CHAPTER 1

Introduction

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1.1 BACKGROUND

The world at present is caught between two major crisis emerging out of fossil fuel depletion and environmental degradation. Thus it has become essential to identify clean-burning alternative fuels – not only to retain the present growth rate of civilization, but also to protect the earth from the obnoxious pollutants. The problem is of significant concern in our country where consumption of diesel oil is almost about seven times more than that of petrol. Diesel oil in India is the main fuel in the public transportation system, in mechanized agricultural system including the irrigation and water pumping and in several decentralized energy units. Hence, it is essential that alternatives to diesel fuel are to be developed. This work focuses on assessing the viability of using Bio-Diesel in the existing diesel engines. An acceptable alternative fuel for use in engines should fulfill the environmental and energy security needs without sacrificing the operating performance. Vegetable oils have energy density, cetane number, heat of vaporization and stoichiometric air/fuel ratio comparable to that of petrol/diesel, but as mentioned earlier, neat vegetable oils have not been found suitable for long-term application in diesel engines [1].

1.2 HISTORICAL PERSPECTIVE

The inventor of the diesel engine, Rudolf Diesel used vegetable oils (Peanut oil) in a diesel engine for demonstration at the 1900 world exhibition in Paris. Speaking to the Engineering Society of St. Louis Missourie, in 1912, Diesel had said, “The use of vegetable oils for engine fuels may seems insignificant today, but such
oils may become in course of time as important as petroleum and coal tar products of the present times” [2].

1.3 **BIO-DIESEL – WORLD PERSPECTIVE**

Bio-Diesel – a fuel made up of esters derived from oils and fats from renewable biological sources, has proved to be an environment friendly and a potential alternative fuel for diesel oil. The use of vegetable oils by converting them to fatty acids methyl esters as an alternative fuel to diesel oil is gaining importance in European and other developed countries of the world. This fuel is generated from renewable bio-resources and hence it is known as Bio-Diesel. The main advantage of it is renewable in nature and also gives low emissions of \( \text{SO}_x \), \( \text{NO}_x \) and Poly cyclic aromatic Hydro Carbons (PAHS) and hence it is environmental friendly compared to diesel oil. Hence employing Bio-Diesel as an alternative fuel in I.C Engines for various applications is gaining importance in recent days in many countries. Malaysia has begun to build up the largest Bio-Diesel production unit with annual capacity of 500,000 tones / year using Palm oil.

1.4 **BIO-DIESEL IN INDIAN CONTEXT**

In most of the countries Bio-Diesel is produced from Saffola, Sun flower, Soya bean, Peanut, Canola, Rapeseed etc. that are essentially edible in Indian context. On the other hand there is vast resource of wild crops from which oil can be extracted to produce adequate amount of Bio-Diesel by way of Esterification. In Indian context there is a vast potential of non-edible oilseeds viz. Neem, Karanja, Mahwa, Sal, Undi, Kusum, Khakan etc., which can be employed to produce Bio-Diesel. There are many tree species, which bear seeds rich in oil, of these some promising tree species have been evaluated and it has been found that there are a number of trees such as Pongamia Pinnata (‘Karanja’) and Jatropha curcas, which would be very suitable to
grow in Indian conditions. Thus all these large resources of oilseeds can be utilized for the production of Bio-Diesel. The process of producing Bio-Diesel does not involve any high-tech mechanism and by growing large number of plants at suitable locations (nearer to points of utilization) makes it more cost effective. It can be effectively implemented even in rural sector.

The other features that make Bio-Diesel as an alternative fuel for our country are clean burning, safe to handle, transport and storage. In addition it is non toxic, biodegradable, free of Sulphur and toxic emissions. The absence of Sulphur and aromatics in Bio-Diesel increases the life time of the catalyst employed in automobile exhaust system [3].

1.5 COMBUSTION IN C.I ENGINES

In compression-ignition engines, fuel is injected by the fuel - injection system into the engine cylinder towards the end of the compression stroke, just before the desired start of combustion. The liquid fuel, usually injected at high velocity as one or more jets through small orifices or nozzles in the injector tip, atomizes into small drops and penetrates into the combustion chamber. The fuel vaporizes and mixes with the high- temperature high- pressure cylinder air. Since the air temperature and pressure are above the fuel’s ignition point, spontaneous ignition of portions of the already- mixed fuel and air occurs after a delay period of a few crank angle degrees. The cylinder pressure increases as combustion of the fuel- air mixture occurs. The consequent compression of the un burnt portion of the charge shortens the delay before ignition for the fuel and air, which has mixed to within combustible limits, which allows in rapid combustion. It also reduces the evaporation time of the remaining liquid fuel. Injection continues until the desired amount of fuel has entered the cylinder. Atomization, vaporization, fuel-air
mixing, and combustion continue until essentially all the fuel has passed through each process. In C.I engine, the 4-strokes help in proper regulation of air and gas mixture throughout the combustion and expansion processes.

