A STUDY OF PERFORMANCE AND EMISSIONS CHARACTERISTICS OF FUEL ADDITIVES USING THEIR BLENDS WITH DIESEL FUEL

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DECLARATION

I hereby declare that the work which being presented in the major thesis entitled **"A STUDY OF PERFORMANCE AND EMISSIONS CHARACTERISTICS OF FUEL ADDITIVES USING THEIR BLENDS WITH DIESEL FUEL"** in the partial fulfilment for the award of the degree of Master of Technology in **"Thermal Engineering"** submitted to Delhi Technological University (Formerly Delhi College of Engineering), is an authentic record of my own work carried out under the supervision of **Dr. RAJIV CHAUDHARY,** Department of Mechanical Engineering, Delhi Technological University (Formerly Delhi College of Engineering). I have not submitted the matter of this dissertation for the award of any other Degree or Diploma or any other purpose what so ever. I confirm that I have read and understood 'Plagiarism policy of DTU'.

Place: Delhi **NITESH BANSAL**

Date**:** **Roll No. 2K15/THE/09**

CERTIFICATE

This is to certify that NITESH BANSAL, (Roll no. 2K15/THE/09), student of M.Tech., THERMAL ENGINEERING, Delhi Technological University, has submitted the dissertation titled **“A study of performance and emissions characteristics of fuel additives using their blends with diesel fuel”** under our guidance towards the partial fulfilment of the requirements for the award of the degree of Master of Technology under our guidance and supervision.

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ABSTRACT

Fossil fuels are diminishing with each passing day and there are many emissions from the internal combustion engines. Diesel engines are widely used in many of the vehicles because of its fuel efficiency and lower fuel cost than petrol engines. They produce lower carbon mono-oxide and unburnt hydrocarbon emissions as compared to gasoline engine, but the presence of particulate matter (PM) in engine exhaust is more than that of gasoline engines. The Indian government has revised the restricted norms on the usage of the fuel keeping in mind the emissions and most of the people believe in being environmentally friendly.

This research aims to reduce the emission from the diesel engine exhaust using different fuel additives, which promotes the ignition. Cetane improving substances, also known as ignition promoters added in the diesel fuel to enhance its cetane number and help in reducing overall emissions from the exhaust of the engine. Different ignition promoter additives can increase the cetane number of diesel fuel upto 12-15 and reduces carbon mono-oxide, nitrogen oxides and hydrocarbon emissions. Oxygen class cetane improvers such as Dipropylene glycol or diethyl ether, added in the diesel fuel in about 5~15% concentration increases the oxygen content of the fuel. In addition, Nitrogen class improvers such as 2-Ethylhexyl Nitrate or cyclo-hexyl nitrate are used in comparatively smaller concentration i.e. 0.1~0.3% in order to increase the cetane number of the fuel.

The additives used in this work are Dipropylene Glycol, ethyl decaneperoxoate and 2-butoxyethanol. These were mixed with diesel fuel in the concentration of 10% by volume and were used to conduct experiments in a single cylinder diesel engine. The research work was divided into four stages. At first stage, diesel was analyzed for performance and emissions. At second stage, blend in diesel fuel was prepared with ethyl decaneperoxoate and Dipropylene glycol with 10% in concentration each. On third stage, 2-butoxyethanol and ethyl decaneperoxoate were used in 10% concentration each. At final stage Dipropylene glycol and 2-butoxyethanol were used in 10% concentration each.

The results showed that by using these additives the percentage of smoke, carbon mono-oxide, oxides of nitrogen and hydrocarbons in the engine exhaust were reduced. Cetane number got improved upto 2-5%, Carbon mono-oxide emissions were reduced upto 20-25%, hydrocarbon emissions reduced upto 3-5%, and Oxides of nitrogen were reduced upto 4%. Generated brake power was 3-8% lower than that of mineral diesel, also brake specific fuel consumption increased by 6-8%. In addition, the efficiency of the engine was not much affected, but reduced a little bit as compared to mineral diesel. In India, cetane number of diesel fuel must be at least 48 in order to use in internal combustion engines.

Keywords- Alternative fuel, CI engine, Fuel additives, Cetane improvers, ignition promoters, engine emissions, performance, oxygenative additives, Dipropylene glycol, ethyl decaneperoxoate etc.

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LIST OF SYMBOLS USED

CO_2	Carbon di-oxide
CO	Carbon mono-oxide
UHC	Unburnt hydrocarbons
NO_x	Oxides of nitrogen
SO	Sulfur Oxide
PM	Particulate matter
DPM	Diesel particulate matter
Mg/Kg	Milligram/ Kilogram
CN	Cetane number
EHN	Ethyl hexyl nitrate
CI	Combustion ignition
DDCL	Direct diesel coal liquefaction
C/H	Carbon/Hydrogen
Ppm	Parts per million
PODE	Polyoxymethylene dimethyl ethers
Vol	Volume
BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
BMEP	Brake mean effective pressure
BSEC	Brake specific energy consumption
BTE	Brake thermal efficiency
CA	Crank angle
DBE	Di butyl ether
DEE	Di ethyl ether
CHN	Cyclo-hexane nitrate
DTBE	Di tertiary butyl ether

K	Kelvin
°C	Degree Celsius
°F	Degree Fahrenheit
g/mol	Gram/mol
DPG	Di propylene glycol
BC	Butyl Cellosolve
ED	Ethyl decaneperoxoate
SFC	Specific fuel consumption
HRR	Heat release rate
IP	Indicated power
BP	Brake power
Da	Dalton
KJ/mol	Kilo joule/ mol
Mpa	Mega Pascal
IQT	Ignition quality test
CR	Compression ratio
Cs	Centistokes
Kg	Kilo gram
KWh	Kilo-watt-hour
80D10A10B	80% Diesel +10% ED + 10% DPG
80D10B10C	80% Diesel + 10% DPG + 10% BC
80D10C10A	80% Diesel + 10% BC +10% ED
CFPP	Cold filter plugging point
Lit	Liter
Rpm	Revolution per minute
g/KWH	Gram/Kilo watt hour
CV	Calorific value
HC	Hydrocarbons
SG	Specific Gravity

CHAPTER-1

INTRODUCTION

1.1 ENVIRONMENTAL ISSUES:

The burning of non-renewable energy sources prompts the arrangement of CO_2, CO, unburnt hydrocarbons, NO_x, SO, ash, and particulate matter. Liquid fuels, by nature, are unpredictable and create unstable natural compounds, as produced particularly by gasoline. Occasionally many nations have been endeavouring to authorize controls to limit these harmful emissions. Their administrators have prompted major industrial participation to enhance fuel quality, lubricant quality, and vehicle outlines. [1]

The advances in these businesses are interrelated; in spite of the fact that biofuel improvement has the strong linkages to natural concerns, restricting government legislation, engine performance improvement, exhaust analysis, and the economy of the fuel. [2]

Ozone depletion, a dangerous atmospheric deviation, and climate changes are other important issues identified with fuels. Around 10,000 years gone between the ice age and Industrial Revolution. Amid that time, the air CO_2 level changed by just around 5%. From the beginning of mechanical Revolution of 2030, in around 150 years, measure of environmental CO_2 will have twice. World carbon di-oxide emissions are anticipated to ascend from 28.8 billion ($28.8x\ 10^9$) metric tons in year 2007 to 33.1 billion ($28.8x\ 10^9$) metric ton by 2015 and 40 billion metric ton by 2030. [3] [4]

The best way to decrease CO_2 emissions is diminishing the burning of hydrocarbon fuels as well as enhance the productivity of engines and equipments utilizing hydrocarbons. In hydrocarbon fuels the CO_2 outflow is corresponding to the measure of aggregate energy produced, a decrease in energy utilization will decrease the CO_2 discharge too. This requires a consolidated effort to present fuels that can be more effective, better power frameworks, and new materials and procedures.

Through facilitated activity, it might be possible to bring down the concentration of these greenhouse gasses in environment to around 450ppm (mg/kg) of the CO_2 equivalent. This would relate to the worldwide temperature objectives of environmentalists of not surpassing the 2°C ascend in the pre-mechanical period temperatures. To get this objective, energy related CO_2 emissions should be lowered to near 26.4 gigatonnes by 2030 from 28.8 gigatonnes of 2007. [5]

1.2 OVERVIEW OF DIESEL FUEL:

Diesel is a distillate in raw petroleum generally used in ic engines in which ignition is caused by pressure, not with an electric spark.

- It has a high compression ratio i.e. 16 to 22
- Volatility: less than petrol but it also has a higher heating value (Long chain).
- Heat of compression ignites fuel as sprayed in the engine cylinder. It does not require an ignition source.
- The smallest particles burn rapidly, but larger ones take more time to ignite because heat has to reach them to bring them to self-ignite.

1.3 FUEL ADDITIVES:

Fuel additives added into fuel in order to enhance its chemical properties. Different types of additives used in different types of fuel. In diesel fuel, many additives used in order to enhance its cetane number, cold flow properties, lubricity etc.

- Cetane number improvers (Ignition promoters)
- Lubricity improvers
- Cold flow properties improver
- Detergents
- Water dispersants

In present day fuels, a blend of different additives added to utilize the fuel to meet the best execution level. These added substances in little dose leads to enhance the properties of fuels that cannot be acquired through the refining forms. The most essential are the substances that enhance the flow of petrol and diesel oils. In some cases the added substance is used even to acknowledge better edges by using a value added item to different applications. [6]

For instance, a few added substances used to enhance the yield of distillates got by cutting further into the base of the unrefined barrel. Added substances are likewise utilized as a part of other oil based commodities like heating oil, the aviated fuels and oils to enhance the performances.

There are some main reasons to use these additives:

- To enhance ignition properties of fuel
- To enhance the fuel stability
- To improve the economical utilization of the fuel
- To build up or upgrade the brand picture of the fuel
- To decrease emissions by fuel ignition
- To give the engine cleanliness

Conventionally, these substance if used in higher amount (i. e. >1%) at the refinery are known as blending segments, and if used lower amount (i.e. <1%) at the refineries are called refinery added substances. The even lower amount of additive mixes used at stations and terminals by organizations are known as performance additives. Blending parts are basically refined petroleum streams or oxygenates, while performance and function added substances are primarily blends of chemical mixes disintegrated in solvents. The amount of added substances in fuels are not controlled. [6]

The concentrations of additive are exceptionally proprietary; also, the levels of treat will shift to a huge degree as the product, the refinery and kind of added substance utilized. Manufacturers utilize extra substances to offer some value addition. The concentration of added substance can be regulated according to the blend's chemistry and composition of compounds in the fuels. Nevertheless, the dose ought to be calculated experimentally, at the ideal focus to meet fuel guidelines.

Table 1.1: Gasoline fuel additives and functions

FUEL ADDITIVE	FUNCTIONS	CONCENTRATION (mg/kg)
Anti-knock substances	Improve octane number	25-1000
Detergents and dispersants	Cleans (Injection and exhaust system)	15-1000
Combustion Enhancers	Improve burning characteristics	10-50
Octane req. increase inhibitor	Inhibit octane req. Increase	20-1000
Antioxidants	Improve storage stability and stops the formation of resin	10-50
Corrosion inhibitors	Fuel system corrosion protection	5-50
Anti-wear additives	Reduce wear (mainly in fuel pump)	15-50
Metal-deactivators	Deactivates surfaces of metal that acts as oxidizing agents	5-20
Dehazers	prevent the formation of haze	2-40
Friction Modifiers	Save fuel with decreasing friction in moving objects	30-50
Anti-static additives	Enhance conductivity	3-20
De-icing agents	Inhibit carburetor ice forming	10-30
Dyes	Differentiates the fuel	3-25

Table 1.2: Additives for diesel fuels and functions

ADDITIVE	FUNCTIONS	CONCENTRATION (mg/kg)
Combustion improvers	Reduces the emissions (improved burning of PM)	10-30
Cetane improvers	Enhance cetane number (reduced emissions and noise, higher life of engine)	100-300
Antioxidants	Inhibit resin, increase storage stability	10-30
Deposit control Agents	Agents to clean, prevent formation of deposits; reduce the consumption of fuel and CO_2 emission	30—330
Metal-deactivators	Deactivates the surface of the metal acting as oxidizing agents	5-20
Corrosion inhibitors	Protects ion of the fuel system	20-25
Lubricity improvers	Improves the lubricity of the fuel	25-100
Demulsifiers	Inhibit the formation of haze by in-soluble compounds	10-20
Pour point additives	Lowers the pour point	80-300
Cloud point depressants	Reduces the initial temp of the paraffin crystallization	150-500
De-icing agents	Prevent the formation of ice crystal	3-10
Flow improvers	Give desirable cold-flow prop.	160—500
Friction modifiers	Reduces friction and decreases fuel consumption	60-100
Anti-foam additives	Prevent formation of foam while filling	2-5
Biocides	Improve forming of micro-organisms to prevent quality degradation	1-10

Diesel contain another set of additives. Some of them are similar to additives, as indicated by functions, used as a part of gasoline, however they may vary in compound synthesis and structure. Different sorts of markers are likewise utilized as a part of diesel fuel, in kerosene, to show their inceptions. Details of diesel fuel additives and their proposed examples are given in Table 1.2. [6]

1.4 CETANE NUMBER IMPROVER:

It is the measure of the preparation of a fuel to self-ignite when infused in the diesel engine. It is due to the time delay in the fuel injection into the chamber and the ignition. Cetane is integrated operational and environmental parameter in diesel. The assurance sets a cetane limit 51 (minimum).

The estimation of the cetane number depends on the determination of ignition delay of engine fuel, which is time delay of the injection and the beginning of the combustion. Thus, the later the combustion start of the compacted engine fuel is, the lesser the cetane number. Along this, there is a reduction in the effectiveness of the ignition and pressure (peak) inside the cylinder. For these reasons, there is a reduction in the effectiveness of engine and its emissions.

1.4.1 CETANE IMPROVING SUBSTANCES:

Many substances have been used to improve the cetane number of diesel. A thermally unstable cetane additive may degrade fuel quality and could cause poor performance. Accordingly, for commercial acknowledgment the cetane improver added substances must be steady, thermally and oxidatively, under genuine conditions. DTBP has been accounted for more thermally steady when contrasted with alkyl nitrates in low sulfur diesel fuels.

Cetane improvers have been accounted for to enhance fuel economy, engine strength, and emissions in substantial diesel engines. It is likewise detailed that higher cetane numbers enhance cold start properties and in ordinary climatic conditions reduce emissions.

1.4.2 NEED FOR CETANE IMPROVERS:

Cetane additive is used in the diesel engine to control NOx emissions. There are many types of cetane additives used widely such as Ethyl-hexyl nitrate, diethyl ether, cyclohexane nitrate etc. [5]

Lower cetane is related to:

- Engine running on the fuel with a lower cetane number will cause cold starting issues.
- Peak cylinder pressure and combustion noise will increase.
- Extra fuel will be injected before the ignition. There will be lesser time for the combustion.

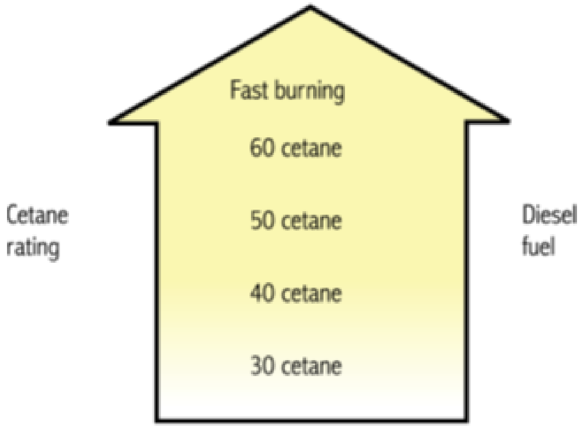

Fig. 1.1: Higher the cetane number, faster will be the burning

Cetane number is in the range of;

- Around 50-60, For HSD Engines,
- 25-45, For LSD engines,
- Mineral diesel fuel cetane number, 40-55.

1.5 DIESEL EMISSIONS:

CI engines convert the chemical energy of the diesel fuel into the mechanical power. Table 1.3 shows typical values of emission from a common diesel engine. The lesser emission values can measured in new and clean engines, and higher values can be obtained in old engines. [7]

Table 1.3: Emissions from Diesel engine

CO	NO_X	HC	SO_2	DPM
Vppm	Vppm	Vpm	Vppm	g/m^3
5-1500	50-2500	20-400	10-150	0.1-0.25

1.6 TYPES OF CETANE ADDITIVES: Cetane number additives are either nitrogen based additives or oxygen based additives. Oxygen based additives are also known as oxygenative additives. Nitrogen based additives are always used in smaller concentration as compared to oxygen class additives as they can wear the engine if used in higher concentration.

1.6.1 NITROGEN BASED ADDITIVES:

Nitrogen based additives are used in blend with diesel fuel in usually smaller amount i.e 0.1-0.3 %. Despite using in smaller concentration, these type of additives give good results and are widely used in the industries because they are more effective than those of oxygen class additives.

A widely used cetane additive 2-EHN, can be used to improve the diesel fuel instability, it is widely used in industries. The chemical formula is $C_8H_{17}NO_3$, ethylhexane molecule and one H-atom replaced by NO_3. EHN decomposes at temperatures in the range of 450-550K.

