STUDY OF PERFORMANCE AND EMISSION CHARACTERISTICS OF DIESEL ENGINE USING DIESEL-FUEL ADDITIVE

Project Report

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ABSTRACT

Its been ages since mankind has been dependent on Fossil fuels. It is a known fact that the availability of the fossil fuels is a political and economic gamble. Diesel engines have high efficiency, durability, and reliability together with their low-operating cost. These important features make them the most preferred engines especially for heavy-duty vehicles. But the high dependence on conventional fossil fuels and its variance in terms of supply and prices causes varying impact on a nation's growth. The increasing use and dependence on conventional energy sources has led to a sharp increase in the demand for electricity and fossil fuels across the globe. On the other hand, the world seems to be running out of cheap sources of energy and the steep increase in the price of energy is hindering the development of energy-dependent countries like India. Added to this are the environmental concerns and growing world pressure on reaching an international consensus for curbing greenhouse gas (GHG) emissions. It is also evident that the uncertainty of energy supplies will only grow in the near future due to the complex dynamics of demand and supply which adds to the volatility of oil prices in world energy markets.

The usage of diesel engines has risen drastically day by day. In addition to the enormous use of these engines with many advantages, they play an important role in environmental pollution problems. Diesel engines are considered as one of the largest contributors to environmental pollution globally and are caused by exhaust emissions. They are responsible for several health problems as well. Many policies have been instated worldwide in recent years to reduce negative effects of diesel engine emissions on human health and environment. Many researchers have been carried out on both diesel exhaust pollutant emissions and after treatment emission control technologies. In the present work, the emissions from diesel engine, held at the lab (Make- Kirloskar) are reviewed. Further, the emission and performance using the Fuel Additive with diesel have been analyzed using the Software. Once the parameters were established, the tests were carried out on the Engine to verify the results. The four main pollutant emissions from diesel engines (carbon monoxide-CO, hydrocarbons-HC, particulate matter-PM and nitrogen oxides-NOx) along with other gases have been comprehensively examined.

Applicability of an alternate/altered fuel on CI engine fuelled with diesel necessitates careful study of the thermodynamic, transport and gas phase kinetics of the fuel intended to be used in addition to thorough understanding of working of CI engine. In addition effect of the fuel on various ancillaries that are associated with the engine cannot be overlooked. Amongst the various thermo physical properties that affect the performance of a CI engine calorific value, cetane number, viscosity, auto ignition temperature, Heat Release rate are of significant importance.

An effort was undertaken to study the effects of using the fuel on SEMT Pielstik make engines (16 PA6V STC 280) fitted onboard certain class of naval ships. Through a control volume approach, efforts are directed towards calculation of heat release, ignition delay and other in cylinder parameters that determine the performance of the engine first hand. CEA and CHEMKIN have been used to arrive at equilibrium compositions, adiabatic flame temperatures and other thermo physical properties of the fuel in use.

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LIST OF ABBREVATIONS

AFT	Adiabatic Flame Temperature
ATDC	After top dead centre
B	Bore
BTDC	Before Top Dead Centre
BDC	Bottom Dead Centre
BPCL	Bharat Petroleum Company Ltd
BP	British Petroleum
CA	Crank angle
CC	Combustion Chamber
CI	Compression ignition
CO	Carbon Monoxide
CO2	Carbon dioxide
CR	Compression ratio
CEA	Chemical Equilibrium Analysis
CHEMKIN	Chemical Kinetics
CN	Cetane number
CR	Compression Ratio
DI	Direct Injection
dT	Change in temperature
dt	Change in time
dV	Change in volume
ECAs	Emission Control Areas
EEDI	Energy Efficiency Design Index
FTIR	Fourier-transform infrared spectroscopy
GAHRR	Gross Apparent Heat Release Rate
FAME	Fatty Acid Methyl Esters
HC	Hydrocarbons
HFO	Heavy Fuel Oil
IN	Indian Navy
IOC	Inidan Oil Corporation

IMO	International Maritime Organisation
LSHSD	Low sulphur High speed Diesel
MT	Metric Tonnes
NBM	National Biodiesel Mission
ONGC	Oil & Natural Gas Corporation Ltd.
O2	Oxygen
PM	Particulate matter
Pmean	Mean effective pressure
Qgen	Heat generated
Qloss	Heat lost to surroundings
RPM	Revolutions per minute
ROHR	Rate of heat release
PPM	Parts per million
NOx	Nitrous oxides
SOx	Sulphur Oxides
SECAs	Sulphur Emission Control Areas
SEEMP	Ship Energy Efficiency Management Plan
UBHC	Unburned Hydrocarbons
UBHC	Un Burnt Hydrocarbon
ULSD	Ultra lowsulphur Diesel
%	Percentage

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CHAPTER 1 - INTRODUCTION

1.1 HISTORY

The human dependency on fossil fuels like petrol, diesel etc. is increasing every second. This dependency has a huge impact on the economic stability of the country. The easy availability and low running costs of fossil fuels are preventing mankind from switching over to the other energy forms. But the advancement of technology, exhaustive nature of fossil fuels, environment concerns and many other constructive factors have made it necessary to avoid the inappropriate usage of petrol, diesel etc. An exponential increase in the consumption of fossil fuels during the last few decades has resulted in rapid decrease in the fossil fuel reserves. Environmental concerns coupled with sustainability issues have forced the developed and developing countries to turn towards renewable and non-conventional sources of fuel to meet energy demands.

It has been observed that the usage of diesel engine as a fuel efficient and reliable source of power for various applications, inducing the transportation sector, industrial applications and various societal needs like the generation of power in agricultural applications has witnessed an exponential growth over the past few decades. In many of the above mentioned fields, the Compression Ignition engines are favoured over the Spark Ignition type engine for their relatively lower emissions of Carbon Monoxide (CO), Unburnt Hydrocarbons (UBHC) and Carbon Dioxide (CO_2), thus making the use of CI engines greener for certain applications. One more important advantage of the diesel engine is their capacity to work under biodiesel which have relatively lower energy content, which is attributed to the engine's capacity to operate at higher compression ratios.

However, the usage of diesel engines isn't without any inherent problems, they have a tendency to produce higher amounts of Particulate Matter (PM) and Oxides of Nitrogen (NO_x), which cause damage to the local flora and fauna and the particulate emissions are observed to be carcinogenic in nature leading to adverse effects on health of humans coming in contact with it regularly. It is widely accepted that the CI engines that are employed for commercial purpose are an important source of particulate emissions in atmosphere. Now with the stringent emission norms being applied worldwide, the present generation of CI engines are becoming more and more greener and efficient. The modern engines show a lesser PM and NO_x emissions. But, in the developing countries like China, Brazil and India where the usage of old CI engines without any facilities for after treatment is highest, are a major source of particulate emissions. One of the reasons for this is the lack of availability of modern technologies and current advancements being unattainable for the local populous due to their economic status and poor government laws. On the other hand, it is these countries that are witnessing one of the greatest increase in the demand for the fossil fuels which are directly influencing the country's development rate. Taking into account these conditions, researchers around the world are developing new, cleaner, greener and economic biodiesel and additives. Based on a report from the International Energy Agency(IEA), the renewable sources of energy like the biofuels and waste have the maximum potential to satisfy the growing energy trends of the world in an eco-friendly and economic way.

1.2 BACKGROUND

In an auto ignition type diesel engine, the combustion mixture is formed by mixing of air and diesel inside the combustion chamber and the ignition takes place due to injection of diesel by the fuel injector. It is necessary that the air inside the combustion chamber is highly compressed for the combustion of diesel to take place, thus the diesel engines have a higher compression ratio compared to Spark Ignition engines. The high pressure and the temperature created inside the combustion chamber are high enough that the diesel fuel undergoes combustion at the instant it is injected into the cylinder chamber. Thus the CI engine employs the high pressure compression to release the energy stored in diesel in the form of natural chemistry and converts it into useful mechanical work. In case of reaction equilibrium, the combustion would result only in water and carbon dioxide (CO_2).

In case of actual combustion process, due to various factors like ignition timing, chamber temperature, air-fuel ratio, compression ratio, injection pressure etc., the end products of combustion include many harmful products like NO_x, CO, UBHC and other PM. The figure 1 shows the approximate emission composition of a typical CI engine's exhaust. It is evident from the chart that among the emissions, the pollutant emissions account about 1%. Among the 1% pollutant emissions, the Oxides of Nitrogen (NO_x)

account to about 50% of the total, followed second by the Particulate Matter (PM) emissions. Among the pollutant emissions, trace amounts of SO_2 can also be found depending on the type, quality and the specification of the fuel being used. The production of SO_2 is due to trace amounts of sulphates present in the fuel. Although the quantity emitted is very small, it has the most adverse effect and can lead to environmental degradation by the form of acid rain. Presently there is no method to control the emission of SO_2 from the CI engine and research is being done in this field. With advanced ultra-low sulphur diesel being researched and sold by distributors, the harmful effects of SO_2 is being controlled.

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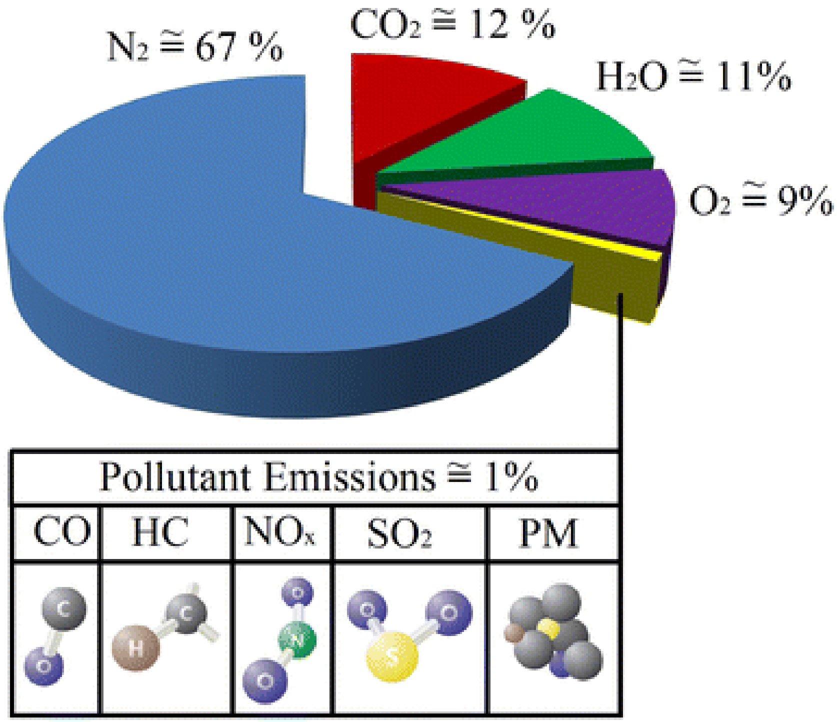


Figure 1: Emissions of PM, CO, HC and NO_x from a typical CI engine

1.3 SCENARIO IN INDIA

In 2016 and 2018, India has overtaken China as the leading nation in the incremental oil consumption. This growth of India accounts for 21.8% of the global oil consumption growth, according to the statistics published by BP. In 2016, the consumption was at 212 million tonnes and the rate of growth was at a steady 8.3% while in the same year, the oil consumption rate of the world was at a 1.5%. In a similar fashion, the growth rates were at 8.0% and 9.5% in 2017 and 2018 respectively, which was about

4.8% of the total consumption of world. However, according to the annual Report of 2014-15 Ministry of Petroleum and Natural gas, the production of Natural gas and crude oil has stagnated over the years as shown in figure 2. This has led to significant increase in the amount of oil being imported and thus affecting the country's GDP.

Thus in order to keep up with the current rate of development and keeping in mind the geographical limitations that are observed in case of India, India's fuel consumption is bound to only increase in the future unless and until alternative fuels are not looked into. The other aspect to improve in this is the usage of other additives with the fuel that are capable of increasing the wanted properties of the fuel and thus making the already existing fuel utilization optimal. Currently many research institutions across India are developing new and cheaper additives that can be blended with diesel in order to enhance the performance as well as be more environmental friendly.

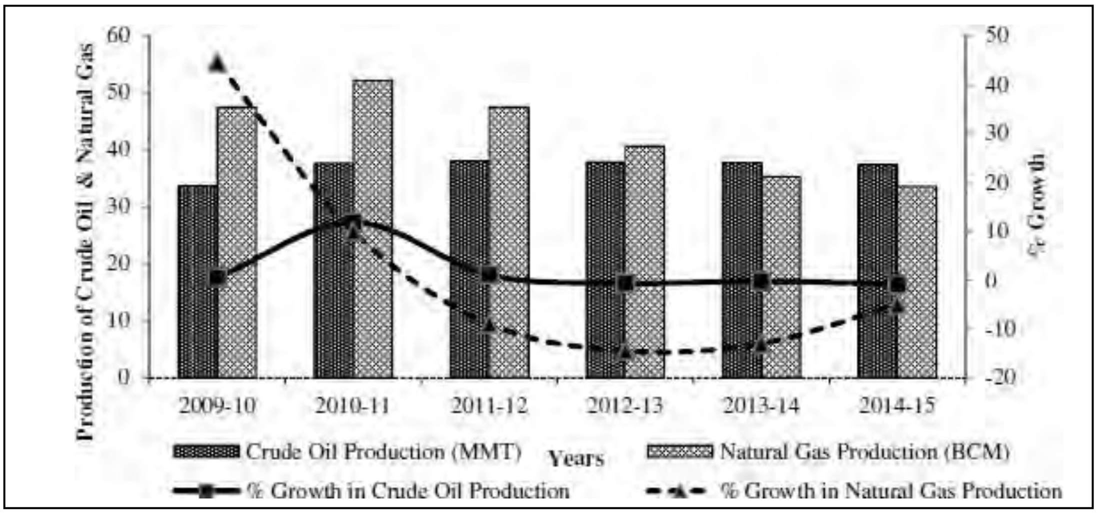


Figure 2: Representation of trends in the crude oil and natural gas production

1.4 WAY AHEAD

Owing to the fact that the fossil fuels are a non-renewable in nature and are bound to undergo extinct at a certain point, it has become an impending need to explore alternate methods that can either substitute the fuels or optimize the efficiency of use of the existing fuel. Based on the research and advancement in technologies worldwide, the following alternatives are being considered to cater to the current demand of fuels

a. Liquefied Natural Gas (LNG)
b. Fuel Additives/substitutes
c. Liquefied Petroleum Gas (LPG)
d. Biodiesels

For all of the above mentioned fuels, the following data is needed to ascertain its suitability in the aforesaid context:

a. The Chemical and physical Properties of the fuel.
b. Availability, cost and the production methods that can be employed and also the current infrastructure, facility available or to be provided in order to produce it in a larger volume and faster rate.
c. Practical applications and integration methods that are to employed; cost of integration, modifications required, storage and handling issues, transportation and inventory requirements.
d. Safety considerations.
e. Economic and environmental related consequences.

However, if we consider the existing inventory of large ships and other commercial equipments and propose moving to gaseous fuels, it becomes a non-viable solution as it would entail major modifications in the fuel storage system as well as engine fuel system. Safety aspects, in case of leakage of gaseous fuel, due to its odorless nature is another area of concern. Additionally, fuel injection systems consisting of pump for injection, high pressure pipes, injection system & fuel centrifuge will have to be replaced or modified to meet the requirements of gaseous fuel as opposed to existing liquid type fuel systems.

Further limited infrastructure for LNG bunkering will hamper the operational capabilities for which the engine or equipment is designed. On the other hand, liquid biofuels can be considered as a significantly better alternate owing to its miscibility properties with diesel as well as adaptability to existing engines with minimum modifications.

Microalgae are also considered to be better and attractive source for energy for many reasons, such as:

a. The algae require much less time to produce the same biomass as other higher plants through the process of photosynthesis.

b. The growth rate of microalgae under various conditions are high. It is also verified that the starch and the lipid contents of certain microalgae are over 30% *w/w*.

c. Microalgae are very easy to grow as they don't require fresh water to grow. They can easily be grown in non-arable land or in sea water.

Thus, it can be said that the process of producing energy from algae doesn't compete with food production in terms of land requirement. But, it is also observed that the cost of production of biodiesel from the cultivated algae is a very costly affair due to its sparse availability and low biomass. Cultivating algae on a larger scale is yet to be established in an economic way as it faces a lot of opposition in terms of land use and fresh water usage from the local boards which view it as a threat to the food production. Making it an activity bound to only coastal areas where the investment becomes high. Certain companies are exploring the process of growing algae commercially and produce biodiesel from it and use the dry mass as nutrient supplement thus further reducing the cost of biodiesel.

Currently, the biofuels being explored belong to 3rd generation of fuels. The biofuels of 1st generation included biomass consisting of starch from animals, waste, biodegradable wastes, sugars, vegetable oils etc., they also included waste from household, factories, agriculture etc., extracted using conventional technologies.

In 2010, India witnessed a highest rise in biofuels production with a registered increase of 85% over the previous year's rate. This growth was at 0.151 million tons equivalent and thus shows India's tendency to convert to this form of energy in the future. Approximately 11.2 to 13.4 hectares of land has been set as an ambitious target to cultivate Jatropha and extract oil from it. Numerous facilities including monetary benefits and support have been set up so that the farmers can grow these plants in a profitable way. This was proposed as a goal in the 11th five-year plan by the central government of

India. The states of Bihar, UP and MP have already given resources including active fiscal benefits for the growth of Jatropha and other non-edible seeds. However, owing to the food vs energy crisis, the first generation biodiesel hasn't been gaining the necessary momentum and aren't attracting the farmers or manufacturers. Still further research and development is being done in the field of oil rich seeds to develop a drought resistant strain which can be easily grown without heavy dependence on water.

Second and third generation biofuels have shown further promise as compared to the biofuels of first generation. The second generation biofuels refer to fuels prepared once the primary purpose of the crop has been met. India being the second largest producer of sugarcane, the alcohols extracted from the sugarcane molasses can play a major part in meeting India's future energy demand through non-conventional fuels. It is worth noting molasses from sugarcane are utilized for production of sweeteners consumed in Maharashtra leading to reduced ethanol production. Presently India accounts for only 14.3% of ethanol production worldwide. But judging from current trends, this is going to change as India is changing its mandatory biofuel content requirement from the current E10 (Fuel contains 10% of ethanol) to E20 in the upcoming years. Ethanol certainly has the potential to mitigate the future sustainable fuel demand.

1.5 TRENDS IN ADDITIVES

The major dependency on the fossil fuels has motivated researchers to find new ways to optimize the utilization of fuel and get as much energy from the fuel while trying to reduce the emission trends in the combustion process. A lot of research has been undertaken in the field of fuels blended with additives and their performance and emission trends are studied. By using these additives in a certain calculated concentration in fuel, the performance as well as the emission trends can be modified. There is a plethora of fuel additives that are available that are targeted to improve certain combustion aspects. Organic, Inorganic, Bio chemical etc. are some of the types of additives that are available for use with fuel.

Amongst the various fuel-additives, the ethers find a wide variety of application, some of the ethers that are used are

a. EGEE - Mono ethylene glycol ethyl ether

b. EGBE - Mono ethylene glycol butyl ether

c. DEGEE - Diethylene glycol ethyl ether

It is observed that when these ethers are added to the fuel, the lubricity of the resulting mixture is improved and also results in a slight decrease in the viscosity. It is also noteworthy that when DEGEE is added to diesel, the cetane number of diesel increases and when EGEE and EGBE are added to diesel, the cetane number decreases. Globally a stringent emission norms have been established which are critical towards the pollutant emissions that are originating from the Compression Ignition engine. The usage of the fuels mixed with additives that are capable of altering various properties of fuel such as volatility, density, flash point, Heat of evaporation, low Sulphur content are being explored to reduce the harmful emissions originating from the engines. Also many nano particles like Aluminum, Copper and Carbon nano tubes are added to the fuel to enhance the combustion characteristics by acting as secondary energy carriers due to their property, also many researchers are conducting experiments on diesel engines fueled by these additive blends to validate the claims put forth.

The metals like Fe, Cu, Ce, Pt and Co are being widely used as nano additives with diesel and other biofuels and are going to be available soon commercially. Similarly, the organic compounds of Ca, Cu, Mn and Mg are also being explored as additives in diesel fuel. They are specifically used to reduce the viscosity and flash point (Mg) based, while producing an observable reduction in the emission components. Also Jatropha biodiesel blended with nano particles of CeO_2 have produced a reduction in HC and NO_x emissions originating from combustion and an increase in the BTE as the CeO_2 nano particles have a property to act as catalysts. Another research has shown the use of Aluminium nano blends with petrol and has verified better combustion and reduction in combustion effluents. The use of CuO (Copper Oxide) in the form of nano particle i.e., as a ground brown powder has resulted in the reduction of Hydro Carbon and CO emissions, this is due to the better reaction surface availability and better atomization in the diesel fuel.

1.6 BIOCHEMICAL ADDITIVE

The current project deals with the exploration of use of a BIOCHEMICAL ENZYME that is obtained through the fermentation of excretion of microorganisms. The additive mainly consists of proteins and amino acids.

The main components of the additive are as follows:

a. Bio enzyme groups
b. Proteins and amino acids
c. Emulsifying agent (Iso-Propyl Alcohol)

These additives have the property of reducing the time that is required for a reaction to take place and this property of the additive can be exploited in order to enhance the rate of reaction in the combustion process. Many researchers have conducted research on exploring such enzyme additives sourced from plants, algae, micro-organisms etc. in order to find a suitable additive. One of the most promising sources of enzymes that can catalyse many reactions and serve as an additive is micro-organisms.

Microorganisms can be categorized as a type of effective sweepers of nature. The micro-organisms have the capacity to activate certain genes inherent in it to generate/excrete specific enzymes, which have the capacity to act as bio-catalysts for certain reactions and decrease the energy barrier necessary to carryout reaction of biochemical type. This enzyme has the capacity to reduce the high temperature and high pressure requirement of the biochemical reaction and catalyse the reaction to take place at a lower pressure and temperature at a much faster rate. Thus, reducing the reaction time.

With the addition of certain chemicals to this fermentation enzyme, it can be made to target any specific reaction. In this case the combustion process of diesel is targeted. The additive is thus prepared and is doped in different concentration with diesel to find the optimal concentration at which the functional efficiency of the enzyme will reach its maximum.

CHAPTER 2 - LITERATURE SURVEY

2.1 CONVENTIONAL FUELS

It is a well-known fact that the primary source of energy being consumed in the world originates from the fossil fuels namely coal, petrol, kerosene, diesel etc. An exponential increase in the consumption of fossil fuels during the last few decades has resulted in rapid decrease in the fossil fuel reserves. Environmental factors besides sustainability issues have forced the world to turn towards the renewable and non-conventional sources of energy to meet the demands of these fossil fuels. Diesel like any other fuel is complex, it has the tendency to change its chemical structure i.e., the chemical structure of the diesel when it is in the tank of an automobile is largely different from the structure it possessed when it was in the refinery and also different from that when it was in the storage tanks of the fuel pumping station. The molecules of diesel undergo oxidation and the structure changes and with it, the energy released/unit volume also changes with it which directly influences the engine's performance.

P. E. Hodgson, who is a senior research fellow at Corpus published that at every interval of 14 years, the world is doubling its energy requirements and if the current consumption trends keep growing at the current rate then it is going to overtake this value too. He also published in 2008 that the quantity of oil produced per year is going to reach a peak value in a span of 10 years and witness a steep decrease. Thus by his calculations the fuel resources reached their peak value in 2018 and over the period of next few years we will observe a gradual decrease in the fuel reserves. The current trends in the consumption of fossil fuel as studied by the Stanford University suggest that the depletion of resources is much more imminent than forethought and the likely scenario is that they will deplete completely by the next 2 decades.

2.2 DIESEL ENGINE

Diesel engine is Internal Combustion – Compression Ignition type, which means that only air is compressed inside the engine cylinder to a very high pressure and the diesel fuel is spray injected into the combustion chamber for the ignition to take place just before the power stroke i.e., just 5^0 to 20^0 before TDC. Here, by varying the quantity of fuel being injected the load control can be done since the quantity of air flow is constant for a given speed of engine. The efficiency and the running costs of CI engines are low thus they find application in many sectors like automobiles, industrial equipment, Marine, Transportation sector etc.