The compression-ignition combustion process is extremely complex. It is an unsteady, heterogeneous, three-dimensional combustion process. This process mainly depends on the characteristics of fuel, the design of combustion chamber, the fuel injection system and on the operating conditions of the engine. While an adequate conceptual understanding of combustion process has been developed, to date and ability to describe many of the critical individual processes in a quantitative manner is lacking [4].

Diesel engines are divided into two basic categories according to their combustion chamber design: (a) Direct-Injection (DI) engines, which have a single open combustion chamber into which fuel is injected directly, (b) Indirect-Injection (IDI) engines, where the chamber is divided into two regions and the fuel is injected into the “pre-chamber” which is connected to the main chamber (situated above the piston crown) via a nozzle or one or more orifices.

1.5.1 Different Phases of DI Engine Combustion

The following stages of the overall compression - ignition diesel combustion process can be defined. They are identified on the typical heat- release- rate diagram for a DI engine in Fig.1.1.

Ignition delay (ab): The period between start of fuel injection into the combustion chamber and the start of combustion [determined from the change in slope on the P - θ diagram, or from a heat-release analysis of the P (θ) data].

Pre mixed or rapid combustion phase (bc): In this phase, combustion of the fuel which has mixed with air to within the flammability limits during the ignition
delay period occurs rapidly in a few crank angle degrees. When this burning mixture is added to the fuel which become ready for burning and burns during this phase, the high heat-release rate characteristic of this phase results.

![Fig.1.1 Typical DI engine heat-release-rate diagram identifying different diesel combustion phases.](image)

Mixing-controlled combustion phase (cd): Once the fuel and air which premixed during the ignition delay have been consumed, the burning rate (or heat-release-rate) is controlled by the rate at which mixture becomes available for burning. Several processes are involved in liquid fuel atomization, vaporization, mixing of fuel vapor with air, pre flame chemical reactions. The rate of burning is controlled in this phase primarily by the fuel vapor–air mixing process. The heat-release rate may or may not reach a second (usually lower) peak in this phase; it decreases as this phase progresses.

Late combustion phase (de): Heat release continues at a lower rate well into the expansion stroke. There are several reasons for this. A small fraction of the fuel may not have burned. A fraction of the fuel energy is present in soot and fuel-rich
combustion products and can still be released. The cylinder charge is non-uniform and mixing during this period promotes more complete combustion and less-dissociated product gases. The kinetics of the final burn out processes becomes slower as the temperature of the cylinder gases fall during expansion.

1.6 EMISSIONS FROM DIESEL ENGINES – AN OVERVIEW

I.C. engines generate undesirable emissions during the combustion process. The emissions exhausted into the surroundings pollute the atmosphere and causes serious problems like global warming, acid rain, smog, odors, respiratory and other health hazards. The major causes of these emissions are non-stoichiometric combustion, dissociation of nitrogen, and impurities in the fuel and air. The emissions of concern are unburnt Hydro-Carbons (HC), Oxides of Carbon (COₓ), Oxides of Nitrogen (NOₓ), Oxides of Sulphur (SOₓ) and solid Carbon particulates. It is the dream of engineers and scientists to develop engines and fuels such that very few quantity of harmful emissions are generated, and these could be let into the surroundings without a major impact on the environment.

As world population grew, power plants, factories, and an ever-increasing number of automobiles began to pollute the air to the extent that it is no longer acceptable. Though there are many other sources of causing air pollution, automobile is one of the major contributors to the problem. By making engines more fuel efficient, and with the use of exhaust after treatment, emissions per vehicle of HC, CO and NOₓ were reduced by about 95% during the 1970s and 1980s [3]. More fuel-efficient engines were developed, and by the 1990s the average automobile consumed less than half the fuel used in 1970. However, during this time the number of automobiles greatly increased, resulting in no overall decrease on fuel consumption.
1.6.1 Emission Norms

As world population grows, emission standards have become more and more stringent out of necessity and many countries have started following the European emission norms, called ‘Euro Norms’. In India, automobile industries have followed the “Euro” norms. Euro-I emission norms were enforced in the New Delhi Capital Region from June 1999 and Euro-II norms have taken effect from April 2000 throughout India.

