humans by damaging the ecosystems they rely on in water and on land—harming animals and plants. NOx emissions can be reduced by lowering the combustion temperature, typically by Exhaust Gas Recirculation (EGR).

Some exhaust gas is cooled and injected back into the combustion chamber. There is less oxygen in the exhaust gas because some has been consumed by previous combustion, so there is not as much to feed the flame. The exhaust gas also has a higher heat capacity than air, so it takes longer to heat up.

Particulate Matter (PM):

Particulate matter—most commonly associated with diesel engines—is responsible for the black smoke traditionally associated with diesel powered vehicles. The existing medical research suggests that PM is one of the major harmful emissions produced by diesel engines. Exhaust from trucks, buses, trains, ships, and other equipment with diesel engines contains a mixture of gases and solid particles. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron - 5 - microscope. These particles come in many sizes and shapes and can be made up of hundreds of different chemicals.

Particulate matter contains microscopic solids or liquid droplets that are so small that they can be inhaled and cause serious health problems. Some particles less than 10 micrometers in diameter can get deep into your lungs and some may even get into your bloodstream. Of these, particles less than 2.5 micrometers in diameter, also known as fine particles pose the greatest risk to health. Fine particles are also the main cause of reduced visibility (haze) in parts of the United States, including many of our treasured national parks and wilderness areas.

1.5 Techniques to Control Emissions

The particulate and NO x emission cause several serious health problems; therefore, it is necessary to reduce these emissions from the tailpipe. In the past decades, significant technological advancements have been made in the field of engine emission control. In modern diesel engines, smarter electronic fuel injection strategies are being employed.

Control of engine emissions can be done by two ways:

1. Active control techniques
2. Passive control techniques

Active control techniques:

Active control techniques are those which restrict the formation of the pollutants in the combustion chamber itself. These techniques include advancement in the combustion chamber design, use smarter electronic fuel injection system, exhaust gas recirculation, high-pressure multi-fuel injection with precise injection timing, homogenous charge compression ignition, etc.

Passive control techniques:

Passive control techniques refer to after-treatment devices. Although active control techniques are able to reduce the emission up to some extent, but in order to meet the modern emission regulations, passive techniques are also required in addition to active techniques. Passive control technique involves after-treatment devices like diesel oxidation control, diesel particulate trap, NO x absorber, selective catalytic reduction.

1.6 Injection Pressure

Fuel injection pressures in diesel engine plays an important role for engine performance obtaining treatment of combustion. The present diesel engines such as fuel direct injection, the pressures can be increased about 100 – 200 MPa bar in fuel pump injection system.

In present diesel engines, fuel injection systems have designed to obtain higher injection pressure. So, it is aimed to decrease the exhaust emissions by increasing efficiency of diesel engines. When fuel injection pressure is low, fuel particle diameters will enlarge and ignition delay period during the combustion will increase. This situation leads to increase pressure. Engine performance will be decrease since combustion process goes to a bad condition. When injection pressure increased of fuel particle diameters will become small. Since formation of mixing of fuel to air becomes better during ignition period, engine performance will be increase. If injection pressure is too higher, ignition delay period becomes shorter. Possibilities of homogeneous mixing decrease and combustion efficiency decreases.

Injection Timing:

In an internal combustion engine, thermal energy transfers into mechanical energy. The created power moves an engine's pistons, therefore, moving the crankshaft. Thermal energy comes from the combusted air-fuel mixture inside the cylinder. A piston moves inside the cylinder from the bottom dead centre to the top dead centre during combustion.

Injection timing, also called spill timing, is the moment when diesel fuel enters the cylinder during the combustion phase. When you adjust the timing, you can alter when the engine injects the fuel, therefore changing when combustion occurs.

An injection pump is often driven indirectly from the crankshaft by chains, gears or a timing belt that also moves the camshaft. The timing of the pump determines when it will inject fuel into the cylinder as the piston reaches the BTDC point.

There are a few terms you'll need to know to understand how the piston moves inside the cylinder, including:

- **Top Dead Centre (TDC):** Top dead centre is when the piston is at the top of the cylinder, positioning itself farthest from the crankshaft.
- **Bottom Dead Centre (BDC):** Bottom dead centre is when the piston is closest to the crankshaft at the cylinder's lowest point.
- **Before Top Dead Centre (BTDC):** Before top dead center is the point right before the piston reaches the highest area of the cylinder.

Advantages from adjusting fuel injection timing:

- Boosted engine power capabilities
- Higher peak cylinder pressure
- Lower exhaust temperatures
- Higher NOx emissions
- Increased fuel efficiency

1.7 Fuel Injection System

The fuel injection system lies at the very heart of the diesel engine. By pressurizing and injecting the fuel, the system forces it into air that has been compressed to high pressure in the combustion chamber.

The purpose of the fuel injection system is to deliver fuel into the engine cylinders, while precisely controlling the injection timing, fuel atomization, and other parameters.

1.8 Single Point Injection System

Single point fuel injection system is the type of fuel injection system that uses a single fuel injector for mixing of the fuel. It has only one injector that injects the fuel before entering into the intake manifold.

In this system, the fuel is mixed with fuel before the throttle valve. The single-point fuel injection system is also known as throttle body injection. In a single-point fuel injection system, the fuel injector is arranged before the throttle body.

The amount of fuel to be injected is decided by the engine control unit. The engine control unit takes the input from different sensors and decides the amount of fuel to be supplied for the injection. The fuel injector sprays the fuel for mixing with the flow of air and this air-fuel mixture enters the intake manifold. The intake manifold further distributes the mixture to all cylinders.

Advantages of single point fuel injection system:-

1. Simple construction.
2. Accurate fuel supply.
3. Easy maintenance.
4. It uses only single injector.
5. Reliable operation.

Disadvantages of single-point fuel injection system:-

1. Uninform fuel supply to all cylinders.
2. Less efficient.
3. It wets the intake manifold by forming a layer of fuel on the intake manifold.
4. Lower fuel economy.

1.9 Multi-Point fuel injection system:

While conventional fuel injection systems employ a single injection event for every engine cycle, newer systems can use multiple injection events. One or more injections before the main injection, pre-injections, provide a small amount of fuel before the main injection event.

The Multi-Point Fuel Injection system is a way of injecting the fuel in an internal combustion engine through multiple ports located on the intake valve of every cylinder . These ports work together to deliver the optimum quantity of fuel at the right time to every cylinder. In all, there are three varieties of MPFI units – Batched, Simultaneous, and Sequential.

In the first kind of Multi-Point Fuel Injection system, the fuel is released to the cylinders by the ports in batches without getting their intake stroke together. In the Simultaneous MPFI systems, the fuel is released in all the cylinders of the engine simultaneously, while in the sequential type, the fuel release is timed to take place at the same time as the intake stroke for each cylinder of the engine.

The term split injection is occasionally used to refer to multiple injection strategies where a main injection is split into two smaller injections of approximately equal size or into a smaller pre-injection followed by a main injection.

Advantages of Multi Point Fuel Injection System:

1. Improvement in Fuel Efficiency
2. Lower Carbon emissions
3. Improvement in Engine Performance
4. Improvement in Engine Refinement

Split injection:

The major pollutants from diesel engines are NOx and soot. NOx and soot emissions are of concerns to the international community. They have been judged to pose a lung cancer hazard for humans as well as elevating the risk of non-cancer respiratory ailments.

Stringent exhaust emission standards require the simultaneous reduction of soot and NOx for diesel engines; however, it seems to be very difficult to reduce NOx emission without increasing soot emission by injection timing. The reason is that there always is a contradiction between NOx and soot emissions when the injection timing is retarded or advanced.

Split injection has been shown to be a powerful tool to simultaneously reduce soot and NOx emissions for direct injection & indirect injection diesel engines when the injection timing is optimized. It is defined as splitting the main single injection profile in two or more injection pulses with definite delay dwell between the injections.

In the recent years, the main studies about the effect of the split injection on the combustion process and pollution of DI and IDI diesel engines showed that the nitric oxide and the particulates could be reduced by over 83 % and almost 24 %, respectively while maintaining a reasonable value of specific fuel consumption.

1.10 Indirect Injection System

IDI diesel engines utilize a pre-combustion chamber, typically referred to as a swirl chamber or prechamber. Fuel is injected into the prechamber where it rapidly mixes with air and auto ignition occurs. As the flame expands in the pre-chamber, it forces the fuel to enter the combustion chamber rapidly, effectively mixing the fuel with air in the cylinder and atomization is achieved. The glow plug is also located in the prechamber, and the shape of the pistons in an IDI tend to resemble those of a gasoline engine.

1.11 Direct Injection System

DI diesel engines inject fuel directly into the combustion chamber, right into the top of the piston. The pistons on a DI engine typically have a bowl or cup machined into them that the fuel is directed into. DI engines operate at higher injection pressures and therefore more complete atomization occurs, meaning these engines do not require a prechamber to ensure proper diffusion of the fuel into the air.

Fig.2(a)

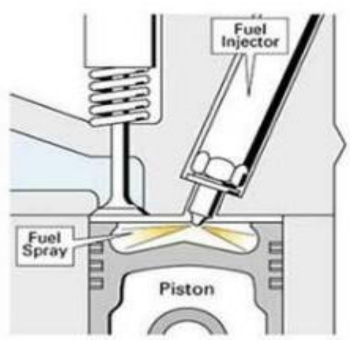


Fig.2(b)

1.12 COMMON RAIL DIRECT INJECTION SYSTEM

The term CRDI stands for Common Rail Direct Injection. The technology directly injects fuel into the cylinders of a diesel engine through a single, common line, known as the common rail. The common rail is connected to all the fuel injectors.

Regular diesel direct fuel-injection systems have to build up pressure for every new injection cycle. Engines featuring the new common rail maintains a constant pressure regardless of the injection sequence. This pressure is said to be permanently available throughout the fuel line. Instant atomization takes place and this spray is very fine and evenly distributed aiding efficiency and power delivery. Also, the injectors can inject up to 5 times per combustion cycle which gives a more uniform and controlled combustion and helps extract maximum energy from the combustion cycle.

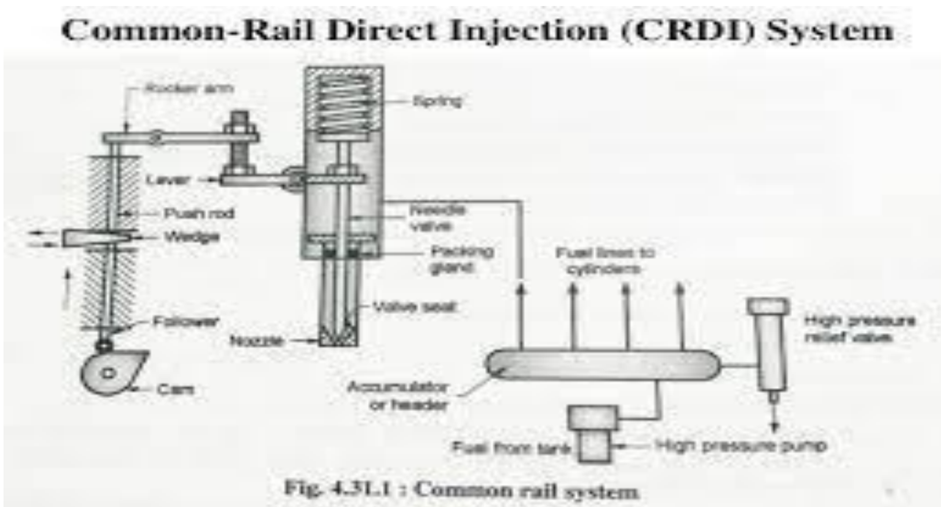


Fig.3

1.13 Working of CRDI System:

1. As you can see in the diagram of the CRDI system, the high-pressure pump is used to supply fuel to the accumulator or common rail. In case pressure in the accumulator increases beyond the limit, the high-pressure relief valve which is connected to the accumulator helps to reduce the pressure.
2. Now, this fuel from the accumulator supplied to engine cylinders using fuel lines with the help of injectors.
3. Another spring-loaded high-pressure relief valve used to maintain the constant pressure in the system for smooth operations. It also returns the extra fuel of the accumulator to the fuel tank.
4. The needle valve is used to control the opening and closing of the nozzle while it sprays the fuel into the cylinders. The upward and downward motion of the nozzle is measured by the cam.

5. Cam is connected to the spring with the help of a rocker arm and lever. During the dwell period of the cam, spring with the help of the needle valve prevents the injection of the fuel into the cylinder.
6. The packing gland ensures the level of the fuel above the valve seat for better injection of the fuel into the cylinders.
7. The wedge plays the main role in this system. It controls the amount of fuel to be injected into the cylinder in accordance with the power required for the engine. The wedge is operated by a governor, or it can be operated manually as per requirement.

1.14 Components of Common Rail Direct Injection System:

1. High Pressure Fuel Pump
2. Common Fuel Rail
3. Injectors
4. Engine Control Unit

High Pressure Fuel Pump:

The high-pressure pump compresses the fuel and supplies it in the required quantity. It constantly feeds fuel to the high-pressure reservoir, thereby maintaining the system pressure. The required pressure is available even at low engine speeds, as pressure generation is not linked to the engine speed. Most common rail systems are equipped with radial piston pumps. Compact cars also use systems with individual pumps which operate at a low system pressure.

Common Fuel Rail:

Common rail is a fuel injection system found in modern diesel engines. Common rail systems provide a level of flexibility which can be exploited for class leading emission control, power and fuel consumption

Injectors:

The injector in a common rail system consists of the nozzle, an actuator for Piezo injectors or a solenoid valve for solenoid valve injectors, as well as hydraulic and electrical connections for actuation of the nozzle needle.

Engine Control Unit:

The Engine Control Unit is a central part of the Engine Management System, which is virtually the ‘Brain’ of the engine. It plays an important role in collecting, analyzing, processing, and executing the data.

Advantages of CRDI System:

1. Cars fitted with this new engine technology are believed to deliver 25% more power and torque than the normal direct injection engine.
2. It also offers superior pick up, lower levels of noise and vibration, higher mileage, lower emissions, lower fuel consumption, and improved performance. 3. In India, diesel is cheaper than petrol and this fact adds to the credibility of the common rail direct injection system.

Disadvantages of CRDI System:

Like all good things have a negative side, this engine also have few disadvantages. The key disadvantage of the CRDI engine is that it is costly than the conventional engine. The list also includes high degree of engine maintenance and costly spare parts. Also, this technology can't be employed to ordinary engines.

Applications:

The most common applications of common rail engines are marine and locomotive applications. Also, in the present day they are widely used in a variety of car models ranging from city cars to premium executive cars.