The diesel engines have a much higher compression ratio in the range of 14 to 26 depending on the application and are higher than that of Spark Ignition engines. The range of temperature and the pressures attained inside the combustion chamber of these engines is also very high, the atmospheric air that is drawn into the cylinder is compressed to a pressure as high as 4-5 MPa and reach a temperature of around 800 K to 900 K inside the cylinder. At about 15^0 before TDC, the fuel injection starts and the fuel vapours mixes with air inside the chamber in combustible proportions. The conditions inside the cylinder are such the temperature and pressure are higher than the self-ignition temperature of diesel thus the non-uniform mixture of fuel and air spontaneously ignites and initiates the process of combustion. The flame spreads at a very fast rate through the fuel-air mixture and engulfs the entire cylinder. Because of the travelling flame, the mixing of the combustion gasses and the fuel air mixture also happens leading to a small decrease in the amount of heat released. The exhaust process in the engine is similar to that of a SI engine, an exhaust port opens at the end of the power stroke and vets out the exhaust gasses. Then the piston goes back to its original position and the cycle repeats.

In case of naturally aspirated engines, atmospheric air is directly introduced into the combustion chamber without any compression. Turbocharged engines are those in which the intake air is compressed to higher pressure by an exhaust gas driven compressor-turbine unit called as the turbocharger. In supercharged engines, the atmospheric air is compressed to a high pressure with help of an air compressor that is mechanically driven by engine or external source. The advantage of Supercharging and Turbocharging is that it leads to an increase in output of engine by increasing the mass of air flow per unit volume displacement of the cylinder thus allowing to extract a better power from the same engine configuration. The advantage of these methods is that the size and weight of engine can be reduced for a certain power output. This method is suitable only for larger engines and fails in case of smaller engines where the addition of a turbocharger or a supercharger leads to heavy weight which is not preferred.

2.3 FUEL ADDITIVE

In 1974, the (ATC) Technical Committee of Petroleum Additive Manufacturers in Europe was found, which is currently the leading enterprise on the evaluation of different additives that are or can be used as potential additives for use with fuel

The usages of certain fuel additives reduce the degradation of diesel fuel, enhances the cetane number of fuel, reduces the emissions and enables more power to be extracted from the fuel. Fuel additives are predominantly employed so that the economy of consumption of diesel can be improved, reduce emission like smoke, NO_x, CO, HC, and particulate emission. Researchers have conducted a series of experiments to examine the emissions and performance of the CI engine by running the engine on fuel with and without different proportions of the additives to determine the legitimacy of such additives and to confirm their claim that the additive has the capability to alter the properties of combustion and emission.

Manish K. Nandi et al has studied the effect of Fuel Additives that are based from peroxide in CI engines. It is a cost effective option to use high cetane diesel fuel additive that can be used to reduce the engine emission. Both the nitrates and peroxide show cetane improvement additive significantly reduce all regulated and unregulated emission including NO_x.

Ali Keskinet al have done experiments in Fuel Additives that are based on manganese in the diesel fuel. They have found that the performance of the engine and the carbon monoxide emission and smoke liberated were reduced drastically.

R.D. Misra el al reported that additives of various types can be used for increasing the performance and reducing emission of the CI engine. It was also found that Carbon

Monoxide and particulate emissions along with hydro carbon emissions were reduced considerably when using Fuel Additives.

The Marsol F.T has shown that the SO-2E Fuel Additives added to the diesel shows improved performance of diesel engine and reduces the NOx significantly for both additives. Further it was reported that smoke increases by almost 35% and also the emission.

In recent research on additives, it has been found that the Nano-Particle additives are much better, promising and novel type of additives that are capable of producing observable decrease in pollutant emissions in exhaust emissions and at the same time produce an increase in the performance of CI engine. This has attracted many researchers to explore the field of metallic nano additives, bio-enzyme additives, organic compounds of metal additives etc., for achieving a better emission and performance characteristics in the engine.

It is known that globally stringent emission norms have been established which are critical towards the pollutant emissions that are originating from the Compression Ignition engine. The usage of the fuels mixed with additives that are capable of altering various properties of fuel such as Volatility, Density, Flash Point, Heat of Evaporation, low Sulphur content are being explored to reduce the harmful emissions originating from the engines. Also many nano particles like Aluminum, Copper and Carbon Nano Tubes are added to the fuel to enhance the combustion characteristics by acting as secondary energy carriers due to their property, also many researchers are conducting experiments on diesel engines fueled by these additive blends to validate the claims put forth.

Skillas et al. has explored the effects of using a nano additive made of Cerium and has studied the composition and distribution of Particulate Matter. Along with it he reported an increase in the efficiency of power generation by addition of the Nano Additive which can be attributed to the additive’s ability to modify the Physio-Chemical properties of diesel.

Sajith et al conducted tests with Cerium Oxide [CeO_2] as additive and stated that owing to the very large surface area of the molecule, it acted as a catalyst and catalyzed the reaction to take place at a faster rate and also increased the efficiency of the combustion process. It was reported that it also leads to better emission trends in PM, CO and NO_x.

Another main concern of using additives in fuel blends is their stability in the final solution i.e., the additives tend to settle after a certain period of time due to difference in density. This can be solved by adding a calculated amount of surfactant to stabilize the blend or by mechanical stirrer which stirs the mixture after a calculated period of time. It is observed that this coagulation of additives, if not treated or rectified could lead to blockage of the injector or orifices in the injection system. Thus it is necessary to add a surfactant or an anti-coagulation agent to stabilize the blend.

2.3.1 PEROXIDE BASED FUEL ADDITIVE

Peroxide based fuel additives are employed to increase the Cetane Number and control certain pollutants originating from the engines. Di-butyl peroxide additive has an advantage over the alkyl nitrate additive in reducing the exhaust emissions, since it does not contain any amount of Nitrogen. The additive reacts through the formation of free radicals that have capacity to accelerate the combustion and to react with the aromatic fragment compared to the aliphatic hydrocarbon fragment that exists in the fuel. It was observed that the oxidative stability and storing for a long period of time is not a problem for peroxide based Fuel Additive.

2.3.2 HYDROCARBON BASED FUEL ADDITIVE

Fuel additives based on Hydrocarbons are currently being explored, one example is a solution of Nitro aliphatic compound and Ferrous Picrate which are blended with a mix of antioxidants. When it is blended with fuel, the active ingredients decomposed during the first stages of combustion to increase turbulent mixing and create a more complete oxidation in the short period allowed by the firing cycle. These additives have a very stable, non-corrosive nature and cost of them is low.

2.4 BIOCHEMICAL ADDITIVES

The current trends in the field of fuel additives are moving towards a greener and environment friendly sourced additives such as the biochemical, Bio-lipids, enriched amino acids etc., which can be locally sourced from small scale production plants. Further research is being conducted on whether the utilization of such additives can be economical or not. These additives can be obtained through the fermentation process that is seen in the naturally occurring microorganisms. These organisms have the ability to produce such enzymes that have capability to breakdown the reaction time and catalyse the reaction. This property can be exploited to utilize the extracted enzyme to support the combustion reaction.

Thomas Bobik, who is a molecular biology and biochemistry professor from USA, introduced a new manufacturing process for Isobutylene (Isobutene) by isolating an enzyme which is capable of producing the fuel organically. This Bio synthesized isobutylene has better combustion properties and this can be used for commercial purposes. This can be transformed into Iso-Octane through chemical treatment that has the property to replace an additive used in fuels called as Methyl Tertiary-Butyl Ether (MBTE) which is not eco-friendly. This Iso-Octane also has the property to reduce the knocking tendency of CI engines.

The company named “Xmile” has blended biochemical additive with the fuel as an additive, it significantly improves fuel consumption and reduces CO emissions when it is mixed with fuel in a dose of 1:10,000 i.e., one part of additive in ten thousand parts of fuel. It is reported to improve the efficiency and also the exhaust gas temperatures. [13]. Thus opening up a new possibility of sourcing such organic enzymes to be used in many industrial as well as commercial applications.

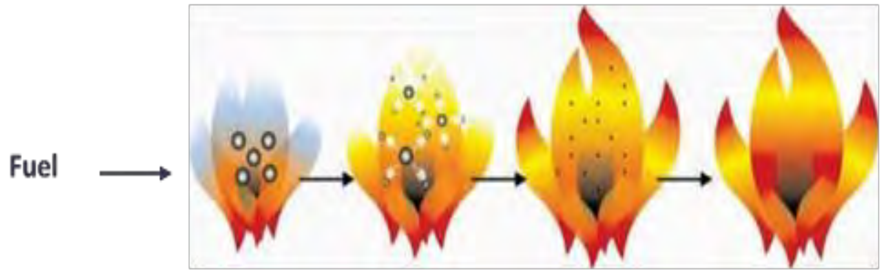
2.4.1 Why Fuel Additive Improves Fuel Oil Energy Efficiency

a. Micro-Emulsification

The fuel additive contains a Micro-Emulsification agent component in it. This agent has the capacity to convert the existing Oil/Water Micelle which is not good for combustion process into Water/Oil Micelle which promotes good combustion.

b. **Cracking of water molecules**.

At higher temperatures of combustion, the cracking of water molecule takes place which can release additional energy. Thus the use of biochemical



$$C + H_2O = CO + H_2$$

Figure 3: Reaction without using Bio-enzyme additive

additive can produce extra energy in the combustion process making the engine more powerful. The addition of bio additive promotes the reaction process and more energy is extracted by the following reaction.

c. Micro-Dispersion.

The fuel additive consists of Bio-Chemical enzyme that enhances the fluidity and viscosity of diesel oil. Figure 3 is a representation of the dispersion that occurs in a typical diesel oil combustion in a combustion chamber, the rate of atomization and the extent of atomization are both less. The Bio-enzyme additive has the capacity to give a better atomization rate and thereby reduce the ignition delay and also promote better/complete combustion. Figure 4 is a representative image of the above said process and shows better atomization of the fuel blend

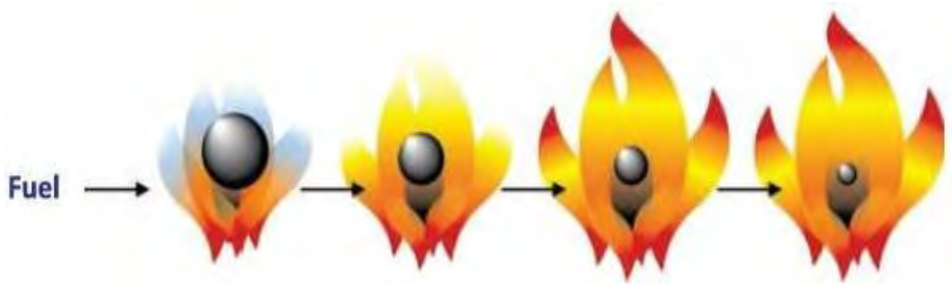


Figure 4: With use of Bio-enzyme additive

d. Ignition Booster

The fuel additive had the capacity to act as an ignition booster. Both the explosion and combustion reaction belong to a severe reaction course. When the Bio-enzymes are added to the fuel, the combustion process leads to formation of unique formulates of combustion such a Metallo-enzymes, Bio-activators and Co-enzymes which further have the tendency to boost energy conversion and make oxidation process take place at a faster rate.

2.4.2 Main causes of heat erosion

Inorganic or Organic metals and sulphide present in the fuel oil will form small fine droplets in the process of combustion. When the air flow takes place, these droplets gets picked up and are deposited onto the inner metallic cylinder surface and forms a kind of compound that has very high corrosive property but a low melting point. Because of this action, the inner walls of the combustion chamber may get corroded and reduce the structural integrity of the chamber. Prominent erosion occurs due to the following compounds.

a. Sodium Sulphate - Na_2SO_4

b. Vanadium Pentoxide - V_2O_5

c. Lead Oxide - PbO

a. Na_2SO_4 high temperature erosion due to sulfuration (M. P. 884 °C)

At higher pressures than equilibrium pressure, the Na_2SO_4 starts to stick to the inner surface of the cylinder walls due to the effect of coagulation and undergoes chemical reaction with certain protective oxide coating layer like Cr_2O_3 and form Na_2O-Cr_2O_3 which is a complex compound that has low melting point and destroys the protective layers on the surface. This reaction also releases Sulphur which further leads to sulfidation by penetrating into the metal surfaces. Thus the reaction of Na_2SO_4 with Cr_2O_3 reduces the Cr_2O_3 protective layer.

b. V_2O_5 Vanadium Attack (M. P. 690°C)

At lower temperature, Vanadium will be in the form of V_2O_3 or V_2O_4, which are relatively less volatile and very stable compared to its pentoxide form. But at higher temperatures i.e, above 550^0 V_2O_5 will be formed (M. P. 690 °C) in the process of combustion of fuel. It was seen that Vanadium will react with metals like Na, Fe, Ni, Mg, Ca etc. (whose MP between 500 °C - 1200 °C) and form low melting point compounds with them. Also some of the Vanadium will form a low melting point compound like Cr_2O_3-V_2O_5 (M. P. 665°C), NiO-V_2O_5 (M. P. 640°C) with Cr_2O_3 and NiO which are present in the cylinder surface protection layer and lead to further deterioration due to erosion

c. PbO metal oxide.

PbO - MoO_3 -V_2O_5 are of prominent corrosivity to steel materials. PbO will be non-reactive at lower temperatures and at higher temperatures, PbO will react with the protective Cr_2O_3 layer on the inner surface of the cylinder and form a complex $PbCr_2O_3$ which offers no protection against wear and tear.

The additive will prevent the thermal erosion from happening because it catalyses special bio-chemical reactions of Sulphur (S), Oxygen (O) and Nitrogen (N) present in diesel and converts them into stable oxidized state.

2.5. THERMOPHYSICAL PROPERTIES

The Thermophysical properties of the fuel include adiabatic flame temperature, cetane number, flash point viscosity etc., which play an important part in determining the ignition delay, knocking characteristics, flame speed, atomization etc., These can be analyzed to find the optimal timing and metering for efficient combustion.

Density is one of the important Thermophysical property which influences the performance of the engine directly [14]. The density of the fuel directly affects the Cetane number which is an index of combustion capacity [14-15]. Another property to be considered while selecting the type of additive which is added to diesel is its Calorific Value or Heat of Combustion. A lower Calorific Value or Heat of Combustion directly affects the amount of energy that is released in the combustion of fuel. In case of additive added to diesel for the present experiment, the Calorific value of the blend was found to be higher than that of diesel, meaning that the amount of energy released by blend will be higher than that of diesel. The following table 1 shows the properties for the diesel additive blend compared to that of diesel and the tests were conducted at ICER lab.

Table 1: Thermophysical Properties of fuel

FUEL PROPERTY	DIESEL	DIESEL + ADDITIVE
Calorific Value	35.786	35.803
Self-Ignition Temp (^0C)	256-315	265-325
Cetane number	40-55	42-57
Boiling point(^0C)	188-343	200-355
Flash point(^0C)	52-96	53-91

2.6. FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR)

Fourier Transform Infrared Spectroscopy abbreviated as FTIR is a method which is used to obtain an Infrared Spectrum of either the emission or absorption of a gas, liquid or solid. The FTIR equipment can be used to collect the high resolution data over a large spectral range. This method of spectroscopy has huger advantages over a dispersive type of spectrometer which can only measure intensity of wave over a very small range of wavelengths [16]. Illuminating a sample by infrared source, depending upon its absorptivity and reflectivity the molecular structure of the sample can be found out. This spectroscopy is feasible for the materials which react to the visible range as well as infra-red spectrum.

This method gives the infrared fingerprint which is unique for each material as they have unique molecular structure which can be assumed to a “human finger print”. FTIR is not a destructive type of testing. It is a rapid, sensitive, precise and able to scan very tiny molecules [17]. Figure 5 shows a typical FTIR equipment

Figure 5: FTIR equipment

2.7 EFFECT OF INJECTION PRESSURE

The efficiency of the process of combustion and the products of combustion produced in an engine greatly depend on the pressure at which fuel is being injected into the combustion chamber. Also the pressure at which fuel injection takes place into the combustion chamber is directly affecting the ease of atomization and thus the speed at which flame traverses.

Because of these factors, the injection pressure is of great importance whenever the combustion analysis is done in a compression ignition engine that is run with zero to full load. At high pressure the rate of atomization also increases and vice-versa. For low pressure of injection during combustion, the ignition delay period and the diameters of the fuel particles increases and results in lesser power generation.

Here the increase in the pressure of injection leads to reduction in the diameter of the fuel particles, leading to a better mixing of the fuel and air particles i.e., better atomization can be achieved with higher injection pressure [18]. In the case of a typical commercial diesel engine, the injection pressure ranges from 190 to 250 bar based on the employed combustion system and also the size of engine. With the increase in injector pressure, the fuel jet penetration distance became longer, formation of fuel and air mixture was significantly better and uniform and the combustion delay duration was also witnessed to be shorter. Figure 6 shows a typical diesel fuel injector.

The effects of high injection pressure benefits are:

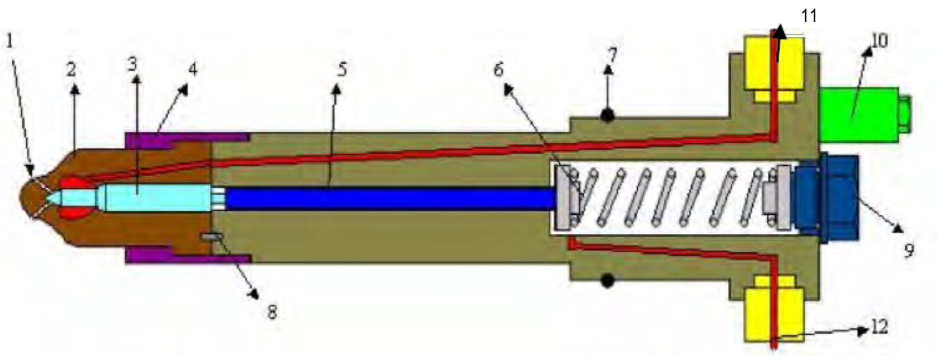
a. Improves fuel atomization producing a finer level of fuel particles.

b. The smaller fuel droplets evaporate at a faster rate resulting in rapid fuel-air mixing.

c. Shorter injection duration.

d. With shorter injection duration, injection timing may be retarded.

e. Higher spray penetration and better air utilization.



PART NAME			
1.	ATOMIZATION HOLE	7.	"O" RING
2.	NOZZLE BODY	8.	DOWEL PIN
3.	NEEDLE VALVE	9.	ADJUSTING NUT AND WASHER
4.	NOZZLE CAP NUT	10.	RETAINING NUT
5.	INTERMEDIATE SPINDLE	11.	INLET CONNECTOR
6.	SPRING	12.	LEAK OFF CONNECTOR

Figure 6: A typical fuel injector

2.8 DIESEL INJECTOR VARIATION

The fuel injection system used in CI engine is direct injection type and in order to enable better evaporation of fuel particles a higher degree of atomization is preferred in a very short period of time. Also in order to utilize the entire amount of air charge inside the cylinder, it is necessary that the optimal amount to spray penetration must take place inside the combustion chamber. Thus the spray system must be able to cater to the above requirements for the combustion process to be effective. It must be flexible enough to control the quantity of fuel being injected and the time at which the fuel is injected depending on the engine speed and loading conditions. The injection of fuel must be precise and at the correct time for the combustion to occur at the required rate. Further, the appropriate structure and spray shape must be formed in conjunction with the geometry of the combustion chamber. Depending on size of engine and applications, the system generates pressure in the range of 110 MPa to 220 MPa. In the system, the fuel is carried inside high pressure resistant pipes that can withstand very high pressure and any fluctuations in flow. The fuel is pumped to the injection nozzle located at the head of the cylinder head and any excess fuel is sent back to storage tank.

The functioning or operation of the unit injector system used to pump fuel is same or identical to that of the functioning of a unit-pump and has almost the same benefits and disadvantages. In case of an injection system of engine, the nozzle and pump are not grouped into a single unit. The high pressure pump is driven with the help of the camshaft of the engine. The camshaft is mounted on the engine and rotates in conjunction with the engine thus the speed of rotation of camshaft depends on the speed of engine. The cylinder head consists of a nozzle holder which houses the injection nozzle and is connected to the high pressure pump through a series of high pressure capacity pipes. The main feature of the system is that the pump and the nozzle aren't nearby thus reducing the effective size of the arrangement. The components have been integrated into the head of the cylinder in a seamless way to make sure the maximum utilization of space and weight reduction.

In the experiment, the effects of the pressure of injection on the performance of engine have been studied on a Kirloskar 8 hp Compression Ignition engine. The performance and emission characteristics of the above engine along with the rate of fuel consumption have been measured at fixed speed of operation. The tests were conducted with varying the injection pressure between 220 – 280 bar and the performance and emissions characteristics were evaluated. Precise or exact control over the fuel injection, fuel-air mixing and spray atomization is very essential in making any kind of improvement to the existing combustion process. The injection pressure coupled with right injection timing will play a significant role in the combustion process of fuel, which influences the performance, exhaust emissions and noise levels of diesel engine.

The high injection pressure of fuel contributes to the reduced size of fuel droplet and a very fine atomization and a significant improvement in the process of combustion. Also it produces a reduction in the emission of smoke and other particulates. The low pressure of injection is also important in the operation of an engine as it is necessary to maintain a lower injection pressure during idling conditions to reduce the consumption of fuel.

2.9 PROBLEM STATEMENT

The experiment was undertaken to analyze the effect of using fuel additive on the performance and exhaust emission characteristics on Kirloskar made 5.5 kW compression ignition engine.

The problem is specifically modelled keeping in mind the propulsion requirements and power that has to be generated to meet the specified task of the engine. It is also to be noted that the additive added to the fuel must try to reduce the harmful effects on the environment while improving on the specific fuel consumption and the efficiency of the combustion process. Thus the experiment is conducted to validate if the additive can be used as a feasible solution to reduce emissions and improve performance.

CHAPTER 3 – THEORETICAL STUDY

To understand and make the quantitative analysis the processes undergoing during the combustion of fuel in an engine, it is necessary to familiarize or have knowledge of the engine performance parameters. Some of the parameters under study are as follows

3.1 MASS OF FUEL CONSUMED (M_f)

$$M_f = \frac{X_{cc} \text{ x Specific gravity of fuel x } 3600}{1000 \text{ x } t} \text{ Kg/hr} \qquad (1)$$

Where, t - time taken in seconds

X_{cc} - fuel consumed in m^3

3.2 ENERGY IN FUEL / HEAT INPUT (HI)

It is defined as the energy that is contained in the fuel oil before it undergoes chemical combustion and is converted into emission particulates. It is the total energy that is contained in the fuel oil molecules. The expression for this is given by the equation 2.