Generous earlier research presumes that addition of Ethyl hexyl nitrate does not increase Nitrogen oxide emissions, but rather reduce it. Nevertheless, these investigations were completed with regular diesel combustion. In respect to the high amounts of NOx produced by diesel ignition, measure of NOx resulting because of EHN decomposition will not be significant. Increasing the fuel CN, which happens while EHN is added, decreases premixed burn a small amount of ordinary burning, prompting lower pre-ignition temp and reduces NOx emissions. This decrease would dominate any NOx specifically formed due to EHN decomposition. For combustion process, bringing about low engine out NOx levels, the measure of NOx produced directly with EHN decomposition might be higher. [8]

1.6.2 OXYGEN BASED ADDITIVES (OXYGENATES):

Oxygen class additives are generally ethers and esters or glycols/glycol ethers also. They can be used in 10-15% in concentration with diesel fuels. These additives increase the oxygen content of the fuel and make the combustion process better. Oxygen class additives are for the most part polar in nature, that may prompt compatibility issues when mixed with diesel fuel. The most widely recognized diesel oxygenates are fatty acid esters.

Low sub-atomic weight oxygenates are normally not perfect with diesel fuel, while some heavier alcohols and ethers are treated as good diesel-mixing segments. Some engines may be competent to utilize non-compatible oxygenates, in any case, an ideal oxygenate would be perfect with existing engines and foundation. [9]

These requirements ought to be met when oxygenates are mixed in diesel fuel. Fuel properties in these oxygenates rely upon, e.g., length and sort of alkyl chains. Higher sub-atomic weight oxygenates frequently have high density and boiling point. It has high viscocity and low volatility than individual oxygenates with bring less sub-atomic weight. In this manner, oxygenates with higher sub-atomic weight are favored as diesel components.

Distillation range of diesel fuel is about 170--330°C and new segments are expected to fall into this range to guarantee proper ignition in CI engine. Neverthless, conventional refining techniques may not be applied to oxygenates. The storage controls depend on the flash point, which is the cutoff temperature for the development of an ignitable air--fuel vapor blend. Flash point (diesel) in Europe is more than 55°C. [10-13]

If some is good, is more better?

Diesel engines are designed to work optimally with fuel that has a specific cetane rating. If engine runs on cetane 45, and you have cetane 42, adding cetane will definitely help. However, if you have the same engine (that needs 45 cetane), and your diesel fuel is already 45 cetane but you want to make it better? You might think that adding more cetane to fuel will be good. Nevertheless, that is where the misconception comes in. In both gasoline and diesel engines, using fuel in excess of what the engine needs is not really going to do anything substantive. [14]

1.7 ADDITIVES USED IN THIS STUDY:

The additives being used in this study are, Butyl decaneperoxoate ($C_{12}H_{24}O_3$), Di propylene Glycol ($C_6H_{14}O_3$), and 2-Butoxy Ethanol ($C_6H_{14}O_2$).

1.7.1 DPG (DI-PROPYLENE GLYCOL):

DPG is a blend with three isomeric synthetic mixes, 4-oxa -2, 6-heptandiol, 2- (2-hydroxy-propoxy) -propan-1-ol, and 2- (2-hydroxy-1-methyl-ethoxy) -propan-1-ol. This is a drab, almost scentless fluid with high breaking point and less lethality. [15]

Uses:

DPG is a moderate in mechanical synthetic responses, as polymerization, and as dissolvable. It is lesser danger and dissolvable property makes it a perfect added substance for fragrances and skin and hair mind items. It is likewise a typical fixing in business mist liquid, utilized as a part of media outlet machines. [16]

1.7.2 ETHYL DECANEPEROXOATE:

It is a high carbon alcohol, and help in reducing overall emissions when mixed in diesel fuel in CI engines. It is straight-chain, 12-carbon having medium-chain with saturated fatty-acid having strong properties. It is the major fatty acid used in the coconut oil and kernel oil. It is also called texanol and 2,2,4- trimethyl-1, 3-pentanediol monoisobutyrate.

1.7.3 BUTYL CELLOSOLVE (2-BUTOXYETHANOL):

It is a natural compound with having chemical formula $C_6H_{14}O_2$. The vapid fluid has sweet smell like ether, as gets from group of glycolethers. It is butylether from ethylene glycol. It is generally non-volatile, modest dissolvable of less toxicity and is utilized as a part of numerous local and mechanical items.

It is normally acquired with two procedures; ethoxylation response of butanol within sight of the catalyst

$$C_2H_4O + C_4H_9OH \rightarrow C_4H_9OC_2H_4OH$$

Then again the etherification butanol having 2-chloroethanol. It can be acquired in the lab with playing out a ring opening of 2- propyl-1,3- dioxolane having borontrichloride. It is frequently delivered mechanically with consolidating ethyleneglycol and butyl aldehyde with a palladium on carbon.

The European creation of butyl-glycol ethers added 181 kilotons, in which around half was this 2-Butoxy-ethanol. World creation is evaluated to be (200 to 500) kt/a, in which 72% is for the paints and the coatings and 20% for the metal cleaners and family cleaners. This is viewed as a higher produced volume chemical on the grounds that more noteworthy than 120 million pound of it is delivered each and every year. [17]

Uses:

It is a glycolether with humble surfactant property (may be utilized as common dissolvable). Being used from the 1930s, glycolethers are the solvents that break down water-dissolvable and hydro-phobic substances.

Glycolethers comprise of two parts, a liquor and an ether. As indicated by way of liquor, atoms in this class may be separated in two gatherings: E arrangement or P arrangement which compare to the ethylene and the propylene individually. Glycolethers are chosen for particular reasons, for example, dissolvability, inflammability, and unpredictability. [18]

Commercial uses:

It is a dissolvable for the paints and the coatings, and additionally cleaning items and the inks. Items that consist of 2-butoxyethanol incorporate pitch details, black-top discharge specialists, firefighting froth, calfskin defenders, oil slick dispersants, degreaser applications, photographic strip arrangements, whiteboard cleaners, fluid cleansers, makeup, cleaning arrangements, veneers, varnishes, latex paints and lacquers. Items consisting this are usually met at development destinations, car repairing hubs, printing hubs, and offices that create sanitizing items. It is the primary element of many home, business and modern cleaning arrangements.

As the atom has both polar and non-polar closures, butoxy ethanol is valuable in expelling both non-polar and polar closures, similar to oils. This is likewise affirmed to utilize as immediate or circuitous nourishment added substances, which incorporate antimicrobial specialists, stabilizers, and glues. [19]

In the petroleum industry:

It is generally created for oil business in view with surfactant property. In oil business, 2-butoxy ethanol is an essential part of breaking liquids and penetrating stabilizers. When fluid is drawn in the well, then the cracking liquids are pumped into extraordinary weight, so 2-butoxy ethanol is utilized to balance out them with decreasing surface tension. As surfactant, 2-butoxy ethanol adsorbs the oil-water inter-face of the fracture. This compound is additionally utilized to encourage arrival of gas with avoiding congealing.

This is likewise utilized as an unrefined petroleum water coupling dissolvable for a broader oil well work-overs. Due to the surfactant property, this is a noteworthy constituent (30–60 % w/w) in oil slick dispersant, which were generally utilized as a part of the fallout of the 2010 deepwater horizon oil slick. [20]

CHAPTER-2

LITERATURE REVIEW & RESEARCH GAP

2.1 LITERATURE REVIEW:

There are many research papers published on cetane improvement of fuel, effects of cetane improvement on performance of engine and combustion characteristics, and the emissions reduction with the use of cetane improvers.

2.1.1 IMPROVING CETANE FOR DIESEL FUEL:

S.S. Goldsborough et al. [21], This study investigated the auto-ignition behavior of two gasoline surrogates doped with an alkyl nitrate cetane enhancer, 2-ethyl-hexyl nitrate (2-EHN) to better understand dopant interactions with the fuels, including influences of accelerating kinetic pathways and enhanced exothermicity.

At the experimental conditions, it is found that the doping effectiveness of 2-EHN is similar between the two fuels, though 2-EHN is more effective in the aromatic blend at the lowest temperatures, while it is slightly more effective in the non-aromatic blend at intermediate temperatures.

R.C. Santana et al. [22], shows that Improvement of CN of diesel is not a straight forward task. First, severe hydro-treating is needed. Otherwise, the ring opening of the partially hydrogenated products would lead to a dismal loss of CN compared to the CN of the fully hydrogenated molecules.

In general, ring opening of only one ring of the fully hydrogenated products would not result in a substantial gain of CN compared to the initial CN of the fully hydrogenated molecule. Therefore, the opening of the second ring is crucial, but the catalyst employed to open the second ring must be extremely selective towards the rupture of substituted C–C bonds so branching is minimized and linear alkanes can be obtained.

Ambadas B. Rode et al. [23], found that Symmetrically cyclic or acyclic substituted 1,2,4,5 tetraoxane (peroxide dimer) and 1,2,4,5,7,8-hexaoxonane (peroxide trimer) derivatives were synthesized, and their cetane numbers (CNs) were investigated to evaluate their viability for use as CN improvers.

Ambadas concluded that Tetraoxane and hexaoxonane derivatives were synthesized by the two step process of gem-dihydroperoxide synthesis followed by acid-catalyzed cyclocondensation with ketones, and their CNs were compared. All tetraoxane and hexaoxonane derivatives evaluated in this study provided good CN improvement. Some tetraoxane and hexaoxonane derivatives show more efficacy than traditional nitrate additive 2-EHN.

Hui Liu et al. [24], shows that Diesel from direct coal liquefaction (DDCL) is a product obtained from direct coal liquefaction (DCL). Compared with petrodiesel, DDCL contains almost no sulfur element. Other than this feature, several other properties of DDCL are similar to those of petrodiesel. Therefore, DDCL is applicable to automobile diesel fuel.

Hiu Liu concluded that First, fatty acid esters can improve the CN of DDCL effectively when 1 vol% is added. Several esters can increase the CN of DDCL from 44 to 45. These esters include methyl myristate (C14:0M), methyl palmitate (C16:0M), methyl stearate (C18:0M), ethyl stearate (C18:0E), and methyl oleate (C18:1M). Second, several factors affect the performance of the CN improver. These factors include chain length, unsaturation, and esters generated by different alcohols.

H. An et al. [25], aimed to gain better insights on the effects of oxygenated fuels on the diesel oxidation and emission formation processes under realistic engine operating conditions. To do that, various blend fuels formulated from diesel, biodiesel, ethanol and DMC fuels were obtained with different oxygen concentrations, cetane numbers and C/H ratios. Simulations were conducted using the coupled kiva-chemkin code on a light duty diesel engine at a fixed engine speed of 2400 rpm under full load conditions. Constructed numerical simulation models integrated with detailed chemical kinetics were validated against the experimental results with reliable accuracies.

H. An concluded in his modeling study on the effects of diesel combustion blended with oxygenated fuels using the coupled kiva-chemkin code to investigate the impacts of oxygen concentration, cetane number and C/H ratio of the blend fuel on the engine's performance and emissions characteristics under realistic engine operating conditions.

Prasenjeet Ghosh et al. [26], presented a composition-based model that predicts the effect of cetane improver (specifically 2-ethyl hexyl nitrate) on the cetane number of diesel fuels. A total of 206 different diesel fuels were considered in this work containing varying amounts of improver. The fuels were chosen to span a wide range of compositions, from highly paraffinic to highly naphthenic and, in some cases, highly aromatic fuels.

The model predicts the cetane boost within a standard error of 0.8 numbers for a wide array of improver concentrations from 0 to 3500 ppm (v/v). A square root dependence on the improver concentration and a linear dependence on the CN of the base fuel and the bulk composition is found to best describe the effect of the improver on the cetane boost of the fuel.

2.1.2 EFFECTS OF CETANE IMPROVING SUBSTANCES ON PERFORMANCE AND EMISSIONS OF CI ENGINE:

Jie Liu et al. [27], said that as a kind of alternative energy, ethanol is widely and successfully used in the gasoline engine. However, when it is used in the diesel engine, a cetane number (CN) improver, such as isoamyl nitrite, is generally added in diesel/ethanol blends to compensate for the decrease of CN because of ethanol addition.

Jie Liu concluded that the addition of ethanol has a chemical effect on the ignition delay. The chemical kinetic model indicates that ethanol consumes OH radicals through the hydrogen-atom absorption reactions, leading to a reduction in OH radicals during the low temperature oxidation period. This may delay the low-temperature oxidation and, consequently, delay the high-temperature oxidation.

J. Liu et al. [28], said that polyoxymethylene dimethyl ethers (PODE) is an emerging biofuel with properties of high cetane number (CN), high oxygen content and no C–C bond, which shows a significant potential to achieve high efficient and clean combustion and to be one of the competitive alternative fuels for diesel engine. In the current study, the effects of diesel/PODE blends on the combustion and emission characteristics with the PODE volume blending ratio of 15% and 25% have been experimentally investigated in a heavy duty diesel engine.

The combustion and emission characteristics of diesel, PODE15 and PODE25 are compared at low, medium and high loads. The experimental results show that blending PODE can accelerate the combustion rate in the late combustion phase and it is also beneficial for soot emission reduction, especially at low excess air ratio conditions.

Nihanth chaluvadi et al. [29], said that The performance of cetane improvers can be evaluated by an index called as cetane number. Cetane number is a measurement of combustion quality of diesel fuel during compression ignition. This report also focuses of the manufacturing process of cetane improvers, the different types of cetane improvers available and their effect on the performance of diesel engine.

Nihanth chaluvadi concluded that CETANE IMPROVERS plays a vital role in improving the engine performance parameters like indicated power, basic specific fuel consumption, reducing ignition delay, combustion properties. Thermal efficiency is similar to standard diesel fuel but the mechanical efficiency improves via bsfc.

Po-Ming Yang et al. [30], said that isobutanol is one of the next-generation biofuels that may potentially help to relieve the energy crisis and environmental problems. This study investigates the emissions of carbonyl compounds and regulated pollutants that are produced from diesel engine combustion in idle mode. Varied mixtures of diesel, biodiesel (up to 40 vol.%), and isobutanol (10 vol.%) components are compared with premium diesel fuels in terms of their combustion emissions.

Po-Ming Yang concluded that ternary blends of diesel, isobutanol and waste cooking oil biodiesel are considered as alternatives in terms of the combustion efficiency and emission characteristics in a single cylinder direct-injection engine without any engine parameter adjustment.

T. Shaafi et al. [31], Carried out investigation to study the combustion, engine performance and emission characteristics of a single cylinder, naturally aspirated, air cooled, constant speed compression ignition engine, fuelled with two modified fuel blends, B20 (Dieselesoybean biodiesel) and dieselesoybean biodieseleethanol blends, with alumina as a nanoadditive (D80SBD15E4S1 þ alumina), and the results are compared with those of neat diesel.

T. Shaafi concluded that the cylinder pressure at full load condition is higher for all the crank angles during the combustion process, in the case of D80SBD15E4S1 alumina fuel blend, which is due to the higher surface area exposure of the alumina nanoparticle supported by the inherent oxygen present in the soybean biodiesel, that helps in rapid combustion. Hence, the maximum heat release rate is also higher in the case of the D80SBD15E4S1 alumina fuel blend.

Swamy RL et al. [32]; said that The aim of lowering the pollutants and to enhance the performance of diesel engines has intensifed research in diesel engines. The goal of this study was to assess combustion, performance and emission characteristics of diesel engine using diesel-oxygenate blends. In this direction, experimental investigations were carried out on a single cylinder four stroke direct injection water cooled diesel engine using butanol blended fuels in different volume ratios.

Swamy RL concluded following results;

(1) For diesel and alcohol fuelled blends in diesel engine, the BTE showed increasing trend with increased blend ratio of alcohol in diesel up to 20%.
(2) However blends beyond 20% were not considered due to reduced engine power and increased brake specifc fuel consumption because of lower calorifc value of the butanol.

Shenghua Liu et al. [33], said that Ethanol-diesel blended fuel has the potential to reduce diesel engine exhaust smoke and particulate emission as well as partially solve the energy crisis. However, with the increase of the ethanol fraction of the blends, the engine combustion will be affected significantly because of the change of fuel properties.

Shenghua Liu investigated the effects of EHN on the combustion, fuel economy, and emissions on an E30-fueled engine. The following conclusions were drawn:

- Because of the enhancement of the mixture formation and combustion, the equivalent diesel BSFC decreases when ethanol added in diesel and the BTE improves slightly with the increase of the CN improver fraction in blends.
- Both CO and HC emissions decrease with increase in engine loads and then increase over high-load conditions with the engine fueled with the E30 fuel blends.

Lu Xing et al. [34], investigated the influence of cetane number improver on heat release rate and emissions of a high-speed diesel engine fuelled with ethanol–diesel blend fuel. The results show that: the brake specific fuel consumption (BSFC) increased, the diesel equivalent BSFC decreased.

Lu Xing concluded;

1. The BSFC increased, but the diesel equivalent BSFC decreased, and the thermal efficiency improved remarkably when diesel engine fueled with blends. CN improver has a positive effect on BTE and fuel consumption.
2. NOx and smoke emissions decreased simultaneously when diesel engine fueled with blends; and the NOx and smoke emissions further reduced when CN improver was added to blends.

Li Ruina et al. [35], said that Methanol and biodiesel, which have high oxygen content, are high-quality alternative fuels of diesel engine. If blended, the combustion process of diesel engine would be improved and the particulate matter would be reduced effectively. The cetane number improvers are 2-ethylhexyl nitrate, cyclohexyl nitrate and 2-methoxyethyl ether.