Some of the Indian car manufacturers who have widely accepted the use of common rail diesel engine in their respective car models are the Hyundai Motors, Maruti Suzuki, Fiat, General Motors, Honda Motors, and the Skoda. In the list of luxury car manufacturers, the Mercedes-Benz and BMW have also adopted this advanced engine technology. All the car manufacturers have given their own unique names to the common CRDI engine system.

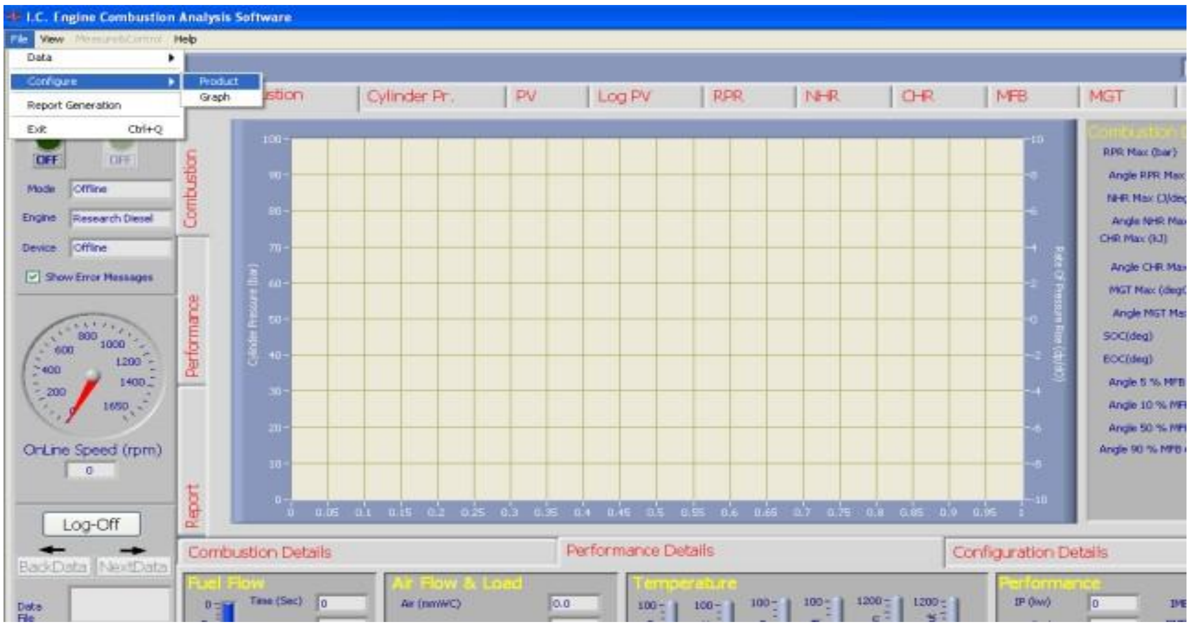
However, most of the car manufacturers have started using the new engine concept and are appreciating the long term benefits of the same. The technology that has revolutionized the diesel engine market is now gaining prominence in the global car industry.

1.15 Introduction to IC Engine Soft:

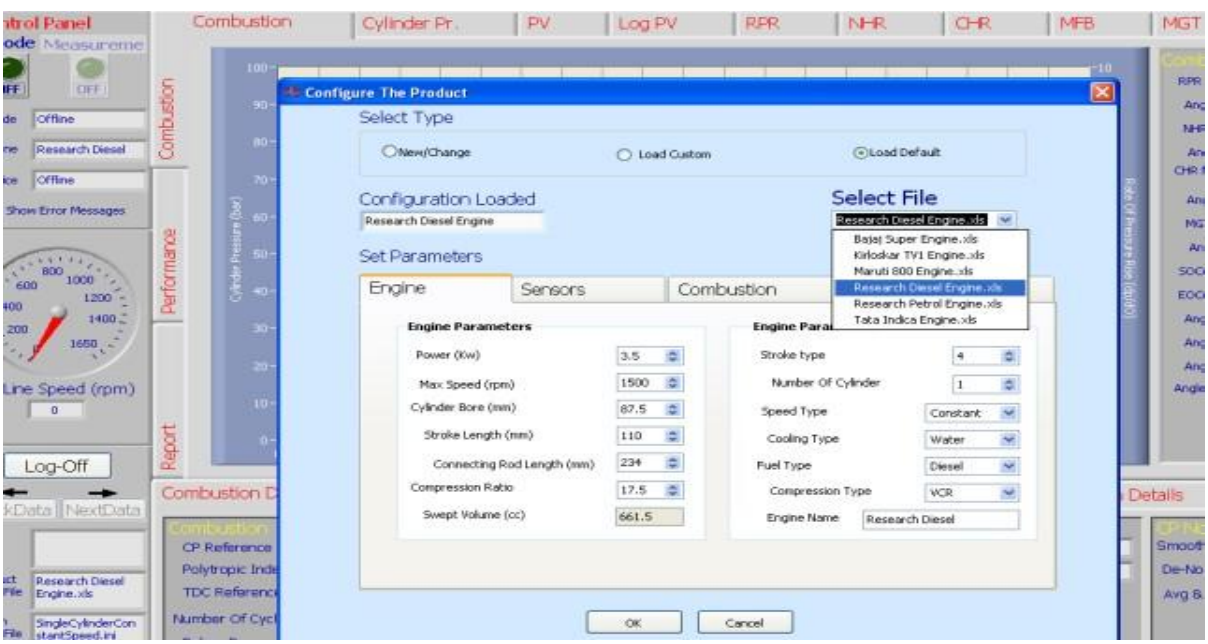
The IC Engine soft also known as Internal Combustion Engine software which is used for the simulation purpose of an IC Engine. This software serves the purposes like monitoring, reporting, data entry, data logging. Necessary signals are scanned and stored through online testing of the engine in RUN mode which can be used for further analysis. By providing the input values of density, heating value of fuel and the ambient temperature of air, the software gives the complete summary of combustion and performance of the engine.

STEPS INVOLVED IN IC Engine Soft:

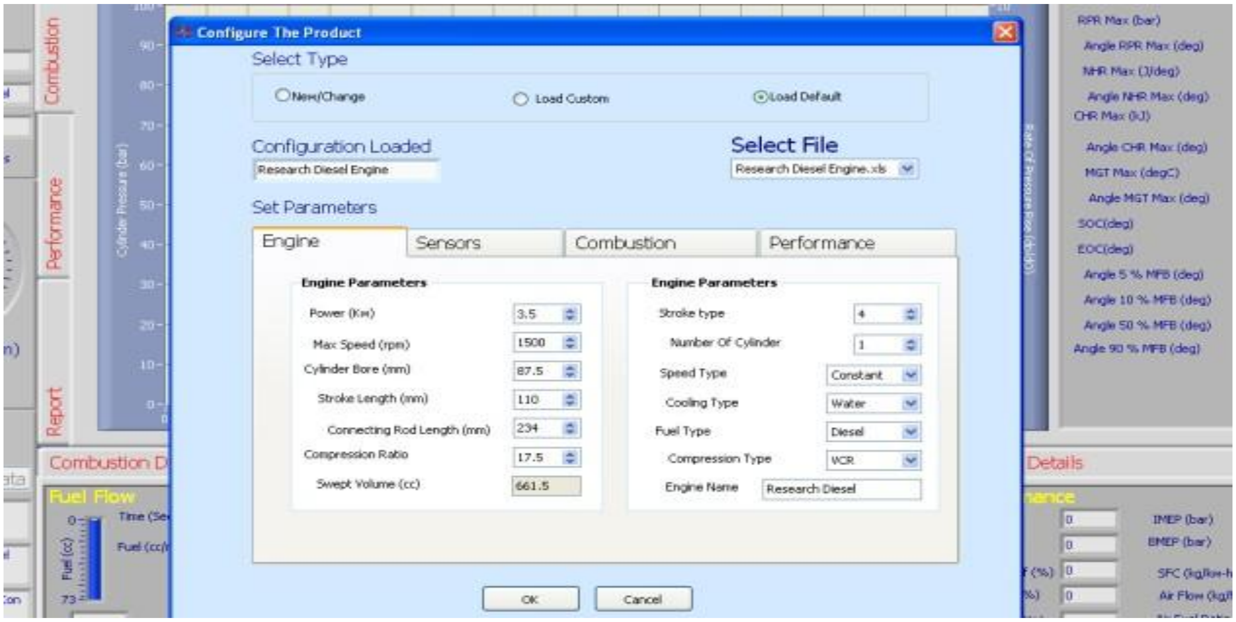
STEP 1: Select: File| Configure |Product



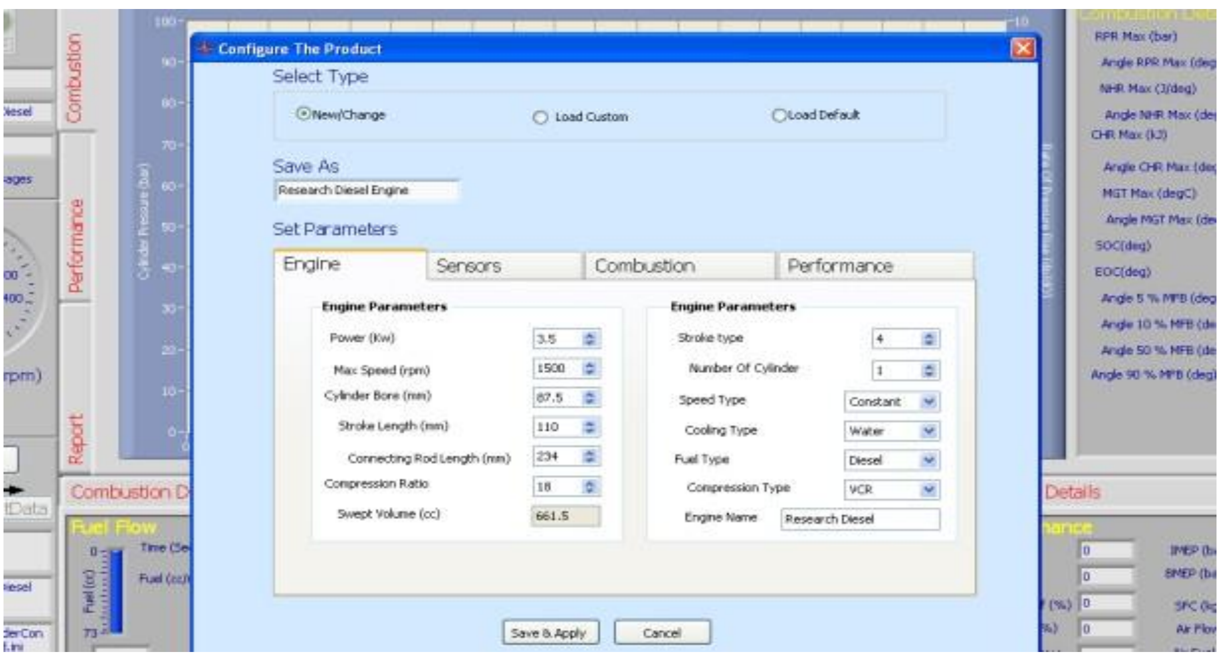
STEP 2: In “Configure the product” window select “Load Default”. Under “Select File” choose your Setup from drop down menu.



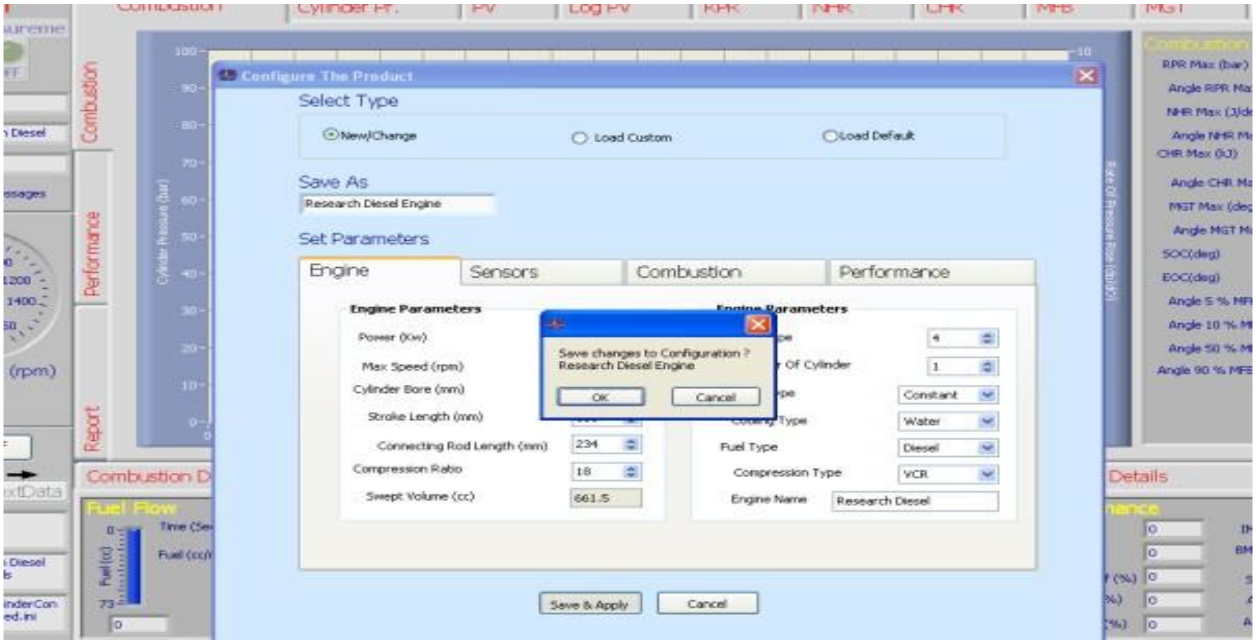
STEP 3: Under "Set Parameters" study the parameters under Engine, Sensors, Combustion and Performance tabs. Click on "OK "