Energy = mass flow rate of fuel x calorific value of fuel (2)

3.3 BRAKE POWER (BP)

The Brake horse power of an engine is defined as the total power that is available at the output and can be used to do useful work. Brake power refers to the final output power that is available from the engine after combustion of fuel. The equation used to arrive at brake power is shown below in equation 3.

$$B.P = 2\pi NT/3600 \qquad (3)$$

3.4 INDICATED POWER (IP)

It is the power output that is available in the cylinder chamber because of combustion of fuel oil. It can be defined as the total energy available in the combustion chamber for doing useful work and is lesser than the total energy in the fuel, this is attributed to the thermal losses and frictional losses in the combustion chamber

3.5 SPECIFIC FUEL CONSUMPTION (SFC)

Specific fuel consumption abbreviated as SFC can be described as the amount of fuel that is consumed by the engine per unit time to produce a unit power in KW. The SFC of an engine is a measure of its efficiency. For less error in data, the readings for SFC and power generated are taken in a controlled environment to be experimentally accurate. The formula used for calculating SFC is shown below in equation 4.

$$SFC = m_f / BP \qquad (4)$$

Where, m_f - Mass of fuel consumed / hr

BP - Brake Power

3.6 BRAKE THERMAL EFFICIENCY (BTE)

It is given by the ratio of Brake Power to the Input Power donated by the rate of flow of fuel and the calorific value of the fuel. It is generally found that the Thermal Efficiencies of naturally aspirated engines are lower than that of the turbocharged engines. Theoretical formula used for calculation of thermal efficiency is shown below in equation 5.

$$\text{Thermal Efficiency} = B.P / (mf \times C.V) \qquad (5)$$

3.7 BRAKE MEAN EFFECTIVE PRESSURE (BMEP)

$$BMEP = \frac{BP \times 60000 \times n}{A \times L \times N \times 100000} \text{ bar} \qquad (6)$$

Where, A – Cross sectional area of combustion chamber

L – Length of stroke

N – Speed in RPM

3.8. MECHANICAL EFFICIENCY

The mechanical efficiency of a system may be given as the ratio of Output Power at the crankshaft to the Indicated Power. Also it is given by the ratio of BTE to the ITE It is given by the equation 7.

$$\text{Mechanical Efficiency} = B.P / I.P \tag{7}$$

CHAPTER 4 - EXPERIMENTAL SETUP

4.1 DETAILS OF ENGINE

For the experimental studies a 5.5KW or 8hp, vertical, Single cylinder, Air-cooled, Four Stroke, Compression Ignition diesel engine was employed which primarily finds application in agricultural field. The engine setup is available at the I C Engine Laboratory available in Mechanical Department in IISc. The figure 7 shows the engine setup available at the IC Engines lab. Details of the engine are as follows:-

S.No	Parameters	Values
1.	No of Cylinders	1
2.	Bore	95mm
3.	Stroke	110mm
4	Cubic Capacity	0.78 Litres
5	Type of fuel injection	Direct Injection
6	Power	5.5KW (8hp)
7.	Fuel	Diesel
8.	Speed	1500 rpm
9.	Compression ratio	17.5 :1
10.	Engine weight	93 Kgs dry weight

Table 2: Engine Specification

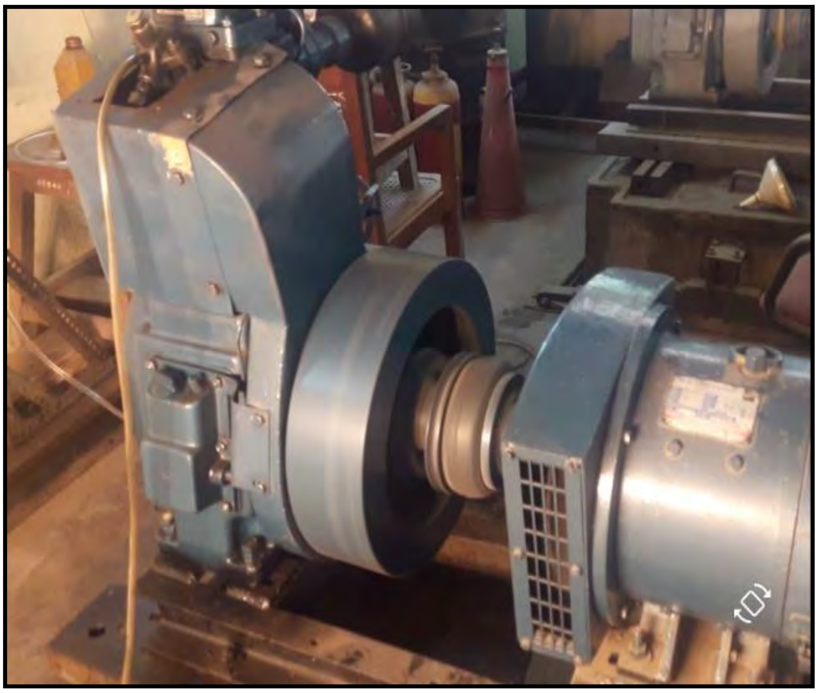


Figure 7: Experimental set up of Diesel engine

The engine is coupled to an alternator and has to be manually cranked for starting. The engine is fitted with a manual governor that maintains the rated rpm with variations in load. It is a clock-wise rotating engine when viewed from the flywheel end. It was learnt that owing to long period of inoperability had rendered the engine to scope of stagnation related defects. Multiple attempts to start the engine were futile and necessitated stepwise defect rectification measures to be undertaken. As a preliminary step, complete servicing of the engine that included servicing of injector, replacement of lubricating oil, replacement of fuel and lubricating oil filter, and cleaning of air filter was undertaken. Photographs of the servicing procedures undertaken are depicted in Figures below.

These procedures ensured the removal of dust and other foreign materials which may have chocked the small passages in fuel and lubricating oil delivery system. For the operating conditions required for the experiment, the fuel pump was removed and cleaned and the pump pressure was set to the required value of 220 bar and the tests were conducted. After this injector was again removed and the pressures of 250 and 280 bar were set respectively and further tests were conducted.

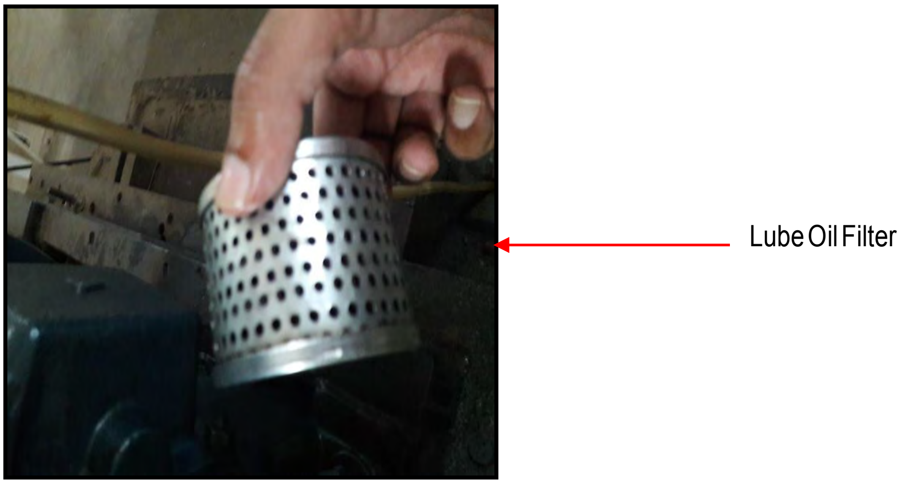


Figure 8: Replacement of lube oil filter

Figure 9: Replacement of fuel filter

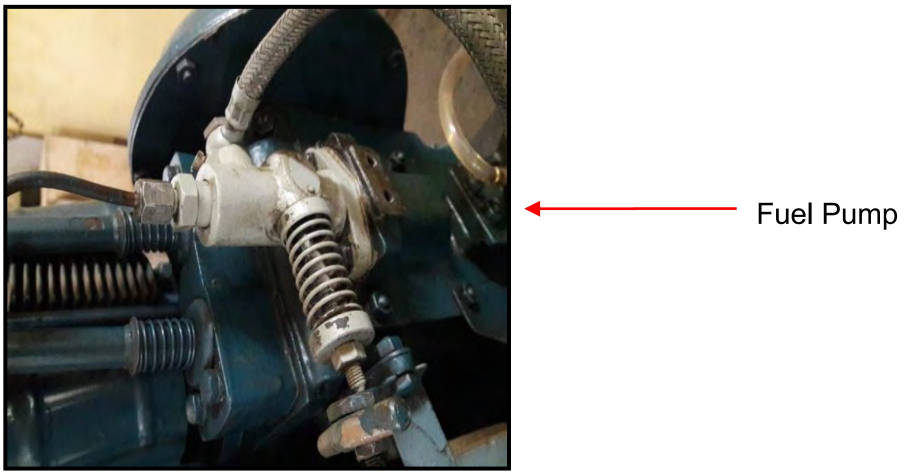


Figure 10: Photograph of fuel pump

4.2 LOAD BANK

The present engine setup is connected to a 3 phase alternator capable of supporting a 5kW load in total**.** Then the load bulbs were cleaned and the broken ones were replaced and the wirings were checked for any further damage. The work involved identification of suitable panel for fitment of light bulbs of varied power connected in series in each phase. Additionally, a circuit breaker with a rating of 12 Amps has also been connected for the purpose of safety.

The electric load was applied on the engine using the above mentioned setup during running and has the capacity to vary the load form 0 kW to 5 kW. The engine is rated at 5.5kW, but for experimental purposes the load was applied till 5kW only

Details of the alternator are as appended below:-

(a) Make - M/s KECL
(b) Rating - S1 to IS4777
(c) kVA - 7.5
(d) Volts - 415
(e) Amps - 10.4
(f) Power rating - 8hp (5.2 kW)

The existing lighting load connected to the alternator was a mere 1 kW. Therefore, to enable testing over a range of load a load bank was developed in house. The development of in house load bank consisted of first identifying the state of alternator windings to ascertain the load carrying capacity in each phase followed by making a detailed circuit diagram of the load to be connected.

The work involved identification of suitable panel for fitment of light bulbs of varied power connected in series in each phase; such that each phase could support a load of 1.7 Kw. Additionally, a circuit breaker with a rating of 12 Amps has also been connected for the purpose of safety. Work is undertaken during the course of preparation of the load bank. The figure 11 shows the load bank setup available at the lab.

Figure 11: Load Bank

4.3 FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR)

Fourier Transform Infrared Spectroscopy **(**FTIR**)** is a method that is used to obtain an Infrared Spectrum of either the emission or absorption of a gas, liquid or solid. The FTIR equipment can be used to collect the high resolution data over a large spectral range. This method of spectroscopy has huger advantages over a dispersive type of spectrometer which can only measure intensity of wave over a very small range of wavelengths.

By illuminating the sample by infrared source, depending upon its absorptivity and reflectivity the molecular structure of the sample can be found out. This spectroscopy is feasible for the materials which react to the visible range as well as infrared spectrum.

FTIR is not a destructive type of testing. It is a rapid, sensitive, precise and able to scan very tiny molecules

For the experimental purpose the FTIR equipment available at the Centre for Nano Science and Engineering was used under the guidance of the operator from CeNSE. The figure 12 shows the equipment available at the institute. The diesel fuel and the additive diesel fuel both were tested to get the idea on the Chemical bonds that are present in the molecules and identify certain functional group. For reference purpose the FTIR Spectroscopy of algae biodiesel was also taken and investigated and conclusions were drawn comparing the spectroscopy of diesel, diesel + additive and that of algae oil.

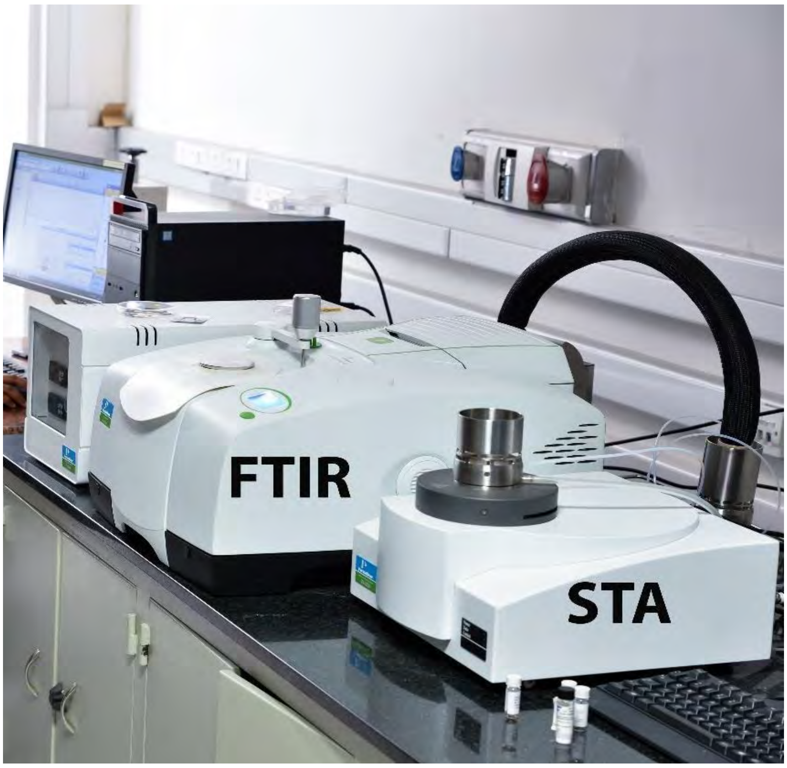


Figure 12: FTIR equipment at CeNSE, IISc

4.4 BOMB CALORIMETER

A bomb calorimeter is a device that is used to find the Calorific Value of the fuel sample by subjecting it to combustion. Accelerated rate calorimeters, Differential scanning calorimeters, Isothermal micro calorimeters and Titration type calorimeters are among the various types that are available in market. The figure 13 shows a typical Bomb Calorimeter, the main parts of a bomb calorimeter are:

a. Crucible
b. Heater and ignition coil
c. Bucket/Tank
d. Insulating jacket
e. Stirrer
f. Oxygen Supply
g. Sample Holder
h. Electrical Supply

The sample to be tested is placed in a sample holder/crucible inside a steel bomb. The bomb is covered by a sleeve or a jacket of water around it. The sample is provided with an oxygen supply to help with combustion and an ignition wire to ignite the sample to start the combustion process. An electric charge is used to ignite the fuel sample, when the combustion of sample takes place, the heat liberated due to combustion of sample is transferred to the surrounding water jacket around it. The exchange of heat is facilitated by the use of a stirrer which ensures that the heat exchange takes place at a faster rate. This heat exchange causes the temperature of the water to rise to higher level. The initial and the final value of temperature of the water jacket are noted down with help of a thermometer so that the heat can be calculated. The total thermal energy gained by the Calorimeter is the sum of the heat gained by the various parts of the calorimeter and the heat gained by water jacket of the calorimeter. This can be expressed as follows:

$q_{cal} = q_{water} + q_{bomb}$

$q_{cal} = m_{water} X Cs_{water} X dT + C_{bomb} X dT$

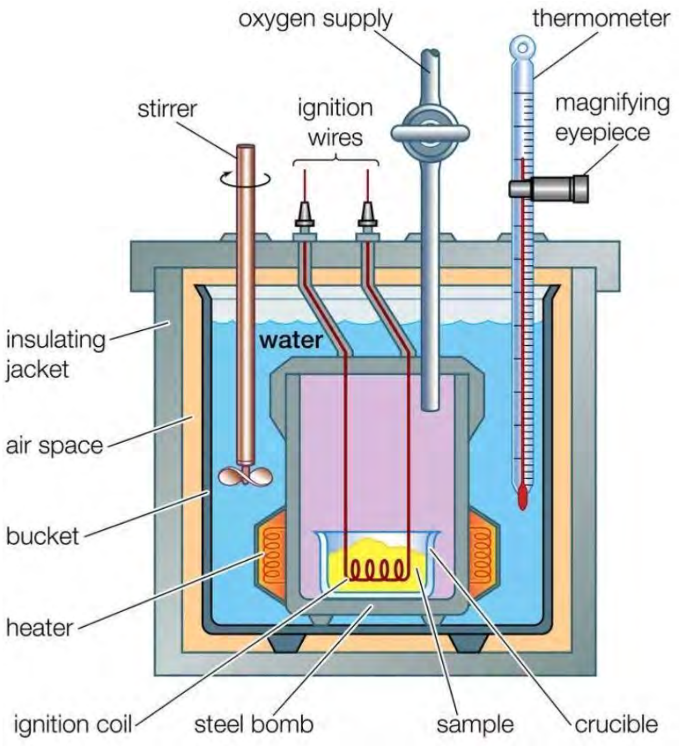


Figure 13: Bomb Calorimeter

4.5 PREPARATION OF FUEL

Diesel is a fuel which is extracted from crude petroleum oil, having calorific value as 45.3 MJ/Kg. It is mostly used in Heavy duty vehicles. The Fuel Additive which is from a family of isopropanol with the chemical formula $CH_xCHOHCH_y$.It is a colourless, flammable chemical compound with a strong odour. For the experiment it is necessary to run the engine on pure diesel and then on the diesel-additive mixture and compare the results. Thus the preparation of the blend is necessary. The blend solution is prepared by mixing the 25 ml of enzyme in 10 ltr of diesel with constant stirring for 15 min and then allowing for a settling down period of 12-24 hrs. The mixing is done at a ratio of 6000:1 which has been decided from previous experimental data.

The blend is prepared in a careful laboratory environment taking caution as the mixture is flammable. The following figure 14 shows the blend that was prepared in the lab using a stirrer.

Figure 14: Blending of additive in diesel oil

It was observed that for the additive to be operate effectively, the mixture must be stirred once in 3-4 days to make the mixture more uniform. For practical applications, it is advised to use an inbuilt stirrer into the fuel storage tank and run the stirrer for a period of 15 minutes between interval of 3-4 days. The prepared fuel blends were loaded into the fuel tank and then the supply was connected to the injector to conduct tests.

4.6 TESTING ON THE ENGINE

The fuel blend and pure fuel were loaded into the fuel tank and the engine was run and readings were taken at different loading conditions

a. Engine Speed

Type – Tacho-Generator / Non-Contact Proximity.
Range – 0 – 9999 RPM.

Stand Alone Signal Conditioning.
Make – Suraksha Sensors

b. Torque at Dynamometer

Type – Strain Gauge.
Range – 0 – 50 Kgs.
Stand Alone Signal Conditioning.
Make – SURAKSHA SENSORS

c. Emission analyser

The Additive + Diesel fuel blend were used on the test engine and the readings were obtained using KaneQuintox exhaust analyzer. This analyzer can be used to identify different types of fuels such as natural gas, LPG, Butane, Propane, user oil, wood pellets and heavy oil. To take the readings, engine was run for a time of 25 min with both diesel and diesel blend for various loads in the increment of 20% in load. The following figure 15 shows the steps followed to get the emissions analyzed.

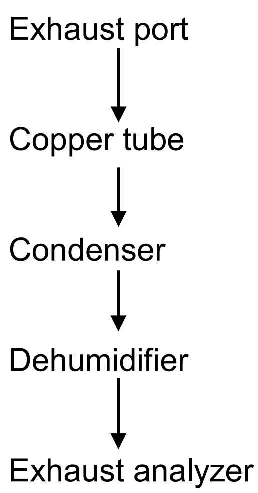


Figure 15: Path for emission test

For taking the emission readings, the exhaust from the engine was passed through a copper tube. The copper tube was connected to a condenser and a dehumidifier so that the readings obtained were as accurate as possible. Figure 16 shows the emission analyser setup. The readings were obtained for the various load conditions in a printed sheet from the analyzer and the results for each of the conditions were compared and conclusions were drawn.

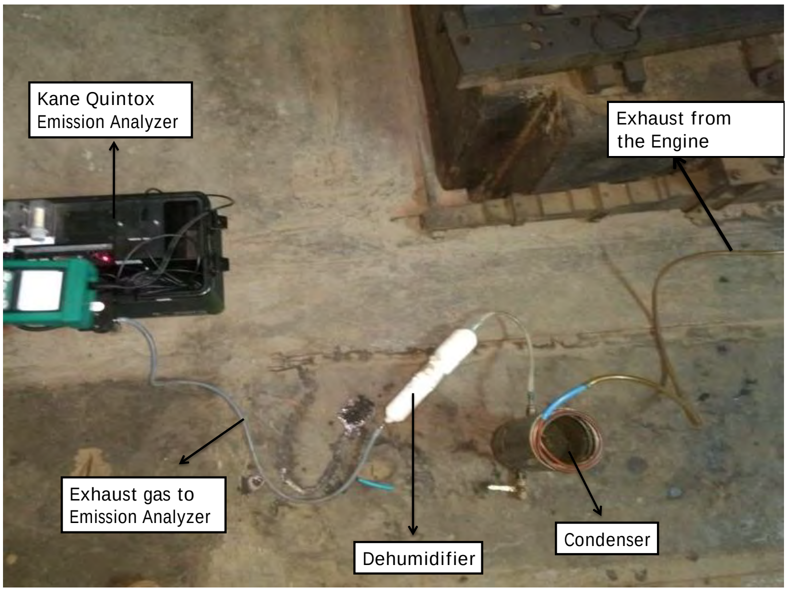


Figure 16: Set up of Emission analyser

4.7 FUEL INJECTOR CALIBRATION

The main function of the injector is to inject diesel into the combustion chamber of the engine. There are three main factors to be kept in consideration for achieving optimal injection pressure. The first two factors are injection timing and the amount of fuel that is being injected into the combustion chamber both of which depend on the injection system employed in the engine. The last factor is the atomization of fuel, which is dependent on the design of the nozzle, the nozzle size and the injector size and other design parameters.

Better atomization leads to a better combustion of fuel because, optimal size and good dispersion of diesel particles lead to a more homogeneous mixture of fuel and air. To achieve these conditions, proper understanding of the injection pressure and the effects of varying it must be studied and analyzed. By modifying the injection pressure to an optimal value, lower emissions and better performance can be achieved along with better noise characteristics of engine.

The judicious requirements of the established standards must be met to maintain the quality of injection so that the operation of the fuel injection system takes place without any hassle. It must be noted that in a CI engine, the variation in injection pressure also causes a variation in other parameters like timing and quality which might lead to unwanted modifications in the combustion characteristics if not checked.

The deviation from the predicted behaviour might result from an injector that has broken down or that has undergone mechanical wear and tear during the period of its operation. Certain manufacturers have strict quality control requirements and check each of the produced injector for its specific properties and then program the necessary data chart into the Electronic Control Unit. But with engines that don’t have an ECU, the pressure of injection has to be changed manually whenever necessary. The injection pressure of the injector used in experiment was changed in house as shown in figures below