Li Ruina concluded;

1. The cetane number of B90M10 increases from 45.5 to 49.3, 57.5 and 63.5 with the addition of cetane number improvers, while the viscosity and density change little.
2. With the addition of the improvers, the ignition delay period of diesel engine is shortened for 1–3 CA and the combustion duration is retarded for 1–6 CA.

W.M. Yang et al [36], introduced a novel emulsion fuel with 82.4% diesel, 5% water and 12.6% nano-organic additives by volume in his work. Unlike other emulsion fuels (milky in color) developed around the world, it is green in color and very stable. This is due to the micro-explosion phenomenon.

The results indicated that a better brake thermal efficiency can be achieved with the emulsion fuel due to the effect of micro-explosion of water droplets. At the same time, NOx emission is reduced because of the presence of water, which brings down the peak flame temperature.

Alpaslan Atmanli et al. [37], said that Among vegetable oils, hazelnut oil (H), because of its high oleic acid content, is an important biofuel resource for use in diesel engines. Microemulsion, which is a viscosity reduction method, is a more practical and less time consuming method as compared to transesterification.

Alpaslan Atmanli concluded that;

- 500, 1000 and 2000 ppm EHN increased the cetane numbers of DnBH and DPnH microemulsions with an average of 13.12% and 12.26%. While density, kinematic viscosity, cloud point and CFPP values slightly decreased, lower heating value and flash point increased as a result of EHN addition.
- As compared to diesel, DnBH and DPnH microemulsions produced 2.91% and 4.69% less brake power. DnBH500 and DPnH1000 had the best performance in terms of the increase in brake power as compared to the two baseline microemulsions..

F. Gomez-Cuenca et al. [38], studied oxygenated additives propylene glycol methyl ether (PGME), propylene glycol ethyl ether (PGEE), dipropylene glycol methyl ether (DPGME) to determine their influence on both the base diesel fuel properties and the exhaust emissions from a diesel engine (CO, NOx, unburnt hydrocarbons and smoke).

S. Imtenan et al. [39]; said that Jatropha biodiesel is considered as one of the most prospective renewable energy sources of Malaysia in recent years. Hence, an investigation was conducted for the improvement of jatropha biodiesel-diesel blend with the addition of 5–10% n-butanol and diethyl ether by vol. which are commonly known as oxygenated cold starting additive.

S. Imtenan concluded that;

(1) Incremental addition of n-butanol and DEE reduced the density and viscosity of the diesel–biodiesel blend chronologically.
(2) J20 showed 5.4% higher BSFC than diesel because of lower calorific value and inferior atomization quality.
(3) J20 produced about 8.2% higher NO than diesel. 5% n-butanol and DEE blends showed slight higher NO emission than J20 due to higher oxygen content.

Amr Ibrahim et al. [40]; said that diethyl ether (DEE) is a renewable oxygenated fuel, which has favorable characteristics to be used as a fuel additive for the diesel engines. The aim of this study was to experimentally investigate the effect of blending the DEE with the diesel fuel in different proportions up to 15% by volume on diesel engine performance, combustion characteristics, and engine stability.

In this paper, the performance, combustion characteristics, and stability of a diesel engine fuelled by different blends of DEE and diesel fuels, with a maximum DEE proportion of 15% by volume, were experimentally investigated and compared at a constant engine speed of 1500 rpm and different engine load conditions. DEE fuel is recommended to use as oxygenated additive without modifications as it improved the engine performance and resulted in a tolerable change in engine stability and combustion characteristics compared to the diesel fuel for all of engine conditions.

Xing-cai Lu et al [41]; said that According to the fuel design concept, three oxygenated fuels including ethanol, dimethyl carbonate (DMC), and dimethoxy methane (DMM) were selected to mix with diesel fuel. The results show that, with the increase of the oxygen content in blend fuels, the ignition timing delays.

HC emissions increase at overall operating ranges and increase much more with the increase of oxygenated fuel volume and decrease of the engine load. To solve this problem, the cetane number improver was added to the 15% ethanol-diesel blend fuel. As a result, the HC and CO emissions at overall operating ranges reduce substantially, and NOx emissions further reduces.

H.K. Imdadul et al. [42]; said that pentanol is a long chain alcohol produced from renewable sources and considered as a promising biofuel as a blending component with diesel or biodiesel blends. However, the lower cetane number of alcohols is a limitation, and it is important to increase the overall cetane number of biodiesel fuel blends for efficient combustion and lower emission.

The thermal stability of the modified ternary fuel blends was evaluated through thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) analysis, and the physic-chemical properties of the fuel as well as engine characteristics were studied and compared. The addition of EHN to ternary fuel blends enhanced the cetane number significantly without any significant adverse effect on the other properties.

O.C. Chukwuezie et al. [43]; said that Use of biodiesel fuel was considered as a panacea to high exhaust gas emission in compression ignition (CI) engines. The review reported high cetane number (CN) as an ignitionquality of biodiesel responsible for low carbon monoxide (CO), hydrocarbon (HC) and particulate matter (PM) but increase in nitrogen oxide (NOx) emissions compared to conventional diesel.

CN increases with molecular weight of the fatty acid and alcohols moiety, and when the position of carbonyl ‘side-chain’ is closest to the end of the molecular chain was reported. Methods of CN ratinglike use of Ignition Quality Test (IQT) and use of two reference hydrocarbon compounds. The review also discussed the suitable limits or ranges of CNs within which complete combustion and low gas emission are favoured.

Soner Gumus et al. [44]; aimed to examine the effects of nanoparticles added to diesel fuels. Nanodiesel fuels were prepared by adding aluminum oxide and copper oxide nanoparticles. These nanoparticles were blended with diesel fuel in varying mass fractions by the means of a mechanical homogenizer and an ultrasonicator. Physicochemical properties of nanodiesels were measured and compared with neat diesel fuel.

The results showed that the stability of nanodiesel can be increased by regulating pH and using dispersant. The storage and combustion characteristics were also improved by adding nanoparticles.

Punam Mukhopadhyay et al. [45]; said that Diesel engine emission is a major contributor of harmful pollutants viz., nitrogen oxide, hydrocarbon, carbon monoxide, carbon dioxide and smoke emission. To suit stringent emission norms, the polluting components in the fuels need substantial reduction.

Punam Mukhopadhyay concluded that glycerol based additives can effectively improve fuel properties via reduction of harmful exhaust emissions when blended with diesel or biodiesel. Thus, many research efforts are being undertaken to synthesize promising additives; nevertheless, high reaction time and temperature along with other severe operating parameters pose real challenge to the researchers and practicing technologists.

P.R. Ayyappan et al. [46]; Biodiesel developed from non-edible oils promise to be a very important prospective alternative fuel for diesel engines in India. Vegetable oil has slightly lower calorific value than diesel fuel. This can be attributed to presence of oxygen in the molecules of vegetable oils. Vegetable oil has cetane number about 35 to 40 depending upon the composition where as diesel fuel has a cetane number around 45.

Jatropha-curcas as a non-edible methyl ester biodiesel fuel source is used to run single cylinder, four-stroke diesel engine. An attempt has been made in this paper to give an overview by comparing its performance and emission characteristics with diesel – biodiesel blend by adding with cetane improver & diesel – biodiesel blend of B50.

Yunsung LIM et al. [47]; This paper described the effect of the diesel cetane number on exhaust emissions characteristics according to various additives. In addition, the emission characteristics of test fuels blended with three additives (GTL, biodiesel and additive for improving CN) were analysed and the potential for uses of these additives were evaluated in this study. To achieve this purpose, the test diesel vehicle with a two-thousand cubic centimeter displacement was used to analyze the emission characteristics according to the CN.

To analyze the characteristics of HAPs, the VOCs and PAHs were analysed from the BTEX and the particulate matter, respectively. The analysis results revealed that the CO emissions show the largest reduction rate while the NOx+THC emissions are reduced at a low as the CN got higher.

Jianxin Wang et al. [48]; In order to meet Euro IV emission standards, diesel vehicles are compelled to install exhaust aftertreatment devices, which largely increases the overall cost. This paper explores the possibility to significantly reduce the particulate matter (PM) emissions by new fuel design.

The total PM and its dry soot (DS) and soluble organic fraction (SOF) constituents were analysed corresponding to their specific fuel physiochemical properties. A blended fuel that contains biodiesel, DMC, and high cetane number diesel fuels was chosen eventually to enable the diesel engines to meet the Euro IV emission regulation.

Deng Yuanwang et al [49]; said that decoupling cetane number from the other compositions and properties of diesel fuel, the individual effect of cetane number on the exhaust emissions from an engine may be researched. This paper presented a back-propagation neural network model predicting the exhaust emissions from an engine with the inputs of total cetane number, base cetane number and cetane improver, total cetane number and nitrogen content in the diesel fuel.

An optimal design completed for the number of hidden layers, the number of hidden neurons, the activation function, and the goal errors, along with the initial weights and biases in the back-propagation neural network model. HC, CO, PM and NOx have been predicted with the model, the effects of cetane improver and nitrogen content on them have also been analysed, and better results have been achieved.

N. Ladommatos et al. [50]; In this work, existing CN data of fatty esters are complemented by studying C18 esters with differing double bond positions and double bond configurations. For the first time, CNs, determined as derived cetane number (DCNs), of neat trans fatty acid methyl esters, methyl elaidate (methyl 9(E)-octadecenoate) and methyl linolelaidate (methyl 9(E),12(E)-octadecenoate), were determined as were the CNs of the C18:1 positional isomers methyl petroselinate (methyl 6(Z)-octadecenoate) and methyl asclepate (methyl 11(Z)-octadecenoate).

The CNs of the positional and geometric isomers of methyl oleate are close to the CN of methyl oleate. These data are compared to other previously determined CN data. The CNs of compounds with ‘‘indeterminable’’ data were predicted with some saturated long-chain compounds giving CNs above 100.

K. Velmurugan et al. [51]; Exhaust gases of an engine can have upto 2000 ppm of oxides of nitrogen.Most of this will be nitrogen oxide(NO), with a small amount of nitrogen dioxide(NO_2). NOx is very undesirable.Regulations to reduce NOx emissions continue to become more and more stringent year by year.

Released NOx reacts in the atmosphere to form ozone and is one of the major causes of photochemical smog.NOx is created mostly from nitrogen in the air. Nitrogen can also be found in fuel blends. At high temperature and pressure higher levels of NOx is created and at low temperature lower level of NOx is produced.

K.Balasubramaniyan et al [52]; said that The diesel engines are widely used in variety of vehicles due to its fuel efficiency and low cost compared to petrol engines. Even though they produce low carbon monoxide and hydrocarbon emission than gasoline engine, the major problem with the diesel engines is the presence of particulate matter that is present in the exhaust emission. During last five decades, these emissions have been regulated through legislation.

This research aims to reduce the exhaust emission from the diesel engines using fuel additives. The additives used in this work are 1-2 Di methoxy ethane. It was mixed with diesel in the concentration of 1%, 3%, &5% by volume and this was used to conduct experiments in Kirloskar TV-I single cylinder diesel engine.

Sina Khorramshokouh et al. [53]; investigates the fundamental aspects of air pollutants, fuel properties, and engine performance during transient operation of naturally aspirated and turbocharged diesel engines in addition to comparing them to new experimental results using methanol as an oxygenate additive.

Meanwhile, the additives used for increasing the engine performance are nanometallic additives, such as, silica, alumina, cerium, and manganese. This research demonstrates the effect of various additives on the performance of the diesel engine, emission, and diesel fuel properties by different models, to address the optimum and best conditions.

Vadim O. Samoilov et al. [54]; performed a study on The catalytic dehydration of 1-butanol on γ-alumina, zeolites, and Amberlyst ion-exchange resins for the production of di-n-butyl ether (DBE) in a fixed-bed flow reactor at 130–300 °C and 1–70 bar. The activity and selectivity of the catalysts were evaluated, and the effects of operating parameters (T, p, and VHSV) on the kinetics of the test reaction were studied for the most active catalyst samples. Based on mass balance data, a conclusion was made that zeolites and Amberlyst ion exchangers are suitable catalysts for DBE production from 1-butanol; at a feed conversion of about 70%, selectivity for DBE was 90%.

He found that different catalysts were active in different temperature ranges. γ-Alumina is a commercially available and inexpensive catalyst; however, it requires relatively high temperatures for the conversion of butanol to affect the cost efficiency of the process.

2.1.3 PROPERTIES OF DI-PROPYLENE GLYCOL:

Tongfan Sun et al. [55]; In this peper, the density, viscosity, and thermal conductivity of propylene glycol + water, dipropylene glycol + water, and tripropylene glycol + water mixtures were measured at temperatures ranging from 290 K to 460 K and concentrations ranging from 25 mol % glycol to 100 mol % glycol.

The temperature behavior of the excess properties was also examined, and large deviations from ideal behavior were observed. The data were correlated using an empirical relationship, the modified rough-hard-sphere method, and the GCSP method. The GCSP method was able to co-relate each property over the entire range of temperatures studied using two adjustable parameters per property.

Fei Zhang et al. [56]; In this paper, the density (ρ) and viscosity (η) data were measured on the binary system of dipropylene glycol (DPG) + 1,2- ethanediamine (EDA) with the different mole fractions at (293.15, 298.15, 303.15, 308.15, 313.15, and 318.15) K under atmospheric pressure.

On the basis of the experimental ρ and η data, the excess molar volumes (Vm E) and dynamic viscosity deviations (Δν) were calculated. Meanwhile, the Redlich-Kister type function was employed to calculate the coefficients and evaluate the standard deviation between the experimental and calculated data by using Vm E and Δν values.

2.1.4 PROPERTIES OF BUTYL CELLOSOLVE:

Sateesh Yalavarthi et al. [57]; said that the addition of oxygenated compounds to diesel, supply additional oxygen which results in more burning of the fuel and thereby reducing emissions. In the present study, two oxygenated compounds, such as Ethoxy ethanol and Ethylene glycol are considered on a 3.7KW, water cooled, and kirloskar engine. The selected oxygenated compounds are blended with diesel fuel in proportions of 5% and 10% by volume and the experimental study is conducted to evaluate the performance and emissions of the diesel engine. The data obtained is compared with the conventional diesel fuel and the results reveal that Brake Thermal Efficiency (BTE) decreased with increase in the blend percentage. CO_2, HC emissions decreased while NOx emissions increased.

Diesel combustion and emissions with two kinds of oxygenates having suitable ignitability were investigated over a wide range of blend ratios. The results may be summarized as follows:

- By addition of oxygenate to ordinary diesel fuel, significant improvements were simultaneously obtained in emissions, SFC, Brake Thermal Efficiency
- Improvements in Brake Thermal Efficiency depended on the content in the fuel and the blended ratios and type of oxygenate.
- The bsfc of oxygenated blends are higher than diesel fuel due to lower heating value as compare to diesel fuel.

Giorgia F. Cortinovis et al [58]; determined NRTL actity model parameters for the following binary systems: 2-ethoxyethanol + 2-ethoxyethyl acetate, 2-ethoxyethanol + 2-butoxyethanol, 2-ethoxyethanol + 2-butoxyethyl acetate, 2-ethoxyethyl acetate + 2-butoxyethanol, 2-ethoxy ethyl acetate + 2-butoxyethyl acetate, and 2-buthoxyethanol + 2-butoxyethyl acetate. For the estimate of NRTL activity model parameters, measurements of the bubble point of binary mixtures of a known composition were made at atmospheric pressure from (93 to 101.3) kPa. Ideal behavior was considered for the vapor phase. It was assumed that no reaction occurs between the acetates and alcohols of the binary mixtures.

In this work, pTx data for six binary mixtures of system 2-ethoxyethanol + 2-ethoxyethyl acetate + 2-butoxyethanol + 2-butoxyethyl acetate were correlated to the NRTL activity coefficient model. For the six pairs evaluated, small deviations from ideality were found in the liquid phase.

Taihe Deng et al. [59]; In this paper, experimental solubilities were reported for anthracene dissolved in ternary 2-butoxyethanol + 1-propanol + 1-butanol, 2-butoxyethanol + 1-propanol + 2-butanol, 2-butoxyethanol + 2-propanol + 1-butanol, and 2-butoxyethanol + 2-propanol + 2-butanol solvent mixtures at 25 °C and atmospheric pressure. For each of the four solvent systems, 19 compositions were studied. Results of these measurements are used to test the predictive ability of the ternary solvent form of the Combined NIMS/Redlich-Kister equation. Computations showed that the model predicted the observed solubility behavior to within an overall average absolute deviation of about 1.5%, which is comparable to the experimental uncertainty of 1.5%.

Conceptually, these ideas can be extended to solute solubilities in binary solvent mixtures. However, there has never been up until recently a sufficiently large solid solute solubility database to warrant computerized storage in equational form. With computerized data storage and retrieval becoming increasingly popular, it seems appropriate to discuss the various mathematical expressions that have been proposed in the chemical literature for describing the variation of solute solubility with binary solvent composition.

Henry Mensah-Brown et al. [60]; This paper contains the results of new measurements of the thermal conductivity of mixtures of water and 2-n-butoxyethanol in the liquid phase within the temperature range of (304 to 346) K at pressures up to 150 MPa. The measurements were carried out with a transient hot-wire instrument and have an accuracy of 0.3%. The investigation is the first conducted at high pressures on partially miscible mixtures whose components are of greatly differing thermal conductivity.