1.6.2 Engine Emissions

Engine emissions can be classified into two categories: Exhaust emissions and Non-exhaust emissions. Major exhaust emissions are Unburnt Hydro Carbons (HC), Oxides of Carbon (CO and CO$_2$), Oxides of Nitrogen (NO$_x$ and NO$_2$), Oxides of Sulphur (SO$_2$ and SO$_3$), Particulates, Soot and Smoke, are the main non-exhaust emissions and the unburnt Hydro Carbons from fuel tank and crankcase blow by.

1.6.2.1 Hydro Carbon Emission

As C.I engine operate with an overall fuel-lean equivalence ratio, C.I engines have only about one-fifth the HC emissions of a S.I engine. The components in diesel fuel have higher molecular weights on an average than those in a gasoline blend, and these results in higher boiling and condensing temperatures. Therefore, soot formation is more in C.I engines. Some HC particles condense on to the surface of the solid Carbon soot that is generated during combustion. Most of this is burnt as mixing and the combustion process continues. Only a small percentage of the original Carbon soot that is formed comes out of the cylinder. The HC emission condenses on the surface of the Carbon particles, in addition to the solid Carbon particles themselves; contribute to the higher HC
emissions of the engine.

Because of the non homogeneity of fuel-air mixture some local spots in the combustion chamber will be too lean to combust properly. Other spots may be too rich, with not enough Oxygen to burn all the fuel local spots range from very rich to very lean. With under mixing, some fuel particles in fuel-rich zones never react due to lack of Oxygen. In fuel-lean zones, combustion is limited and some fuel does not get burnt. With over mixing some fuel particles will be mixed with already burnt gas and will therefore not combust totally.

1.6.2.2 Carbon Monoxide Emission

Carbon Monoxide is a colorless and odorless but a poisonous gas. It is generated in an engine when it is operated with a fuel-rich equivalence ratio. When there is not enough Oxygen to convert all Carbon to CO$_2$, some fuel does not get burnt and some Carbon ends up as CO.

$$\text{CO} + \frac{1}{2}\text{O}_2 \rightarrow \text{CO}_2 + \text{heat} \quad (1.1)$$

Maximum CO is generated when an engine runs rich. Rich mixture is required during starting or when accelerating under load. Even when the intake air-fuel mixture is stoichiometric or lean, some CO will be generated in the engine. Poor mixing, local rich regions, and incomplete combustion will also be the sources for CO emissions. C.I engines that operate overall lean generally have very low CO emissions.

1.6.2.3 Oxides of Nitrogen

NO$_x$ is mostly Nitric oxide (NO), with a small amount of Nitrogen Dioxide (NO$_2$) and also traces of other Nitrogen-Oxygen combinations. NO$_x$ is very undesirable. Released NO$_x$ reacts in the atmosphere to form Ozone and is one of the major causes of photochemical smog. NO$_x$ is created mostly from Nitrogen in
the air. Nitrogen can also be found in fuel blends. There are a number of possible reactions that form NO. All the reactions are probably occurring during the combustion process and immediately after combustion.

\[
\begin{align*}
O + N_2 & \rightarrow NO + N \\
N + O_2 & \rightarrow NO + O \\
N + OH & \rightarrow NO + H
\end{align*}
\]

(1.2)

(1.3)

(1.4)

NO, in turn, can further react to form NO\textsubscript{2} by various means, including

\[
\begin{align*}
NO + H_2O & \rightarrow NO_2 + H_2 \\
NO + O_2 & \rightarrow NO_2 + O
\end{align*}
\]

(1.5)

(1.6)

Although maximum flame temperature will occur at a stoichiometric air fuel ratio, maximum NO\textsubscript{x} is formed at a slightly lean equivalence ratio of about 0.95. At this condition flame temperature is still very high, and in addition, there is an excess of Oxygen that can combine with the Nitrogen to form various oxides. In addition to temperature, the formation of NO\textsubscript{x} depends on pressure and air fuel ratio. Combustion duration plays a significant role in NO\textsubscript{x} formation within the cylinder.