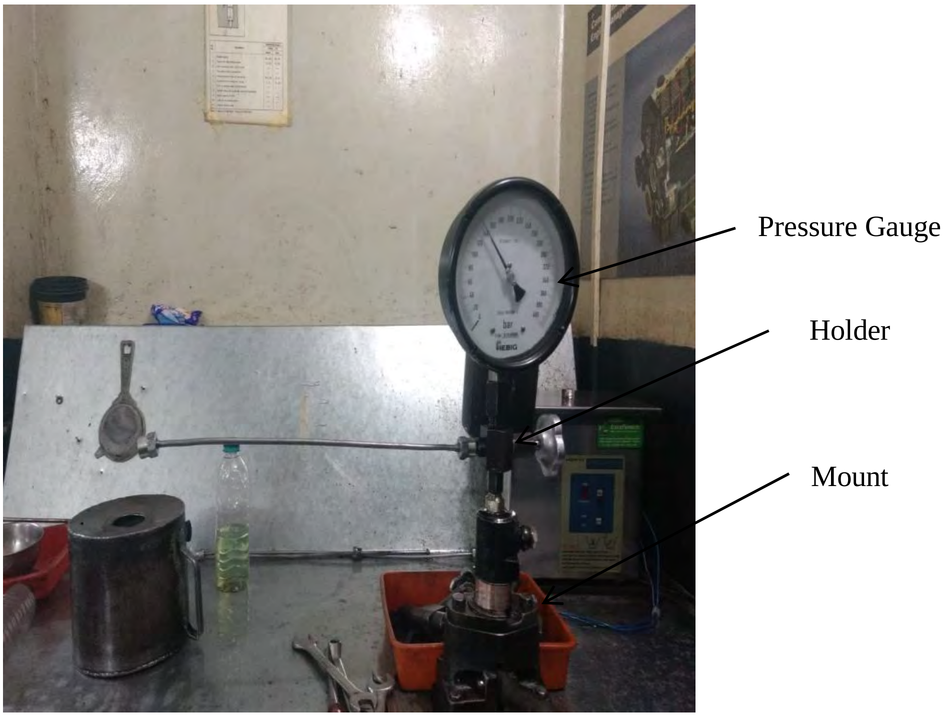


Figure 17 : Injection pressure changing kit

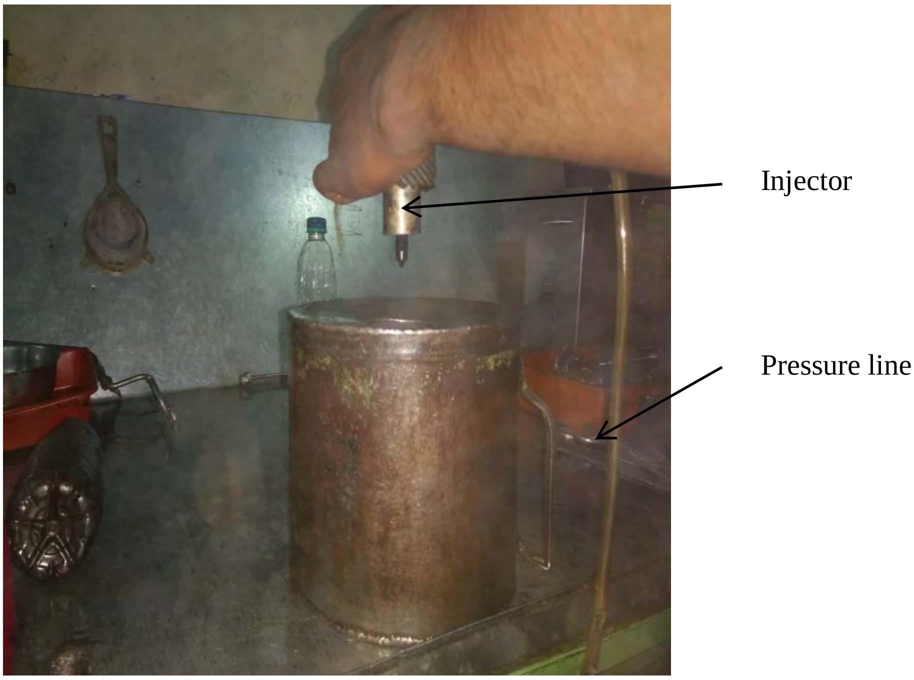


Figure 18: Injector testing

Experimental setup for analyzing effect of injector pressure

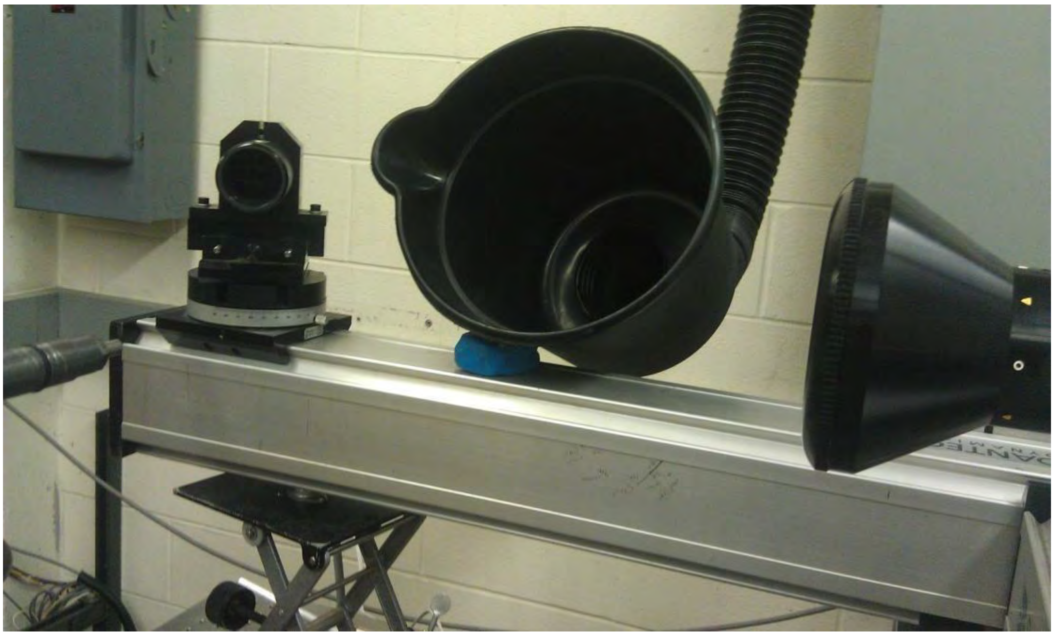


Figure 19 : Fuel Injector collection device

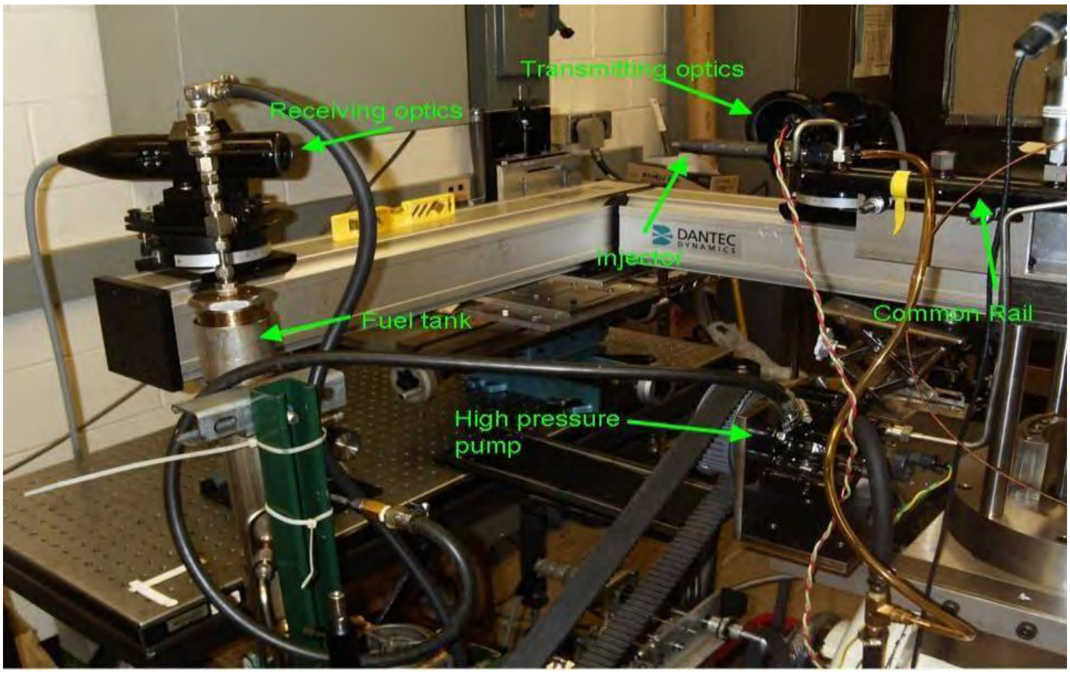


Figure 20 Experimental Setup

CHAPTER 5 - RESULTS AND DISCUSSIONS

The experiments were conducted on the Kirloskar make 5.5 KW (8hp) Engine available at the I C Engine Laboratory in IISc, Bangalore. Before running the performance and emission tests on the engine, it is necessary to know the properties of the fuel that is being used. For the combustion process to be optimal the formulated blend should have least or no is OH group. Fourier Transform Infrared Resonance (FTIR) test need to be carried out to test the concentration of the OH as well as other chemical functional groups that may be present in the blend. The other requirement was to know the exact calorific value of fuel (diesel) that is employed in the experiment, to calculate the theoretical amount of heat released and thereby form a basis to control other aspects of the experiment. So for this purpose a Bomb Calorimeter was used.

5.1 FUEL TEST RESULTS

It was necessary to know the functional groups and the calorific value of the fuel and additive blend that was being used so the following tests were conducted on the blend sample:

a. Fourier Transform Infrared Spectroscopy (FTIR).

b. Bomb Calorimeter Test.

5.1.1 Fourier Transform Infrared Spectroscopy

Prior using the diesel+ Fuel Additive in the test engine, the components of the fuel were determined using Fourier Transform Infrared Spectroscopy **(FTIR)**. The FTIR equipment can be used to collect the high resolution data over large spectral ranges. From the obtained spectral peaks, the functional groups can be identified by referring to the appendix shown in table 3.

Sl. No.	Functional Group	Frequency(cm^{-1})
1	Water -OH	3700-3100
2	Alcohol -OH	3600-3200
3	Carboxylic acid -OH	3600-2500
4	-N-H	3500-3350
5	≡C-H	~3300
6	=C-H	3100-3000
7	-C-H Aldehydic	2900-2800,2950-2840
8	-C≡N	~2250
9	-C≡C-	2260-2100
10	-C=O Aldehyde	1740-1720
11	-C=O Anhydride	1840-1800,1780-1740
12	-C=O Ester	1750-1720
13	-C=O Ketone	1745-1715
14	-C=O Amide	1700-1500
15	-C=C- Alkene	1680-1600
16	-C=C- Aromatic	1600-1400
17	$-CH_2$ Bend	1480-1440
18	$-CH_3$ Bend	1465-1440,1390-1365
19	-C-O-C-	1250-1050
20	-C-OH	1200-1020
21	$-NO_2$	1600-1500 and 1400-1300
22	-C-F Fluorine	1400-1500
23	-C-Cl Chlorine	800-600
24	-C-Br Bromine	750-500
25	-C-I Iodine	~500

Table 3: Appendix for FTIR functional group identification

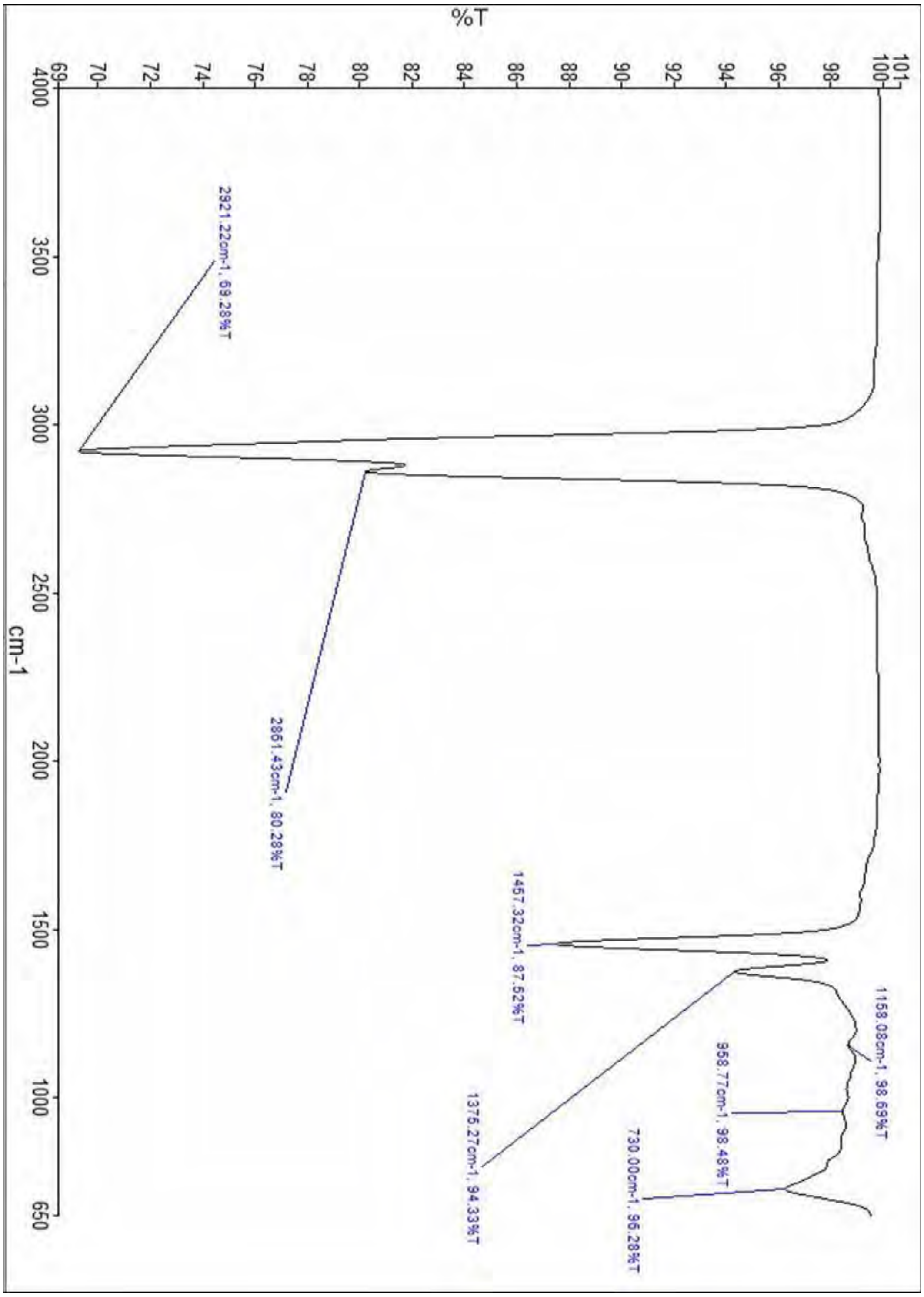


Figure 21: FTIR Spectroscopy of the Diesel + Additive blend

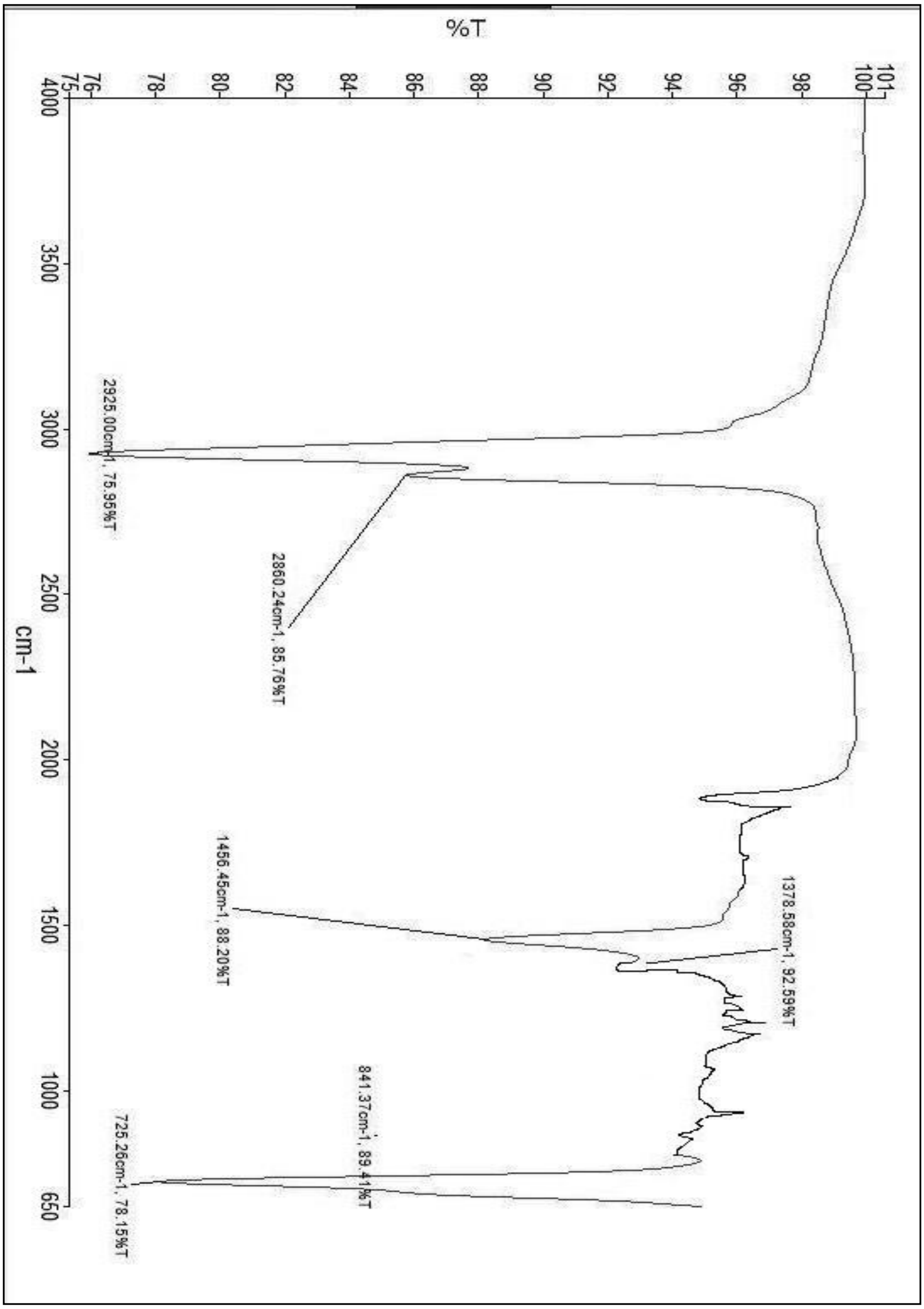


Figure 22: FTIR Spectroscopy of Diesel

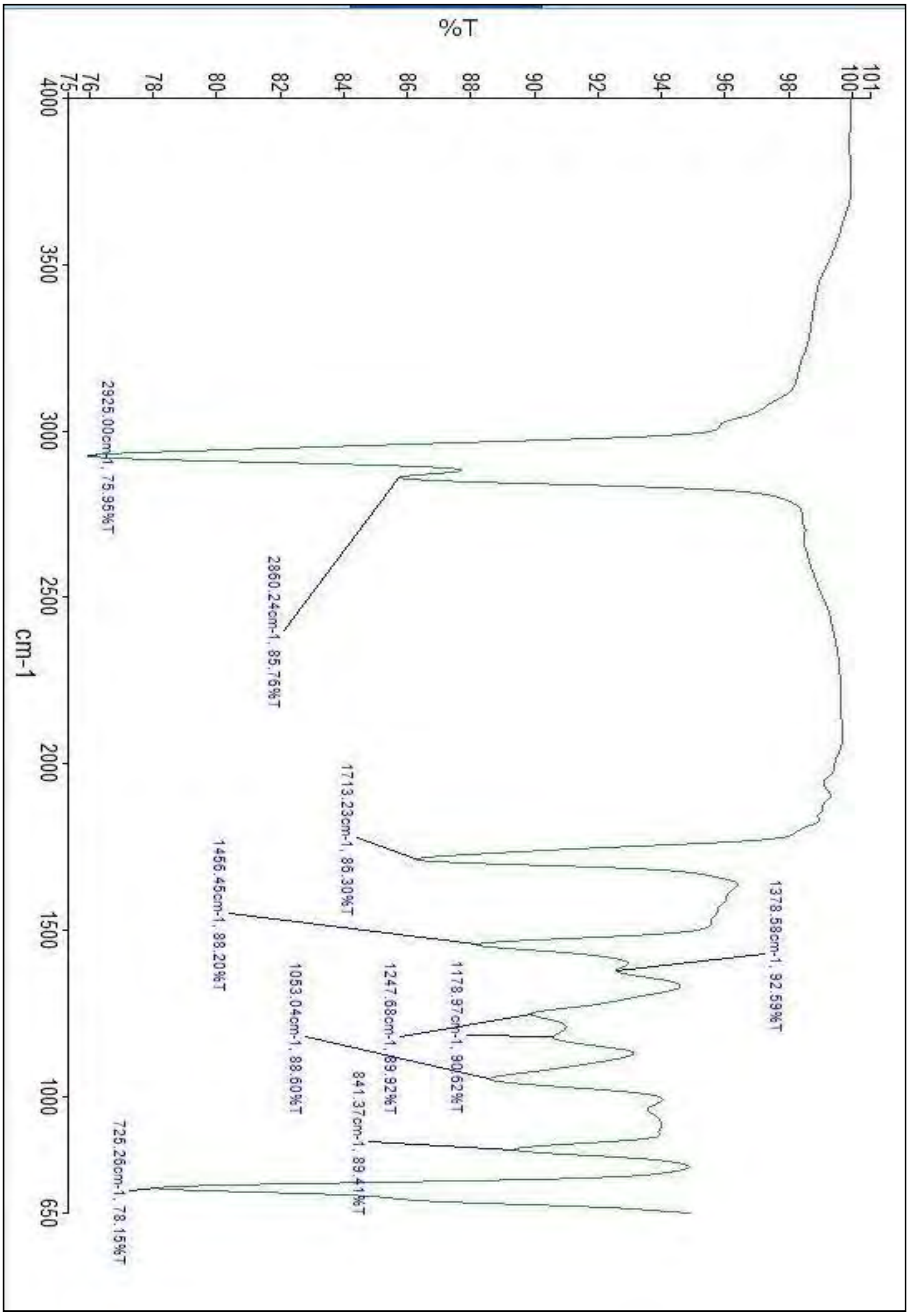


Figure 23 FTIR spectroscopy of Algae Biodiesel

Each of the molecules in the fuel sample will produce a spectral fingerprint that is unique to it, hence the usage of FTIR analysis helps in identifying the exact chemical group that is present in the sample. When sample is exposed to IR light, some of the molecules absorb energy and this absorbed energy is transformed into rotational or vibrational energy by the fuel specimen. This results in an absorption spectrum that is picked up by the detector and plotted in the range of 400cm^{-}1 to 4000 cm^{-1} on a digital display or a chart. The obtained spectra can be used to understand the molecular composition sample and is referred to as the molecular fingerprint of the fuel specimen

From the FTIR spectroscopy of the Additive + Diesel oil in Figure 21, the following transmittance peaks were obtained

a = 2921.22 cm^{-1} and 69.28% T
b = 2851.43 cm^{-1} and 80.28% T
c = 1457.32 cm^{-1} and 87.52% T
d = 1375.27 cm^{-1} and 94.33% T
e = 1158.08 cm^{-1} and 98.59% T
f = 0958.77 cm^{-1} and 98.48% T
g = 0730.00 cm^{-1} and 96.28% T

Thus from Table 3, it can be inferred that (a) identifies as –C-H aldehydic groups, (b) identifies also as the aldehydic group, (c) and (d) identifies as CH_3 bend, (e) identifies as C-O-C, (f) identifies as C-Halogens and (g) identifies as C-Br. Hence it can be noted that the blend has very less OH groups. This means that the absence of large number of OH groups can lead to better combustion of the fuel

Figure above is given as a reference to compare the FTIR Spectra of Diesel and that of Diesel + Additive blend. It can be inferred from the above mentioned spectroscopy that even the pure diesel has very little OH groups present in it and further drives the conclusion that the additive blend can function as an efficient combusting fuel.

Figure 23 is an FTIR spectroscopy for the Algal Biodiesel which is extracted from microalgae source. The extract from the algae and has been subjected to Esterification and Transesterification to obtain the Biodiesel sample. From the spectroscopy, it is evident that the sample has large amounts of OH groups that are present it. The presence of these algal groups leads to decrement in efficiency of combustion and an increment in SFC of the engine when compared to same engine running on normal diesel.

From the FTIR test, the functional groups in the fuel blend are identified mainly to be -C-H aldehydic groups, -C=C-, C-Halogens, CH_3. Thus Proteins and Amino Acids are the main composition of the additive that has been added to the diesel blend.

5.1.2 Bomb Calorimeter

The calorific value of the diesel + additive blend was tested using the bomb calorimeter that was available at the Institute. A bomb calorimeter is an equipment which is used to find out the calorific value of the fuel sample by subjecting it to a complete combustion. A water jacket surrounding the combustion chamber was used to collect the heat of combustion from the sample and the calorific value of the sample was found out.

$q_{cal} = q_{water} + q_{bomb}$

$q_{cal} = m_{water} X Cs_{water} X dT + X dT$

where,

m_{water} is the mass of water

Cs_{water} denotes the specific heat of water

C_{bomb} denotes the heat capacity of water

dT is the temperature difference recorded

The fuel sample was subjected to this testing and the calorific value of the diesel + additive was found out to be 35.803 MJ/liter and that of diesel as 35.786 MJ/litre.

5.2 PERFORMANCE CHARACTERISTICS

Diesel Engine Characteristics: The characteristics of the diesel engine are discussed in this section:-

(a) **Brake Thermal Efficiency.** The figure below shows the variation of brake thermal efficiency versus load for varying load conditions in steps of 25%

of full load condition. Brake thermal efficiency attains a peak of around 30% at a load of 75%, and then plateaus from 90%.

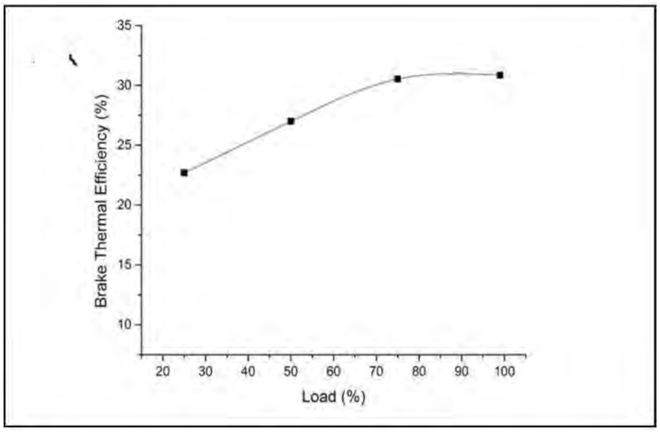


Figure 24: Brake thermal efficiency vs. load

(b) **Peak Cylinder Pressure**. The comparison of peak cylinder pressure with load is shown in Figure below. As the load increases, the peak pressure also increases. The curve is not linear

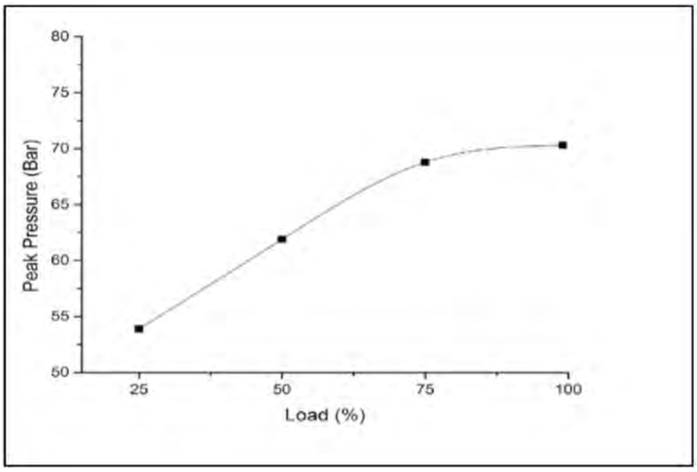


Fig: 25 Peak Cylinder Pressure v/s Load

c. **Heat Release Rate**. The heat release rate variation of diesel fuel with respect to load is studied. A significant increase in the values of heat release rate for increasing loads can be seen, owing to the fact that at high loads, more fuel is burnt and thus a much higher heat release rate is achieved, and the maximum heat release is encountered at a slightly later crank angle

d. **Emission Analysis (Oxides of Nitrogen)**. NO_x emissions for the various load operations are shown in Figure 26. At full load conditions, the determined values of NO_x are 1010 ppm for diesel. NO_x emissions are found to increase with % load.