However, a more detailed analysis of the results reveals small but systematic deviations from the universal behavior of the thermal conductivity as a function of molar volume that the predictive procedure and the hard-sphere theory have as their basis. New experimental data for the thermal conductivity of aqueous mixtures of 2-n-butoxyethanol have been obtained over a wide range of temperatures.

Ray L. Brinkley et al. [61]; said that he measured extent of intra- and intermolecular hydrogen bonding in these compounds dissolved in n-hexane at varying concentrations and temperatures. Intramolecular hydrogen bonds are present at all conditions, whereas intermolecular bonds appear at higher concentrations. Using lattice-fluid-hydrogen-bonding theory, equilibrium constants for the formation of intra- and intermolecular hydrogen bonds are determined.

The results show that the equilibrium constant for intermolecular bond formation is approximately 6 times the intramolecular equilibrium constant for 2-methoxyethanol systems at 35 °C. Experiments at higher temperature, 45 °C, with 2-methoxyethanol show less hydrogen bonding as expected due to higher thermal energy. Due to steric hindrance, 2-butoxyethanol has a lower degree of hydrogen bonding than 2-methoxyethanol at the same temperature and concentration.

2.1.5 CONCLUSION AND RESEARCH GAP:

In 2002, Deng Yuanwang analysed the effect of cetane improvers on emissions of ic engine. He used different additives and found that nitrogen content in the fuel may also have an effect on NO_x emissions. In 2004, Tongfan Sun tested DPG for viscosity and thermal conductivity and in the same year Lu Xing Cai analysed HRR and emissions of HSD engines. He used AVL Di Gas4000 for emissions calculations.

In 2005, Roberto C. Santana suggested different strategies to improve the cetane number of the fuel. And predicted the cetane number of 2-Methyl-heptane 47, 3-Methyl-heptane 45, n-Butyl-cyclohexane 47, 1,3,5-Trimethyl-cyclohexane 31, and Decalin 33. In the same year Xing Cai Lu used oxygenated fuel additives combined with cetane improvers to improve the combustion and emission characteristics of ic engine.

In 2008, Prasenjeet Ghosh predicting the Effect of Cetane Improvers on Diesel Fuels. He chosen the fuels to span a wide range of compositions, from highly paraffinic to highly naphthenic and, in some cases, highly aromatic fuels. Improver concentrations were varied between 0 to 3500 ppm (v/v), which exceeds the usual commercial application range of 500–1000 ppm.

In 2009, Jianxin Wang used oxygenated blends in order to reduce PM emissions from the exhaust of ic emgine. Several oxygenated blends were obtained by mixing the biodiesel, ethanol, dimethyl carbonate (DMC), and diesel fuels. The tests were conducted on two heavy-duty diesel engines, both with a high-pressure injection system and a turbocharger. The total PM and its dry soot (DS) and soluble organic fraction (SOF) constituents were analysed corresponding to their specific fuel physiochemical properties. In the same year, Andrew Ickes analysed the effect of 2-Ethylhexyl Nitrate Cetane Improver on NOx Emissions from premixed low temperature diesel combustion and the use of 2-ethylhexyl nitrate cetane improver increases the engine-out NOx for premixed low-temperature diesel combustion.

In 2010, Henry Mensah-Brown analysed the thermal conductivity of butyl cellosolve. He studied the thermal conductivity of aqueous mixtures of 2-n-butoxyethanol at pressures up to 150 Mpa.

And in the same year Shenghua Liu anlyzed the effect of a cetane number (CN) improver on combustion and emission characteristics of a compression-ignition (CI) engine fueled with an ethanol-diesel blend and he found that increasing the cetane number reduces the overall emissions from the ic engine. Again in 2010, Ambadas B. Rode worked on the synthesis and cetane-improving performance of 1,2,4,5-tetraoxane and 1,2,4,5,7,8-hexaoxonane derivatives and he used EHN in concentration of 500 1nd 1000 ppm and the effect of ehn on the performance of the engine was positive.

In 2011, Jie Liu analysed the effect Ethanol and Cetane Number (CN) Improver on the Ignition Delay of a Direct-Injection Diesel Engine, A combined complicated mechanism for the autoignition of n-heptane/ethanol/isoamyl nitrite mixtures was validated against the shock-tube data and homogeneous charge compression ignition (HCCI) engine combustion experiment. The effects of ethanol and isoamyl nitrite addition on the ignition delay of diesel were studied, where n-heptane was used to simulate diesel. Numerical analyses showed that the addition of ethanol decreased the amount of OH radicals and, consequently, retarded the ignition.

In 2012, K. Velmurugan analysed the effect of cetane Improver Additives on Emissions, and he found that Addition of cetane improver additive to the diesel fuel is cost effective way to control NOx emission. Diesel fuel with the 3ml additive of neopentane shows the significant reduction in NOx and smoke .The sensitivity of NOx to change in cetane number is higher at low load than at high load.It is found that NOx emissions were reduced at low load than at high load.

In 2013, F. Gomez-Cuenca analysed the influence of propylene glycol ethers on base diesel properties and emissions from a diesel engine. He used Base diesel fuel-propylene glycol ether blends with 1.0 and 2.5 wt.% oxygen contents in order to determine the performance of the diesel engine and its emissions at both full and medium loads and different engine speeds (1000, 2500 and 4000 rpm). In the same year, Sateesh Yalavarthi used selected oxygenated compounds blended with diesel fuel in proportions of 5% and 10% by volume. The data obtained compared with the conventional diesel fuel and the results reveal that Brake Thermal Efficiency (BTE) decreased with increase in the blend percentage. CO_2, HC emissions decreased while NO_x emissions increased.

Again in 2013, Nihanth chaluvadi used isobutanol as cetane improver and concluded that cetane improvers plays a vital role in improving the engine performance parameters like IP, BSFC, reducing ignition delay, combustion properties, thermal efficiency is similar to standard diesel fuel but the mechanical efficiency improves via bsfc. In the same year, W.M. Yang analysed the impact of emulsion fuel with nano-organic additives on the performance of diesel engine. He used a novel emulsion fuel with 82.4% diesel, 5% water and 12.6% nano-organic additives by volume and found that the ignition delay of emulsion fuel is slightly longer than that of pure diesel.

In 2014, Li Ruina added methanol/biodiesel blend with the ratio of 0.3%, 0.3% and 3% respectively. The cetane number of the blend increased from 45.5 to 63.5 and reduced NOx concentration from 3.87% to 12.90% and smoke from 11.76% to 38.24%, but at the same time, they cause another problem–the increasing of HC and CO concentration. In the same year, P.R. Ayyappan investigated on the Effect of Cetane Improver with Biodiesel in CI Engine. Again in 2014, S.S. Goldsborough analysed the fuel interactions with an alkyl nitrate cetane enhancer, 2-ethyl-hexyl nitrate.

In 2015, H. An found that compared to the effects of physical properties such as cetane number and C/H ratio of the blend fuel, the overall oxygen concentration seemed to be the major factor dominating the emissions and major intermediate species formation processes. In the same year, Vadim O. Samoilov studied and analysed the flow reactor synthesis of cetane-enhancing fuel additive from 1-butanol.

Again in 2015, Swamy RL investigated four different blends of butanol on volume basis [B0 (0% Butanol and 100% Diesel), B5 (5% Butanol and 95% Diesel), B10 (10% Butanol and 90% Diesel), B15 (15% Butanol and 85% Diesel) and B20 (20% Butanol and 80% Diesel)] to study the impact of using butanol-diesel blends on diesel engine performance, combustion and emissions. In the same year, S. Imtenan performed a study to evaluate and compare the combustion, performance and exhaust emissions characteristics of jatropha biodiesel blend (J20) and its modified blends with different percentages of n-butanol and DEE which were used to fuel an IDI, high-speed, turbocharged diesel engine.

In 2016, Amr Ibrahim experimentally investigated the effect of blending the DEE with the diesel fuel in different proportions up to 15% by volume on diesel engine performance, combustion characteristics, and engine stability. The engine maximum brake thermal efficiency increased by 7.2% and the lowest brake specific fuel consumption decreased by 6.7%. In the same year, Alpaslan Atmanli added 2-ethylhexyl nitrate (EHN) cetane improver at 500, 1000 and 2000 ppm concentration to the microemulsions of D (70 vol.%)–H (20 vol.%)–nB (10 vol.%) (DnBH) or Pn (10 vol.%) (DPnH) and the effects of the cetane improver on fuel properties and engine characteristics were investigated in detail. Addition of EHN to DnBH and DPnH microemulsions increased the cetane number by about 13.12% and 12.26%, respectively.

Again, in 2016, Jialin Liu investigated the effects of diesel/PODE blends on the combustion and emission characteristics with the PODE volume blending ratio of 15% and 25%. In the same year, Po-Ming Yang varied mixtures of diesel, biodiesel (up to 40 vol.%), and isobutanol (10 vol.%) components. And he found that carbon monoxide (CO), nitrogen oxide (NO_x), and particulate matters (PMs) are decreased by an average of 3.45, 32.5, and 38.5 vol.%, respectively.

In 2017, O.C. Chukwuezie found that an increase in the length of the fatty acid moiety, an increase in the saturation of the fatty acid moiety and an increase in the length of the alcohol moiety, all resulted in a decrease of the ignition delay (Alessandro 2009). Higher cetane number indicates shorter ignition delay time, meaning more combustion products, have a longer residence time at high temperatures for complete combustion. Also, the emission of accumulation mode soot particles was positively correlated with the number of double bonds present in the fatty acid moiety of the molecules.Where there are reversed trend, it was explained that higher CNresulted in a shortened ignition delay period thereby allowing less time for the air/fuel mixing before the premixed burning phase. Consequently, a weaker mixture would be generated and burnt during the premixed burning phase resulting in relatively high CO, HC and PM emission and reduced NOx formation.

CHAPTER-3

SYSTEM DEVELOPMENT & METHODOLOGY

3.1 INTRODUCTION:

CI engines are very demanding among power delivering machines because of its high efficiency but harmful emissions have challenged the researchers to test and produce neat and clean diesel combustion, which reduce these harmful emissions. In addition, government has revised the norms for using the fuels to reduce PM emissions.

To reduce these emissions and to make the combustion process better, cetane number of the fuel should be increased. Higher cetane number will definitely improve the burning quality of fuel and produces lesser emissions. Oxygenative cetane improvers generally increases the oxygen content of the fuel for proper burning. In addition, oxygenative additives do not wear the engine like nitrogen class additives do.

Higher CN demonstrate smaller delay period between the injection of fuel to first noticeable ignition start. Better ignition with a higher CN aids smooth start, start at comparatively lesser temp, less ignition pressure, and very smooth operation with bringing knock intensity down. Fuel having lower cetane have poor start qualities and result in misfiring, higher noise level and rough operation.

Fuel properties enhancers are being used as a part of oil industry since 1920s. At first, cetane improving substances, octane improving substances (tetratethyl lead), and dies were utilized to improve fuel quality. After these substances, metal deactivators and consumption inhibitors came in use in the 1930s. Diesel stabilizing agents and lubricity improver additives were represented in the 1940s.

The ignition is smooth, the effectiveness of combustion is better, and also the engine operation. The impacts of CN improving substances, in the essential amounts and CN boosting impacts, depends on the proportions of higher/lower cetane components in the diesel fuel.

3.2 PROPERTIES OF ADDITIVES USED:

All the additives were made available from Pure Chem's Limited, Chennai ordered via ibuychemicals.com. The company provided some basic data for all the additives after testing of that particular lot.

3.2.1 ETHYL DECANEPEROXOATE C-12:

It is a high carbon alcohol, and help in reducing overall emissions when mixed in diesel fuel in CI engines. It is straight-chain, 12-carbon having medium-chain with saturated fatty-acid having strong properties. It is the major fatty acid used in the coconut oil and kernel oil. [62]

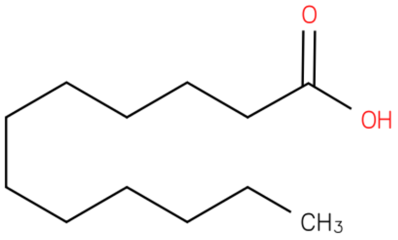

Fig. 3.1: Chemical formula for ethyl decaneperoxoate [63]

Table 3.1 Physical and chemical properties of ethyl decaneperoxoate C-12 [63]

PROPERTY	VALUE
Chemical Formula	$C_{12}H_{24}O_3$
Average mass	216.317 Da
Monoisotopic mass	216.172546 Da
Density	0.95 g/cm^3
Vapour Pressure	0.0 ± 0.5 mmHg @ 25°C
Boiling point	263°C @ 760 mmHg
Flash Point	80.1 °C
Enthalpy of Vaporization	50.1 KJ/mol
Acid Value	0.028
Purity	99.47 %
Water content	0.95 %

3.2.2 DIPROPYLENE GLYCOL:

Dipropylene glycol ($C_6H_{14}O_3$) is utilized as a receptive intermediate in the mfg. of polyester plasticizers. DPG has lower evaporation rate, less odor and higher viscosity, which makes it a chemical inter-mediate of choice in various areas.

Table 3.2 Physical and chemical properties of Dipropylene Glycol [64]

PROPERTY	VALUE
Formula	$C_6H_{14}O_3$
Molecular Weight	134.2 (g/mol)
Vapor Pressure	0.0021 kPa @25°C
Pour Point	-39°C
Viscosity	75.0 centipoise (mPa.s) @ 25°C (77°F) 10.9 centipoise (mPa.s) @ 60°C (140°F)
Density	1.022 g/cm³ @ 25°C (77°F) 0.998 g/cm³ @ 60°C (140°F)
Purity	99.99 %
Water	110 ppm
Acidity	8.9 ppm
Sp. Gravity 20°C	1.0238
Residue on ignition	5 ppm

3.2.3 BUTYL CELLOSOLVE (2-BUTOXYETHANOL):

2-Butoxyethanol is fluid that smells exactly like ether. It is known by many names such as ethylene glycol monobutyl ether, Butyl Cellusolve, and butyl Oxitol. It is utilized in spray lacquers, enamels and varnishes. It is used in soaps, cosmetics, and dry-cleaning compounds also. 2-Butoxyethanol acetate is a colour-less fluid with a fruit like odor. And it is also called as butoxyethyl acetate. It is utilized as solvent for enamels, lacquers, and resins. It is used in ink and spot removing compounds also.

Table 3.3 Physical and chemical properties of Butyl Cellosolve [65]

PROPERTY	VALUE
Formula	$C_6H_{14}O_3$
Molecular Weight (g/mol)	134.2
Vapor Pressure, 25°C (77°F)	0.88 mm Hg
Pour Point	-39°C (-38.2°F)
Density, 20°C	0.9015 g/cm³
Viscosity, 25°C (77°F)	3.15 centistokes (mPa.s)
Boiling Point	340° F at 743 mm Hg
Water	0.1 %
Flash Point	143°F (60°C)
Sp. Gravity 15°C	0.902
Residue on evaporation	0.004 g/ml

3.3 FUEL BLEND PREPARATION:

Fuel blend preparation is not a complex process. This is simply done by mixing the corresponding fuels. In this case, mixing of diesel, biodiesel and decanol is performed by magnetic stirrer around 8-10 minutes to ensure homogenous solution.

TABLE: 3.4 Nomenclature of various test fuel

S.No.	Name	Composition
1.	A	Dipropylene Glycol (DPG)
2.	B	Ethyl decaneperoxoate (ED)
3.	C	Butyl Cellosolve (BC)
4.	80D10A10B	80% Diesel +10% ED + 10% DPG
5.	80D10B10C	80% Diesel + 10% DPG + 10% BC
6.	80D10C10A	80% Diesel + 10% BC +10% ED

A, B and C signifies Dipropylene glycol, ethyl decaneperoxoate and Butyl cellosolve respectively. All blends are formed by fixing the amount of diesel at 80% and varying the amount of ethyl decaneperoxoate, Dipropylene glycol and Butyl cellosolve with the range of 10% each. All the nomenclature is represented in table 3.4. 80D10A10B represents the blend of 10% DPG and 10% ethyl decaneperoxoate and by mixing 80% volume of diesel. 80D10B10C refers to the blend formed by mixing 10% volume of ethyl decaneperoxoate, 10% volume of butyl cellosolve and 80% volume of diesel fuel. Similarly for 80D10C10A blends are formed by mixing 80% by volume of diesel, 10% by volume of butyl cellosolve and 10% by volume of DPG respectively. The different blend formed are shown in fig. 3.2

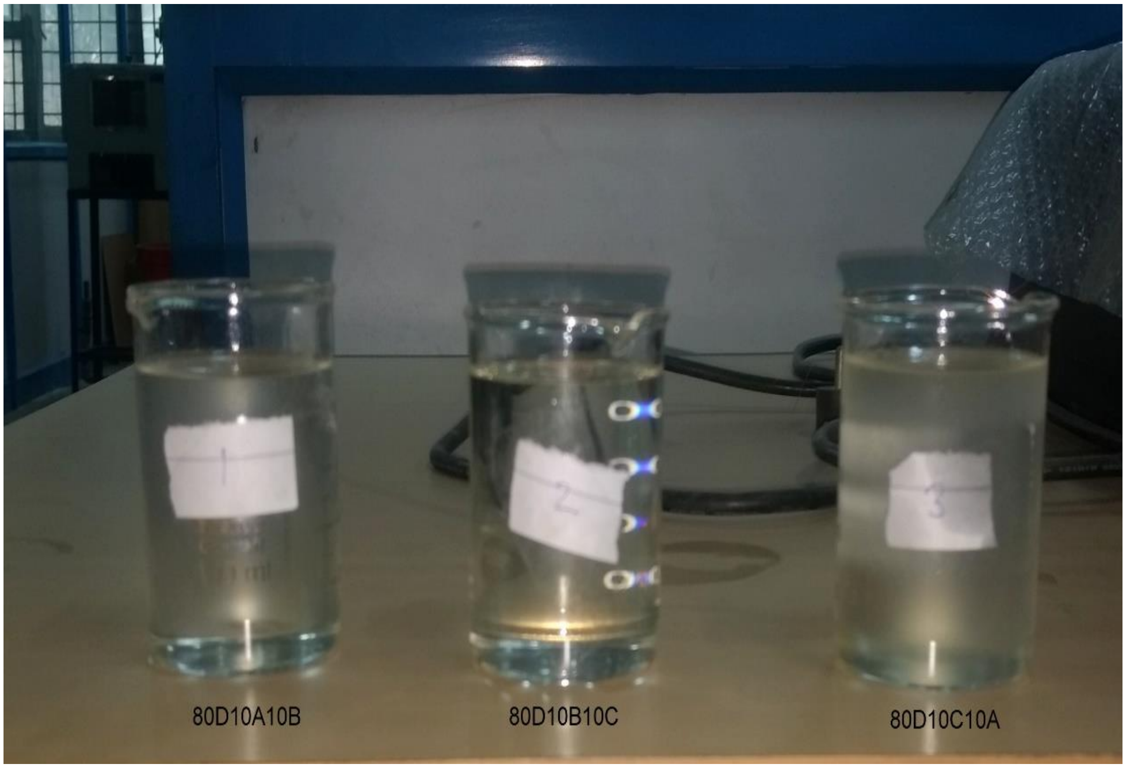

Fig. 3.2: TEST FUEL SAMPLES FORMED DURING EXPERIMENT

3.4 PHYSIO-CHEMICAL PROPERTIES:

Properties evaluated in this experimental study and procedure are mentioned below:

3.4.1 DENSITY

It is defined as mass/unit volume. This parameter got measured at the room temp with the help of U-Tube Oscillating True Density meter of make “Anton Paar”, model number “DMA 4500”. The density of diesel along with all blends were analyzed and compared with density of the diesel. The instrument used for density measurement is shown in Fig 3.3.