**1.6.2.4 Particulates**

The exhaust of C.I engines contains solid Carbon soot particles that are generated in the fuel rich zones within the cylinder. These are seen as exhaust smoke and cause an undesirable odorous pollution. This can be seen in the heavy exhaust smoke emitted when a truck of railroad locomotive accelerates up a hill or from a stop.

**1.6.2.5 Sulphur**

Many fuels used in C.I engines contain small amounts of sulphur. When exhausted in the form of SO\textsubscript{2} and SO\textsubscript{3} they contribute to the acid rain problem of the world.
1.7 ALTERNATIVE FUELS–AN OVERVIEW

Ever since the industrial revolution, human beings have been dependent on using energy in order to fuel their economies and make their lives easier. Unfortunately, in doing so, there have been several unforeseen side effects. Economically, there is a need to utilize new and renewable sources of energy, as the supply of many existing sources of energy is very limited. Also, environmentally, types of energy such as those that burn fossil fuels have been greatly affecting and damaging our planet. Levels of Carbon Dioxide and other green house gases have increased greatly in the atmosphere, leading to global warming and damaging many eco-systems and living conditions. Fast depletion of fossil fuels, rapid increase in the prices of petroleum products and harmful exhaust emissions from the engine jointly created renewed interest among researchers to find the suitable alternative fuels. Thermodynamic tests based on engine performance evaluations have established the feasibility of using a variety of alternative fuels like Alcohol fuels, Gaseous fuels, Fuel-Batteries, Fuel Cells, Vegetable oils, Biogas and Producer gas.

1.7.1 Alcohol Fuels

Alcohols are attractive alternative fuel because they can be obtained from both natural and manufactured sources. Methanol and Ethanol are two kinds of alcohols that seen most promising.

1.7.2 Gaseous Fuels

Gaseous fuels are best suited for I.C engines since physical delay is almost nil. However, as fuel displaces equal amount of air the engines may have poor volumetric efficiency [5]. Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG) became the first choice as clean fuels for implementation in certain metropolitan cities, where the pollution from conventional fuels is beyond tolerable limits and
proved to be a serious health hazard.

1.7.3 Fuel-Batteries

Electric vehicles (battery operated) have been in use all over the world for years now, but mostly for recreation, transport within a campus or a factory. When the I.C engine is designed, and petroleum products freely available, electric vehicle development came to a standstill. With increase in number of vehicles and the need to check the pollution level globally, recently a lot of interest is shown in developing electric vehicles.

Lead acid batteries are the most common type of batteries used in electric vehicles because of their low initial cost and universal availability.

1.7.4 Fuel Cells

A fuel cell is a controlled chemical- electro-energy conversion device that continuously converts chemical energy to electrical energy. A fuel cell requires continuous supply of fuel and an oxidant and generates DC electric power continuously.

1.7.5 Vegetable Oils

Vegetable-oil-based fuels have considerable potential as an appropriate alternative, since the fuel properties are similar to that of diesel. Diesel engines with vegetable oils as fuels produce the same power output as that with diesel but with reduced thermal efficiency and increased emissions [6]. This renewable source of fuel may also help in reducing the net production of CO₂ from combustion sources and the dependence on import of crude oil and saving in foreign exchange. The use of vegetables oils, such as Palm, Soyabean, Sun flower, Peanut, and Olive Oil, as alternative fuels for diesel engines dates back almost nine decades, but due to the rapid decline in crude oil reserves, again a lot of interest is shown in many countries
to employ vegetable oils. Depending upon the climate and soil conditions, different countries are looking for different types of vegetable oils as substitutes for diesel oil. For example, Soya bean Oil in the USA, Rapeseed and Sunflower oil in Europe, Palm oil in South- East Asia (mainly Malaysia and Indonesia), Coconut oil in the Philippines and Jatropha and Mahwah in India are being considered as an alternatives to diesel oil.

1.7.6 Biogas and Producer Gas

Biogas: It is another alternative fuel tried in diesel engines. Biogas can be produced by anaerobic digestion of organic matter. Potential raw materials available on a large scale are cow dung, municipal wastes, and plants specially grown for this purpose like Water Hyacinth, Algae, and certain types of grass. The main advantage of bio - gas is that it can be produced in rural areas from readily available materials. Biogas consists mainly of methane and Carbon Dioxide. Its calorific value is low but its knock resistance (Octane number) is high and ignition quality (Cetane number) is low.