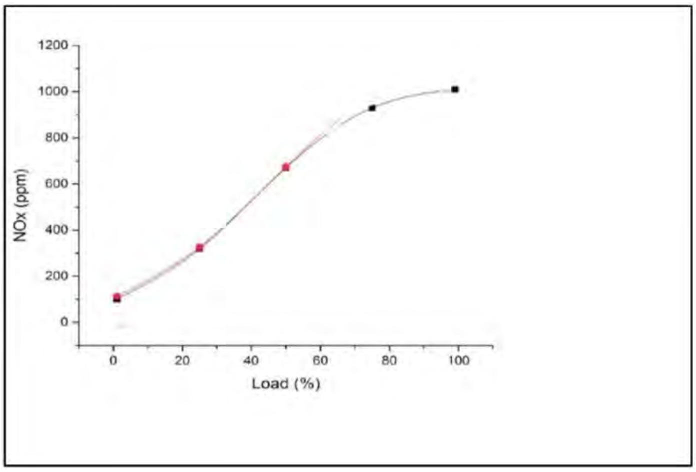


Figure 26: NOx analysis

e. **Carbon Monoxide**. Figure 27 shows the variation of CO emissions with respect to load. At around 70-75% of load, the engine operates at an equivalence ratio of around 0.80. CO emissions are at a minimum. After that the engine starts operating close to Stoichiometric, so CO emissions are constantly rising

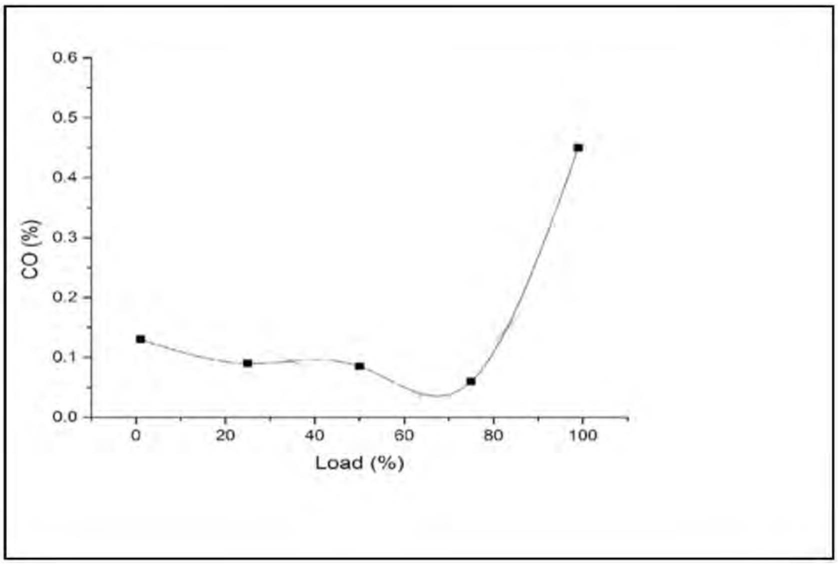


Fig 27: CO Analysis

5.6 Spray patterns and effect of injection pressure on additives

Fig 29 Fuel Injector

Fuel injection is the introduction of fuel in an internal combustion engine, most commonly automotive engines, by the means of an injector. All diesel engines use fuel injection by design. Petrol engines can use gasoline direct injection, where the fuel is directly delivered into the combustion chamber, or indirect injection where the fuel is mixed with air before the intake stroke. On petrol engines, fuel injection replaced carburettors from the 1980s onward. The primary difference between carburettors and fuel injection is that fuel injection atomizes the fuel through a small nozzle under high pressure, while a carburettor relies on suction created by intake air accelerated through a Venturi tube to draw the fuel into the airstream.

Benefits of fuel injection include smoother and more consistent transient throttle response, such as during quick throttle transitions, easier cold starting, more accurate adjustment to account for extremes of ambient temperatures and changes in air pressure, more stable idling, decreased maintenance needs, and better fuel efficiency. Fuel injection also dispenses with the need for a separate mechanical choke, which on carburetor-equipped vehicles must be adjusted as the engine warms up to normal temperature. Furthermore, on spark ignition engines, (direct) fuel injection has the advantage of being able to facilitate stratified combustion which have not been possible with carburetors.

It is only with the advent of multi-point fuel injection certain engine configurations such as inline five cylinder gasoline engines have become more feasible for mass production, as traditional carburetor arrangement with single or twin carburetors could not provide even fuel distribution between cylinders, unless a more complicated individual carburetor per cylinder is used.

5.6.1 **Spray Pattern**

The main work in diesel reforming is done through heterogeneous reactions which involve reactions between gaseous diesel and solid catalysts with the aim to produce a hydrogen-rich gas. Hence, in a diesel PEFC-APU system, the injection system is critical to the atomization and vaporization of the liquid fuel in order to facilitate the heterogeneous reactions. In diesel reforming, different reforming technologies can be employed in which diesel is blended with air, pure oxygen or steam as main reactant. The gas mixture has to be well-blended to avoid local variations, e.g. air/fuel ratios, in order to prevent hot-spots that can cause undesired side reactions such as carbon formation and damage the catalyst.

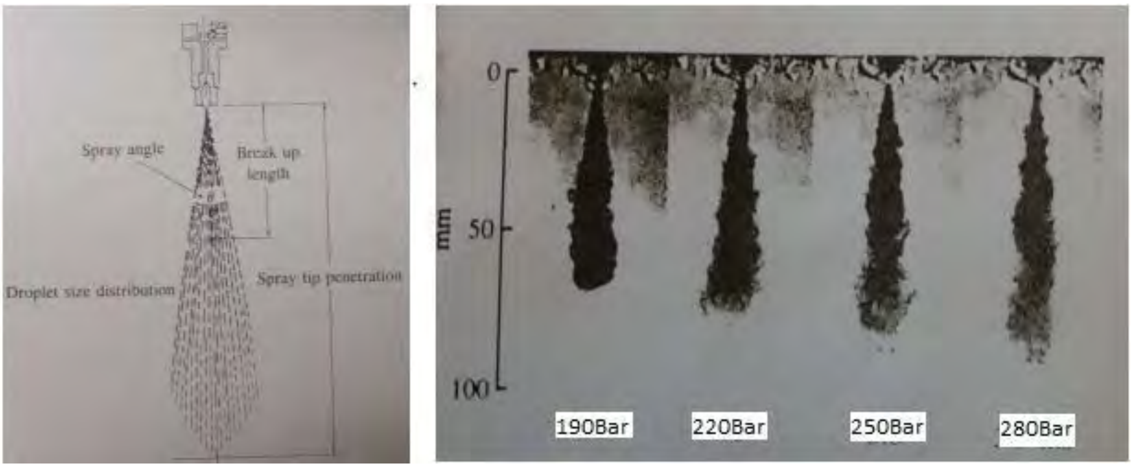


Fig 29: Spray Dimensions

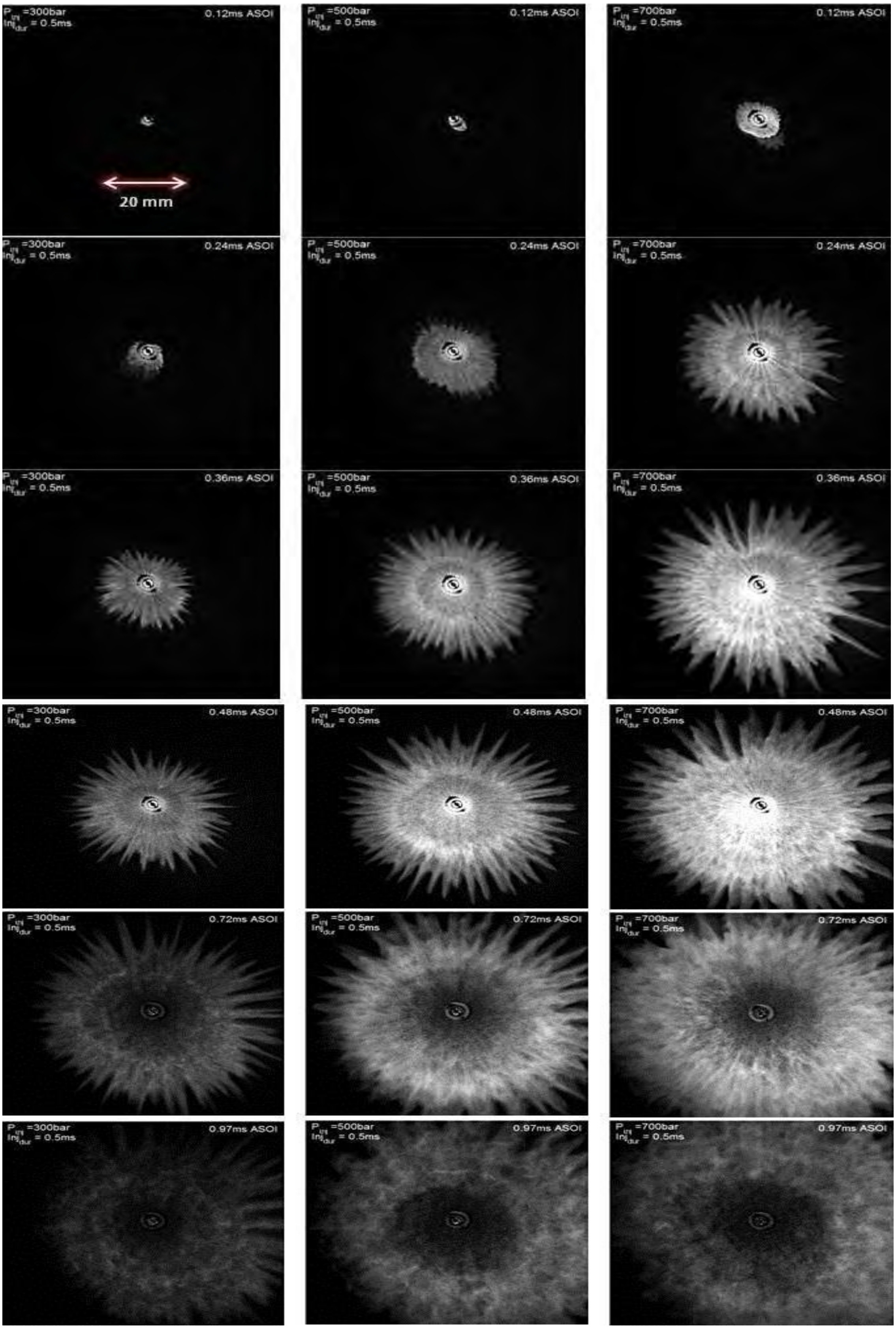


Fig 30: Spray Patter on Film

5.2.1 Brake Specific Fuel Consumption vs Brake power

The brake specific fuel consumption can be defined as the quantity of fuel required to produce a unit Brake Power. It can also be defined as the ratio of rate of consumption of fuel to the power produced at shaft output. The experiment was conducted at different loads from 1KW to 5KW in steps of 1KW. It was observed that the diesel + additive fuel showed the same trend as diesel fuel but there was a slight decrease in BSFC. This fall in BSFC is due to the reason that the diesel additive leads to better atomization and acts as ignition booster. Thus causing a better combustion and releasing more amount of energy for the same quantity as that of diesel.

It is also noted that the reduction in delay of ignition is because of decrease in viscosity of the fuel when additive is blended with diesel leading to a lesser physical delay, this also contributes to the decrease in BSFC in diesel + additive fuel blend. The below figure 31 shows variation of BSFC against brake power. It is noted that the decrease of 1%, 5%, 7%, and 7.5% in BSFC at 20%, 40%, 60% and 80% loads respectively applied on engine.

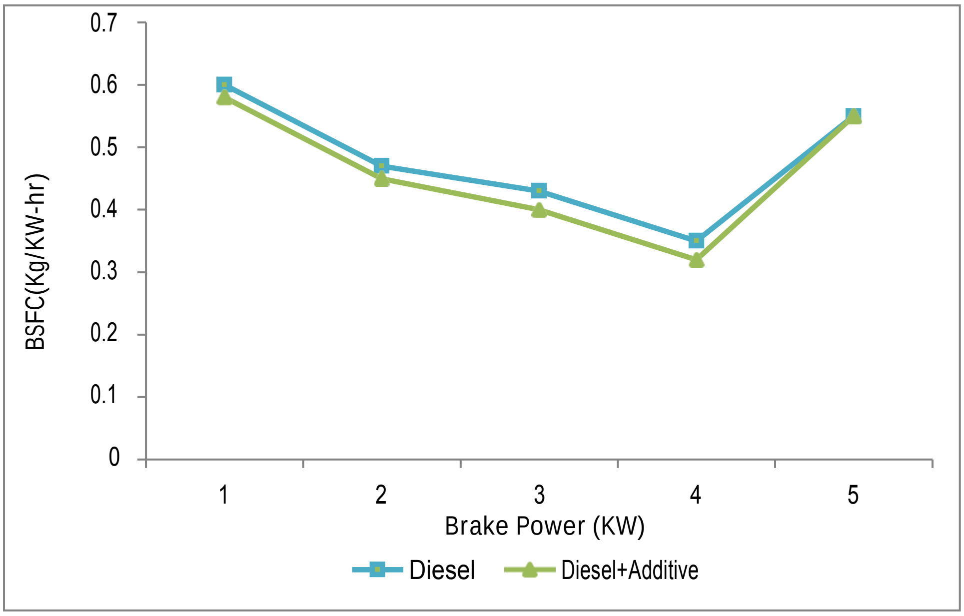


Figure 31: BSFC vs Brake Power at 220 bar

It was also observed that consumption of fuel was minimum between the region of 70-80% of load where the combustion process was nearer to stoichiometric. It can be concluded that the performance of engine is better by about 0.02 Kg/Kw-hr when diesel is blended by the fuel additive.

5.2.2 Brake Thermal Efficiency vs Brake Power

The brake thermal efficiency can be defined as the ratio of brake power to the Input power. It is the amount of power obtained per unit joule of the energy which is expressed in percentage. The experiment was conducted at different loads from 1KW to 5KW in the increments of 1KW. It was observed that the diesel + additive fuel showed the similar trend as diesel fuel. The engine's BTE shows an increase as the load on engine increases because, the friction between the surfaces of cylinder wall and piston decreases. This trend in BTE is also because, with increase in load, the value of brake specific fuel consumption decreases. Another reason is, as the additive acts as an ignition booster, it promotes complete combustion of the fuel, leading to higher thermal efficiency.

Figure 32 shows the trends in variation of BTE with respect to BP. The BTE is same for the both the fuels at 80% of load. At initial loads the BTE of diesel is visibly higher which might be because, the effect of additive is not prominent at the initial low temperature and pressure.

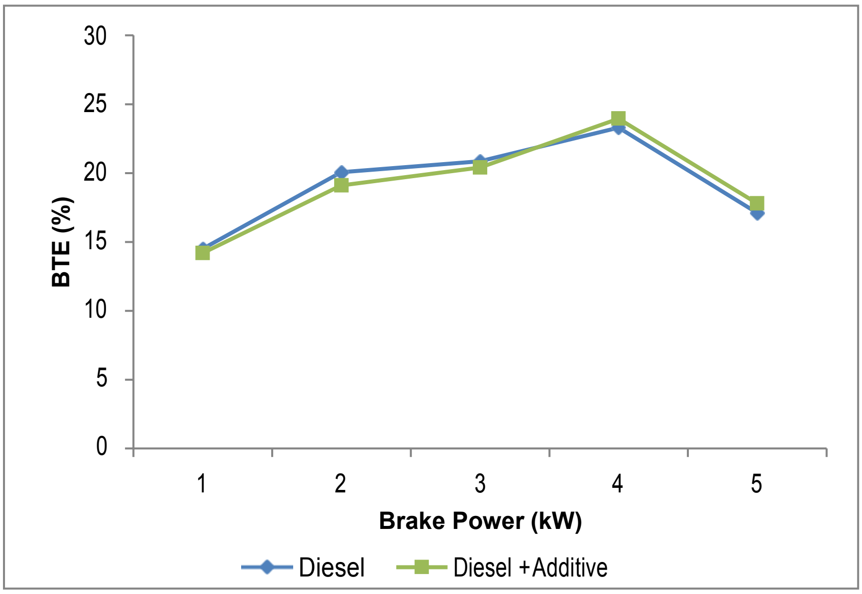


Figure 32: Brake Thermal Efficiency vs Brake Power at 220 bar

5.3 EMISSION CHARACTERISTICS

5.3.1 Carbon monoxide emissions

The carbon monoxide emission as a byproduct in the combustion process is mainly because of the incomplete combustion of the fuel particles. The variation of the CO emissions for the engine using Diesel as a fuel shows nearly linear variation trend till the stoichiometric ratio i.e., $\phi=1$ is reached at about 75-80% of full load. After this, the CO emissions for diesel increases to a very high value near full load conditions, due to the richer running of engine. This is verified by the literature survey.

The experiment was conducted by running the engine using diesel + additive blend and neat/normal diesel fuel and then the corresponding emissions were noted. The tests were done at the injector pressures of 220, 250 and 280 bar pressure respectively. From the experiment results, it was noticed that the amount of CO emissions from the additive + diesel blend was lesser at all applied load conditions and injection pressures compared to that of Diesel. A sharp increase in the CO emissions beyond 75% load regime for all fuel blends is indicative of fuel rich operation in the naturally aspirated engine beyond this region.

The figure below shows the emission trends of additive blend and diesel at an injection pressure at 220 bar. Here the additive fuel additive increases the atomization rate and also acts a catalyst and ignition booster for the reaction to take place, because of which the quality of combustion increases i.e., it leads to complete combustion of fuel mixture. Because of these factors, the amount of the Carbon Monoxide that is released by the blend reduces. The same trend can be observed at the various injector pressures of 250 and 280 bar pressure as shown in figures below respectively. It is imperative to mention that a sharp reduction in CO emissions at high load operations i.e. approx. 30.15% is a major factor that works in favour of diesel + additive blend, since at all the injection pressure conditions the blend consistently gave lesser emissions than diesel.

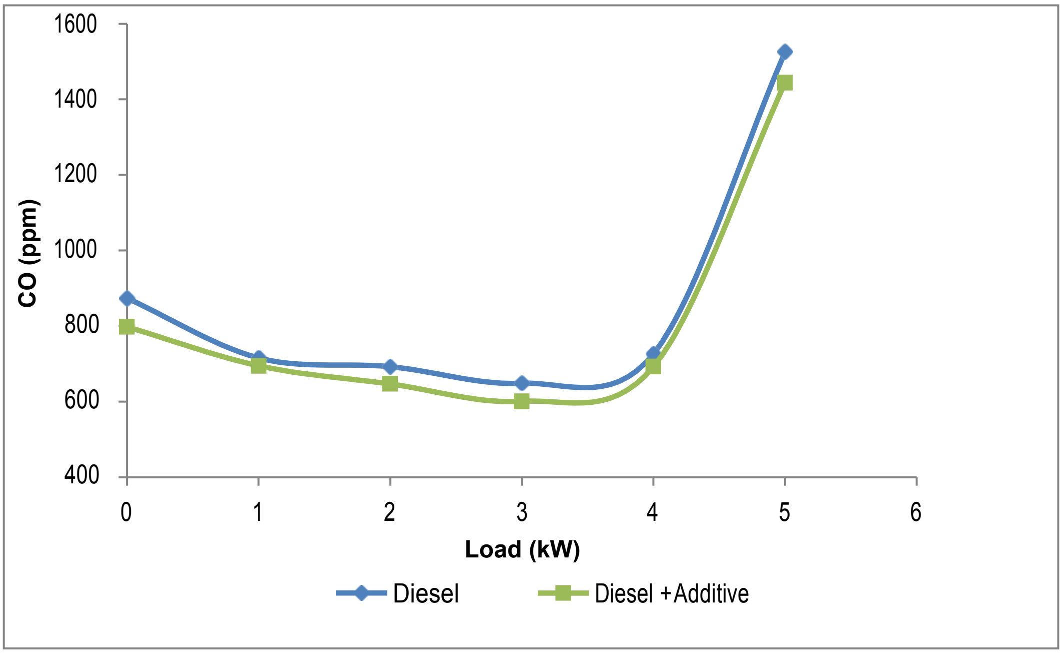


Figure 33: CO Emissions at 220 bar injector pressure

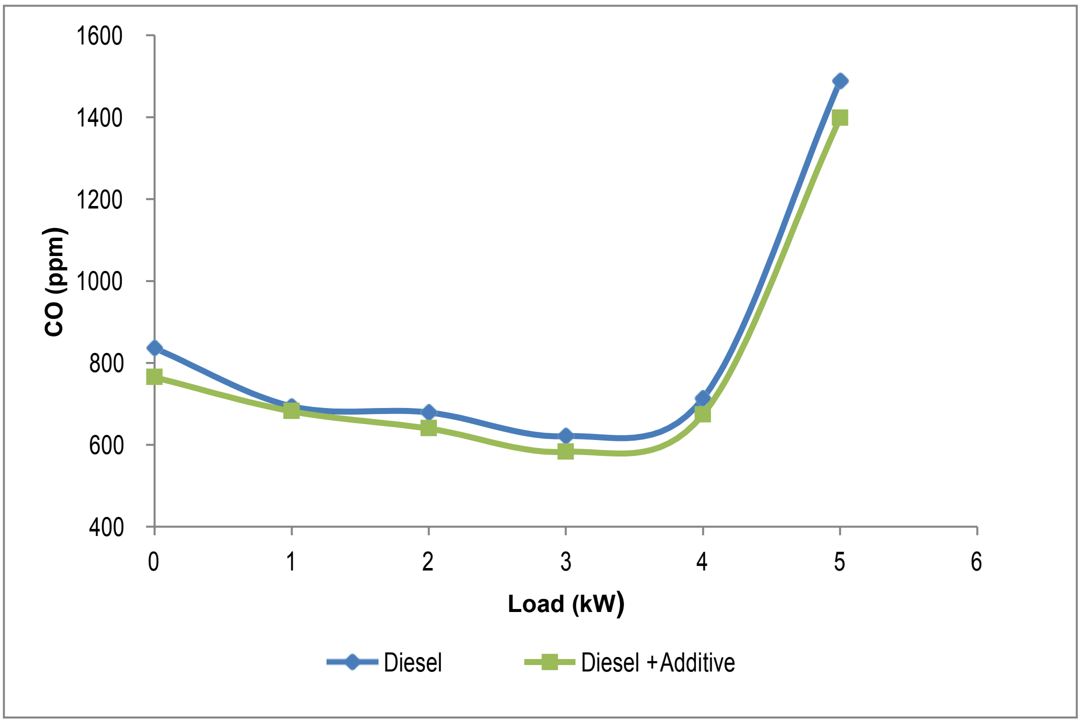


Figure 34: CO Emissions at 250 bar injector pressure

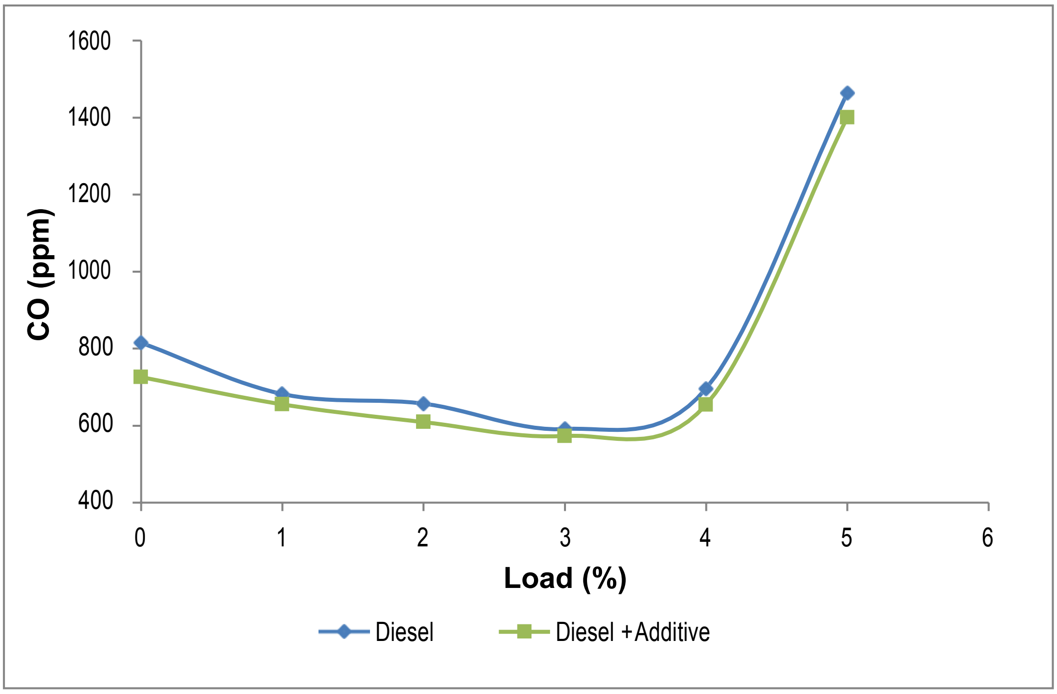


Figure 35: CO emissions at 280 bar injector pressure

5.3.2 Carbon dioxide emissions

The CO_2 emissions from an engine can be considered as an index of complete combustion process of fuel. If the combustion process becomes more complete, then the emission of CO_2 also increases. Complete combustion results in formation of the two stoichiometric products in larger quantities as compared to incomplete combustion namely CO_2 and H_2O. By increasing the load on the engine, CO_2 emissions increases till the engine reaches stoichiometric ratio at about 75% of the load. With further increase in load, the emissions should decrease ideally as it begins to operate in a fuel rich zone. But in practical testing the CO_2 emissions at higher load were showing a slight increase. The tests on the engine were performed by running it with the additive + diesel fuel blend and neat/normal diesel and the corresponding emissions were noted. The tests were done at the injector pressures of 220, 250 and 280 bar pressure respectively.