Fig 3.3: U-Tube Oscillating True Density meter

3.4.2 VISCOSITY

Viscosity is the resistance of flow due to internal friction between fluid layers, which is subjected to external forces. During injection of fuel, atomization of fuel happens which is influenced by viscosity. If the variation in the viscosity value is very low or very high then the mixing of air-fuel, and atomization of the fuel in the combustion chamber may get affected severely.

For different test fuels, viscosity was measured in terms of kinematic viscosity. Kinematic viscosity was measured by Kinematics Viscometer of make "Petrostat" as shown in the figure 3.3 at 40^{o}C for liquid fuels. A standard capillary-tube selected in which fuel is taken in a particular amount that was allowed to flow through the capillary. The schematic figure of the kinematic viscometer is shown in fig 3.4.

To calculate the kinematic viscosity efflux time was measured using stopwatch. The mathematical formula is mentioned below to calculate the viscosity:

$$V = c*t$$

Where,

V = Kinematic Viscosity; cs

t = time, sec

c = constant; mm^2/sec^2

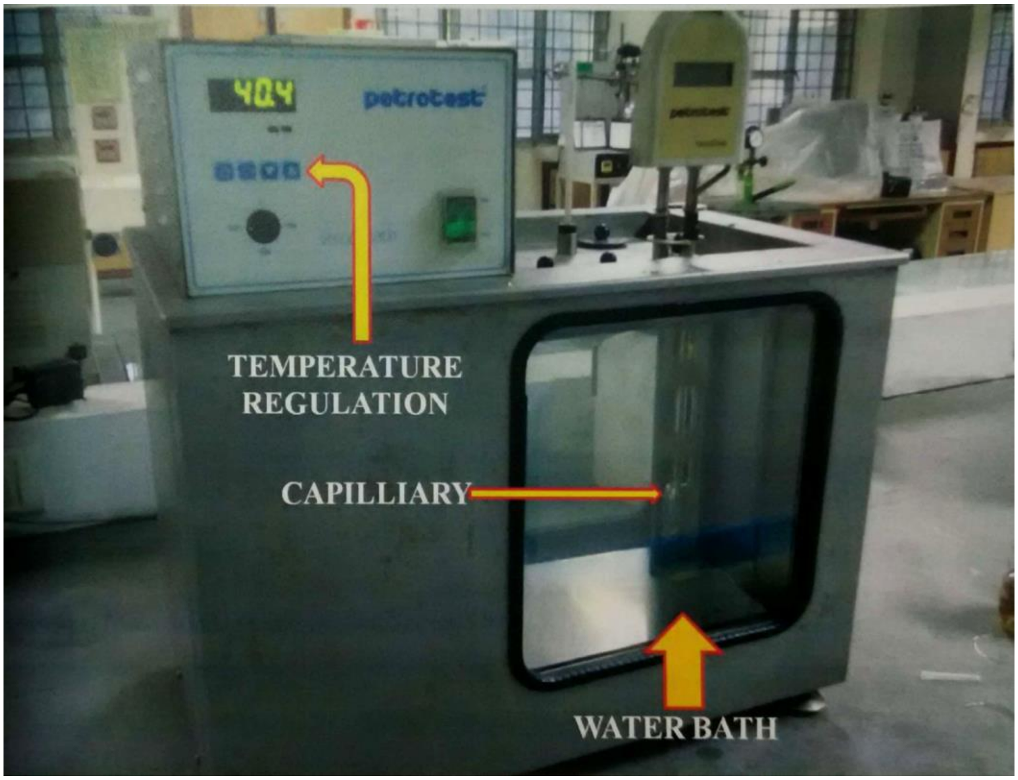

Fig. 3.4: Kinematic Viscometer

3.4.3 CALORIFIC VALUE

The energy which is stored in fuel/ food, and determined by calculating the heat developed by combustion of a particular given quantity is termed as the calorific value of the fuel. This is expressed in joules per kilogram. This parameter was analyzed by the Bomb Calorimeter. The calorimeter model was "Parr 6100 Calorimeter". At constant volume, the burning of fuel occurs in the presence of oxygen. The ignition of fuel was done by electrical method. Oxygen was supplied by cylinder which had compressed oxygen. After few minutes, the fuel had burnt completely and the results were displayed in the instrument. [66]

The schematic diagram of corresponding bomb calorimeter is represented in fig 3.5.

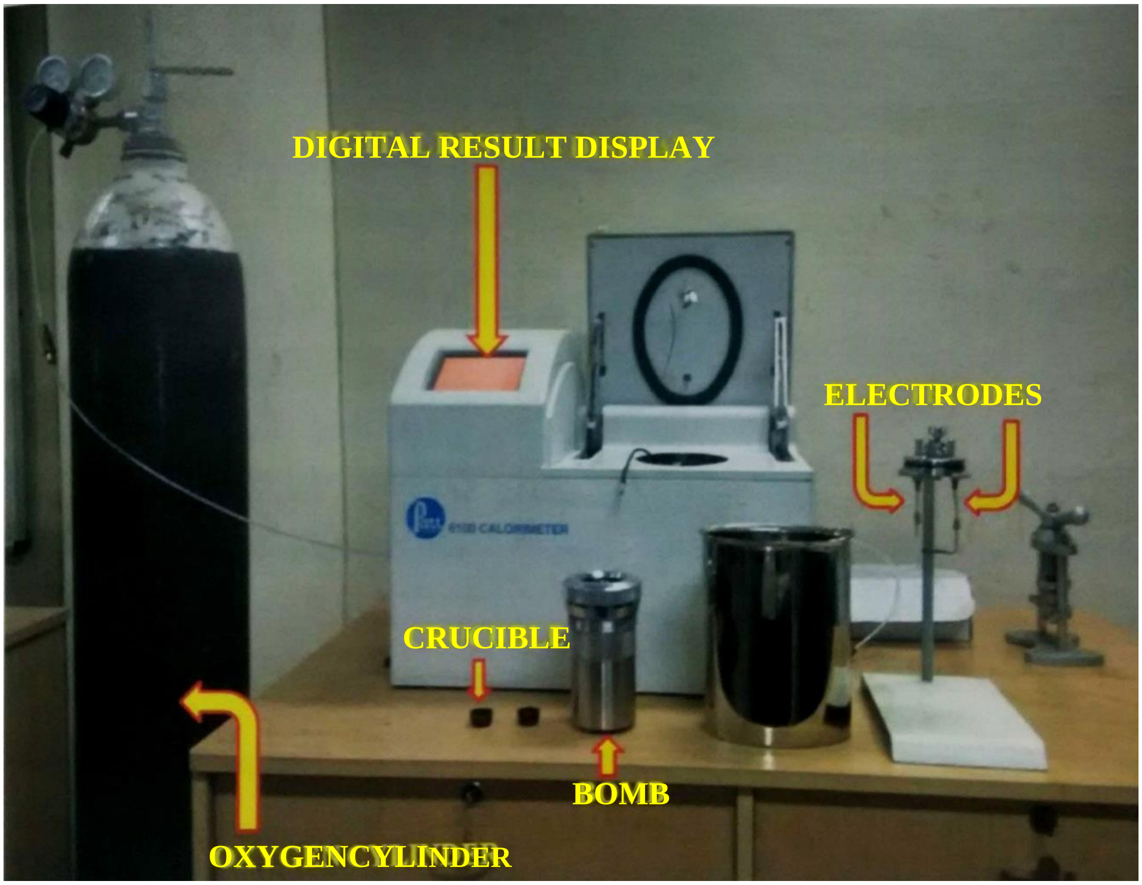

Fig. 3.5: Parr 6100 Bomb Calorimeter

3.4.4 COLD FILTER PLUGGING POINT (CFPP)

The lowest temperature of the fuel filter that does not allow the fuel to pass through it is known as CFPP. Sometimes the temp of fuel becomes low and leads to low performance of fuel pumps and injectors as well as fuel lines due to thickening of fuel. CFPP of standard vegetable oil reflects its performance in cold weather. In other words, it simply defines its limit of filterability. The apparatus of CFPP measurement is shown in fig. 3.6;

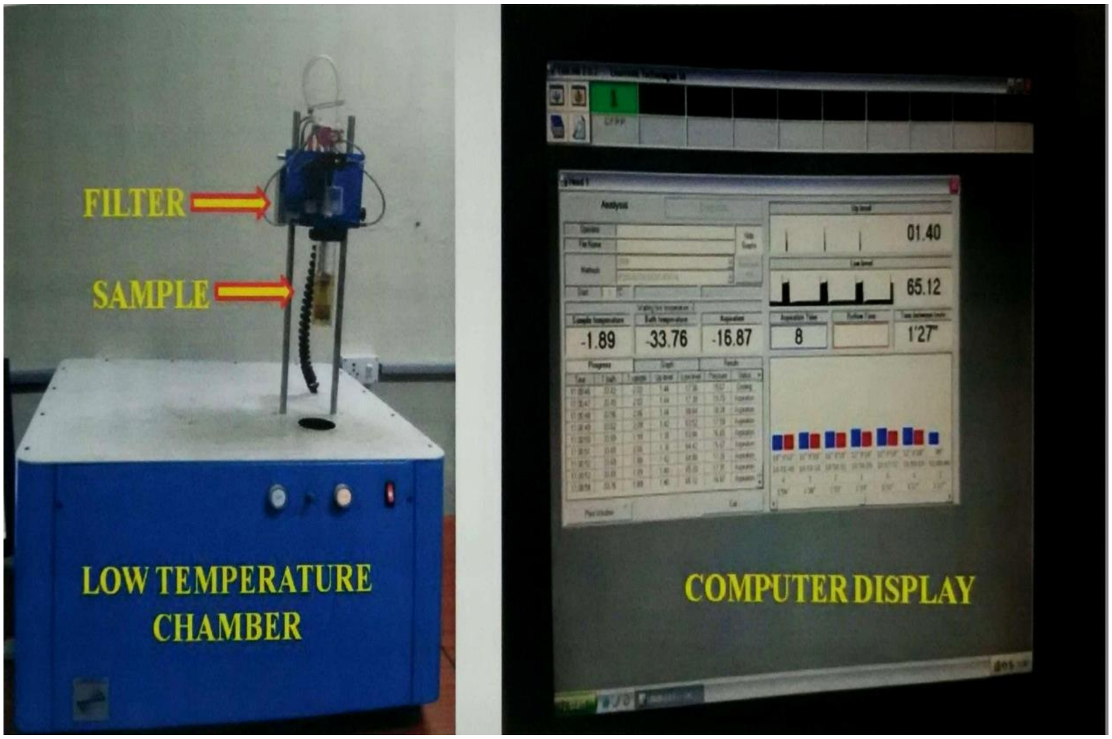

Fig 3.6: CFPP apparatus

3.5 SELECTION OF DIESEL ENGINE

Indian economy is the one of the mainstays of advancement of India. Because of the high effectiveness and rough use of diesel engine. They can be effortlessly utilized as a part of transportation, horticulture and mechanical areas, which eventually prompt solid Indian economy.

On the other hand they also radiate undesirable and unsafe emissions prompting to polluted environment. Consequently, it is essential to manage the trend of increasing emissions by altering the fuel in CI engine, which is the major parameter to have a impressive change in the atmosphere. Concerning about handy viewpoints, a commercial diesel engine, which is for the most part worked in the previously mentioned areas, has been chosen for the current experimental procedure.

3.6 EXPERIMENTAL TEST RIG

The technical specification of the corresponding engine are listed below in table 3.5

Table 3.5: Technical specification of the diesel engine

Make	Kirloskar
No of cylinder	1
Cubic capacity	0.78 Lit.
Bore and stroke	95 and 110mm respectively
Rated Power output	3.5 KW @ 1500 rpm
Compression ratio	17.5 : 1
Fuel tank capacity	11.5 lit.
Starting	Hand start with cranking handle
Cooling system	Air cooled
SFC at rated hp/1500 rpm	251 g/KWh
Weight of flywheel	64 kg
Engine weight w/o flywheel	118 kg
Dynamometer	Eddy current
Rotation while looking at flywheel	Clockwise

For measurement of voltage and current, voltmeter and ammeter were connected between alternator and load bank. A nut was welded on the flywheel with the installation of photo reflective sensor that is mounted on the bracket which is linked to the engine. For measurement of the exhaust temperature, thermocouples wer installed in the exhaust manifold.

Thus a system is designed to study the theoretical as well as practical performance of Decanol, biodiesel and diesel fuel blends. Additionally it was easy to maintain and handle the engine because of presence of single cylinder. The experiment on the engine could be done on hot climate too because of air cooling system.

Fig. 3.7 Test engine

3.7 PARAMETER SELECTION

Engine calculations were done on the basis of specific parameters which were selected sensibly. The test performed on the engine is on the basis of IS:10000. The fundamental parameters needed from the engine are enlisted below:

1. Engine RPM
2. Fuel consumed
3. Temperature analysis
4. Power output from the engine

The parameters mentioned above were calculated by following signals from the test bench.

1. alternator voltage
2. alternator current
3. RPM sensor
4. Exhaust gas temp
5. Fuel consumption rate
6. AVL 437 smoke meter

Based on the selection of parameters, essential instrument were installed for sensing theses parameters in the set-up.

3.8 EXHAUST EMISSION ANALYSIS

There are lot of emissions produced form diesel engine which is analyzed by AVL Di-Gas analyzer (AVL 4000 Light Model). It was done mainly for analysis of unburned hydrocarbon, CO, CO_2, and NO_X. To measure the smoke capacity, AVL 437 smoke analyzer was used. The fundamental measurement of these instruments was recorded in terms of opacity. A beam of light was projected on a flowing stream of the exhaust gases, suspended soot particles absorbed the definite portion of light. The remaining part of light strikes on photocell, generating photoelectric current which defines smoke density.

These instruments are calibrated regularly using standard gas mixture. Insertion of sampling probe for smooth flow of exhaust gas was done on the exhaust pipe. Additionally mounting of a surge tank at the engine exhaust to have consistent exhaust emissions.

The instruments used for the analysis of exhaust emissions are shown in fig 3.8;

Fig. 3.8: smoke meter and exhaust gas analyzer

Technical specifications of AVL Di-gas 4000 light and smoke meter are outlined in following table 3.6

Table 3.6: Specifications of AVL Di-Gas 4000 light and AVL smoke meter

Emissions sensor	Resolution	Measurement range
CO	0.01% vol.	0-10 % vol
CO_2	.1 % vol	0-10 % vol
NO_X	1 ppm	0-5000 ppm % vol
HC	1 ppm	0-20000 ppm % vol
AVL smoke meter	1%	0-100 % vol

3.9 METHODOLOGY:

The parameters for engine performance like total brake power, BSFC, BSEC, BMEP and BSEC are calculated by theoretical approach. The methodology to find out these parameters are described below:

3.9.1 BRAKE POWER

Power is the product of the voltage and current induced. The brake power is calculated by following formula:

$$BP(W) = \; V x\, I$$

Measuring Unit: Watt / Kilowatt (KW)

Where,

V = voltage recorded by voltmeter

I = Current recorded by ammeter

3.9.2 BRAKE MEAN EFFECTIVE PRESSURE

The BMEP is also calculated by following formula:

$$BMEP(bar) = \frac{120\, X\; brake\; power}{L\; x\; A\; x\; N\; x\; 101.325}$$

Measuring Unit: Bar

Where,

L = stroke length(m)

A= piston area (m^2)

N= Engine rpm (rps)

3.9.3 BRAKE THERMAL EFFCIENCY

This is one of the most important parameter in context to performance of the engine. It is calculated by:

$$BTE(\%) = \frac{brake\ power}{\dot{m}x\ CV}$$

Measured in percentage.