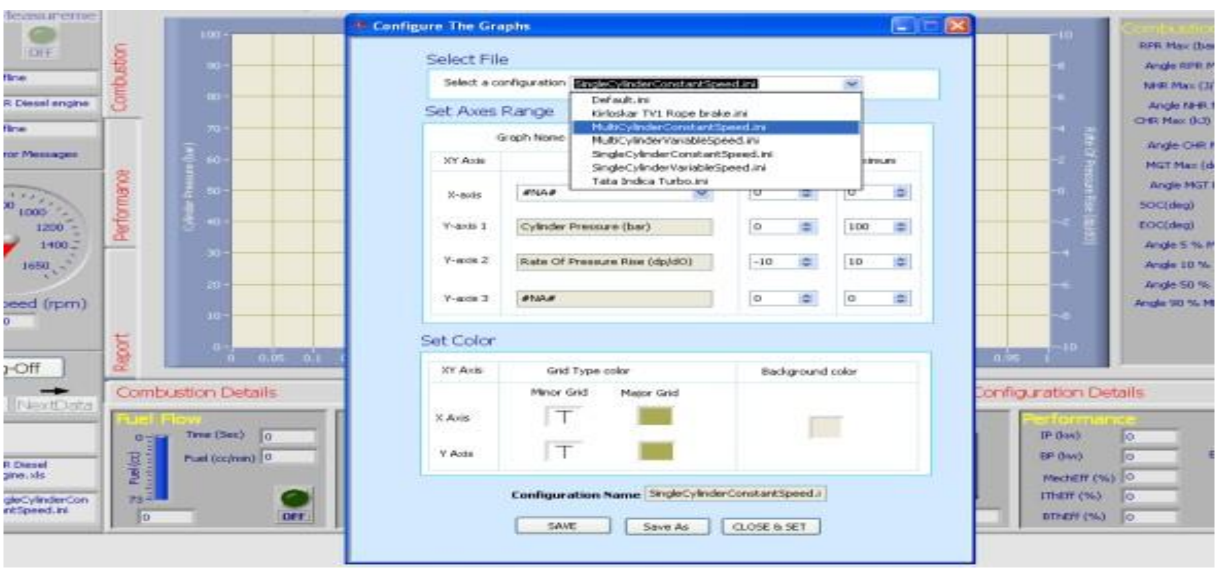
STEP 4: If any parameter is to be changed Click "New/Change". Change the parameter under respective tabs. After all changes click "Save & Apply"



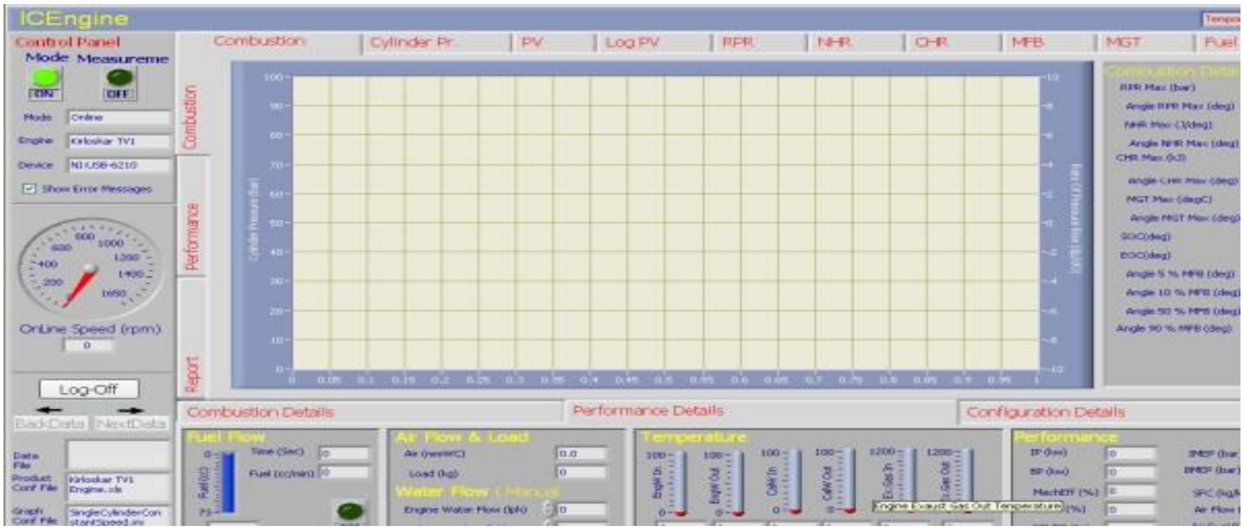
STEP 5: Click "OK" to save changes



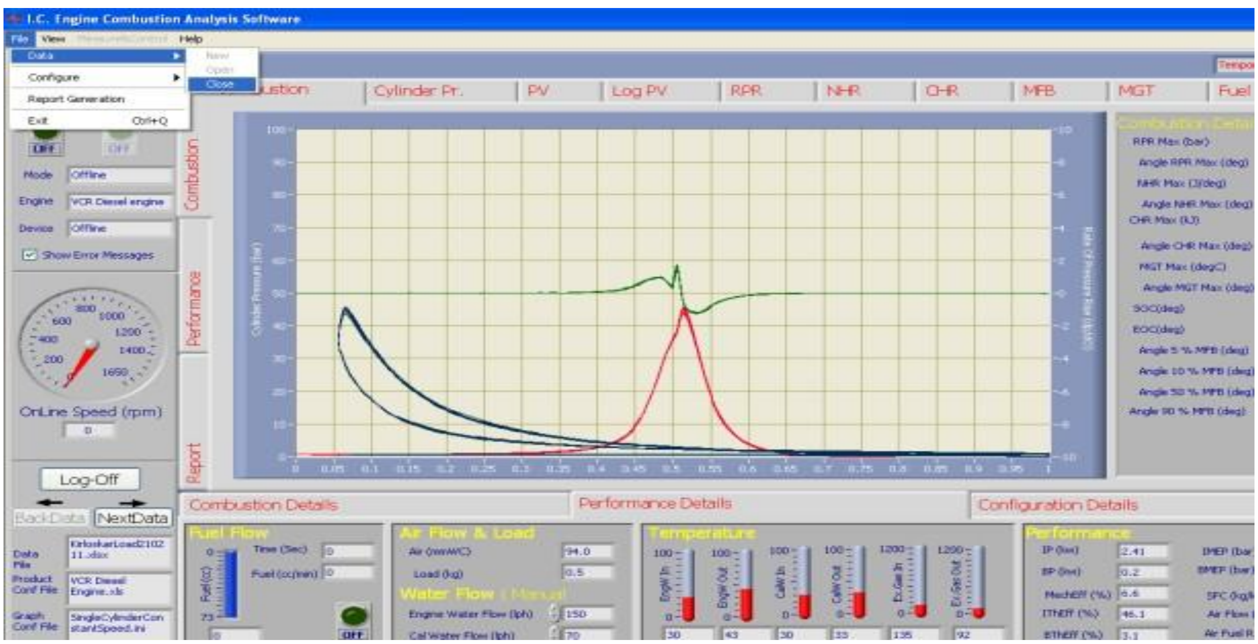
STEP 6: Under "Configure The Graphs" window "Select a Configuration" from the drop down menu. Study the preset configuration of X axis, Y axis, graph ranges, Colors for the selected graphs. Click "CLOSE & SET. Configure the necessary parameters, ranges, colours as required. Click "SAVE" / "Save As" and then"Close & SET".



STEP 7: Switch on the electric supply for engine panel and start the engine. Click toggle switch "Mode" to Start/Stop the device communication. (Green color indicates ON condition). Click toggle switch "Measureme" to Start/ Stop data acquisition. (Green color indicates ON condition).

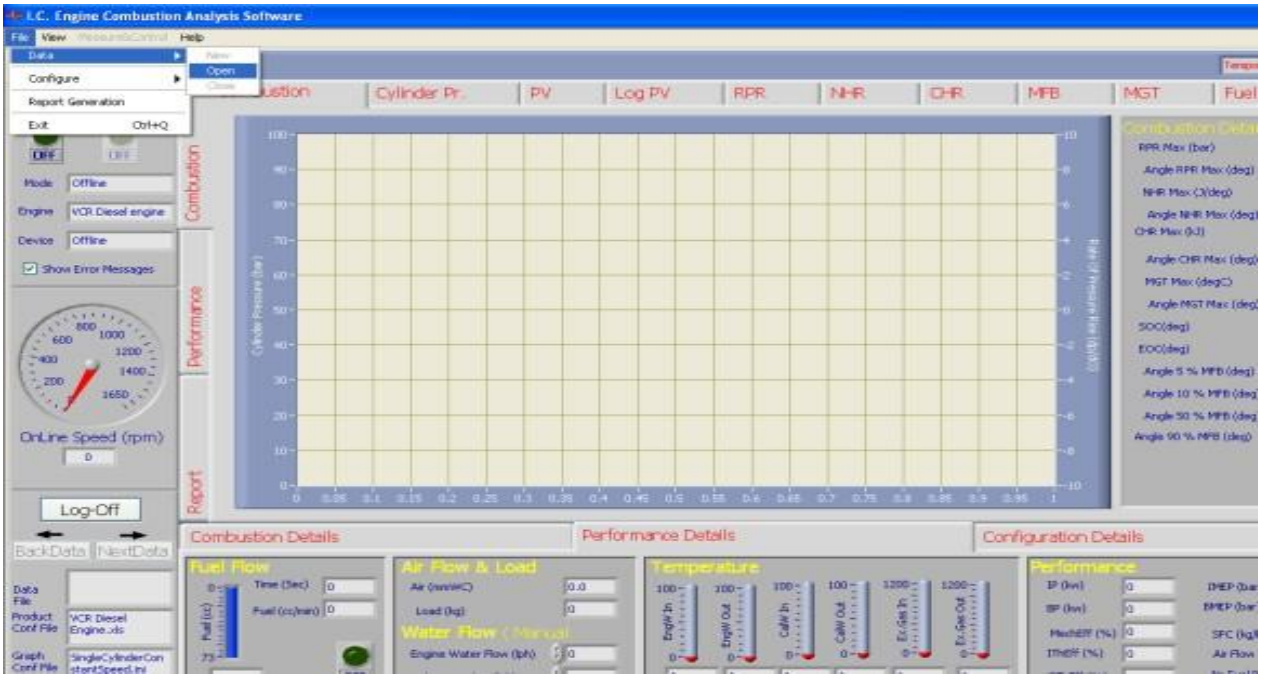


STEP 8: For storing the reading click Log ON and follow the screen instructions. When prompted enter the file name for the data to be logged. Click toggle switch "Measureme" to Stop data acquisition. Click toggle switch "Mode" to Stop the device communication. Click: File|Data|Close.

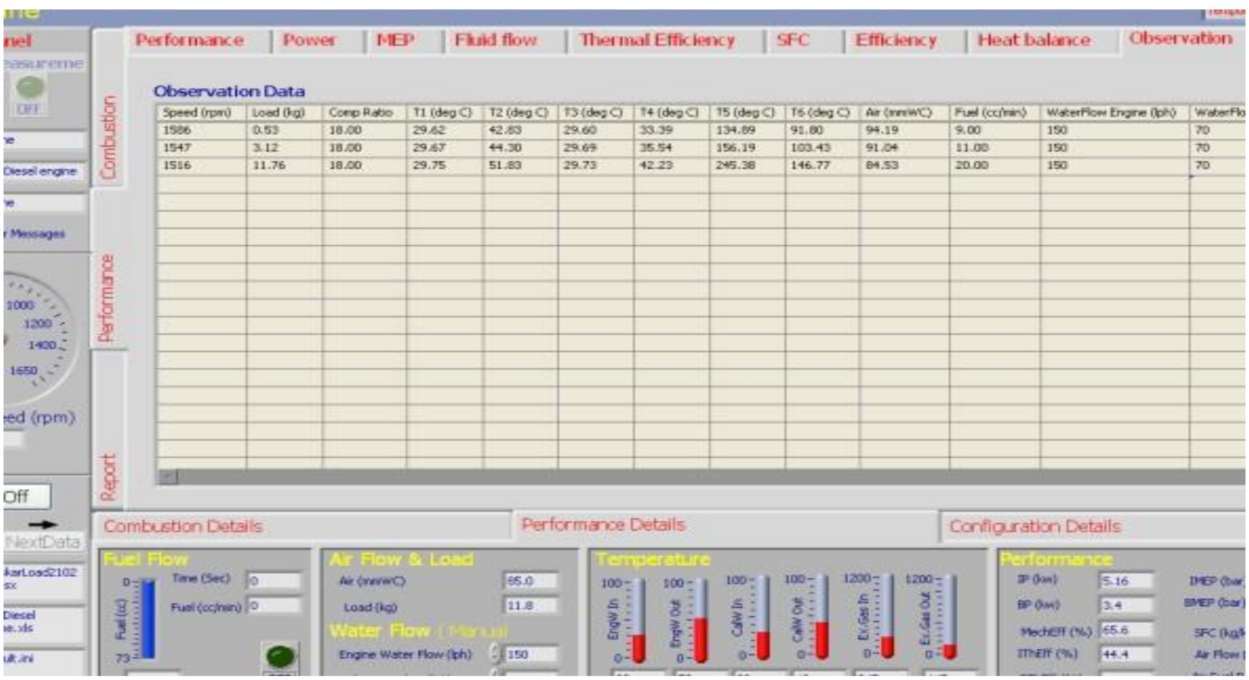


STEP 9: Stop the engine and switch off the electric supply for engine panel.

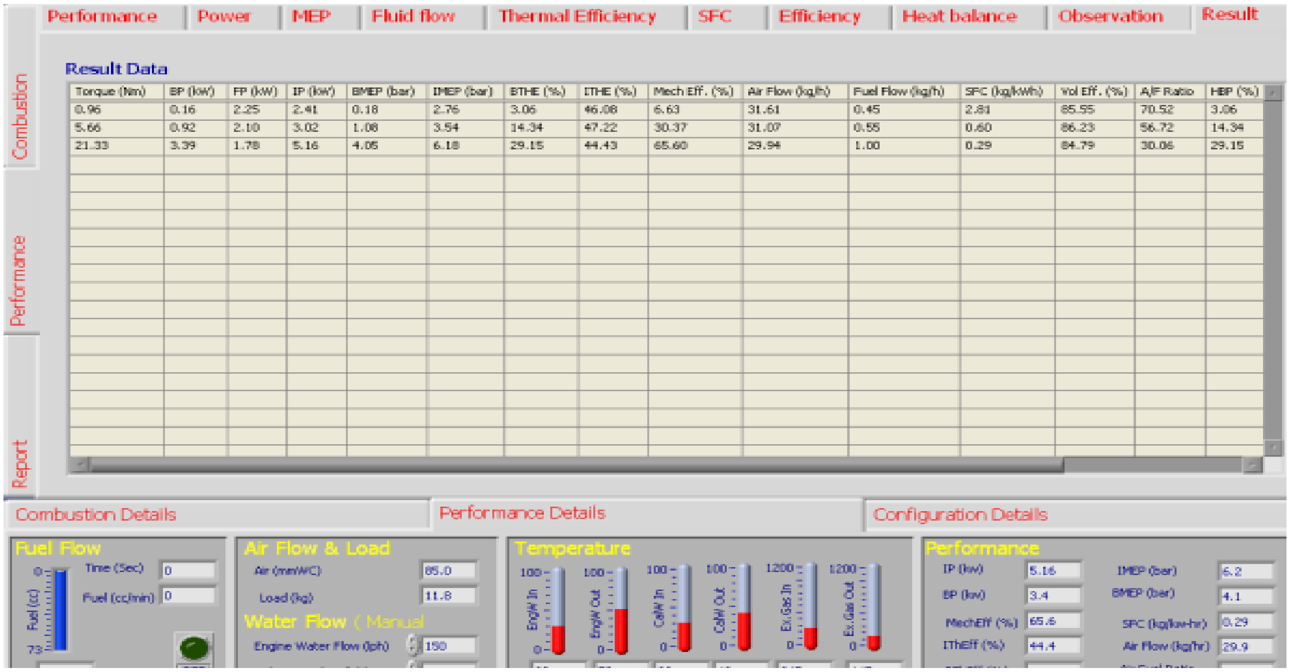
STEP 10: Click File|Data|Open and Select the data file to be viewed.