The figure 36 shows the emission trend of CO_2 when the pressurized fuel is injected at 220 bar, the CO_2 emissions from the diesel+additive blend are lesser than that of diesel at lower loading conditions and are almost equal to diesel at higher loading, this may be because of the fact that the injection pressure is not yet sufficient to atomize the fuel particles effectively.

Thus to explore further variation with injection pressure, tests were conducted at an injection pressure of 250 and 280 bar and the variations were recorded. Figure below shows the emission trends of CO_2 at 250 and 280 bar respectively. During the experiment of the entire loading of the engine, the emissions of CO_2 of diesel fuel are observed to be lower than that of diesel + additive blend, thus indicating that the blend fuel can undergo better and cleaner combustion than diesel. It is due to the reason that the blend has higher oxygen elements in the enzyme additive, can undergo better atomization in combustion chamber, the additive can catalyze the combustion reactions and also fuel consumed at the same engine load is also less.

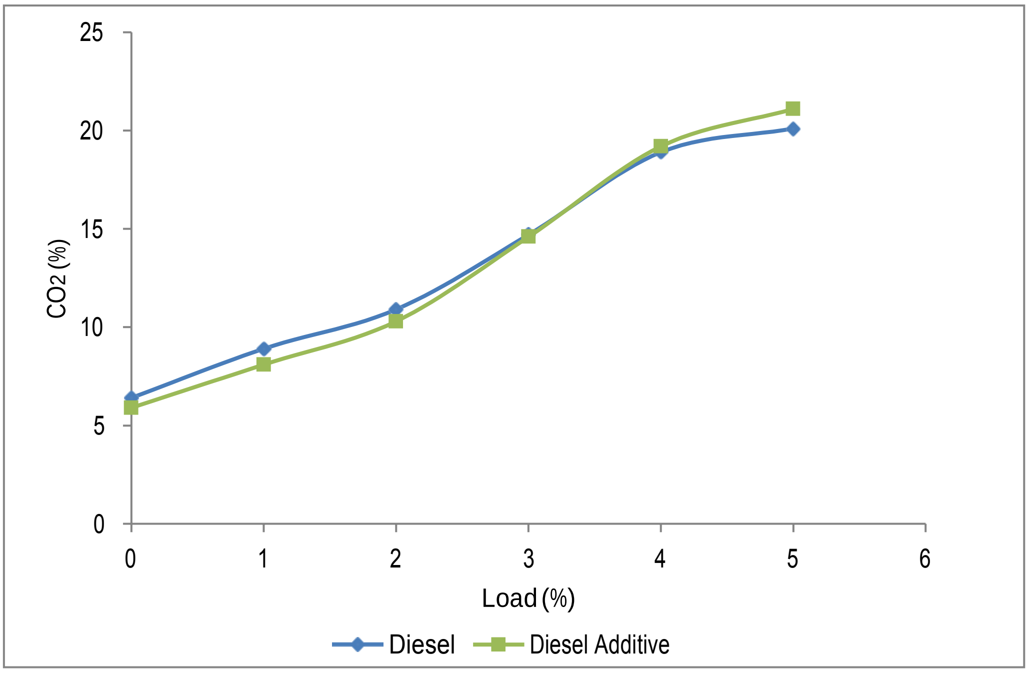


Figure 36: CO_2 emissions at 220 bar injector pressure

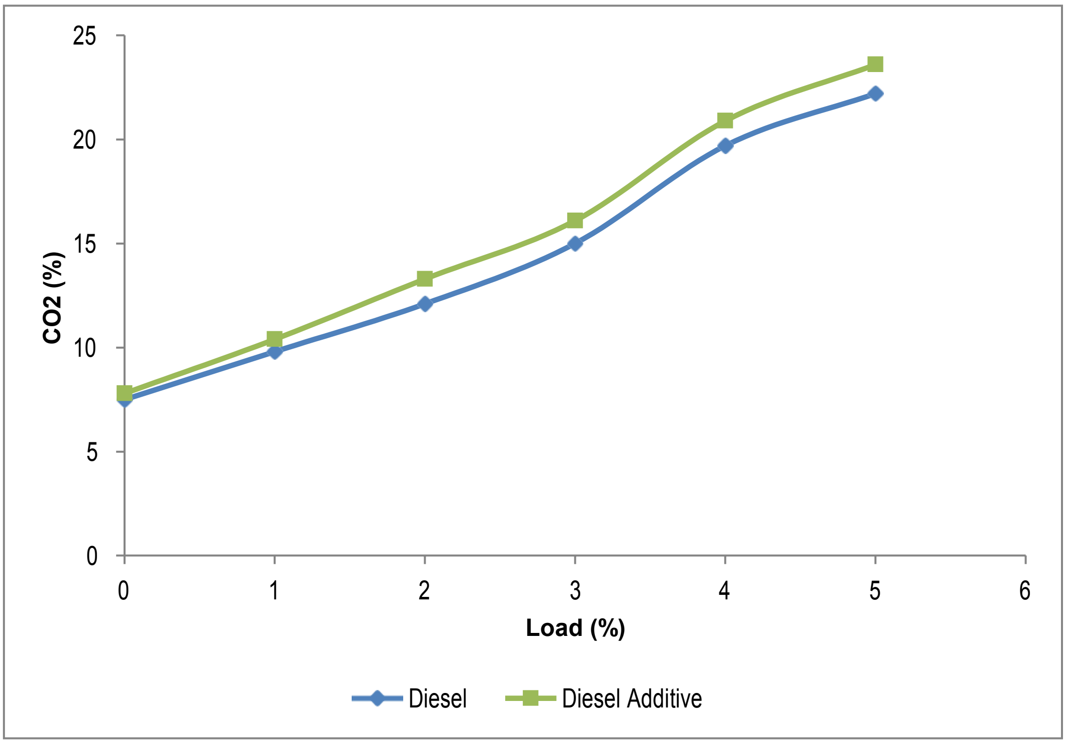


Figure 37: CO_2 emissions at 250 bar injector pressure

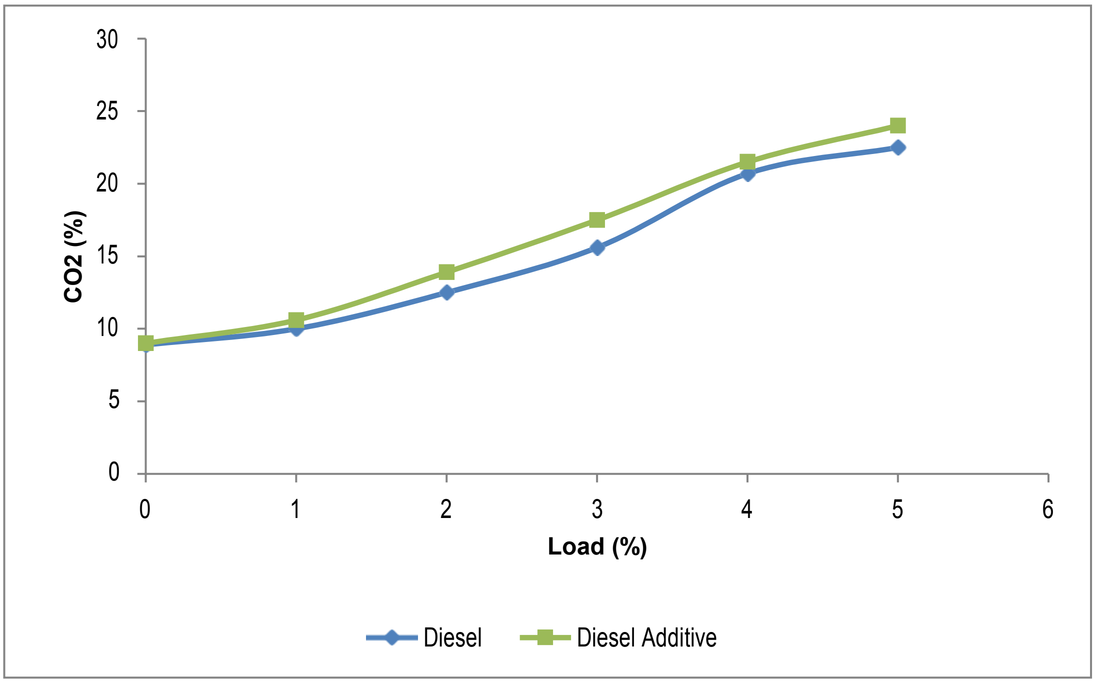


Figure 38: CO_2 emissions at 280 bar injector pressure

5.3.3 NO_x emissions

NO_x is the general term for nitrogen compounds that are obtained as emission components. They are the prime source for the formation of smog, ozone and acid rain. These gases are usually produced when the Oxygen and Nitrogen molecules react during the process of combustion inside the cylinder. The formed gases are carcinogenic and are very harmful to human health.

In the combustion chamber, the NO_x is mainly formed because of high cylinder temperature that is caused due to burning of fossil fuels, availability of oxygen and also on the rate of the combustion reaction. Initially the amount of NO_x produced will be less and increases as the load is increased; this is due to the fact that temperature increases with the increase in load. When the experiment is conducted using diesel + additive fuel blend, initially the amount of NO_X produced is less compared to that of Diesel fuel due to the complete combustion of fuel blend that takes place in presence of the additive. Here the oxygen molecules are utilized in the complete combustion process of fuel thereby the amount of free oxygen molecules are reduced which are about to combine with the nitrogen molecules to form NO_X. The reduction in NO_X can also be attributed to the reduction in the temperature of the fuel because of high heat of vaporization of additive + diesel blend.

After attaining the Stoichiometric ratio, the emission of NO_X is similar to that of diesel because of the reason that the Stoichiometric reactions occur at high temperatures. As discussed earlier, these high temperature accounts to the formation of relatively higher number of NO_X molecules. Thus at higher loads, the trend of NO_X emissions using additive + diesel blend is closer to that of Diesel.

The figure 39 depicts the variation of the NO_x emissions with varying load on the engine running on diesel and diesel + additive blend at 220 bar injection pressure. It can be seen that at till about 60% of the load, the NO_X emissions are lower due to lower temperatures and better combustion of fuel as stated earlier. At higher injection pressures, as the pressure is linearly dependent on temperature the emission of NO_X also increases as seen in figure 40 & 41

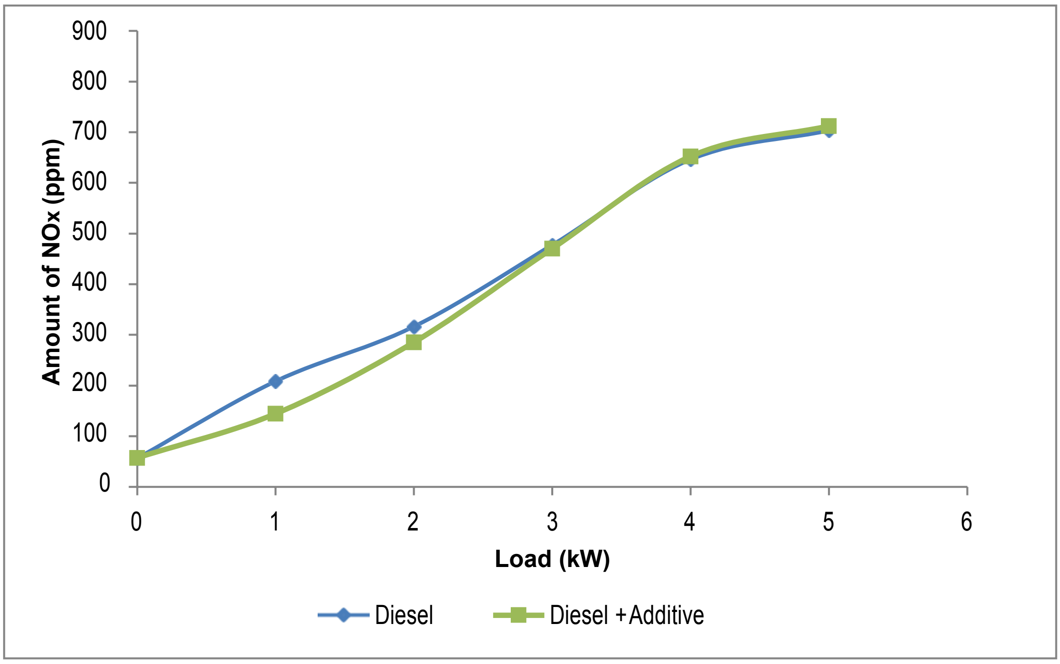


Figure 39: NO_X Emissions at 220 bar injector pressure

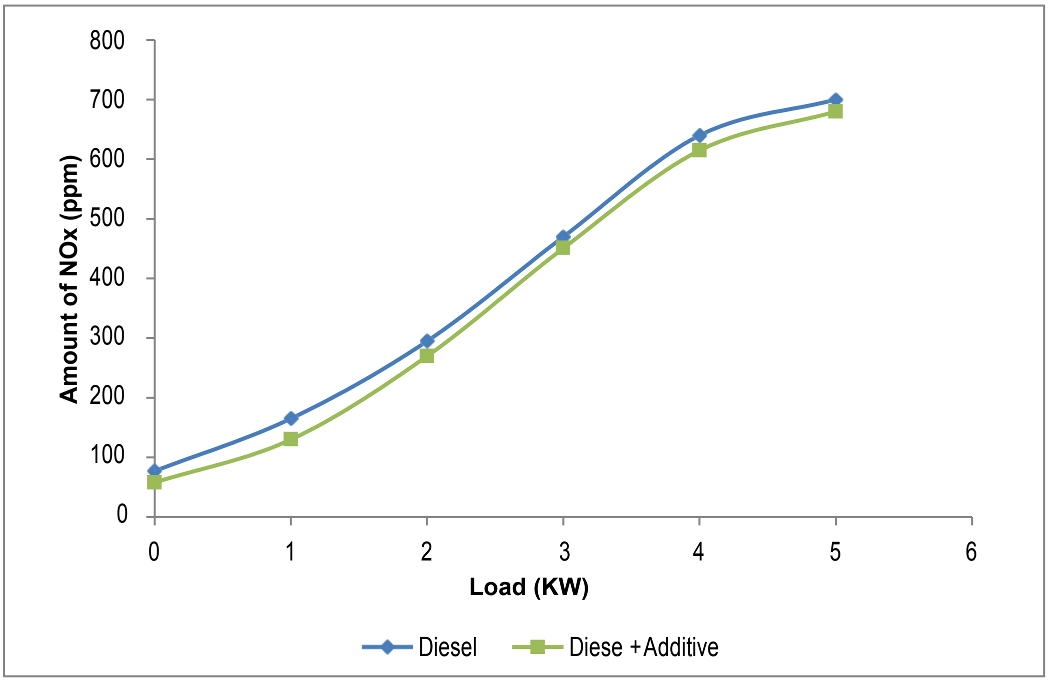


Figure 40: NO_X Emissions at 250 bar injector pressure

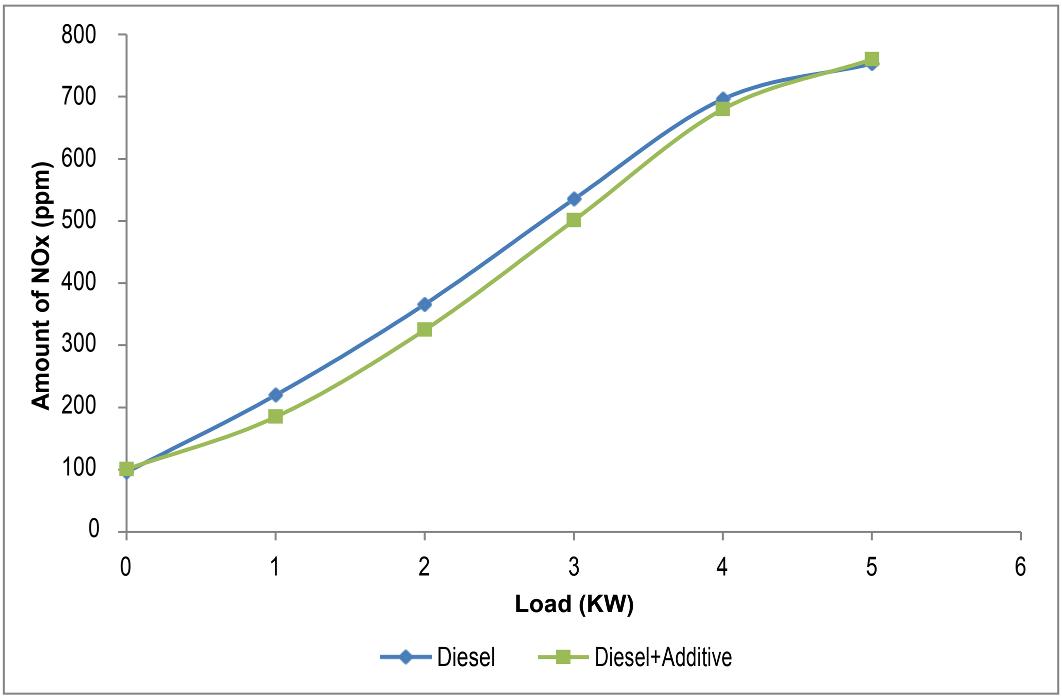


Figure 41: NO_X Emissions at 280 bar injector pressure

From the above tests it was found that as the injector pressure was increased, the emission of NO_X from the diesel blend was less compared to that of diesel at all values. With increase in injector pressure, the atomization also increases which leads better utilization of the free oxygen. This makes the oxygen unavailable for the Nitrogen to form NO_X. But as the load increases, the NO_X emissions become same as that of diesel fuel since the temperature increases and the engine runs rich.

5.4 INJECTOR PRESSURE EFFECT ON PERFORMANCE AND EMISSIONS WITH ADDITIVES IN DIESEL FUEL

The efficiency of the combustion process and the emission products produced are predominantly depends on the pressure of injection of the fuel. The pressure of fuel injecting into the combustion chamber is directly affecting the ease of atomization and thus the speed at which flame traverses. The experiment was conducted for different pressures of injection i.e., 220 bar, 250 bar and 280 bar on the same engine and the performance and emissions characteristics are analysed.

5.4.1 Variation of the Brake Specific Fuel Consumption

Break Specific Fuel Consumption is the estimation of the amount of fuel consumed for unit power generation per unit time. It is noticed that with the increase in the load, the BSFC value decreases as compared with the Diesel fuel. This is due to the fact that the additive + diesel blend can undergo atomization easily in presence of diesel additive and result in complete combustion.

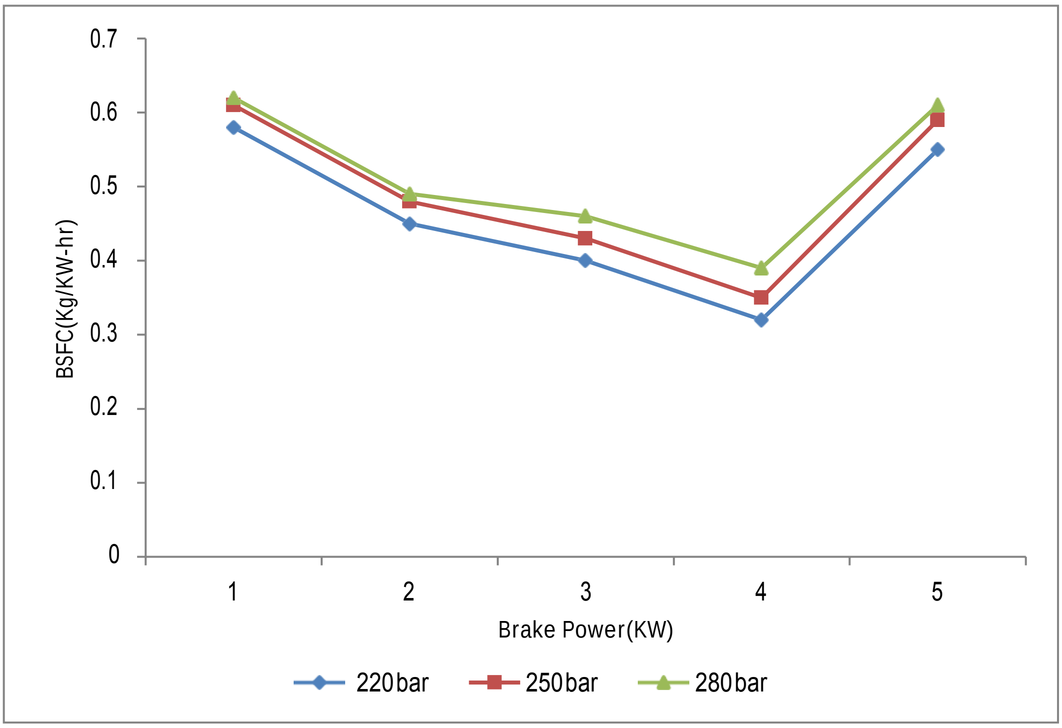


Figure 42: Variation of BSFC with injector pressure

The injector is calibrated for different operating pressures i.e., 220bar, 250bar and 280bar and the performance analysis at each of the above pressures are plotted to analyze. A glance on the Figure 42 reveals that the BSFC increases as the injector pressure increases. This is because of the fact that more fuel gets injected at higher injector pressures as the speed of the engine and the time of injection remains constant in the entire process. As these finer particles are comparatively more combustible, the fuel consumption is lesser than that of diesel fuel at every pressure of injection. Hence the increase in injector pressure results in more consumption of fuel.

The higher pressure of injection promotes in a rapid rate of heat evolution, which is due to the reduction in the ignition delay period i.e., the reduction of physical delay. This physical delay is the consequence of decrease in the fuel’s viscosity at higher injection pressure leading to lesser BSFC than diesel. From Figure above, it can be deduced that the optimal pressure of injection to get a good BSFC for the additive blend was found to be around 250 bar and any further increase in the injection pressure causes an even more high BSFC value which isn’t advised.