Where,

M = fuel mass flow rate (kg/s)

CV = fuel calorific value (KJ/kg)

3.9.4 BRAKE SPECIFIC ENERGY CONSUMPTION

The energy consumed to generate one unit of power is known as brake specific energy consumption

$$BSEC\left(\frac{MJ}{kWh}\right) = \frac{m\ x\ CV^{\cdot}\ x\ 3600}{brake\ power}$$

Where,

M = fuel mass flow rate (kg/s)

CV = fuel calorific value (KJ/kg)

3.9.5 CETANE NUMBER

Cetane number can be calculated by using following formula;

$$\mathrm{CN}_{\mathrm{Petroleum\ diesel}} = \left\{(\upsilon_{20} + 17.8)\left(\frac{1.5879}{\rho_{20}}\right)\right\}$$

3.10 EXPERIMENTAL PROCEDURE

First the engine is hand cranked at sufficient speed followed by pressing the decompression lever at no load condition. After following the above step, feed control was adjusted to attain the engine at rated speed (approx. 30 minutes) till the steady state condition is reached. Time elapsed for the consumption of 10cc, 20cc and 30cc of fuel was recorded and average of them was noted down with the help of fuel measuring unit and stop watch. Exhaust temperature, fuel consumption, smoke density, RPM, NO_X, CO, CO_2, HC and power o/p was measured. Fuel leakage from the injector was also recorded with the help of small cylinder. Engine loaded with corresponding loads keeping speed in acceptable range and values of several parameters were recorded.

Thus, the fundamental data line was carried out by running the engine with diesel. Succeeding to the above step blend of diesel, ethyl decaneperoxoate, DPG and butyl cellosolve were tested and compared with the CI engine fuel. Then subsequently all blends were tested followed by same procedure. Their performance and emission characteristics were also evaluated. Comparison of this parameter was successfully done with diesel. Engine always started with the diesel, run it for 25-30 minutes before switching it on blends to get steady state. To turn the engine off, every blend were replaced by diesel and was run on diesel fuel until whole of the blend is consumed in the fuel pipe and filter.

CHAPTER-4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION:

Some experiments were performed on CI engine without any modification executed in it. The motive of current study is to operate the diesel engine with the blend of ethyl decaneperoxoate, butyl cellosolve, dipropylene glycol and diesel followed by perform the experiment to measure emission and performance parameters.

4.2 COMPARISON OF THE PHYSICO-CHEMICAL PROPERTIES BETWEEN DIESEL AND TEST FUELS:

Analysis of diesel along with different test fuels was studied for corresponding properties like physical, chemical and thermal. Some of the properties like viscosity and density of test fuels have higher value than diesel. Combustion properties and emission have been superior to diesel fuel because of the presence of oxygen in test fuels.

Table 4.1: Comparison of Physico-Chemical properties for different test fuels

PROPERTY	DIESEL	80D10A10B	80D10B10C	80D10C10A
Density (Kg/m^3)	821.5	845.27	830.42	828.49
Specific Gravity	0.8229	0.846	0.8442	0.8423
Viscosity (CS)	2.885	3.58	3.12	3.146
C.V. (KJ/kg)	45817.8	42922	41332	43366
Cetane Number	50.36	52.68	51.12	51.42

However, calorific value of the test fuels is reduced that is around 90% of the diesel. NO_x emission is dependent on the content of oxygen in test fuels. The details of different fuel properties have been presented in table 4.1

4.2.1 DENSITY:

All the fuel additives, which were used, were more dense than that of diesel fuel. When these additives were mixed with diesel fuel in a particular concentration, the overall density of the fuel after blending increased. The denser the fuel, lesser will be the cetane number of the fuel.

DPG and ethyl decaneperoxoate when added into diesel fuel in concentration of 10% each with 80% of diesel, the density of the fuel increased by 2.9% than that of diesel. When Ethyl decaneperoxoate and butyl cellosolve were added into the fuel in same concentration, the density was increased by 1.1%.

In addition, when DPG and butyl cellosolve were added in same concentration, the density of the fuel increased by 0.85% than that of diesel.

The comparison in density of different blends is shown in the chart below;

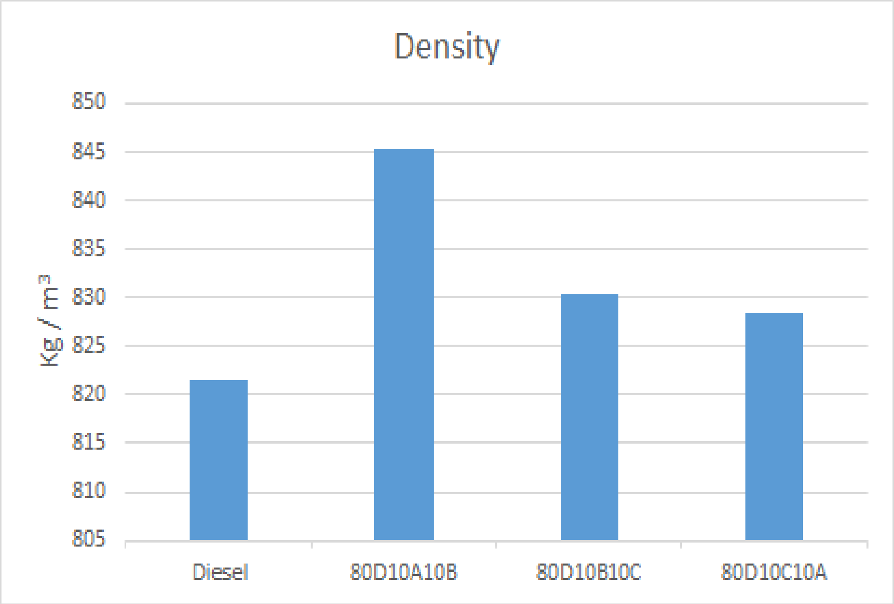

Fig. 4.1: Comparison of Density of different blends

4.2.2 VISCOSITY:

Fuel additives used in this experiment were more viscous than that of diesel fuel. When these additives were mixed with diesel fuel in a particular concentration, the overall viscosity of the fuel after blending increased. More the fuel is viscous, more will be the cetane number of the fuel and will help in a smooth and clean combustion process.

DPG and ethyl decaneperoxoate when added into diesel fuel in concentration of 10% each with 80% of diesel, the viscosity of the fuel increased by 24.9% than that of diesel. When Ethyl decaneperoxoate and butyl cellosolve were added into the fuel in same concentration, the viscosity was increased by 8.15%.

In addition, when DPG and butyl cellosolve were added in same concentration, the viscosity of the fuel increased by 9.05% than that of diesel.

The comparison in viscosity of different blends is shown in the chart below.

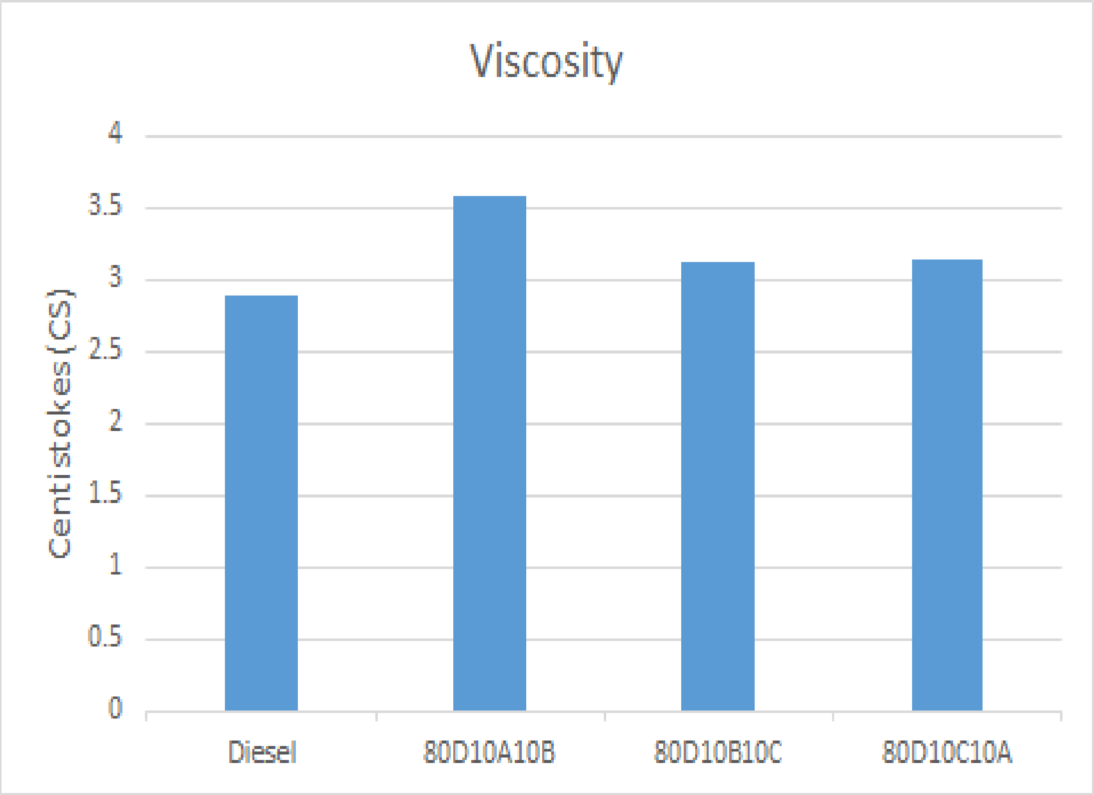

Fig. 4.2: Comparison of Viscosity of different blends

4.2.3 CALORIFIC VALUE:

When cetane improving additives were mixed with diesel fuel in a particular concentration, the calorific value of the fuel after blending was decreased.

DPG and ethyl decaneperoxoate when added into diesel fuel in concentration of 10% each with 80% of diesel, the calorific value of the fuel decreased by 6.3% than that of diesel. When Ethyl decaneperoxoate and butyl cellosolve were added into the fuel in same concentration, the calorific value was decreased by 9.8%.

In addition, when DPG and butyl cellosolve were added in same concentration, the calorific value of the fuel decreased by 5.35% as compared to diesel.

The comparison of CV in different blends is shown in the chart below;

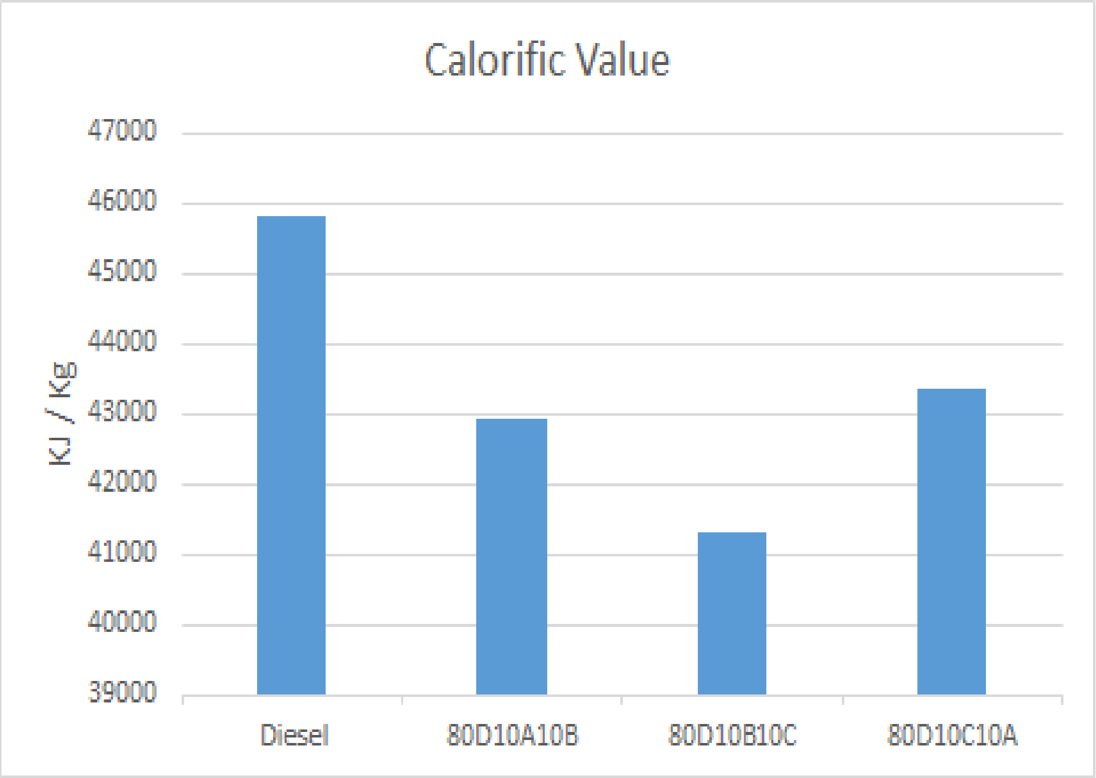

Fig. 4.3: CV comparison of different blends

4.2.4 CETANE NUMBER:

When these additives were mixed with diesel fuel in a particular concentration, the cetane number of the fuel after blending was increased. Higher the cetane number, lower will be the overall emissions from the exhaust of the engine and will help in a smooth and clean combustion process.

DPG and ethyl decaneperoxoate when added into diesel fuel in concentration of 10% each with 80% of diesel, the cetane number of the fuel increased by 2.32 than that of diesel. When Ethyl decaneperoxoate and butyl cellosolve were added into the fuel in same concentration, the cetane number was increased by 0.76% and when DPG and butyl cellosolve were added in same concentration, the cetane number of the fuel increased by 1.06 than that of diesel.

The comparison in cetane number of different blends is shown in the chart below;

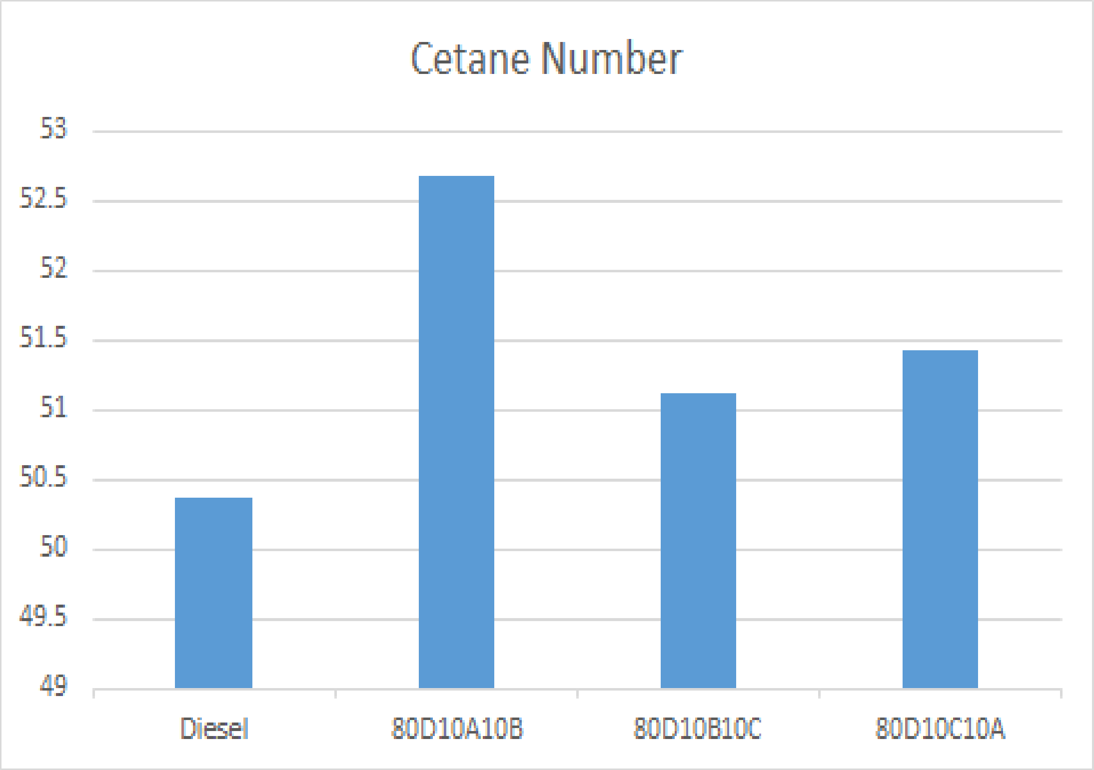

Fig. 4.4: Comparison of Cetane Number of different blends

4.2.5 SPECIFIC GRAVITY:

Cetane additives were mixed with the diesel fuel in a particular concentration, and after mixing the specific gravity of the fuel after blending increased.

DPG and ethyl decaneperoxoate when added into diesel fuel in concentration of 10% each with 80% of diesel, the specific gravity of the fuel increased by 2.8% than that of diesel. When Ethyl decaneperoxoate and butyl cellosolve were added into the fuel in same concentration, the specific gravity was increased by 2.6% and when DPG and butyl cellosolve were added in same concentration, the specific gravity of the fuel increased by 2.36% than that of diesel.