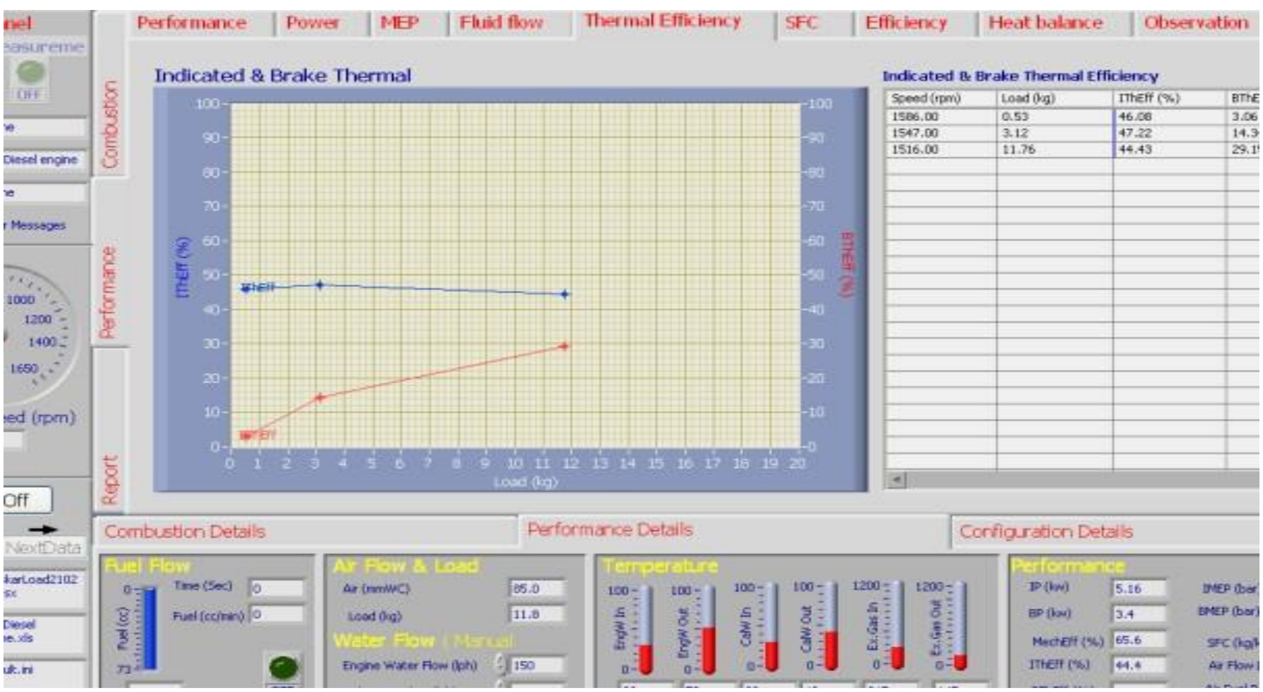
STEP 11: Select “Observation” tab under Performance tab to view “Observation Data“



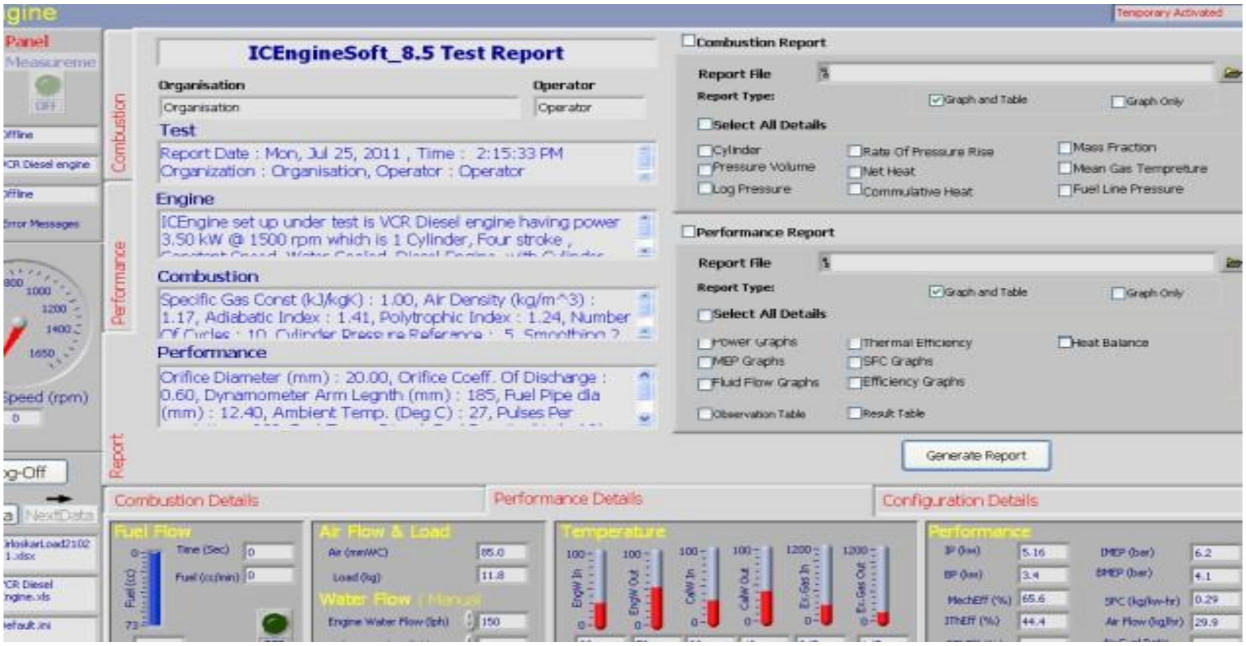
STEP 12: Select "Result" tab under Performance tab to view "Result Data"



STEP 13: Select "Thermal Efficiency" tab under Performance tab to view Indicated and Brake thermal efficiency plots.



STEP 14: Click "Report" tab for generating Performance Report, Combustion Report. Enter File name in "Report File". Select the Report Requirements viz. Result Data, Observation Data, Graph Only OR Graph and Table.



CHAPTER 2

LITERATURE REVIEW

Before commencing our project, we needed some input or a general outlet of our topic, so we resorted towards few study papers of some renowned authors on Performance analysis of CRDI engine, Analysis on injection timing and injection pressure, Analysis on emissions from diesel engines etc. Many authors portrayed different ideas related to their work. The different papers reviewed by us are listed below.

2.1 Combustion, performance and emissions characteristics of a newly developed CRDI single cylinder diesel engine. Avinash Kumar Agarwal∗, Paras Gupta and Atul Dhar [1]

Worked on Combustion, performance and emissions characteristics of a newly developed CRDI single cylinder diesel engine. This paper covers experimental investigations of a simpler version of CRDI system developed for a constant-speed, single-cylinder engine. Modifications in the cylinder head for accommodating solenoid injector, designing injector driver circuit and development of high pressure stage controls were some of the engine modification and development tasks undertaken. SOI timing is an important parameter for improving engine's combustion characteristics. SOI timings were varied between 25◦ and 40◦ BTDC for investigating engine's performance, emissions and combustion characteristics. Advanced fuel injections showed higher heat release rate (HRR), cylinder pressure and rate of pressure rise (RoPR) because of relatively longer ignition delay experienced. Lowest brake specific fuel consumption (BSFC) was obtained for 34◦ CA BTDC SOI. Reduction in engine out emissions except NOx was observed for advanced fuel injection timings for this newly developed CRDI system.

2.2 An experimental investigation of the effect of the injection pressure on engine performance and exhaust emission in indirect injection diesel engines by Ismet Celikten [2]

Worked on the effect of the injection pressure on engine performance and exhaust emission in indirect injection diesel engines. In this experimental study, effects of injection pressure on engine performance and exhaust emissions have been investigated. Experiments have been performed on a turbocharger diesel engine with 4-cylinder, 4-stroke, indirect injection. Emissions and engine performance values such as torque, power, break main effective pressure, specific fuel consumption, and fuel flow have been measured both full and part loads by changing injection pressure from 100 to 250 bar and for different throttle positions. According to results, maximum performance has been obtained at 150 bar. In addition, high injection pressure for O2, SO2, and CO2, low injection pressure for NOx, and smoke level must be preferred for decreasing emissions.

2.3 Effect of fuel injection timing and pressure on combustion, emissions and performance characteristics of a single cylinder diesel engine by Avinash Kumar Agarwal , Dhananjay Kumar Srivastava , Atul Dhar , Rakesh Kumar Maurya , Pravesh Chandra Shukla , Akhilendra Pratap Singh [3]

Worked on The Effect of fuel injection timing and pressure on combustion, emissions and performance characteristics of a single cylinder diesel engine. A single cylinder research engine was used to experimentally determine the effects of fuel injection strategies and injection timings on engine combustion , performance and emission characteristics. The experiments were conducted at constant speed (2500 rpm) with two FIPs (500 and 1000 bars respectively) and different start of injection (SOI) timings. Cylinder pressure and rate of heat release (ROHR) were found to be higher for lower FIPs however advanced injection timings gave higher ROHR in early combustion stages. Brake thermal efficiency (BTE) increased with increased injection pressures while exhaust gas temperature and brake mean effective pressure (BMEP) increased upto 500 bars. These parameters reduced slightly with increase in FIP. For advanced SOI, BMEP and BTE increased, while brake specific fuel consumption (BSFC) and exhaust gas temperature reduced significantly. Carbon dioxide (CO2) and hydrocarbon (HC) emissions decreased however nitrogen oxide (NOx) emissions increased with increasing FIP. Lower CO2 and HC emissions, and significantly higher NOx emissions were observed with advanced injection timings. Particulate number–size distribution increased with increasing engine load however it reduced with increasing FIP

2.4 Spray and atomization of diesel fuel and its alternatives from a single-hole injector using a common rail fuel injection system by Pin-Chia Chen , Wei-Cheng Wang , William L. Roberts , Tiegang Fang [4]

Worked on atomization of diesel fuel and its alternatives from a single-hole injector using a common rail fuel injection system. The spray and atomization characteristics were investigated for commercial No. 2 diesel fuel, biodiesel (FAME) derived from waste cooking oil (B100), 20% biodiesel blended diesel fuel (B20), renewable diesel fuel produced in house, and civil aircraft jet fuel (Jet-A). Droplet diameters and particle size distributions were measured by a laser diffraction particle analyzing system and the spray tip penetrations and cone angles were acquired using a high speed imaging technique. All experiments were conducted by employing a common-rail high-pressure fuel injection system with a single-hole nozzle under room temperature and pressure. The experimental results showed that biodiesel and jet fuel had different features compared with diesel. Longer spray tip penetration and larger droplet diameters were observed for B100. The smaller droplet size of the Jet-A were believed to be caused by its relatively lower viscosity and surface tension. B20 showed similar characteristics to diesel but with slightly larger droplet sizes and shorter tip penetration. Renewable diesel fuel showed closer droplet size and spray penetration to Jet-A with both smaller than diesel. As a result, optimizing the trade-off between spray volume and droplet size for different fuels remains a great challenge. However, high-pressure injection helps to optimize the trade-off of spray volume and droplet sizes. Furthermore, it was observed that the smallest droplets were within a region near the injector nozzle tip and grew larger along the axial and radial direction. The variation of droplet diameters became smaller with increasing injection pressure.

2.5 Effect of injection timing on a DI diesel engine fuelled with a synthetic fuel blend by Arun Kumar Wamankar* , S. Murugan [5]

In this research work, the effect of varying injection timing on the combustion, performance and emissions of a single cylinder, air cooled, four-stroke, direct injection (DI) diesel engine was experimentally investigated, by using a synthetic fuel blend. The synthetic fuel blend was composed of 10% CB and 90% diesel on a volume basis and was denoted as Carbodiesel10. Investigations were carried out with Carbodiesel10 at different injection timings, viz; original (23CA bTDC), two advanced (26CA bTDC and 24.5CA bTDC) and retarded (21.5CA bTDC and 20CA bTDC) injection timings. With the advanced injection timing of 26CA bTDC, the brake thermal efficiency was found to be higher by about 6.4% while the fuel consumption was found to be lower by about 11.9% than those of the original injection timing. The NO emission was noticed to be higher by about 23% and the smoke was lower by about 13.5% at 26CA bTDC than that of the original injection timing.

2.6 Effect of injection parameters on the combustion and emission characteristics in a common-rail direct injection diesel engine fueled with waste cooking oil biodiesel by Joonsik Hwang, Donghui Qi, Yongjin Jung, Choongsik Bae

Worked on The Effect of injection parameters on the combustion and emission characteristics in a common-rail direct injection diesel engine fueled with waste cooking oil biodiesel. The fuel property including fatty acid composition for the biodiesel were measured and compared with those of the conventional diesel fuel. The engine tests were conducted at two injection pressures (80 and 160 MPa) and different injection timings from 25 to 0 crank angle degree (CAD) after top dead center (aTDC) under two different engine loads. The results showed that the indicated specific fuel consumption (ISFC) with respect to the injection timings of the biodiesel was higher than that of the diesel fuel under all experimental conditions. The peak cylinder pressure and the peak heat release rate of the biodiesel were slightly lower, while the ignition delay was slightly longer under all operating conditions. In terms of emissions, the biodiesel had benefits in reduction of smoke, carbon monoxide (CO), hydrocarbon (HC) emissions especially with high fuel injection pressure. The nitrogen oxide (NOx) emissions of the biodiesel were relatively higher than those of the diesel under all experimental conditions.

2.7 Effect of Fuel Injection Timing on the Injection, Combustion, and Performance Characteristics of a Direct-Injection (DI) Diesel Engine Fueled with Canola Oil Methyl Ester-Diesel Fuel Blends by Metin Gumus, Cenk Sayin, and Mustafa Canakci

In this study, the influence of injection timing on the injection, combustion, and performance characteristics of a single-cylinder, four-stroke, direct-injection, naturally aspirated diesel engine has been experimentally investigated when using canola oil methyl ester (COME) and its blends with diesel fuel. The tests were conducted for three different injection timings [15º, 20º, and 25º crank angle (CA) before top dead center (BTDC)] at constant engine speed and different loads. The experimental test results showed that, because of the different properties of COME and diesel, both fuels exhibit different injection, combustion, and performance characteristics for different engine loads and injection timing. Investigation of injection characteristics of the fuels showed that using COME instead of diesel resulted in earlier injection timings. The maximum cylinder pressure, the maximum rate of pressure rise, and the maximum heat release rate are slightly lower, while the ignition timing is higher for COME and its blends for all loads and injection timings. The brake-specific fuel consumption for COME is higher than that of diesel fuel, while the brake thermal efficiency of COME is lower than that of diesel fuel. The original injection timing gave the best results for brake-specific fuel consumption, brake-specific energy consumption, and brake thermal efficiency compared to the advanced and retarded injection timings.