5.4.2 Variation of the Brake Thermal Efficiency

The brake thermal efficiency is interpreted as the amount of brake power produced per unit fuel power. It is expressed as percentage. It is acknowledged that with the increase of the load, the efficiency of the engine increases. This is due to the reduction in the ratio of friction to brake power. This trend of increase in the efficiency is observed till about 80% of the full load and then decreases because after 80%, the engine runs a rich mixture.

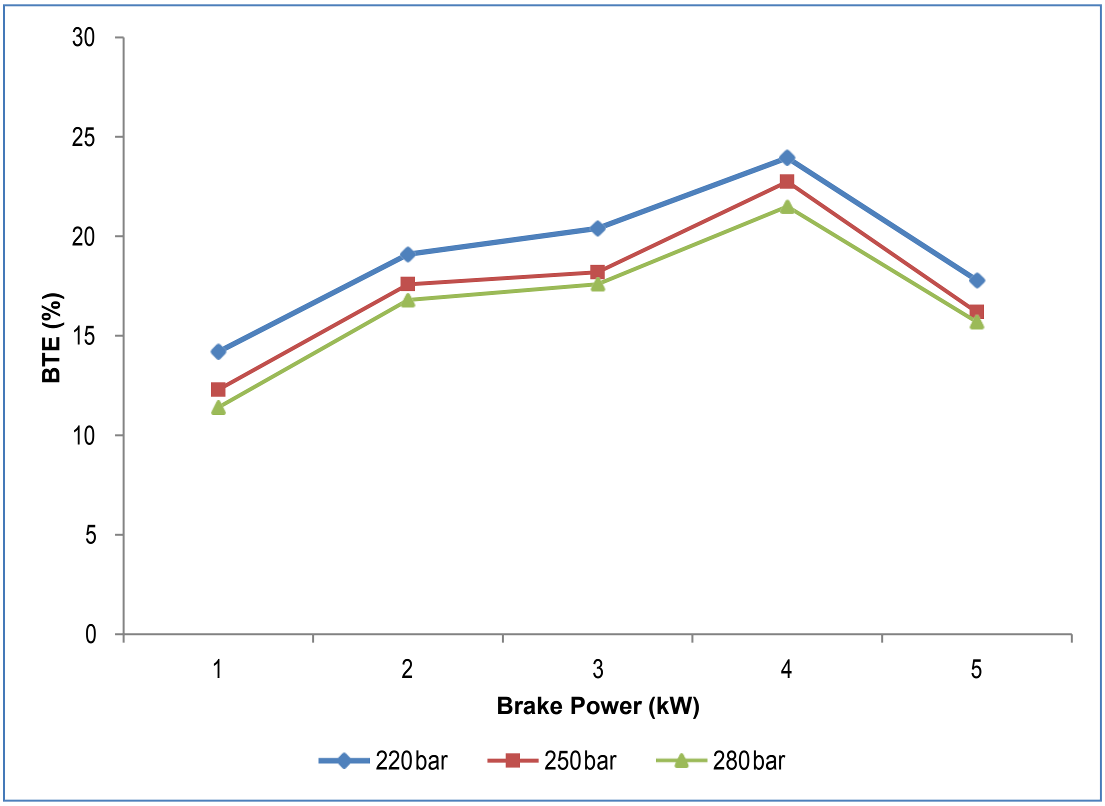


Figure 43: Variations of BTE with Injector Pressure

The engine is run by running at different injector pressure namely 220bar, 250bar and 280bar and the same trends are observed at all the injection pressures. From the figure 43, the efficiency is observed to be the highest at 220bar pressure and decreases as the injection pressure increases.

At the beginning and end of the injection, specific fuel consumption increases with the increase of the injection pressure. Since the injection always takes place at higher pressures and the duration of injection remains same at all values, efficiency drops with increase in pressure. The difference in trend between 250bar and 280bar is very less. This is because of the less momentum of finer particles (already atomized particles) at 280 bar. Here it can be concluded that 250bar to 260bar is the optimum or ideal suitable pressure for obtaining satisfactory results since running the engine at an injection pressure of 280 bar requires a much stronger pump and also requires a higher BSFC.

5.4.3 Variation of the CO emissions

The incomplete combustion of the fuel results in the CO emission and also depends on the key factors like air fuel ratio, concentration of oxygen etc. It is noted that the decrease in the value of CO emissions when the engine is powered with the fuel additive when compared with the commercial diesel at all the injection pressures of 220, 250 and 280 bar. This is because of reason that the enzyme which is present in the additive acts as an oxygen booster releasing more number of oxygen molecules. These supplemented oxygen molecules result in the complete combustion of the fuel thus leading to reduction in CO and converting the CO molecules into CO_2.

From the figure 44, it can be seen that the amount of CO emitted is maximum at 220 bar and minimum at 280 bar, is shows a trend of lesser emission of CO as the injection pressure increases. At 220 bar, it is noted that the CO emission is more when compared to engine running at injection pressure 250 bar and 280 bar. The lack of better atomization at 220 bar results in incomplete combustion that leads to more amount of CO emission concentrations. Furthermore, at 250 bar it can be noted that the CO emission decreases.

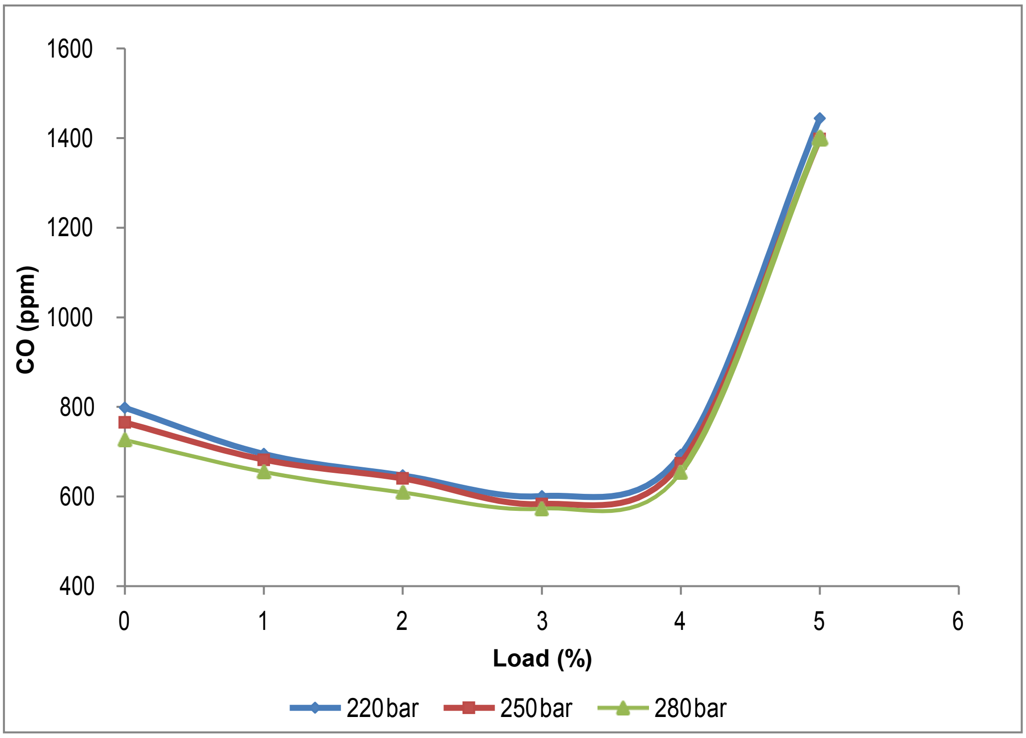


Figure 44: Variations of CO emissions with injector pressure

However, at a pressure of injection of 280 bar, the rise in the pressure of injection fails to provide any significant improvement in CO emission i.e., the amount of CO emission at 280 bar is very much nearer to the CO emission value at 250 bar. This can be attributed to the reason that higher injection pressure leads to atomization levels beyond the optimal point. Hence it is derived that it is ideal to inject fuel blend at a pressure of about 250 - 260 bar.

5.4.4 Variation of the CO_2 emissions

The emission of CO_2 is an index of whether the combustion process is complete or not, i.e., the formation of CO_2 increases with the occurrence of complete combustion. From the experiment, it was observed that the CO_2 emissions from the diesel + additive were more when compared to Diesel fuel at greater loads at 220 bar injection pressure and lesser than Diesel at lower loads owing to lesser rate of atomization at this injection pressure.

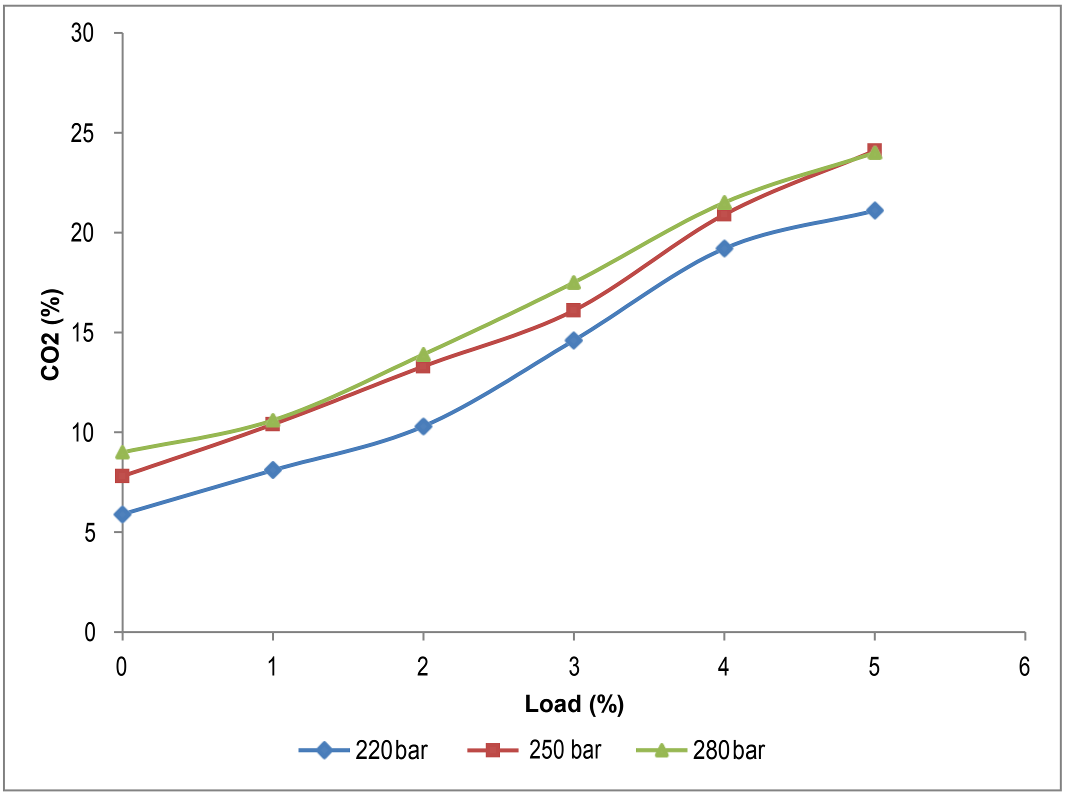


Figure 45: Variations of CO_2 emissions with injector pressure

But at the injection pressures of 250 and 280 bar, the emissions from the diesel + additive fuel blend showed consistently higher CO_2 emissions than that of normal diesel, which can be attributed to the reason that at these higher injection pressures the effectiveness of the enzyme additive is more and produces better dispersion and atomization leading to a complete burning of fuel.

The variation of the CO_2 emissions with the various injector pressures of 220, 250 and 280 bar is represented in Figure 45. The CO_2 emissions were observed to be lowest at 220 bar, which is because of lower injection pressure and relatively lesser atomization than at higher pressures. Similarly, from the graph it can be seen that the CO_2 emissions increases at higher injection pressure which can be attributed to the better atomization, lesser ignition delay and better/complete combustion.

Furthermore, it is also observed that at the injection pressures of 250 and 280 bar, the emissions of CO_2 are very close by indicating that at 280 bar, the pressure of injection fails to provide any significant decrease in the amount of CO_2 emission (compared to CO_2 emission at 250 bar). This may be attributed to fact that at the high injection pressure, the atomization is high beyond optimal level and causes a significant amount of fuel to undergo partial combustion.

5.4.5 Variation of the NO_X emissions

NO_x is the general term for nitrogen compounds that are obtained as emission components. In the combustion chamber, the NO_x is formed mainly because of increase in cylinder temperature that is caused due to burning of fossil fuels, availability of oxygen and also on the rate of the combustion reaction. From the experiment, it was noticed that as injector pressure increases the atomization also increases which leads better utilization of the free oxygen till about 250 bar and the NO_X emissions decreases.

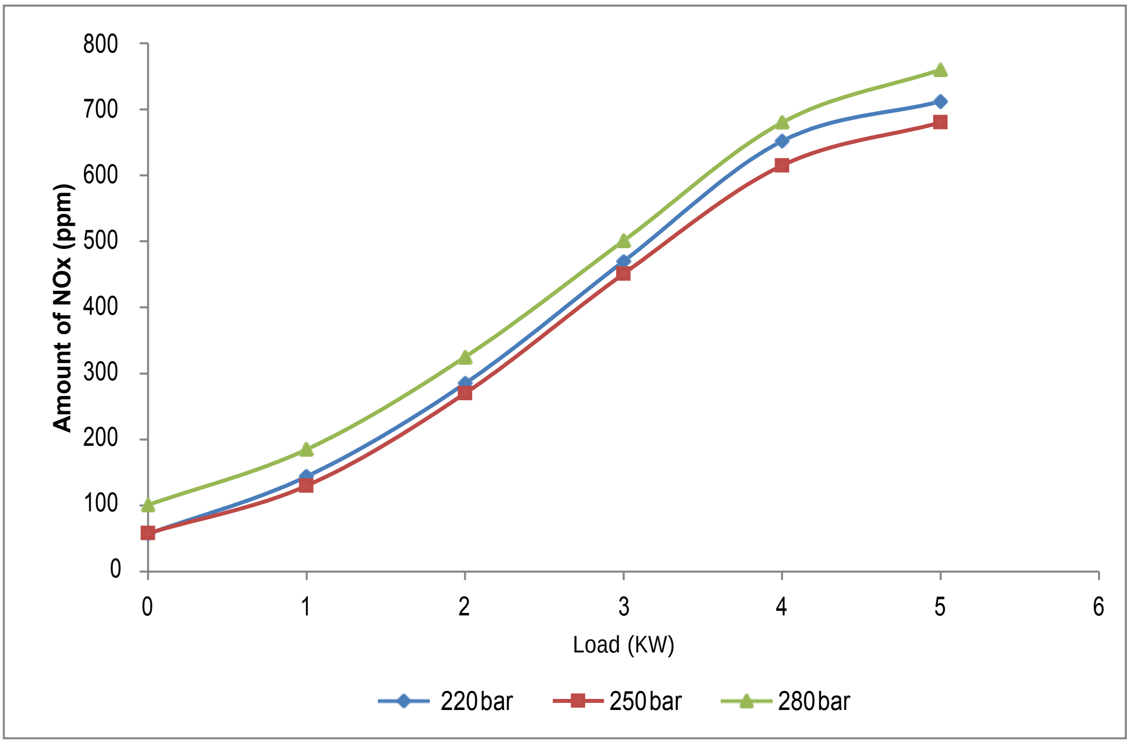


Figure 46: Variations of NO_X emissions with injector pressure

But above 250 bar the effect of temperature, partial combustion and over micro dispersion are high and this causes NO_X emissions to increase. It can be noted that at every injection pressure, the NO_X emissions were lesser than diesel as the load increases and become nearly as same as that of diesel fuel at loads greater than 80% since the temperature increases and the engine runs rich.

Figure 46 shows the emission of NO_x from the diesel blend which lesser than that of diesel for all injector pressures of 220, 250 and 280 bar. It is also observed that as the injector pressure is increased from 220 bar to 250 bar, the emission of NO_x showed a decrease, this is due to the fact that:

a. The extent atomization is better.
b. The ignition delay is decreased at the 250 bar than at 220 bar.
c. The reaction time is less and undergoes better combustion.
d. Availability of oxygen to react with Nitrogen is less.

At 250 bar the amount of NO_x formed was least compared to 220bar and 280bar also. Thus it can be concluded that the 250 bar pressure is the optimum pressure to carry out the best possible atomization. As the atomization process increases, the complete combustion of fuel takes place and the free availability of oxygen decreases thus leading to the reduction in the formation of NO_x.

At 280bar, the amount of NO_x formed is more compared to both at 220 bar and 250 bar. This is because of the fact that higher injection pressure leads to increase in cylinder temperature and the NO_X formation is predominantly depends on the cylinder temperature, thus it increases at 280 bar. This may also be attributed to longer and high pressure injection causes a very high amount of micro dispersion of fuel in combustion chamber. The extent of dispersion at this pressure is far above the optimal dispersion level and leads to partial combustion of the fuel particles, thus leads to higher NO_X emissions.

CHAPTER 6- SIMULATION RESULTS

6.1 About the Simulation

CHEMKIN is a software tool for solving complex chemical kinetics problems and undertaking in-cylinder diagnosis. It is used worldwide in the combustion, chemical processing, microelectronics and automotive industries. Chemical kinetics simulation software allows for a more time-efficient investigation of a potential new process compared to direct laboratory investigation. Measurement of in cylinder combustion characteristics necessitated fitment of pressure sensor for dynamic measurements as the combustion process progressed in the combustion chamber. However no such provision exists in the present experimental setup. Hence efforts have been directed towards obtaining in cylinder combustion characteristics via simulations on CHEMKIN-PRO (part of ANSYS) version 21.0.0.289. The software has been developed by NASA and is currently the go to software for combustion related studies worldwide. The software requires the chemical kinetics, thermal properties and transport data of the respective fuel to be fed as input files in the prescribed format and processes it to arrive at calculated output.

However, the major challenge while using the software arises from the fact that input files of diesel consists of more than 1000 species and ten thousand reactions. Trying to run the software using the diesel input files necessitate need of super computers. As a result surrogate files have been created by various researchers with reduced number of species and reactions. The percentage of error by using these surrogate files increases. Further input files for Diesel+ Fuel Additives are not available and had to be created. This was done using chemical workbench wherein a master file (in our case diesel) is merged with donor file (in our case ethanol). The process is cumbersome and involves step of firstly identifying the common species in both the files, elimination of non important species and lastly elimination of non important reactions. The file thus formed has to be checked for correctness by comparing the results obtained by using merged files as input to the individual fuel component files. The results thus obtained are presented below in the succeeding paragraphs.

a. Adiabatic Flame Temperature (AFT).

As percentage of Fuel Additive in the blend is increased the AFT has been found to decrease as is evident in Fig 47. This can be attributed to the high heat of vaporization of the additive, its increased oxygen content and also the lower heating value of the fuel blends. It is imperative to mention though most of the research papers indicate similar trend, Gangping Mao et al have reported an increase in adiabatic flame temperature with the addition of butanol in diesel fuel: attributing complete combustion due to increased oxygen content as dominating factor. A reduction in approximately 1.39 % has been observed on addition of .36 % Fuel Additive in diesel.

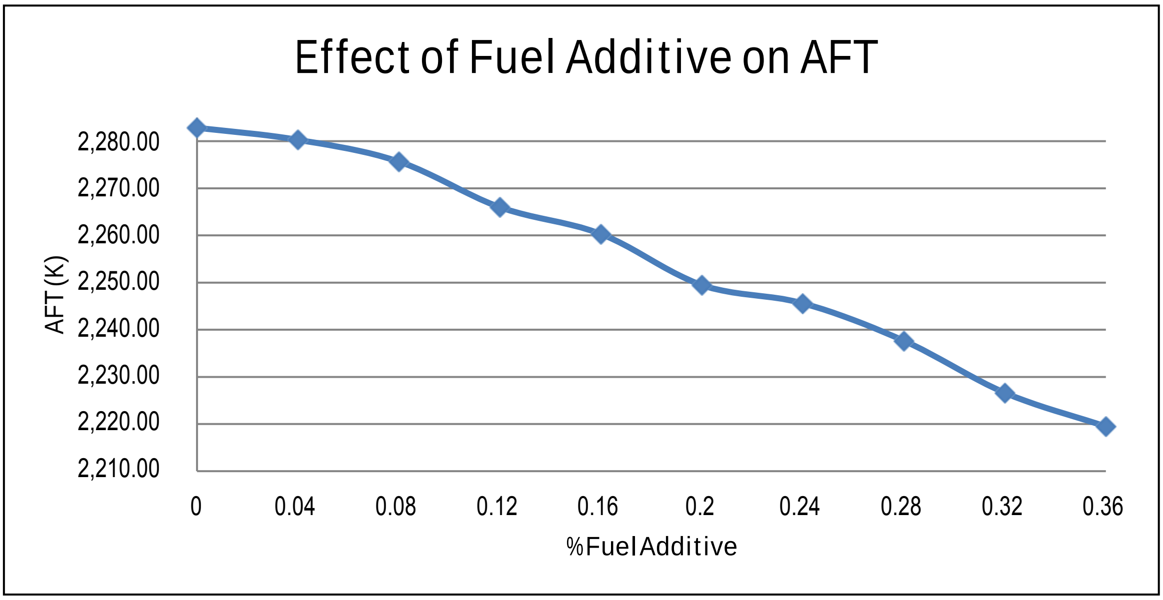


Fig 47: Effect of fuel additive on AFT

Further effect of variance of load (i.e. air fuel ratio) on the AFT has also been studied and is indicative of an increase of 17% with load. It has also been observed that at about 70% load the AFT is higher for the blends as compared to pure diesel indicating complete combustion due to increased oxygen content of the fuel blends as is shown in Figure 48.