The comparison in viscosity of different blends is shown in the chart below.

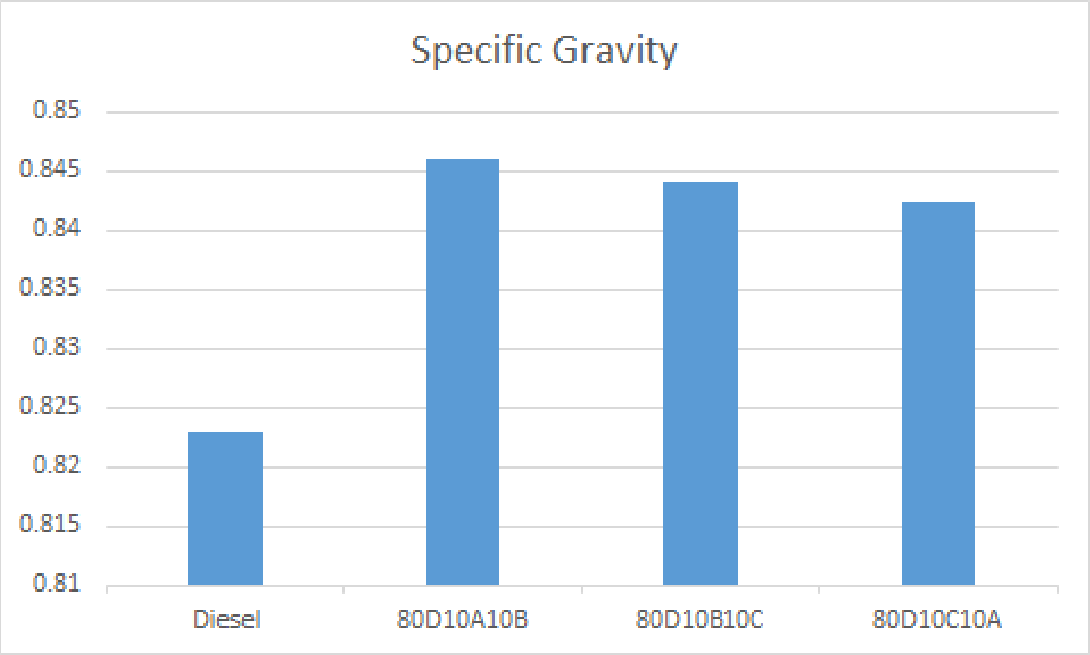

Fig. 4.5: Comparison of Specific Gravity of different blends

4.3 HOMOGENEITY TEST:

Regular inspection followed by centrifugal test were involved to examine the homogeneity of the test samples. The mentioned process was followed about 3 months.

4.4 PERFORMANCE CHARACTERISTICS:

The performance parameters were analyzed by measuring the basic data and calculated by applying theoretical analysis. The determined values were compared with the results of CI engine fuel.

4.4.1 BRAKE THERMAL EFFICIENCY:

The Brake thermal efficiency of engine used was upto 26% when run with diesel fuel. However when cetane additives were used along with diesel, BTE of the engine reduced by 2-4%. The BTE at 80% load was found to be maximum. At full load, the efficiency of the engine decreased because of less RPM of the engine at full load which was the limitations of the engine used.

The comparison of BTE of engine using different fuel blends at loads of 20, 40, 60, 80 and 100% are shown in the chart below;

Fig. 4.6: Comparison of BTE of different blends

4.4.2 BRAKE SPECIFIC ENERGY CONSUMPTION:

The BSEC of the engine used was low as 14 MJ/Kwh when run with diesel fuel. However when cetane additives were used along with diesel, BSEC of the engine increased by 8-15%.

The comparison of BSEC of engine using different fuel blends at loads of 20, 40, 60, 80 and 100% are shown in the chart below;

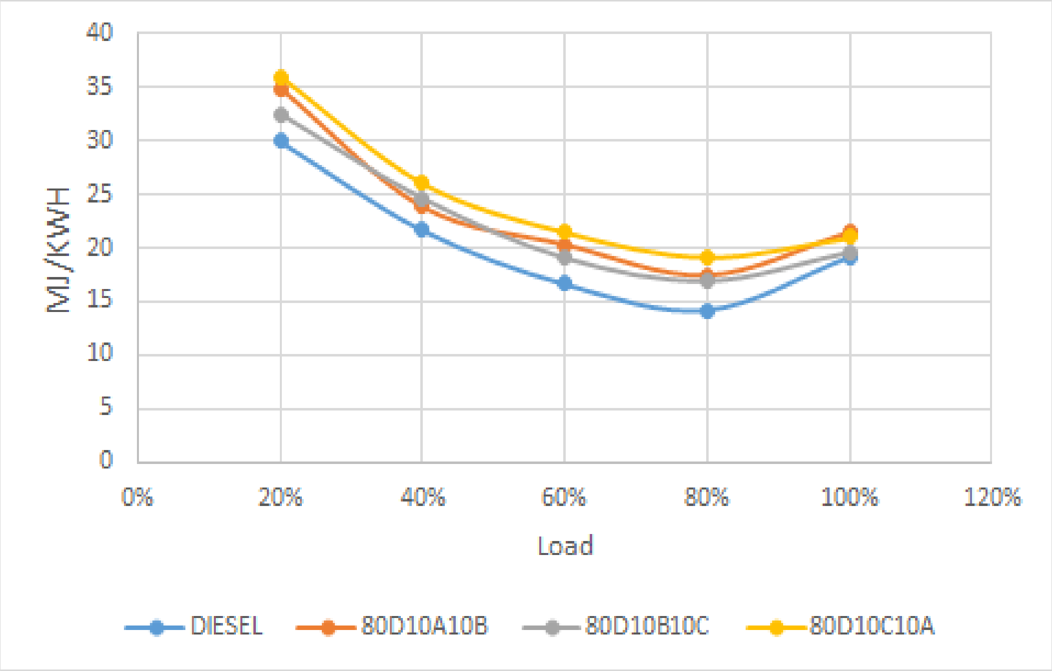

Fig. 4.7: Comparison of BSEC of different blends

4.4.3 BRAKE SPECIFIC FUEL CONSUMPTION:

BSFC in engine used was as low as 300 gms/kwh when run with diesel fuel. However when cetane additives were used along with diesel, BSFC of the engine increased by 3-8%.

The comparison of BSFC of engine using different fuel blends at loads of 20, 40, 60, 80 and 100% are shown in the chart below;

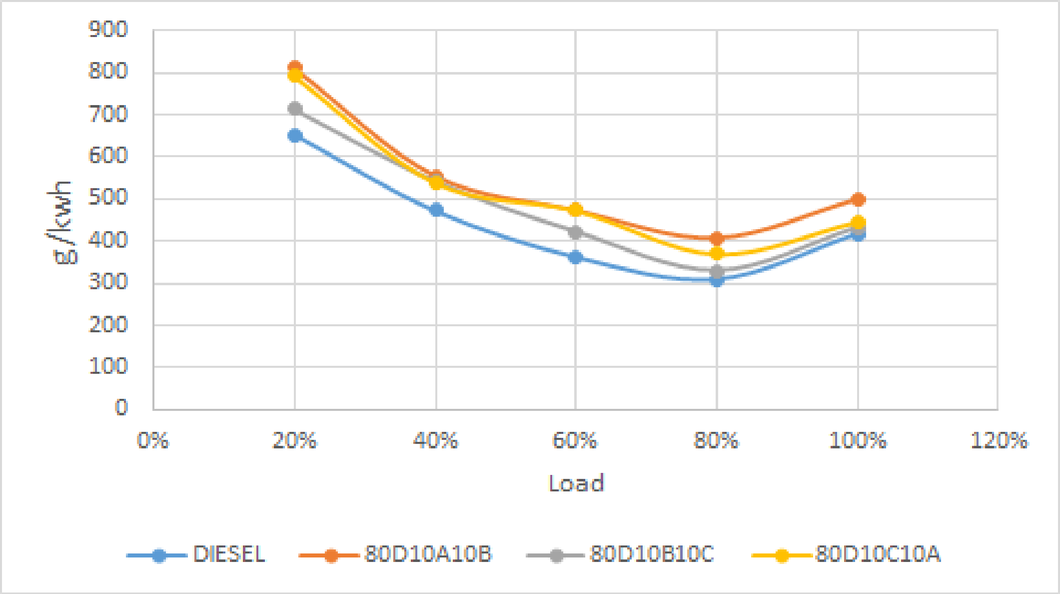

Fig. 4.8: Comparison of BSFC of different blends

4.4.4 BRAKE POWER:

The BP of engine used was upto 3.3 KW when run with diesel fuel. However when cetane additives were used along with diesel, BP of the engine reduced by 4-6%.

The comparison of BP of engine using different fuel blends at loads of 20, 40, 60, 80 and 100% are shown in the chart below;

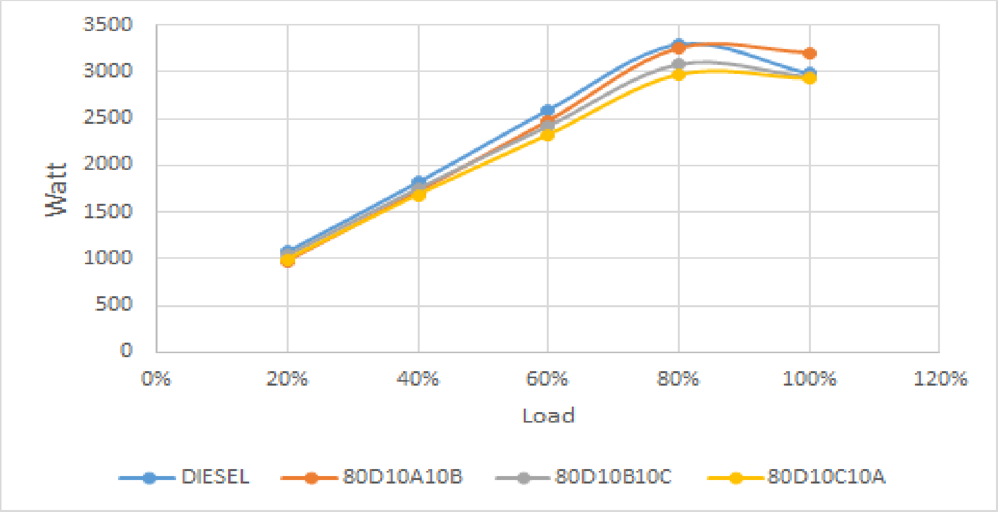

Fig. 4.9: Comparison of BP of different blends

4.4.5 BRAKE MEAN EFFECTIVE PRESSURE:

The variation of BMEP of engine using different fuel blends at loads of 20, 40, 60, 80 and 100% are shown in the chart below;

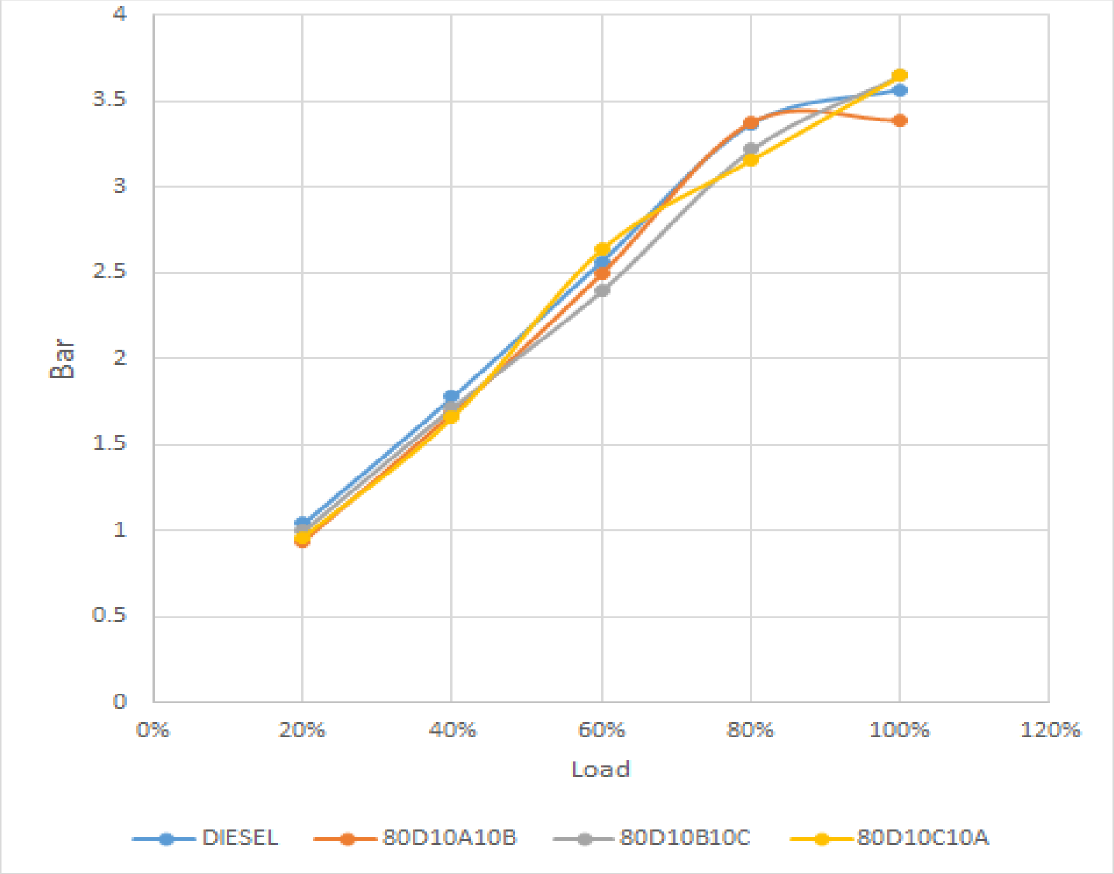

Fig. 4.10: Comparison of BMEP of different blends

4.4.6 EXAHUST TEMPERATURE:

The exhaust temperature from engine run with blends made with additives was more than that of exhaust temperature in the diesel fuel run engine.

The comparison between exhaust temperature of the engine run with diesel fuel and with the diesel fuel blended with cetane additives in different concentrations is shown in the chart below;

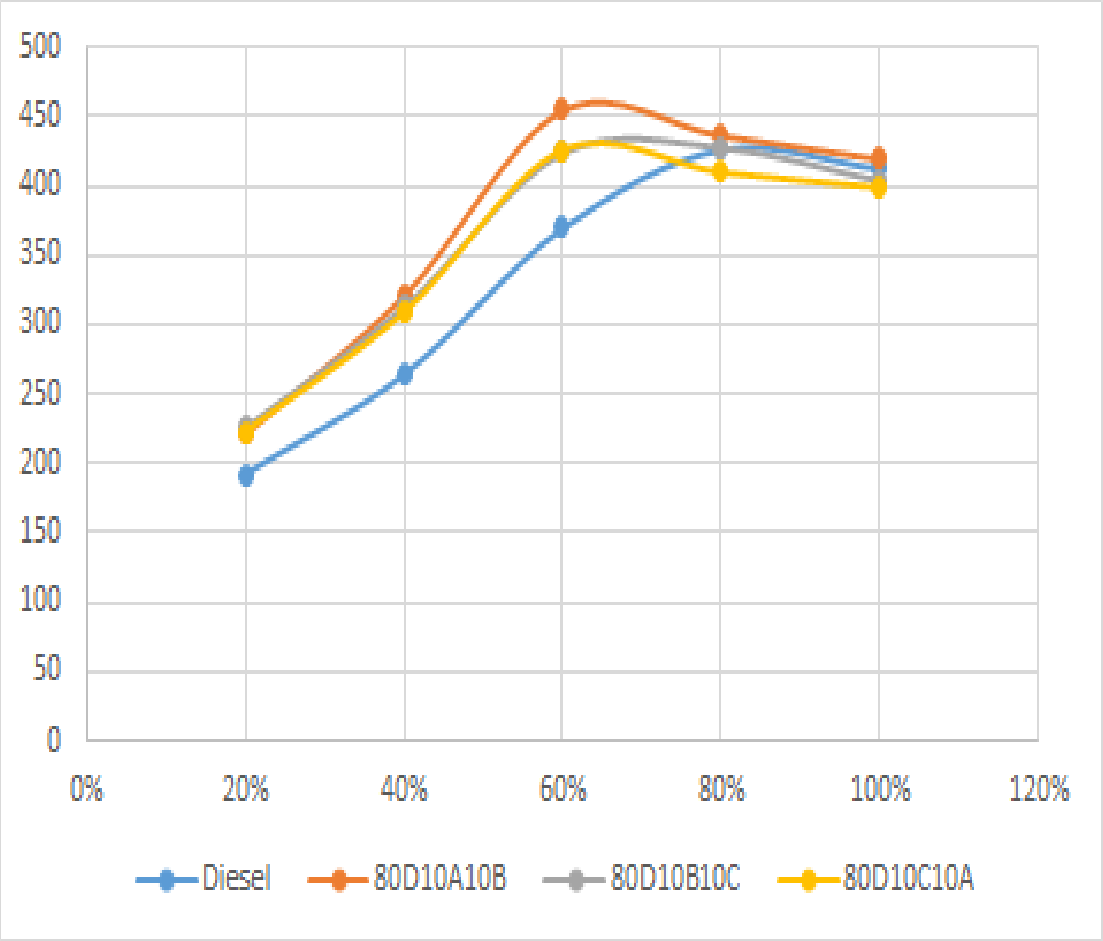

Fig. 4.11: Comparison of exhaust temprature of different blends

4.5 EMISSION CHARACTERISTICS

When cetane additives were used with diesel fuel in smaller concentration i.e. 10% each with different combinations, the overall emissions from the engine exhaust were reduced.