2.8 Effect of injection pressure on performance, emission and combustion characteristics of high linolenic linseed oil methyl ester in a DI diesel engine by Sukumar Puhan , R. Jegan, K. Balasubbramanian, G. Nagarajan

Worked on The Effect of injection pressure on performance, emission and combustion characteristics of high linolenic linseed oil methyl ester in a DI diesel engine. In the present investigation a high linolenic linseed oil methyl ester has been investigated in a constant speed, DI diesel engine with varied fuel injection pressures (200, 220 and 240 bar). The main objective of this study is to investigate the effect of injection pressures on performance, emissions and combustion characteristics of the engine. The test results show that the optimum fuel injection pressure is 240 bar with linseed methyl ester. At this optimized pressure the thermal efficiency is similar to diesel and a reduction in carbon monoxide, unburned hydrocarbon and smoke emissions with an increase in the oxides of nitrogen was noticed compared to diesel. The combustion analysis shows that, the ignition delay is lower at higher injection pressures compared to diesel and the peak pressure is also higher at full load. The combustion duration was almost same at all the injection pressures. It is concluded that linseed methyl ester at 240 bar injection pressure is more efficient than 200 and 220 bar, except for nitrogen oxides emission.

2.9 Effects of highly dispersed spray nozzle on fuel injection characteristics and emissions of heavy-duty diesel engine Guiyang Zhang a , Xinqi Qiao , Xuelong Miao , Jianhai Hong , Jinbao Zheng

The fuel injection rate profile and spray characteristics of both the highly dispersed spray nozzle and the conventional nozzle have been studied through experiments. The experimental results indicate that the highly-dispersed nozzle has a higher fuel injection rate, shorter injection duration, shorter spray tip penetration, fatter spray cone angle, smaller spray projected area and larger spray volume than the conventional nozzle. According to the original experimental results and the fluid collision and breakup theories, the SMD of the highly-dispersed nozzle is smaller than that of the conventional nozzle. Additionally, the combustion and emission characteristics of a heavy-duty diesel engine when equipped with the highly dispersed nozzle and the conventional nozzle respectively have been studied through experiments. The experimental results indicate the tested engine equipped with highly-dispersed nozzles has a lower emission level and better BSFC performance than that equipped with conventional nozzles. All these validate that compared with the conventional nozzle, the highly-dispersed nozzle can shorten the fuel injection duration to save time for the fuel–air mixing, promote the fuel–air mixing and improve the fuel atomization, which are beneficial to the formation of homogeneous mixture.

2.10 Experimental and analytical study on biodiesel and diesel spray characteristics under ultra-high injection pressure Xiangang Wang , Zuohua Huang a, Olawole Abiola Kuti , Wu Zhang , Keiya Nishida

Spray characteristics of biodiesels (from palm and cooked oil) and diesel under ultra-high injection pressures up to 300 MPa were studied experimentally and analytically. Injection delay, spray penetration, spray angle, spray projected area and spray volume were measured in a spray vessel using a high speed video camera. Air entrainment and atomization characteristics were analyzed with the quasi-steady jet theory and an atomization model respectively. The study shows that biodiesels give longer injection delay and spray tip penetration. Spray angle, projected area and volume of biodiesels are smaller than those of diesel fuel. The approximately linear relationship of non-dimensional spray tip penetration versus time suggests that the behavior of biodiesel and diesel sprays is similar to that of gaseous turbulent jets. Calculation from the quasi-steady jet theory shows that the air entrainment of palm oil is worse than that of diesel, while the cooked oil and diesel present comparable air entrainment characteristics. The estimation on spray droplet size shows that biodiesels generate larger Sauter mean diameter due to higher viscosity and surface tension.

CHAPTER 3

EXPERIMENTAL METHODOLOGY

3.1 Experimental Set-up:

All the experiments were conducted on the premises of Apex Innovations Pvt. Ltd., Sangli (MS), India. A single cylinder, naturally aspirated, water cooled, VCR diesel engine coupled with eddy current dynamometer and data acquisition system was used for this investigation. The engine was downsized to develop a maximum power of 3.5 kW by modifying the engine head by specially designed tilting cylinder block arrangement. The set-up was equipped with a jerk type fuel injection pump and a three hole injector. Initial tests were conducted on this set-up to obtain the reference data.

The cylinder head was then modified to incorporate a six-hole injector nozzle without altering the combustion chamber geometry to investigate the effects of various FIPs and SITs on engine performance and emission parameters. The engine was equipped with a CRDI system (Bosch, E099GF231) to control FIP and SIT. This CRDI engine works with programmable Open ECU (Nira i7r, Sweden) for diesel injection; the engine is equipped with fuel injector, common rail with rail pressure sensor and pressure regulating valve, crank and cam position sensors, fuel pump and wiring harness. The test facility was equipped with essential instruments for online measurement of FIP, crank angle, load on the engine, and temperature of inlet air and exhaust gas, coolant at inlet and outlet, lubricating oil. Provision was also made to measure the flow rate of cooling water, air and fuel. The entire signaling system was interfaced to laptop through data acquisition system to record all observation parameters using Windows based engine performance software "ICEngineSoft". This software serves the purposes like monitoring, reporting, data entry, data logging. Necessary signals are scanned and stored through online testing of the engine in RUN mode which can be used for further analysis. By providing the input values of density, heating value of fuel and the ambient temperature of air, the software gives the complete summary of combustion and performance of the engine. The exhaust gases were diverted to a sampling line for the measurement of emissions without increasing the back pressure in the exhaust pipe. Five gas emission analyzer (AVL DIGAS 444) and a smoke meter (AVL 437C) were used to measure vital emissions from the engine.

Fig.4(a)

Fig.4(b)

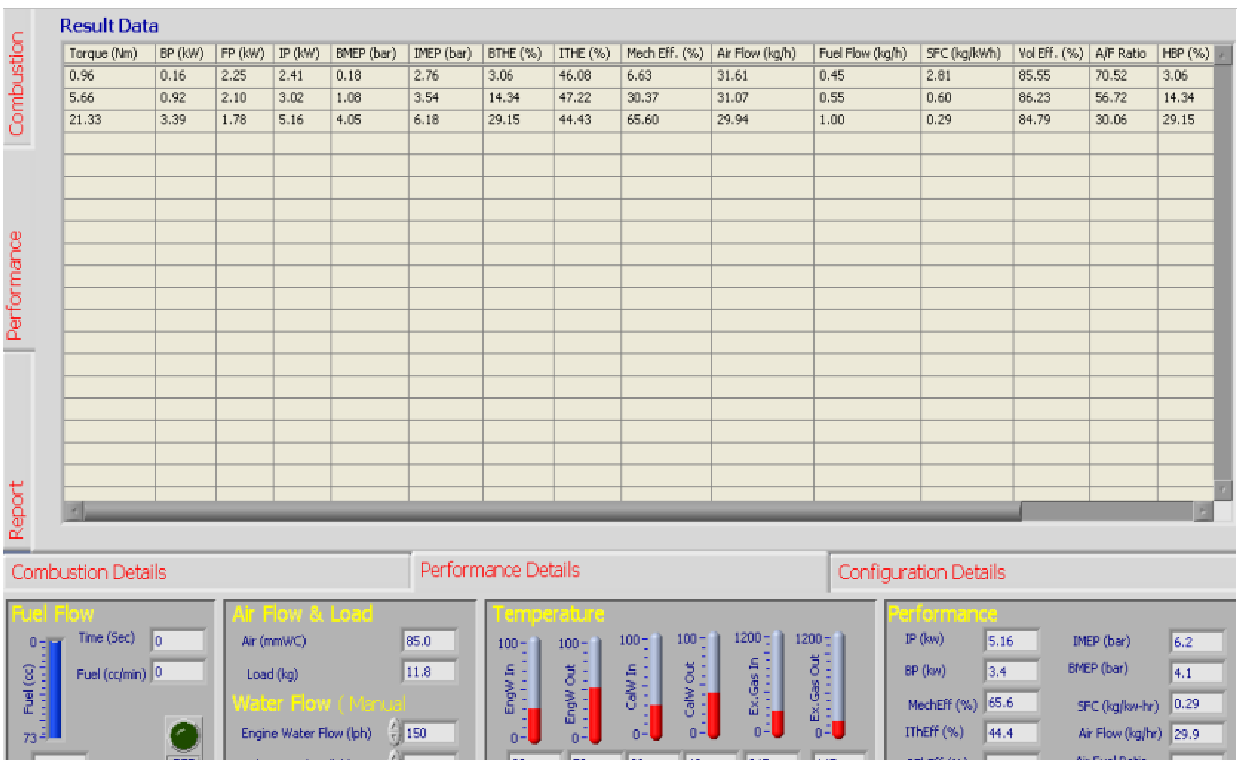


Fig.4(c)

3.2 Specifications and Properties:

Table 1:

Item	Particulars
Make/Model	Kirloskar/TV1
Engine	1 cylinder, 4-S, water cooled, Diesel engine
Bore/Stroke	87.5 mm/110 mm
Cubic capacity	661 cc
Rated power	3.5 kW @ 1500 rpm
Fuel injection	Common rail direct injection with pressure sensor and pressure regulating valve
Injector	Solenoid driven, six holes
Nozzle hole diameter	0.127 mm
Injection angle	152^0
ECU	Nira i7r (with solenoid injector driver) with programmable ECU software and Calibration cable
Loading/Make	Eddy current dynamometer / AG10 of Saj Test Plant Pvt. Ltd., Pune
Cylinder pressure	Piezo sensor (Model – M111A22); Resolution – 0.1 psi;
sensor/Make	Sensitivity – 1 mV/psi; Combustion range: 350 bar with low noise cable / PCB Piezotronics, USA
Fuel pressure sensor/Make	Piezo sensor (Model – M108A02); Resolution – 0.4 psi; Sensitivity – 0.5 mV/psi; Combustion range: 350 bar with low noise cable / PCB Piezotronics, USA
Crank angle sensor/Make	Model – 8.3700.1321.0360; Resolution: 1 deg. Speed 5500 rpm with TDC pulse / Kubler Germany
Data acquisition/Make	NI USB-6210, 16-bit, 250 KS/s / National Instruments
Load sensor/Make	Load cell (Model – 60001), type strain gauge, 0-50 kg / VPG Sensotronics
Fuel flow/Make	Differential pressure transmitter (Model – EJA110A-DMS5A-92NN) / Yokogaw
Air flow/Make	Pressure transmitter (Model – SL1) / Wika, Germany

Table 2:

Item	**Particulars**
Kinematic viscosity(mm^2 /s)	3.31
Density(kg/m^3)	831
Carbon (wt%)	86.11
Hydrogen (wt%)	13.89
C/H	6.2
Flash point (^0C)	64
Fire point (^0C)	72
Calorific Value (kJ/kg)	42880

3.3 Experimental Conditions:

Table 3:

Item	Particulars
Engine speed (rpm)	1500
Compression ratio	18 (Baseline 17.5)
Engine load (% of rated power)	50, 75, 100
Injection pressure (bar)	300, 400, 500 (Baseline 210)
Injection timing (bTDC)	7^0 , 10^0 , 13^0 , 16^0 , 19^0 (Baseline 23^0)
Coolant temperature (^{0}C)	75 ± 2
Lubricating oil temperature (^{0}C)	85 ± 2

3.4 Test Method:

Effects of higher injection pressures and retarded injection timings on performance, and emission characteristics were evaluated in this study. The properties of fuel were found as per the ASTM standards at fuels and IC engines lab, NIT Warangal (TS), India. The engine was first run on no load at a rated speed for about 40 minutes allowing it to reach thermal equilibrium conditions. Coolant temperature at engine outlet was maintained in the range of 75 ± 2 ^{0}C, and the lubricating oil temperature was maintained in the range of 85 ± 2 ^{0}C throughout the testing.

Engine testing was carried out at constant speed by varying load, FIP and SIT for analyzing its performance, combustion and emission parameters. Table 3 presents the details of parameters used during experimentation. At each operating condition, the engine was run for several minutes until all measured and control parameters became stable and then the data were collected. The experiment was replicated for three times at each operating condition to increase the accuracy of test results. CRDI pump equipped with Open ECU was used for online control of the FIP and SIT precisely during testing. It is possible to use FIPs up to 1500 bar employing CRDI pumps in CI engines. However, the unmodified engine was originally designed for the use of FIPs up to 250 bar maximum. Also, it may be required to alter the geometry of the piston bowl to accommodate the use of higher injection pressures in these engines. Apart from these, the engine structural constraints are also to be considered for safe operation and life of the engine. Considering these factors, the compression ratio was fixed at 18, and the maximum FIP was limited to 500 bar in the present analysis. Emissions of NOx, CO, UHC, and smoke capacity measured thrice at each testing condition and the average of the three readings was considered to increase the accuracy of results. “ICEngineSoft” records the data for evaluating various performance and characteristics. The effects of both the fuel injection parameters used in this study on various operating characteristics of the engine are discussed in the subsequent sections.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Performance Characteristics

4.1.1 Brake Thermal Efficiency vs Injection Timing

Observation Tables:

Table (i): at 50% load

	BASELINE	500 bar	400 bar	300 bar
7	25.25	22.25	21.95	21.1
10	25.25	23.4	22.9	22.15
13	25.25	24.45	23.85	22.9
16	25.25	25.4	24.8	23.95
19	25.25	26.5	25.8	24.8

Table (ii): at 75% load

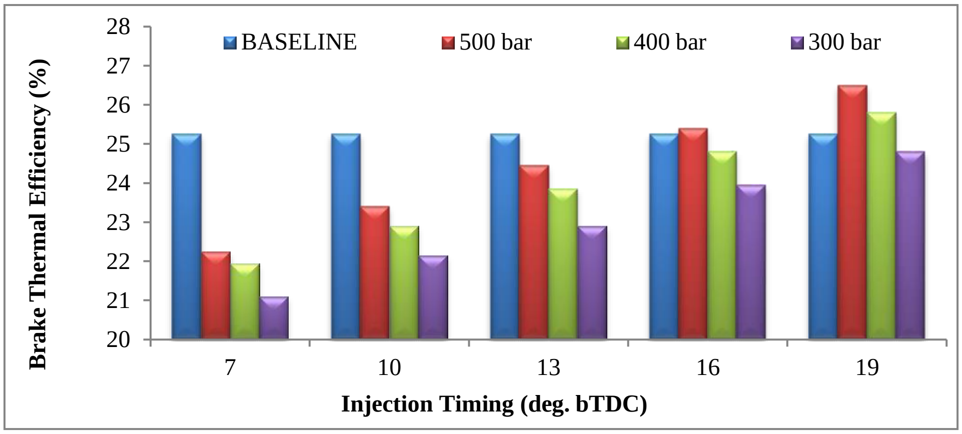
	BASELINE	500 bar	400 bar	300 bar
7	28.15	25.55	25.15	24.25
10	28.15	26.5	26.1	25.1
13	28.15	27.6	27	26
16	28.15	28.75	28.05	26.9
19	28.15	29.65	28.95	27.85