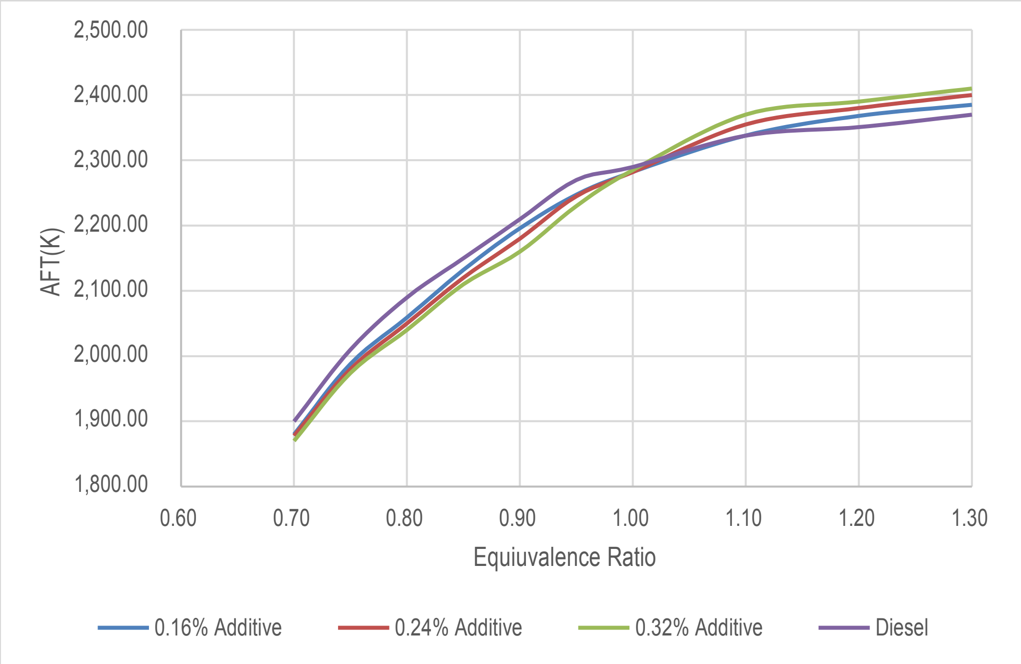


Fig 48: Effect of increasing load on AFT

b. P- theta diagram

The P-theta diagram in a CI engine is one of the most critical combustion related parameter that suggests significant information on progress of combustion within the combustion chamber. Critical information availed from the P-theta diagram includes ignition delay, period of rapid combustion, period of controlled combustion, peak pressures etc. Simulation of these parameters is critical prior designing of engine to arrive at correct metallurgy as well as geometrical details of the engine. Simulation results indicate a slightly lower peak pressure values of 85.1 bar, 83.5 bar and 82.3 bar for D95E5, D90E10 and D85E15 respectively as against 86.1 bar for pure diesel (D100) at 60% load; resulting in reduced work output from the blends as compared to pure diesel. Further peak pressures are achieved at slightly increased crank angles in ethanol diesel blends as is evident in Fig 49. This increase in crank angle is attributed to larger ignition delay in ethanol diesel blend as discussed

c. **No Load condition**

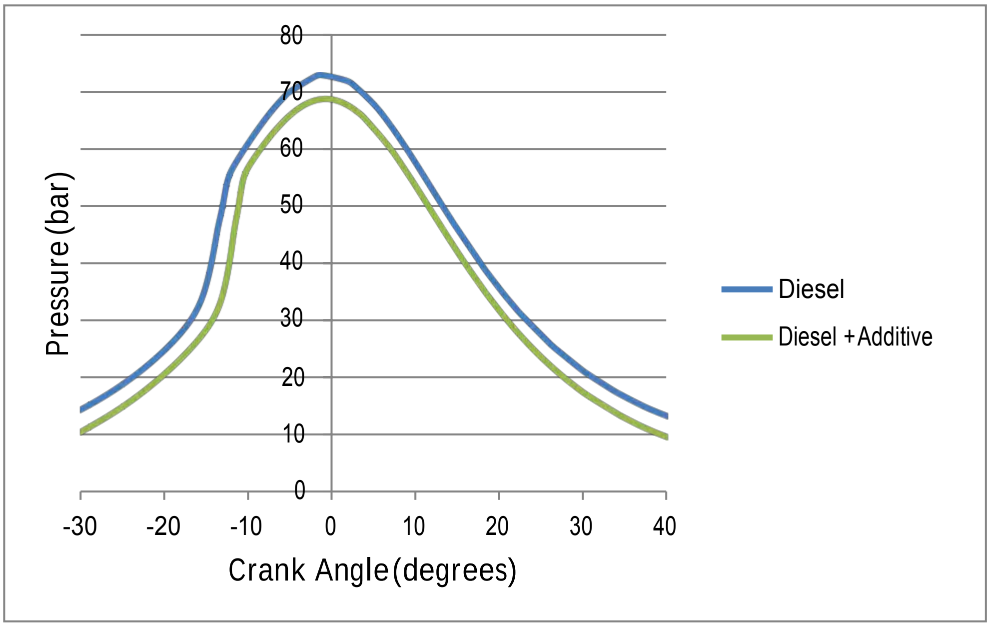


Fig 49: Crank angle v/s pressure variance graph(No load)

As the load on the engine increases, the power output from the engine increases due to higher quantity of fuel being burnt in the combustion chamber resulting in higher peak pressures as presented in Fig 49. It has been observed that the peak pressure at full load is 94 bar as against 72 bar at no load i.e. an increase of approximately 30% for the D90E10. It is also observed when the engine is operated with D90E10, as the load increases the peak pressure moves away from TDC i.e. from 1.5º ATDC to 6º ATDC. The delayed peak pressure as against that in case of lower load can be attributed to higher fuel quantity that was being injected at higher loads in addition to higher heat of vaporisation of the ethanol blends D90E10 and D85E1

d. **Full Load condition**

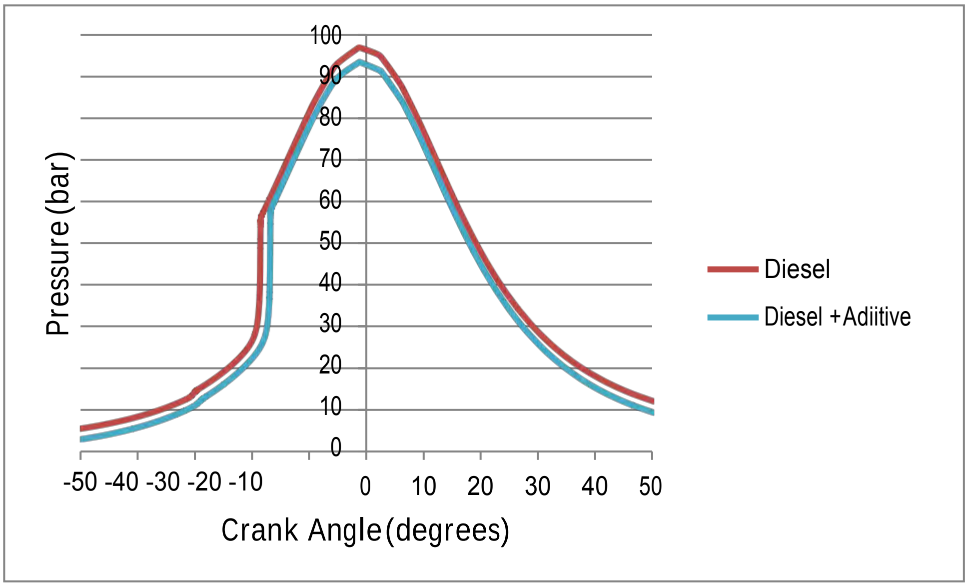
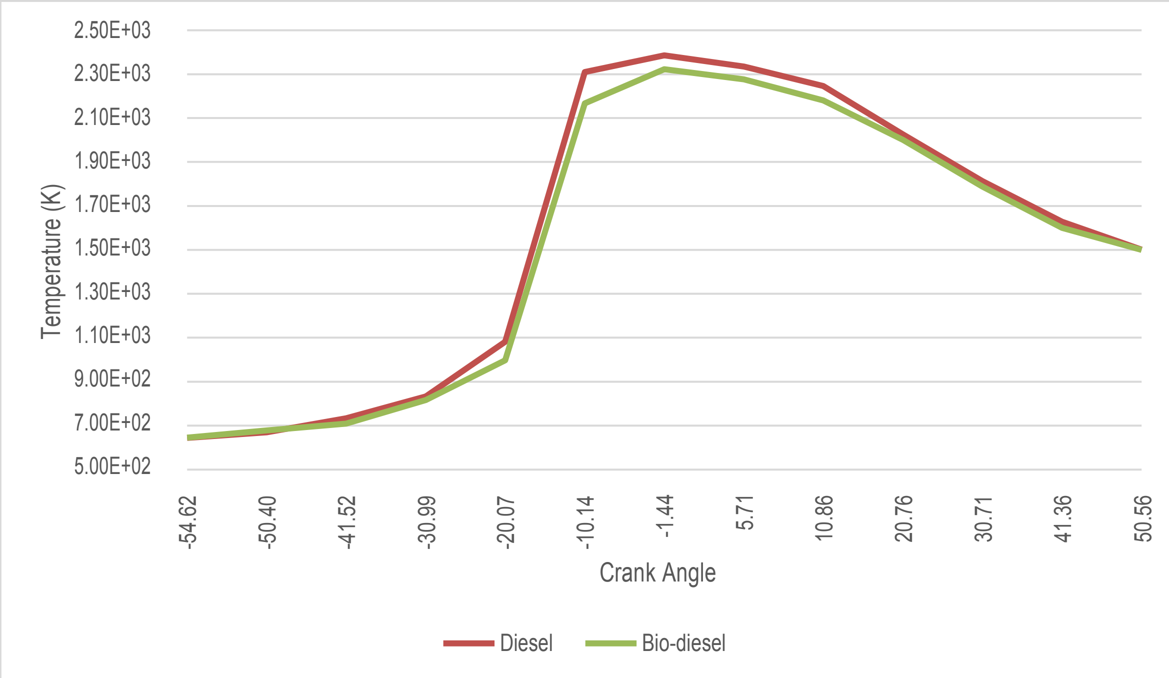


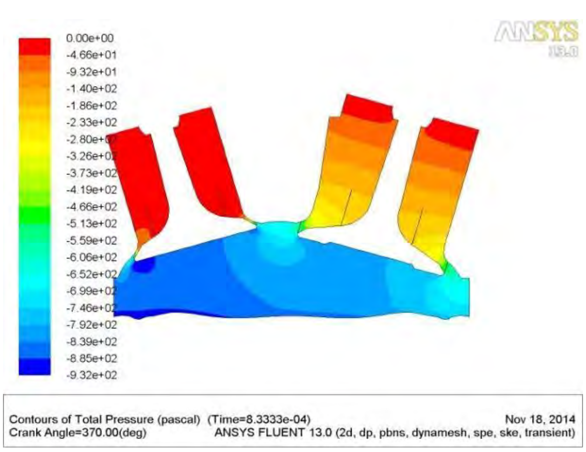
Fig 50: Crank angle v/s pressure variance graph(Full load)

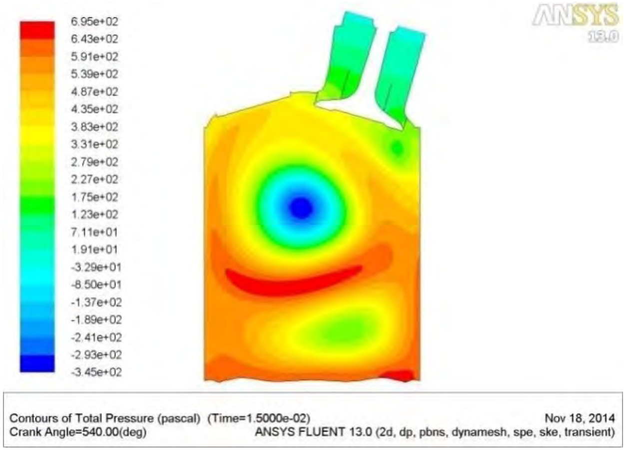
At 100% load, an interesting behaviour with D85 E15 blend is observed as shown below in Fig 50. Though the peak pressures in this case are lower as compared to D100 and D95E5, they are however slightly higher than D90E10. Further peak pressures are achieved a little before as compared to D95E5 and D90E10. This can be attributed to better combustion in the fuel rich zone i.e. $\phi > 1$ owing to higher oxygen content of ethanol blended diesel.

e. **T- theta diagram**

The T theta diagram is another critical combustion parameter that provides the maximum temperature that would be achieved in the combustion chamber and thereupon the metallurgy, cooling requirements etc. Further the diagram also provides information on the period of maximum temperature within the combustion chamber that governs the valve timing diagram of the engine. Similar to the pressure trends, the temperature –theta profile as shown in Fig 6.8 also shows similar behaviour. The temperatures achieved in the case of ethanol blends are slightly lower than that of pure diesel as well as delayed. Conversion of this high temperature into power is governed by the heat losses to the cylinder walls, piston head and cylinder head. It is shown below that heat losses for the case of ethanol blends are slightly lower than that for diesel resulting in increased thermal efficiencies .As the load on the engine increases the temperature in the cylinder also increases as shown in Figure below. However, the increase is found to be higher for loads above 50% owing to better in cylinder temperatures being achieved and complete utilisation of increased oxygen content in the fuel. Though better atomisation and finer droplets are found in the case of ethanol blends the temperatures are still lower as compared to D100. Higher heat of vaporization and lower heating value play a dominant effect leading to lower in cylinder temperatures.







6.2 Comparision between values using only fuel and fuel+ Bio-enzyme

Values	**Before using fuel additive**	**After Using Fuel Additive**
Calculated max power & Speed:	5kw/1500 rpm	5.3kw/1500rpm
Oil consumption at max power	3.5 litres/hr	3.0 litres/hr
Cal max torque and speed	38.20 Nm/1500rpm	38.9/1500 rpm

CHAPTER 7 – CONCLUSION

7.1 The experimental studies were conducted to analyse the performance and emissions of the additive + diesel blend in comparison to commercial normal diesel at various injection pressure of 220 bar, 250 bar and 280 bar. The following conclusions can be drawn from this experimental study :-

a. The performance in terms of BSFC was experimentally evaluated for the additive + diesel blend and is compared with Diesel fuel. At 220 bar, the BSFC for the additive + diesel blend was found to be lesser by 0.02 kg/kW-hr between 50% to 65% load. At the injection pressures of 250 bars, the additive + diesel blend showed a BSFC lesser by 0.03 kg/kW-hr between 50% to 65% load compared to that of diesel. At 280 bar, the variations between the diesel and diesel + additive were very minimal by an amount of 0.01- 0.015 kg/kW-hr for all loading conditions.

b. The performance of engine in terms of BTE is experimentally analysed for the blend and is then compared with the Diesel fuel. At 220 bar, the efficiency of blend is almost similar to that of diesel. At 250 bar, the efficiency of the diesel + additive showed an increase of about 1 to 2% at various loads compared to diesel. At 280 bar, the BTE for the blend showed an increase of 1.5 to 2.5 % over the commercial diesel. At 220 bar injection pressure, the BTE was found to be highest, owing to low BSFC value and the lowest BTE was observed at 280 bar owing to a higher specific fuel consumption rates.

c. From the graph it can be seen that CO emissions during the cold/start up stage is much higher than emissions in the warmed up stage. For the Diesel+ additive mixture, the CO emissions are relatively less. At 220 bar, the difference observed is around 50 to 70 ppm for the various loading conditions, but at full load the CO emissions increases exponentially for both blend anddiesel and become almost similar owing to richer running and incomplete combustion. The same trend was observed for the CO emissions at 250 bar and 280 bar. The blend showed a reduction of 50 to 80 ppm of CO emissions compared to diesel at 250 bar and a reduction of 20 to 30 ppm compared to diesel at 280 bar

c. At 220 bar, initially the CO_2 emissions are less than that of diesel till about 60% of load and then show an increase over diesel at higher loads, which is because the injector pressure isn't sufficient to cause better atomization in the blend. At 250 bar, the reduction in CO_2 emission is observed to be between 1 to 1.9 % compared to diesel. At 280 bar also the same trend was followed and the reduction was found to be about 1 to 1.5 % compared to diesel emissions. Furthermore, the emissions of CO_2 for the injection pressure of 220 bar were minimum and the emission of CO_2 were maximum at an injector pressure of 280 bar, because of better dispersion at higher injection pressure.

d. At 220 bar, it is observed that the emissions of NO_x are lower up to 60% of maximum load when compared to Diesel due to low combustion temperature, lower oxygen availability because of better combustion and high heat of vaporization of the diesel + additive blend. But at higher loads, the emissions become almost same which can be attributed to higher temperature of combustion at higher loads.

e. The amount of NO_x formation decreased by 8 to 10% when using diesel + additive. Further decrease due to increased blending needs to be studied. At 250 bar, for various stages of load, the NO_x emissions were substantially low compared to diesel. At 280bar, the amount of NO_x formed is more compared to emissions at both 220 bar and 250 bar. This is because of the fact that the cylinder temperature increases with increase in the injection pressure. Thus the emissions of NO_x were lowest for 250 bar and the emissions were highest at 280 bar, thus it is advised to run the engine in the optimum injector pressure range of 250 bar to 260 bar to get the NO_x emissions to a minimum value.

f. This additive blend can reduce the amount of air by reducing the CO and NO_x emissions at various running conditions. No additional modifications are required in the regular Diesel engine to use additive + diesel blend as fuel, hence no extra expenses are spared. Only the injector pressure must be optimized and it can be done for a less amount of money in local mechanic shops without any complications.

Some of the other benefits are as follows:-

g. Thus this blend can be favoured over LPG and CNG which require costlier modifications. It can be used as a viable method to reduce pollutions in commercial, defence and other sectors.

e. The air pollution has been substantially reduced

f. The carbon residue cleaning up post operation from the nozzle, pipe line and ignition plugs can be avoided due better detergent properties of the additive

g. The periodic maintenance of the engine is drastically reduced

h. The engine was found to be running with lower noise and vibration. Additionally the start/stopping of the engine was smooth

i. Save oil consumption: approximately 3 - 10% (based on comparison of unit oil consumption and determined by on-site equipment conditions)

j. Reduce carbon deposit in furnace.

q. Save expenses for air pollution treatment.

r. Reduce damages to exhaust apparatus and equipment arising from high and low temperature erosion.

s. Reduce cost arising from timeout (maintenance cost)

t. Reduce labor cost.

u. Reduce material cost for replacement.

v. Reduce emission of toxic gas (air pollution), reduce incidence of respiratory track diseases to operators.

w. Reduce pollution sources for acid rain and air pollution.

x. Reduces smoke from motor vehicles

Before using BIO-POWER | **After using BIO-POWER**

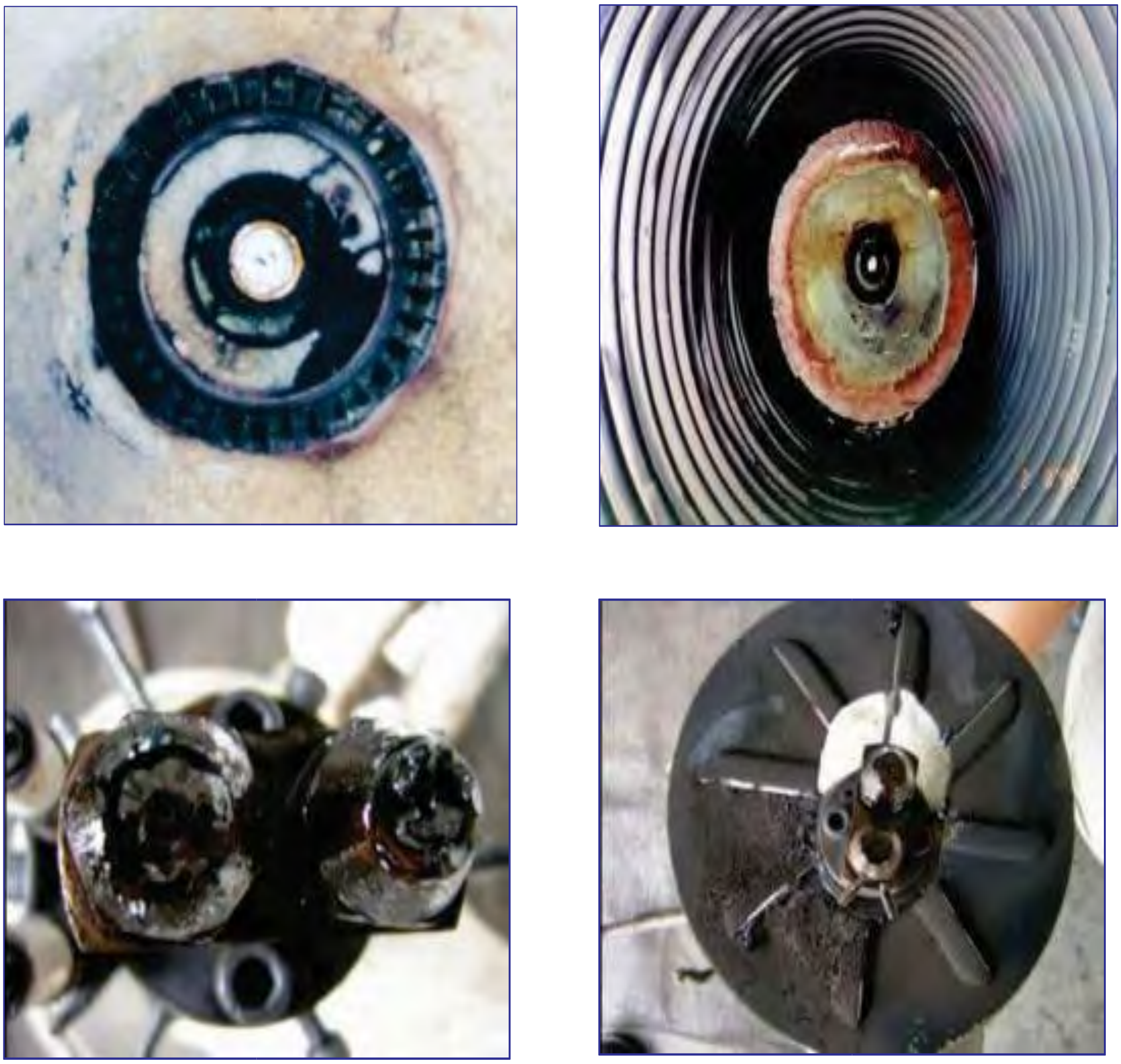


Fig 52: Comparison of Engine components post operation

7.2 The following ways are there to maximize the efficiency of Fuel Additive:

Main components of Fuel Additive fuel oil enzyme are of protein characteristics, and have no adverse effects. However considerations should be give to the following instructions for the initial stage of use of Fuel Additive:

a. In case of too much water content in fuel oil, there will be water drops separated out from the bottom of oil storage tank. Use adequate drainage system.

b. The initial stage of adding Fuel Additive into fuel oil, there will be a prominent increase of emission of black smoke and SO_x .This is a normal phenomenon, since Fuel Additive is proceeding a quick cleaning to the fuel oil at this time.

c. The original holes on the flue will expose because the carbon deposit, which covers these holes, was cleaned up. Carry out adequate repair.

d. There will be some oil leakage at the pipeline connection position or clamping position, because the oil sludge was cleaned up and the oil quality was improved (oil viscosity is reduced). Replace it or re-fasten the pipelines.

e. Special attention should be paid to the oil filter at the initial stage of adding Fuel Additive, so as to assure a smooth oil supply.

f. Oil tank storage temperature should be less than 120°C.

g. When adding Fuel Additive, do not immediately pour it from the top end if the oil tank. Since specific gravity is different, Fuel Additive will retain on the surface of heavy oil and thus not easy to mix well.

7.3 Comparison between Conventional Additive and Bio-Fuel Additive

Function	**Conventional fuel oil additives**	**Bio-Fuel Additive**
Component	Strong chemical solvents and heavy metals	Biochemical enzyme
Action principle	1. Corrode carbon deposit through strong chemical solvents and fill up the "scar" by black metal, so as to recover horsepower of the engine	Chop down carbon bond through biochemical reactions and cut off the chemical bond between oil and carbon deposit so as to remove carbon deposit

	2. Increase octane value through metal containing organic matters	and on the other hand, reduce oil viscosity, Increase combustion efficiency, increase engine power and save energy through crack of carbon molecule in fuel oil.
Remove carbon deposit	Initially it can actually remove carbon deposit at the initial stage of use. But in case of presence of organic compounds, engine wear will increase.	Fuel Additive can continually improve carbon deposit phenomenon and can mix into fuel oil to chop down carbon molecule bond, so as to upgrade oil quality, prevent carbon deposit from forming, and this performance remains effective persistently.
Increase engine power	Can only recover the engine to its original power level	Increase engine power by means of increasing thermal efficiency of oil and action of water gas, and no tetraethyl lead or MTBE is used to increase octane value.
Oil consumption	At the initial stage it does save oil. However, energy saving largely depends on working conditions of the engine. In case of long-term operation, the effect will decrease successively.	Thermal efficiency of fuel oil is increased by means of improving oil quality. Reduce oil consumption at a average of 8 - 15%, and this performance remains effective persistently.
Inhibit corrosion	Chemicals arising from combustion of sulfide in strong chemical solvent and fuel oil may cause corrosion to engine cylinder.	Oxidize the sulfide in fuel oil in the course of chopping down carbon bond, make it to sulfur oxide with extremely high stability, so as to reduce

		emission of sulfide up 35 - 60% and protect the engine from corrosion.
Reduce air pollution	Large quantity of air and oil vapor will mix together and thus NOx is generates under high temperature, therefore no air pollution reduction performance is expected.	After separation of molecule bonds,air demanding quantity for mean unit volume is reduced and total air demanding quantity is reduced accordingly, thus emission of NOx and CO is considerably reduced so as to improve air pollution.
Equipment maintenance & economic benefits	In case of long-term operation, no prominence is expected in equipment maintenance and in economic benefit.	Achieve more complete combustion and remove/avoid carbon deposit by means of improving oil quality persistently, therefore good performance in equipment maintenance and in economic benefits is available.

7.4 Reduces loss of heat conduction

Reduced heat energy loss of heat conduction efficiency caused by carbon deposit. In case of incomplete combustion, lots of carbon deposit will generate and stick on coil pipes of the furnace. After a long time, carbon deposit will result in decrease of heat conduction efficiency, heat energy at the side of flame cannot reach heat exchange and thus dissipation of energy takes place. When the thickness of carbon deposit reaches 1.0 mm, heat conduction efficiency will reduce by 3 - 8%.

Fuel Additive can optimize combustion of fuel oil. The biochemical enzyme will make solvation with fuel oil, and all ashes generated from combustion are fleecy solid state matters, which are not easy to stick on coil pines of the furnace, so as to reduce heat energy loss of heat conduction efficiency caused by carbon deposit

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