Producer gas: It is made by flowing air and steam through a thick coal of coke bed which ranges in temperature from red hot to low temperature. The Oxygen in the air burns the Carbon to CO₂. This CO₂ gets reduced to CO by contacting with Carbon above the combustion zone. Steam gets disassociated, which introduces H₂ and the freed O₂ combines with the Carbon. Producer gas has a high percentage of N₂, since air is used. Thus, it has a low heat value.

1.8 IN-CYLINDER SWIRL INDUCEMENT

To enhance the efficiency of an engine it is important to optimize thermal efficiency, which is obtained at the highest possible compression ratio. However, if the compression ratio is too high, there is a chance to have knock, which should be
avoided at all cost. A solution for this problem is to promote rapid combustion, to reduce the time available for the self-ignition to occur [7].

To promote the rapid combustion, sufficient large-scale turbulence (kinetic energy) is needed at the end of the compression stroke because it will result in a better mixing process of air and fuel which will enhance the flame development. However, too much turbulence leads to excessive heat transfer from the gases to the cylinder walls, and may create problems of flame propagation [8] [9] [10]. The key to efficient combustion is to have enough swirl in the combustion chamber prior to ignition.

In order to provide the complete combustion at a constant rate, there is common design objective of bringing sufficient air in contact with the injected fuel particles. For this purpose, the piston crown and the cylinder head are shaped to induce a swirling motion to air, while during compression piston is moving towards Top Dead Center (TDC). The production of turbulence i.e. swirl by different means, however, is considered necessary for better fuel-air mixing. The limiting factors for wider use are the complexities of production and the higher costs of these methods of creating turbulence.

An increase in air swirl level is noted to increase the air mass of all zones. Thus at the moment when the mixture first ignites in one zone, all other zones approaching their self-ignition temperature contain more air. The increased swirl results in an increase in the initial combustion rate and hence a higher rate of pressure rise is expected [11].

1.8.1 Engine Swirl, Squish and Tumble

Three parameters that are used to characterize large-scale in-cylinder fluid motion are swirl, squish, and tumble [12].
The swirl is defined as the concentric rotation of the charge about the axis of the cylinder. If the inlet flow is brought into the cylinder with an initial angular momentum, it will create swirl [8] [10]. Many engines have a wedge shape cylinder head cavity or a bowl in the piston where the gas ends up at TDC.

The squish is a rapid radial movement of air occurring when the piston approaches TDC, i.e. at the end of the compression stroke in which the compressed gases flow into the piston or cylinder head cavity.

![Swirl and squish action as piston approaches TDC.](image)

During the compression process as the piston approaches TDC more of the air enters the cavity and the inside of air cylinder, moment of inertia decreases and the angular velocity and thus the swirl increases. As the piston reaches TDC, the squish motion generates a secondary flow called the tumble, where rotation occurs about a circumferential axis near the outer edge of the cavity.
1.8.2 Intake Flow

- The intake process governs many important aspects of the flow within the cylinder. The gas come out from the valve opening as a conical jet with radial and axial velocities that are about ten times the mean piston velocity.
- The jet separates from the valve producing shear layers with large velocity gradients which generate the turbulence.
- The jet is deflected by the cylinder wall down towards the piston and up towards the cylinder head producing recirculation zones.
- Additional turbulence is generated by the velocity gradient at the wall in the boundary layer.

1.8.3 Turbulent Flow

- Turbulent flow is characterized by its transient and random nature that is superimposed on a steady mean flow.
Turbulent flows are always dissipative, viscous shear stresses result in an increase in the internal energy at the expense of its kinetic energy.

So energy is required to generate turbulence. If no energy is supplied turbulence decays.

A common source of energy for turbulent velocity fluctuations is the shear in the mean flow, e.g., jets and boundary layers.

### 1.8.4 Mechanism of turbulence

The mechanism by which turbulence is understood to increase flame speed is due to the wrinkling of the flame front by the turbulent eddies, which increases the area of the flame front. The increased flame front area allows increased heat transfer rate to nearby unburnt gas. Since the temperature of the unburnt gas increases more quickly due to the increased heat transfer, it can reach ignition temperature and commence combustion more quickly than without a wrinkled flame front. A schematic diagram indicating the comparison between the laminar and turbulent flame front is shown in the Figure 1.4. It shows the laminar flame front to be smooth, turbulent flame front to be wrinkled, with pockets of burnt and unburnt gas in front of and behind the main flame front [13].