Table (iii): at 100% load

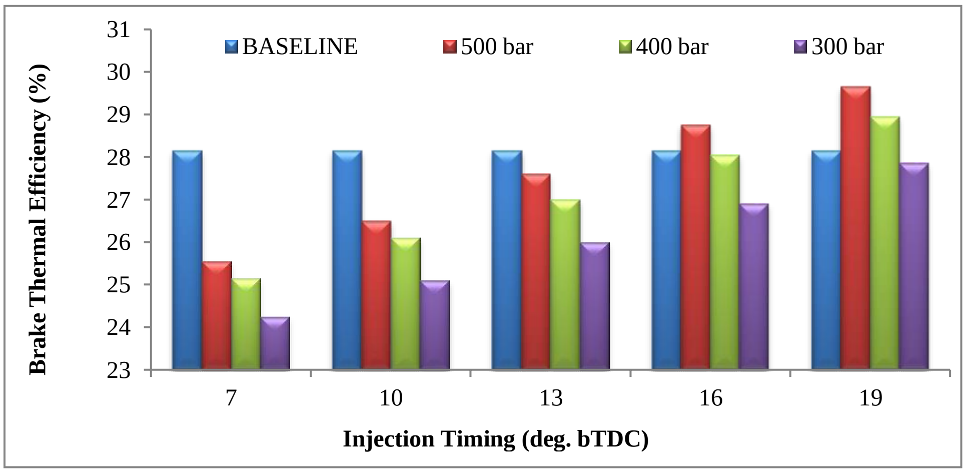
	BASELINE	500 bar	400 bar	300 bar
7	28.7	26.5	26.2	25.6
10	28.7	27.3	27	26.1
13	28.7	28.6	28.3	27
16	28.7	29.4	29.1	28.15
19	28.7	30.3	30	29.2

Graphs:

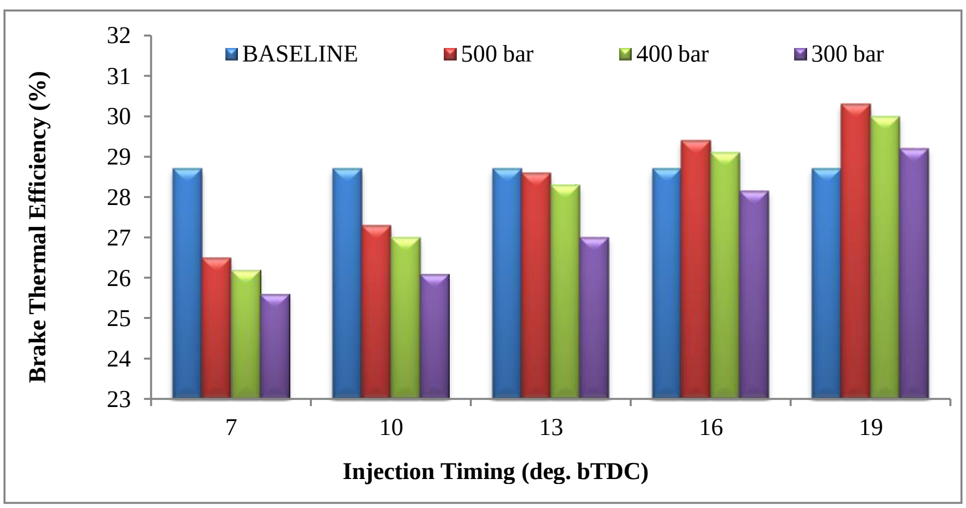
Graph (i): at 50% load



Graph (ii): at 75% load



Graph (iii): at 100% load



4.1.2 Brake Specific Fuel Consumption vs Injection Timing

Observation Tables:

Table (iv): at 50% load

	BASELINE	500 bar	400 bar	300 bar
7	0.3316	0.376274	0.381417	0.396782
10	0.3316	0.357782	0.365594	0.377973
13	0.3316	0.342417	0.351031	0.365594
16	0.3316	0.32961	0.337584	0.349565
19	0.3316	0.315928	0.3245	0.337584

Table (v): at 75% load

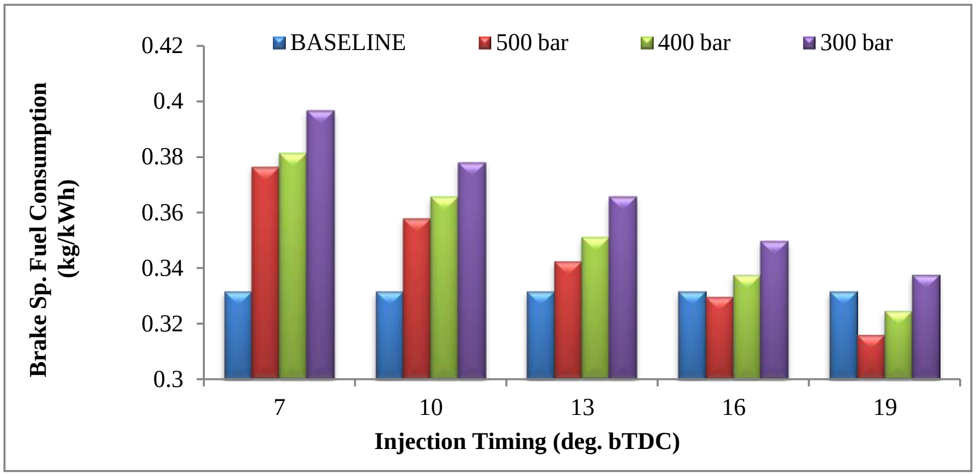
	BASELINE	500 bar	400 bar	300 bar
7	0.297	0.327675	0.332886	0.345241
10	0.297	0.315928	0.32077	0.33355
13	0.297	0.303337	0.310078	0.322004
16	0.297	0.291203	0.29847	0.31123
19	0.297	0.282364	0.289191	0.300614

Table (vi): at 100% load

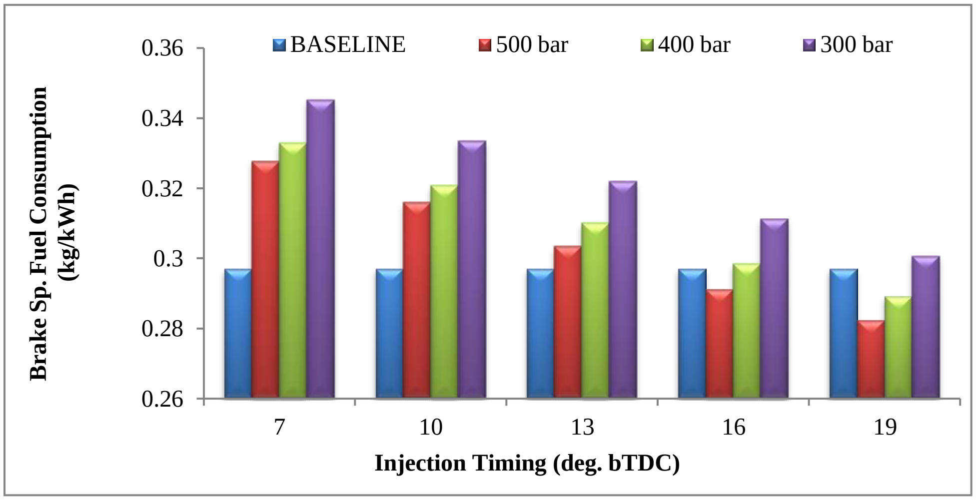
	BASELINE	500 bar	400 bar	300 bar
7	0.292	0.315928	0.319546	0.327035
10	0.292	0.30667	0.310078	0.32077
13	0.292	0.292731	0.295834	0.310078
16	0.292	0.284765	0.287701	0.29741
19	0.292	0.276307	0.27907	0.286716

Graphs:

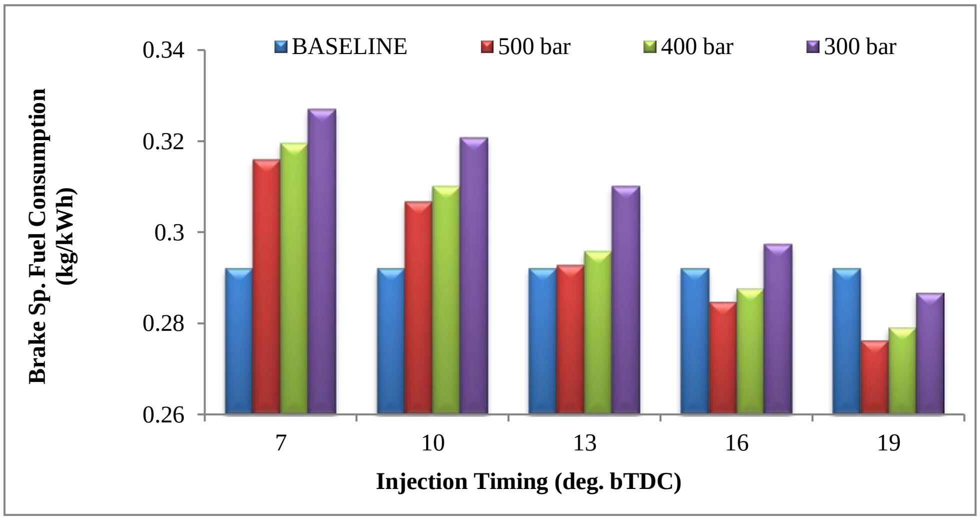
Graph (iv): at 50% load



Graph (v): at 75% load



Graph (vi): at 100% load



Performance characteristics such as BSFC and BTE are calculated based on the experiments performed. Three load conditions are used in the present investigations to understand the effect of SIT and FIP at part and full load operating conditions. Experiments were carried out three times at each operating condition and the average values are reported for increasing the accuracy of the results.

Brake Thermal Efficiency:

BTE of the engine is the fraction of energy supplied by the fuel that is converted into useful brake power. The variation of BTE with respect to the injection timing was shown in the above graphs (refer 4.1.1). With increase in load, BTE increases for all injection parameters. From the above graphs (4.1.1) we can also observe that with increase in FIP BTE also increases. At a given load and pressure BTE reduces with increase in retardation of SIT as shown in the above tables and graphs (refer 4.1.1). The reduction in the engine performance at retarded injection timings may be attributed to the decrease in the fraction of heat release in premixed combustion, late combustion phase and the extension of combustion into the expansion stroke.

Hence, retarding injection timings too much might also lead to a loss in BTE because in such a situation, there is significant fraction of fuel available for mixing controlled combustion as well as late combustion phase and the combustion extends well into the expansion stroke. This leads to effective reduction in the pressure force exerted by the combusting gases on the engine piston pushing it downward during the expansion stroke because of increased combustion chamber volume. Therefore, this effectively reduced the BTE. So, the injection timing must be adjusted in such a way that the maximum pressure inside the combustion chamber is attained before the expansion stroke. This is achieved by injection of fuel just before TDC. When compared to the baseline operation .i.e. SIT of 23^{o} bTDC FIP of 210 bar the BTE increases at FIP of 500 bar and SIT of 19^{o} bTDC may be on account of the improved combustion and lower ID due to fine atomization of fuel.

Brake Specific Fuel Consumption:

BSFC of the engine is the amount of fuel consumed for developing unit brake power. The brake specific fuel consumption is inversely proportional to the brake thermal efficiency for a single fuel. The variation of BSFC with respect to injection timing was shown in above graphs at different loads (refer 4.1.2). BSFC decreased in all experimental conditions with increasing engine load. This reduction in BSFC can be explained by the fact that as the engine load increases, there was continuous improvement in combustion quality and efficiency. Cylinder pressure increased with increasing engine load and increasing injected fuel quantity, which burned more efficiently therefore fuel consumption per unit brake power produced i.e. BSFC decreased.

From the graphs it is observed that BSFC reduces with increase in FIP. This also may be the result of effective combustion and Shorter Ignition Delay (ID) and also due to the fine atomization of the fuel.

At a given load, as the injection timing advances, the BSFC decreases. As the fuel injection timing advances, nearly homogenous mixtures are prepared inside the combustion chamber due to longer ignition delay and hence better combustion leads to lower BSFC. As a result, the better operating conditions are observed at FIP of 500 bar and SIT of 19^o bTDC where the BSFC reduces due to increase in BTE as previously discussed.