Fig: 1.4 Comparison between laminar and turbulent flame fronts during combustion.
The swirl should not be too high; otherwise, it could lead to excessive heat transfer from the cylinder contents. Furthermore, a high swirl is also not desired, as the kinetic energy for the flow is obtained at expense of a reduced volumetric efficiency. An optimal swirl ratio is not only good for optimum combustion, but also for an optimal emission reduction [13].

1.9 OBJECTIVES OF THE PRESENT WORK

As far as fuels for diesel engines are concerned, the alternative fuels are being used in straight or dual fuel modes without many problems. With the increasing concern about the green house effects on the world climate, lower CO$_2$ emission of diesel engine (about 30%) is an advantage compared to gasoline engine. The suitability of diesel engine for supercharging, which is extensively used on stationary and mobile applications, leads to a high power output and reduced smoke and other exhaust emissions from this type of engine.

From the point of their disadvantages, the diesel engines emit high Oxides of Nitrogen, smoke and particulate emissions in exhaust. Larger forces arising out of high compression ratio on various parts of the engine makes these engines heavier. Also, due to lean mixture operation, their power to weight ratio and the power to volume ratio are lower than the S.I engine. Due to heterogeneous nature of charge, there is no regular flame propagation like in S.I engine, hence multiple auto ignition mode makes C.I engines much more noisier than S.I engines. A higher ignition delay in diesel engine leads to a greater accumulation of fuel prior to the onset of combustion, which leads to a higher rate of pressure rise and consequently the roughness in engine operation.
The fuel economy and exhaust emission regulations, new technologies, development time and cost reduction require increasingly sophisticated solutions to improve the diesel engine performance and reduce exhaust emissions. Combustion process is central to the majority of engine development related issues and requires varied approaches to achieve desired improvements. The diesel engine combustion process involves flow of air and fuel into the combustion chamber, their mixing and ignition.

The main factors affecting the engine performance and emission characteristics are the degree of homogeneity of the air-fuel mixture, cycle-to-cycle variation of thermodynamic and mixing parameters, and turbulence intensity variations. Several methods available for improving diesel engine performance and emission characteristics include high pressure injection, split injection, water injection, exhaust gas recirculation, water diesel emulsion, retarded injection timing, intake charge Oxygen enrichment and combustion chamber design for better fuel-air mixing. Among these methods, some require modifications in fuel injection system, while many other methods include modifications in the combustion chamber or fuel. This work, mainly concentrates on investigating the effects of the modifications in the engine combustion chamber and the fuel in order to achieve better engine performance and emission characteristics. The increase in demand for petroleum fuels and consequent depletion of their reserves has given rise to a need for identifying and investigating new energy resources and/or finding the optimum way of using the present resources. In this regard, generally two approaches are pursued. They are:

a) Tailoring fuel at the refining stage i.e. improving refining processes for producing better quality fuel from different crude oils, and b) Improving performance of available fuel i.e. using some additives for improving the quality of existing fuels to a
desired level. The effects of fuel quality variations on diesel engine emissions is rather complex due to wide variation of engine response to fuel quality changes and the extent of inter correlation of the various fuel variables.

The diesel oil has higher Carbon content and is heavier than other conventional fuels and gives rise to problems during use in engine. Due to its high freezing point, diesel fuel causes blockage of filters and nozzles especially under cold conditions. To overcome these and other problems, the use of alternative fuels in diesel engines, the fine atomized fuel particles sprayed into the cylinder mix with air during compression stroke. For efficient combustion in diesel engines, the fuel and air are required to attain proper mixing between them. The requirements of a cylinder fuel-air mixing to the desired range of quality (proper fuel-air mixture), has to be supported by organized and unorganized in-cylinder air motion such as swirl, turbulence, etc. There are various techniques employed to generate turbulence in engine combustion chamber, involving either hardware modifications, or using process like pre-combustion. Also, fuel injection in finely atomized form produces turbulence.

In order to provide complete combustion at a constant rate, there is a common design objective of bringing sufficient air in contact with the injected fuel particles. For this purpose, the piston crown is shaped to induce a swirling motion to air, while during compression piston is moving towards TDC. The production of turbulence by different means, however, is considered necessary for better fuel-air mixing. The complexities of production and the higher costs of these methods of creating turbulence are the limiting factors in their wider use.

The present work is aimed at studying the effects of modifications in fuel and fuel-air mixing respectively for improving diesel engine combustion and emission
characteristics. These modifications include: a) Use of the Bio-Diesel b) In-cylinder turbulence inducement through grooves on the piston crown and c) Exhaust gas recirculation.