4.2 Emission Characteristics:

4.2.1 Carbon monoxide (co) Emissions vs Injection Timing

Observation Tables:

Table (vii): at 50% load

	BASELINE	500 bar	400 bar	300 bar
7	0.098	0.087	0.09	0.098
10	0.098	0.082	0.083	0.087
13	0.098	0.079	0.079	0.082
16	0.098	0.075	0.075	0.078
19	0.098	0.068	0.072	0.075

Table (viii): at 75% load

	BASELINE	500 bar	400 bar	300 bar
7	0.172	0.12	0.135	0.279
10	0.172	0.117	0.127	0.294
13	0.172	0.095	0.092	0.198
16	0.172	0.092	0.09	0.185
19	0.172	0.088	0.081	0.155

Table (ix): at 100% load

	BASELINE	500 bar	400 bar	300 bar
7	0.569	0.199	0.227	1.053
10	0.569	0.207	0.323	0.707
13	0.569	0.211	0.301	0.586
16	0.569	0.107	0.196	0.548
19	0.569	0.156	0.222	0.473

Graphs:

Table (vii): at 50% load

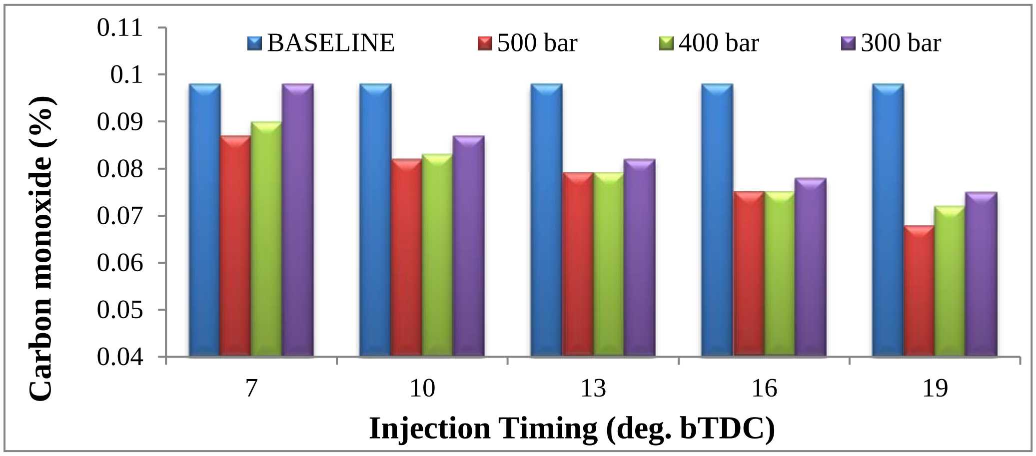


Table (viii): at 75% load

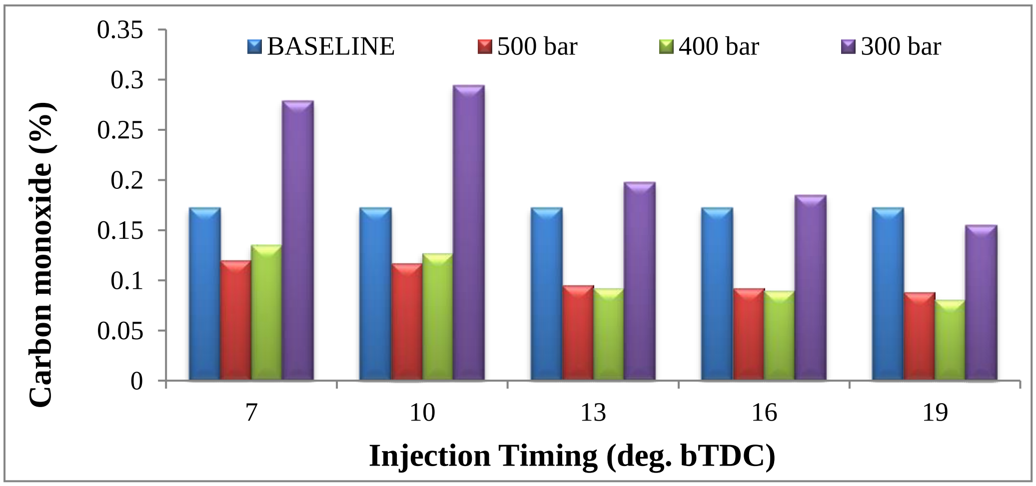
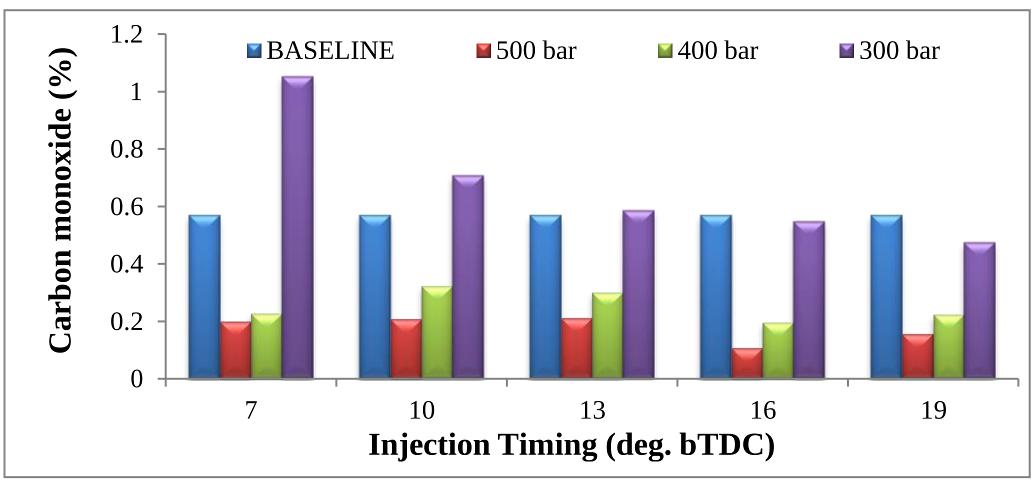


Table (ix): at 100% load



4.2.2 Unburnt Hydro Carbons vs Injection Timing:

Observation tables:

Table (x): at 50% load

	BASELINE	500 bar	400 bar	300 bar
7	46	34	32	30
10	46	31	30	29
13	46	29	28	27
16	46	27	25	24
19	46	25	23	22

Table (xi): at 75% load

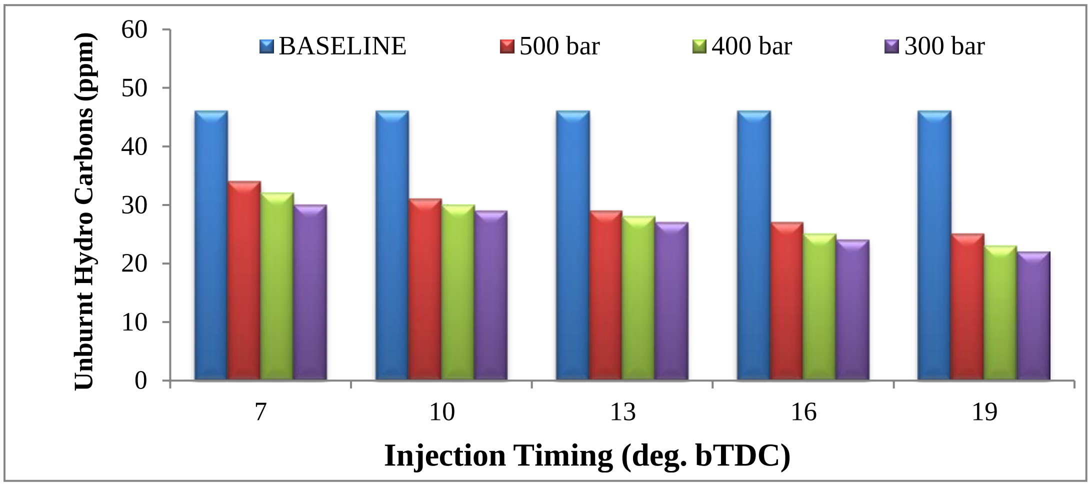
	BASELINE	500 bar	400 bar	300 bar
7	51	45	43	41
10	51	43	42	39
13	51	41	40	38
16	51	39	37	35
19	51	36	34	33

Table (xii): at 100% load

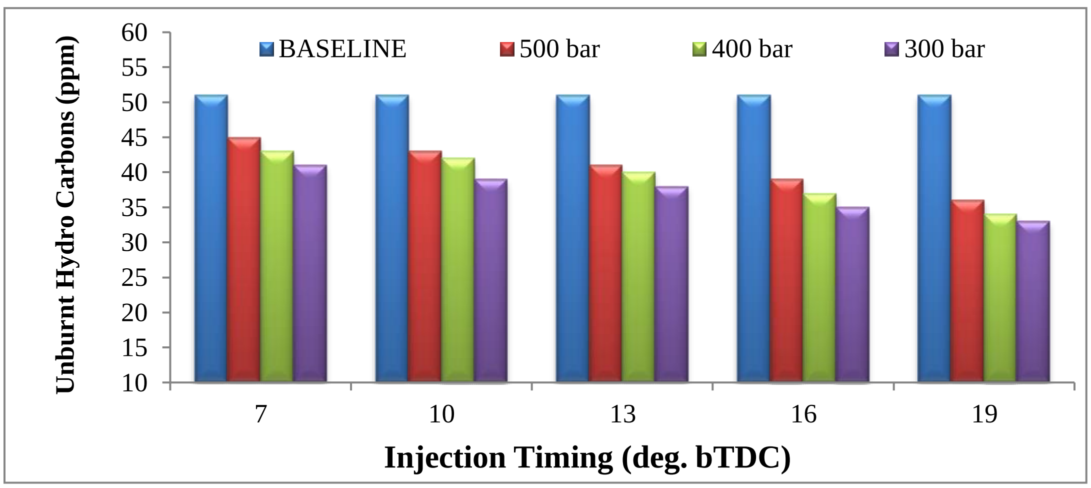
	BASELINE	500 bar	400 bar	300 bar
7	61	54	53	52
10	61	51	50	49
13	61	50	47	46
16	61	47	46	44
19	61	43	43	42

Graphs:

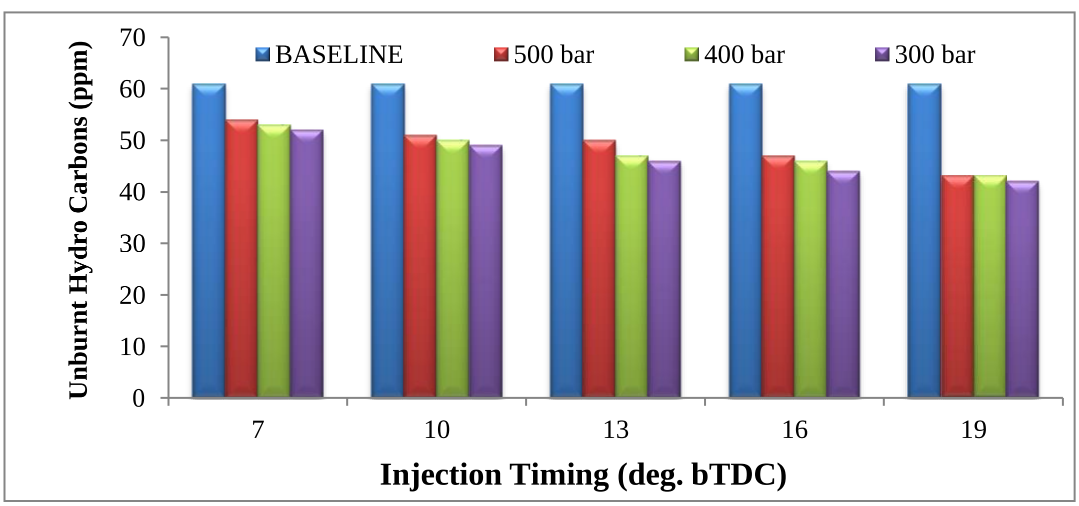
Graph (x): at 50% load



Graph (xi): at 75% load



Graph (xii): at 100% load



4.2.3 Oxides of Nitrogen vs Injection Timing:

Observation tables:

Table (xiii): at 100% load

	BASELINE	500 bar	400 bar	300 bar
7	1021	763	522	364
10	1021	953	752	473
13	1021	1217	946	628
16	1021	1435	1216	855
19	1021	1623	1491	1125

Table (xiv): at 75% load

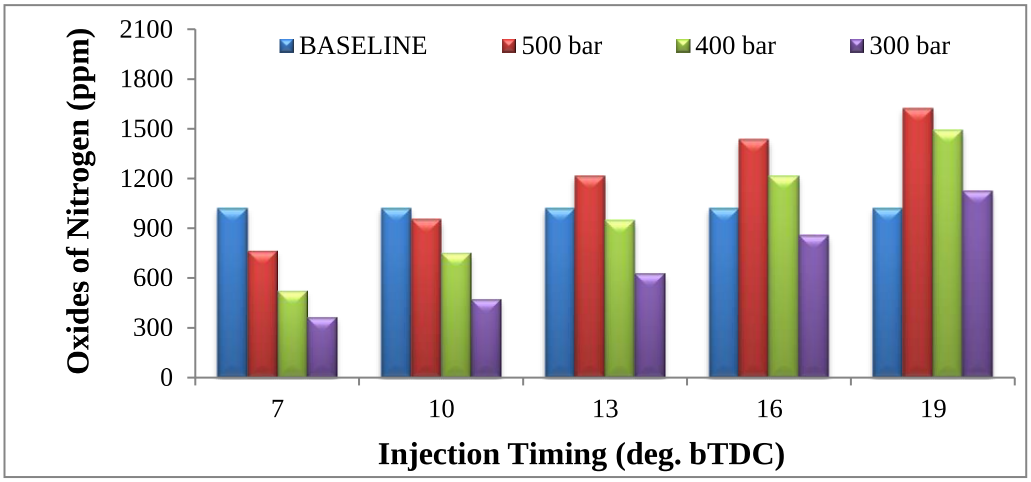
	BASELINE	500 bar	400 bar	300 bar
7	1135	877	674	385
10	1135	1043	814	521
13	1135	1459	1068	722
16	1135	1864	1488	1004
19	1135	2187	1802	1253

Table (xv): at 50% load

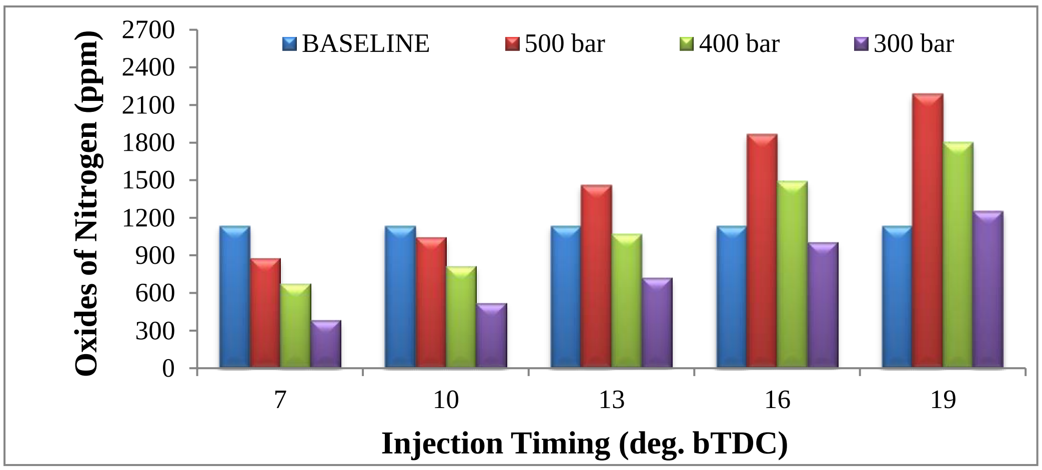
	BASELINE	500 bar	400 bar	300 bar
7	1205	906	756	407
10	1205	1065	859	586
13	1205	1461	1118	805
16	1205	1980	1513	1081
19	1205	2305	1890	1326

Graphs:

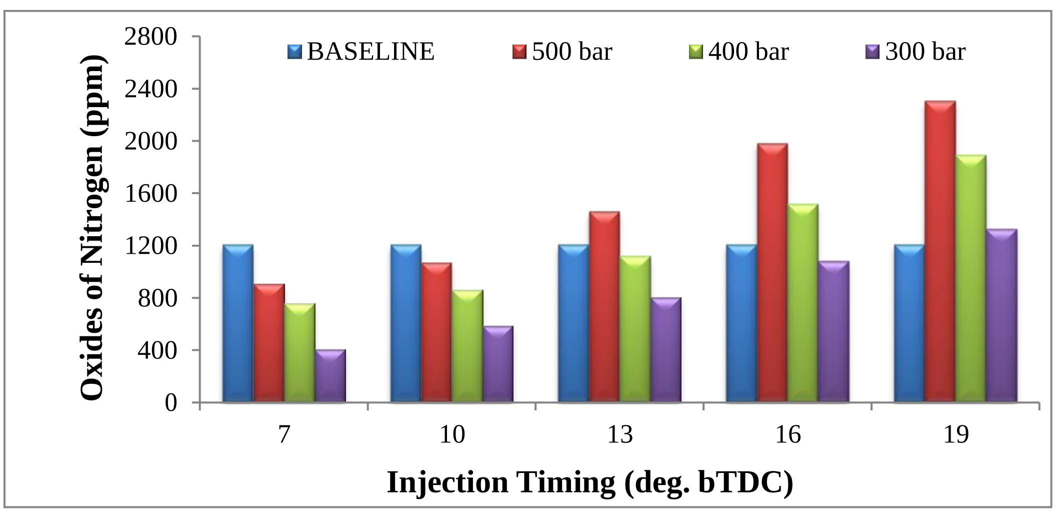
Graphs (xiii): at 100% load



Graphs (xiv): at 75% load



Graphs (xv): at 50% load



4.2.4 Smoke vs Injection timing

Observation Tables:

Table (xvi): at 50% load

	BASELINE	500 bar	400 bar	300 bar
7	6.2	13.5	8.2	22.6
10	6.2	8.2	5.3	13.6
13	6.2	13.1	4.1	7.2
16	6.2	6.2	7.9	6.2
19	6.2	4.9	9.5	5.5

Table (xvii): at 75% load

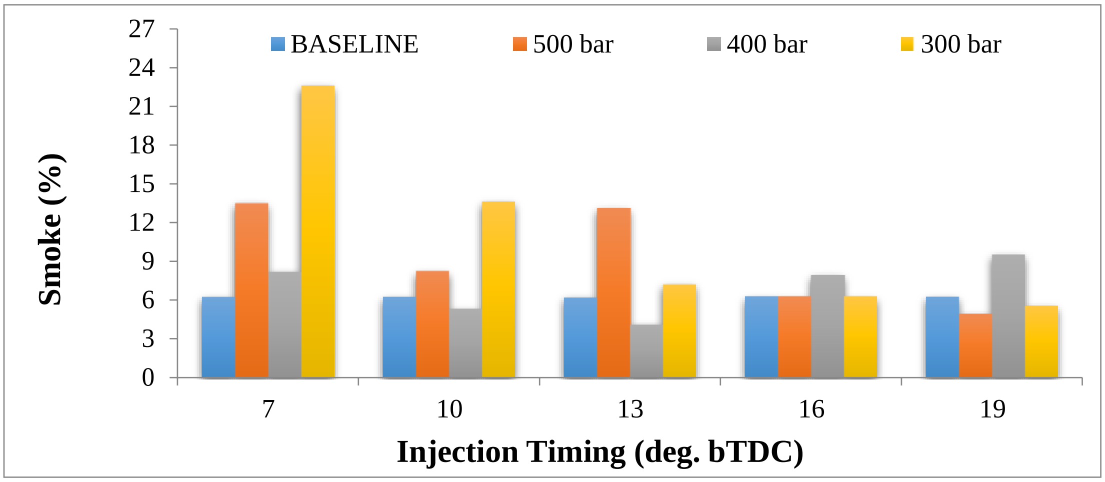
	BASELINE	500 bar	400 bar	300 bar
7	23.1	30.5	29.1	57.8
10	23.1	20.3	23.5	52.4
13	23.1	16.3	16.3	25.9
16	23.1	15.8	15.8	30.5
19	23.1	19.3	14.3	18.4

Table (xviii): at 100% load

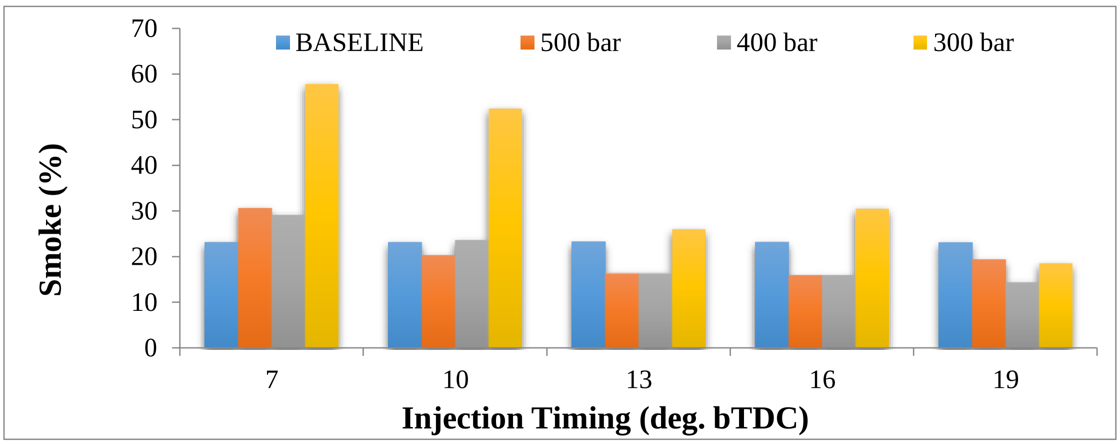
	BASELINE	500 bar	400 bar	300 bar
7	36.5	31.2	40.6	97.2
10	36.5	30.3	38.3	65.6
13	36.5	21.2	24.2	56.8
16	36.5	15.9	18.2	43.7
19	36.5	19.6	21.4	30.1

Graphs:

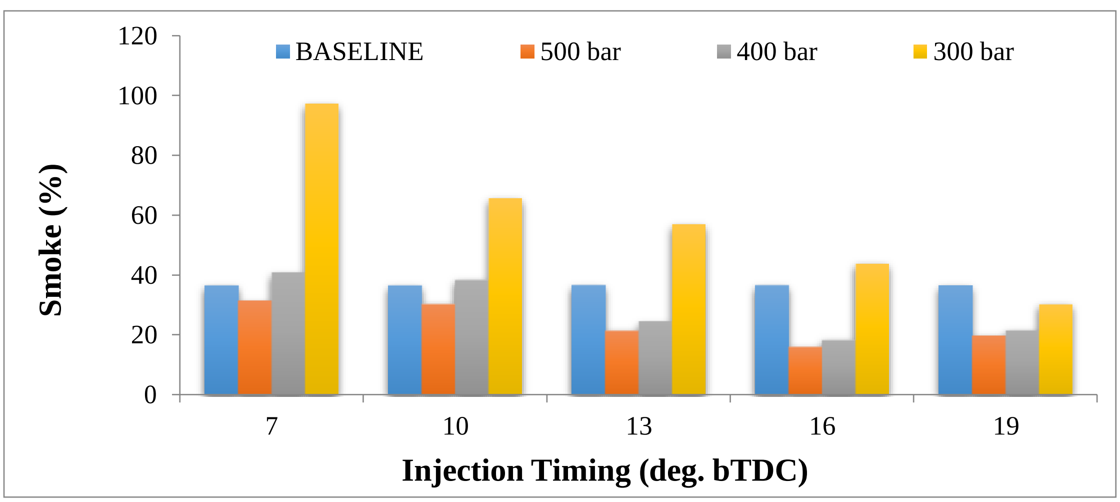
Graph (xvi): at 50% load



Graph (xvii): at 75% load



Graph (xviii): at 100% load



Emission characteristics such as CO, UHC, NOx and smoke are reported for the engine used in the present investigations using diesel as fuel at different load conditions varying SIT and FIP. These raw emissions were also measured three times and the average values are reported for increasing the accuracy of the results.

Carbon monoxide Emissions (CO):

Incomplete oxidation of carbon present in the fuel as a result of heterogeneous air-fuel mixtures leads to the formation of CO emissions. They are largely dependent on fuel-air ratio and increase steadily for fuel-rich mixtures. These toxic emissions can be controlled with the use of higher FIPs owing to enhanced combustion caused by better atomization and evaporation of fuel. Variations in UHC and CO emissions for different loads of operation at various injection start timings and fuel injection pressures are presented in tables and graphs (refer 4.2.1).

It is observed that retardation of SIT increases the CO Emissions. At retarded injection timings, limited time is available for the mixing of air and fuel particles which lowers the oxidation process and hence increases the CO emissions. It is observed that, Advanced SIT improved air–fuel mixing due to availability of more time for mixing process therefore this led to lower CO emissions as well.

Further, more quantity of fuel is injected at higher engine loads. Therefore, the engine operation at higher loads with delayed injection timing does not leave sufficient time for proper mixing of air and fuel apart from a short primary combustion phase. This results in inefficient combustion and increased fraction of secondary combustion phase causing deteriorated CO emissions at higher loads at any given FIP.

It is also observed that the reduction in CO emissions at a given load and SIT with varying FIP. This phenomenon is due to the result of fine atomization of fuel at higher FIP which reduces the ID and improves the Air-Fuel mixture and provides sufficient time for combustion. However when compared to base line operation .i.e. at 23^{o} bTDC SIT and 210 bar FIP reduced CO Emissions are observed at all Experimental Conditions.

Unburnt Hydrocarbons Emissions (UHC):

UHC emissions result from the deficient combustion of the fuel and the partial combustion of lubricating oil in the combustion chamber. Inadequate amount of air present in the rich fuel-air mixture and misfires caused due to lean air-fuel mixtures in the combustion zone are the main causes for deficient combustion. These emissions quantify the combustion efficiency of an engine. Variations in UHC and CO emissions for different loads of operation at various injection start timings and fuel injection pressures are presented in Tables and Graphs (refer 4.2.2).

It is observed that from the data (4.2.2) the improvement of UHC emissions has takes place with increase in FIP. This may occur due to increased wall temperature which reduces the quench layer at higher FIPs. With an increase in retardation of fuel injection, deterioration of UHC emissions increases owing to late SOC. Further, the increase in engine load also diminishes UHC emissions because of the increase in the amount of fuel injected for the same amount of air intake which results in the formation rich fuel-air mixtures at several locations in the combustion space. However, slightly improved UHC emissions are observed with the use of higher FIP (500 bar) as compared to lower FIPs at all operating conditions. This may be attributed to the improved combustion and lower ignition delay as a result of fine atomization of fuel at higher FIP.

As a result it is observed that the increased UHC emissions are not much greater when compared to the baseline operation of the engine. It is observed that for both CO and UHC emissions the optimal operating conditions are observed at SIT of 19^o bTDC and FIP of 500 bar.

Oxides of Nitrogen Emissions(NOx):

NOx emissions are always higher in CI engines as they run typically on lean mixtures. The peak in-cylinder temperatures, the residence time of combustible mixture at the peak in-cylinder temperature and the concentration of oxygen in the combustible mixture are the main precursors for NOx formation in diesel engines. The variation of NOx emissions with respect to injection timing as shown in data (4.2.3).

The results showed that there is overall reduction in the mass emission of NOx with increasing engine loads. There are several factors responsible for reduction in mass emission of NOx with increasing engine load namely: (i) reduction in oxygen concentration in the combustible mixture because of higher fuel quantity being injected; (ii) increase in turbulence level at higher engine loads, resulting in lower residence time for NOx specific reactions; and (iii) relatively lower combustion temperatures for richer fuel–air mixtures because of longer combustion durations and heat release rates.

Advanced SOI timings result in relatively higher NOx emissions due to higher heat release rate in premixed combustion phase, which leads to very high peak combustion pressures and temperatures. It is also observed that with increase in FIP further increases the NOx emissions. This may be the result due to higher FIP increases the peak cycle temperatures and hence increases NOx emissions which may be attributed to improved combustion. For a given SIT and engine load, deteriorated NOx emissions are observed with the increase in FIP due to improved combustion.

As compared to the baseline results the NOx emissions are increased at all injection timings except at 7^{o} bTDC and 10^{o} bTDC at all injection pressures. The lighter NOx emissions are observed at 7^{o} bTDC of SIT and 500 bar of FIP. The NOx emissions are inversely proportional to CO emissions.

Smoke Emissions:

Solid carbon particles present in the exhaust emissions due to incomplete combustion are termed as smoke emissions and are generally formed in core regions. Larger droplets, and bigger core as a result of poor atomization at lower FIPs, lead to increased smoke emissions. The variation of smoke with respect to injection timings are discussed in above graphs and tables (refer 4.2.4).

There is an overall increase in smoke opacity with increasing engine load, which indicates that the exhaust stream is having higher particulate emissions. Increasing engine load results in an increase in fuel–air equivalence ratio and longer mixing controlled combustion phase, which results in higher combustion temperatures as well as lower oxygen concentration in the engine combustion chamber, therefore the smoke capacity increases.

Retarded SIT timings increase smoke capacity due to lower in-cylinder combustion temperatures and reduction in the time available for oxidation and re-burning of soot already formed during expansion stroke. Advanced SOI timings lead to more complete combustion at relatively elevated in-cylinder temperatures, resulting in lower soot capacity. These trends are exactly opposite to the ones observed for NOx emissions.

With increase in FIP, it is observed that the smoke emissions are reduced at all experimental conditions. This is the result due to the occurrence of complete combustion due to the fine atomization of fuel. When compared to the baseline operation .i.e. SIT of 23^{o} bTDC and FIP of 210 bar it is observed that there is reduction in smoke emissions at 100% load at all conditions and at some conditions are also observed at remaining loads. By taking other emissions into account the optimal operating condition was observed at a SIT of 19o bTDC and FIP of 500 bar.

CHAPTER 5

CONCLUSION

The present study dealt with performance and emission analysis of a VCR single cylinder water cooled constant speed engine, CRDI incorporated system equipped with open ECU. The ECU equipped system enabled to precisely control the injection timings and FIPs. These modifications enabled online control of FIP, SIT, injection pulses, injection rate, and injection duration more precisely under varied engine operating conditions. The impact of delayed SITs and higher FIPs on various performance and emission parameters of this modified engine was experimentally investigated. With the use of delayed start of injection timings and high injection pressure it is observed to reduce NOx emissions simultaneously with deteriorated Smoke, UHC and CO emissions. increase in FIP owing to better mixture formation and enhanced combustion at higher FIPs. Among the parameters chosen, better performance of the engine is observed at baseline operating conditions as compared to the other operating conditions except at SIT of 19^0 bTDC and FIP of 500 bar. Engine operation at 7^0 bTDC (SIT) and 500 bar FIP, 10^o bTDC SIT and 500 bar FIP offered significant reduction in NOx emissions with considerable penalty on UHC and CO emissions. Finally, the study revealed that by incorporating electronic controls, in automotive sector, simultaneous reduction and trade-off between performance and emission could easily be achieved.

CHAPTER 6

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