Although in some cases, NO_x emissions and smoke opacity were increased, but overall emissions were decreased. The reduction in various type of emissions can be compared with the help of bar charts which are drawn below;

4.5.1 CO_2 Emissions:

DPG and ethyl decaneperoxoate when added into diesel fuel in concentration of 10% each with 80% of diesel, the CO_2 emissions from the engine exhaust reduced by 3-10% than that of diesel exhaust. When Ethyl decaneperoxoate and butyl cellosolve were added into the fuel in same concentration, the calorific value was decreased by 2-8%.

In addition, when DPG and butyl cellosolve were added in same concentration, CO_2 emissions decreased by 4-12% than that of diesel exhaust.

The comparison of CO_2 Emissions of engine using different fuel blends at loads of 20, 40, 60, 80 and 100% are shown in the chart below;

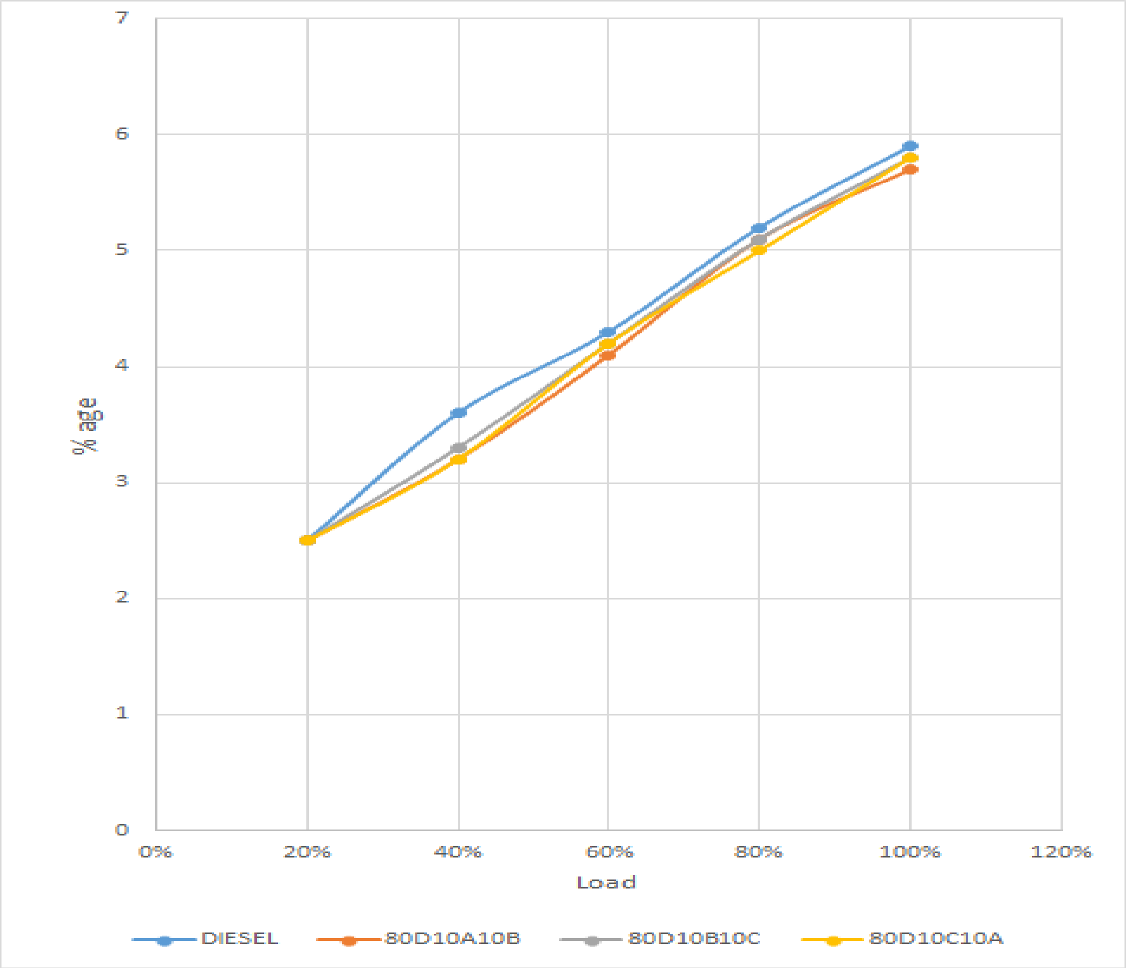

Fig. 4.12: Comparison of CO_2 emissions from engine exhaust

4.5.2 CO EMISSIONS:

DPG and ethyl decaneperoxoate when added into diesel fuel in concentration of 10% each with 80% of diesel, the CO emissions from the engine exhaust reduced by 20-25% than that of diesel exhaust.

When Ethyl decaneperoxoate and butyl cellosolve were added into the fuel in same concentration, the CO emissions decreased by 15-20%. In addition, when DPG and butyl cellosolve were added in same concentration, CO emissions decreased by 20-33% than that of diesel exhaust.

The comparison of CO Emissions of engine using different fuel blends at loads of 20, 40, 60, 80 and 100% are shown in the chart below;

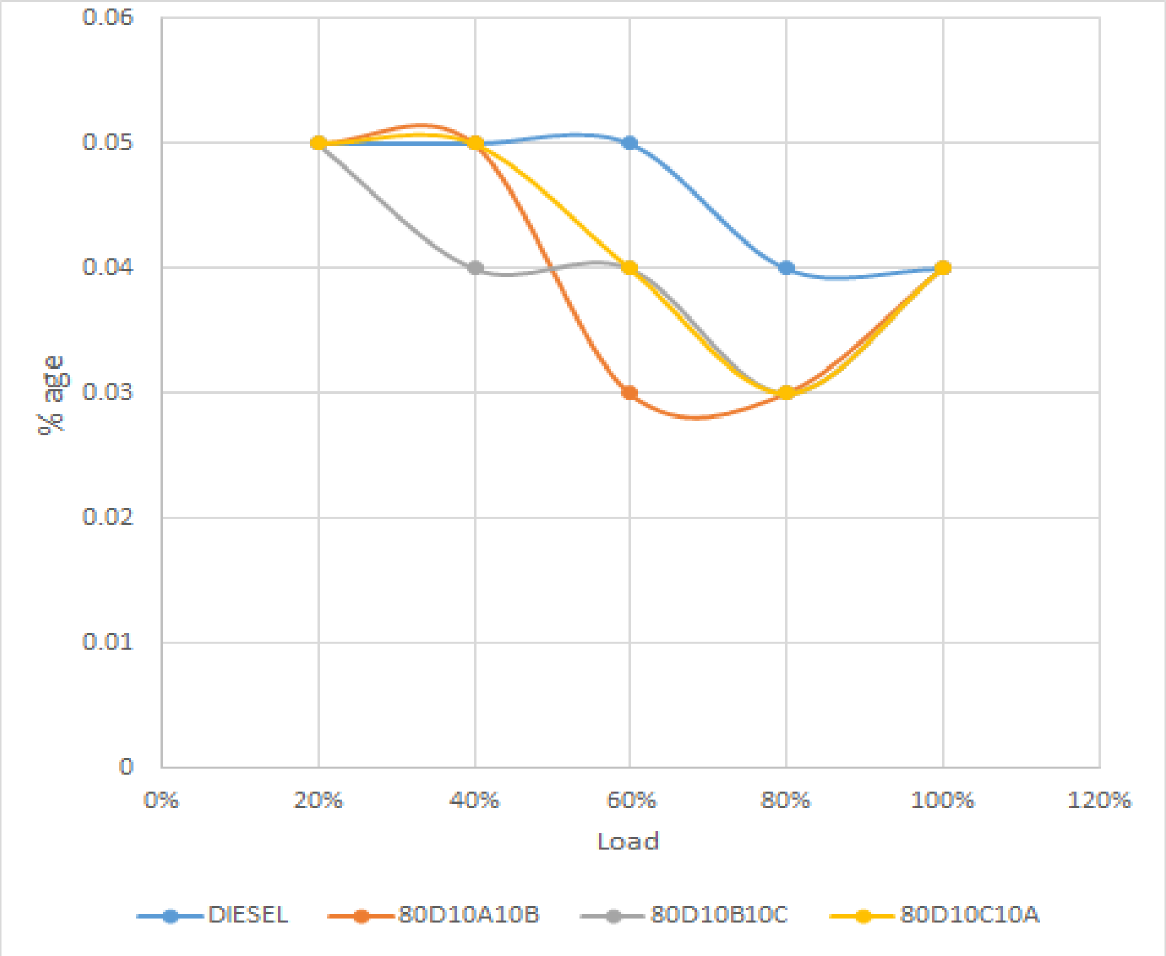

Fig. 4.13: Comparison of CO emissions from engine exhaust

4.5.3 UNBURNT HYDROCARBONS:

DPG and ethyl decaneperoxoate when added into diesel fuel in concentration of 10% each with 80% of diesel, the UHC emissions from the engine exhaust were decreased by 3-10% than that of diesel exhaust. When Ethyl decaneperoxoate and butyl cellosolve were added into the fuel in same concentration, the UHC emissions were decreased by 3-6%.

In addition, when DPG and butyl cellosolve added in same concentration, the UHC emissions decreased by 2-12% than that of diesel exhaust.

The comparison of UHC Emissions of engine using different fuel blends at loads of 20, 40, 60, 80 and 100% are shown in the chart below;

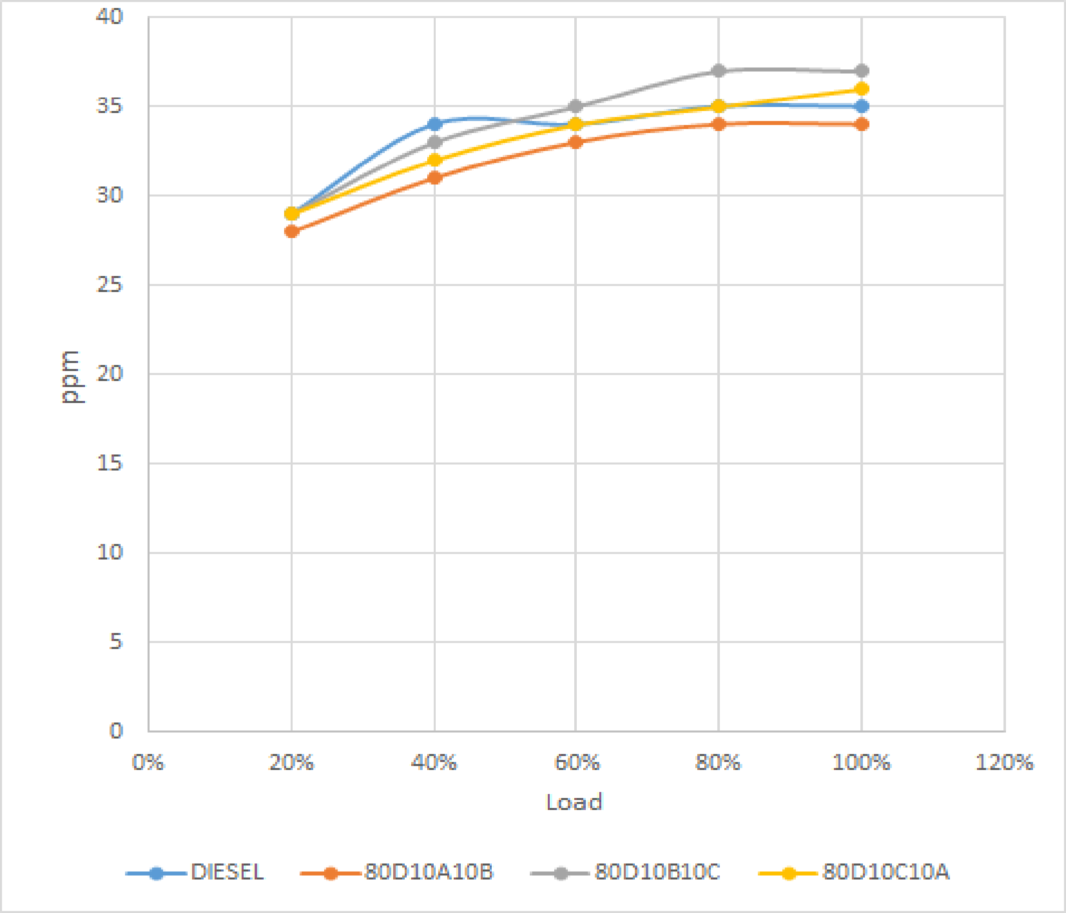

Fig. 4.14: Comparison of UHC emissions from engine exhaust

4.5.4 NO$_x$ EMISSIONS:

DPG and ethyl decaneperoxoate when added into diesel fuel in concentration of 10% each with 80% of diesel, the NO$_x$ emissions from the engine exhaust were increaseed by 1-3% than that of diesel exhaust. When Ethyl decaneperoxoate and butyl cellosolve were added into the fuel in same concentration, the NO$_x$ emissions were decreased by 1-4%. In addition, when DPG and butyl cellosolve were added in same concentration, the NO$_x$ emissions decreased by 1-4% than that of diesel exhaust.

The comparison of CO Emissions of engine using different fuel blends at loads of 20, 40, 60, 80 and 100% are shown in the chart below;

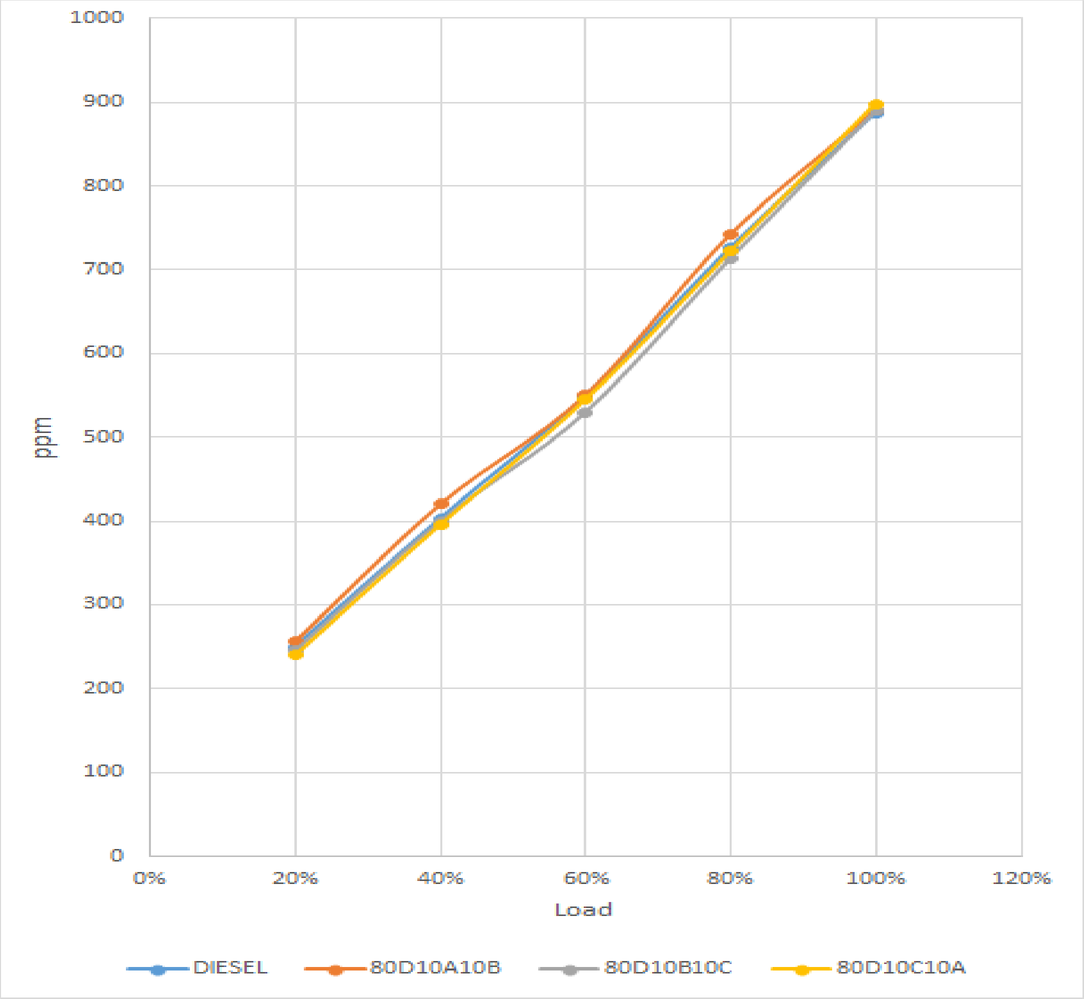

Fig. 4.15: Comparison of NO$_x$ emissions from engine exhaust

4.5.5 SMOKE OPACITY:

DPG and ethyl decaneperoxoate when added into diesel fuel in concentration of 10% each with 80% of diesel, the smoke opacity from the engine exhaust increased by 15-25% than that of diesel exhaust. When Ethyl decaneperoxoate and butyl cellosolve were added into the fuel in same concentration, the smoke opacity was increased by 10-20%.

In addition, when DPG and butyl cellosolve were added in same concentration, the smoke opacity decreased by 10-20% than that of diesel exhaust.

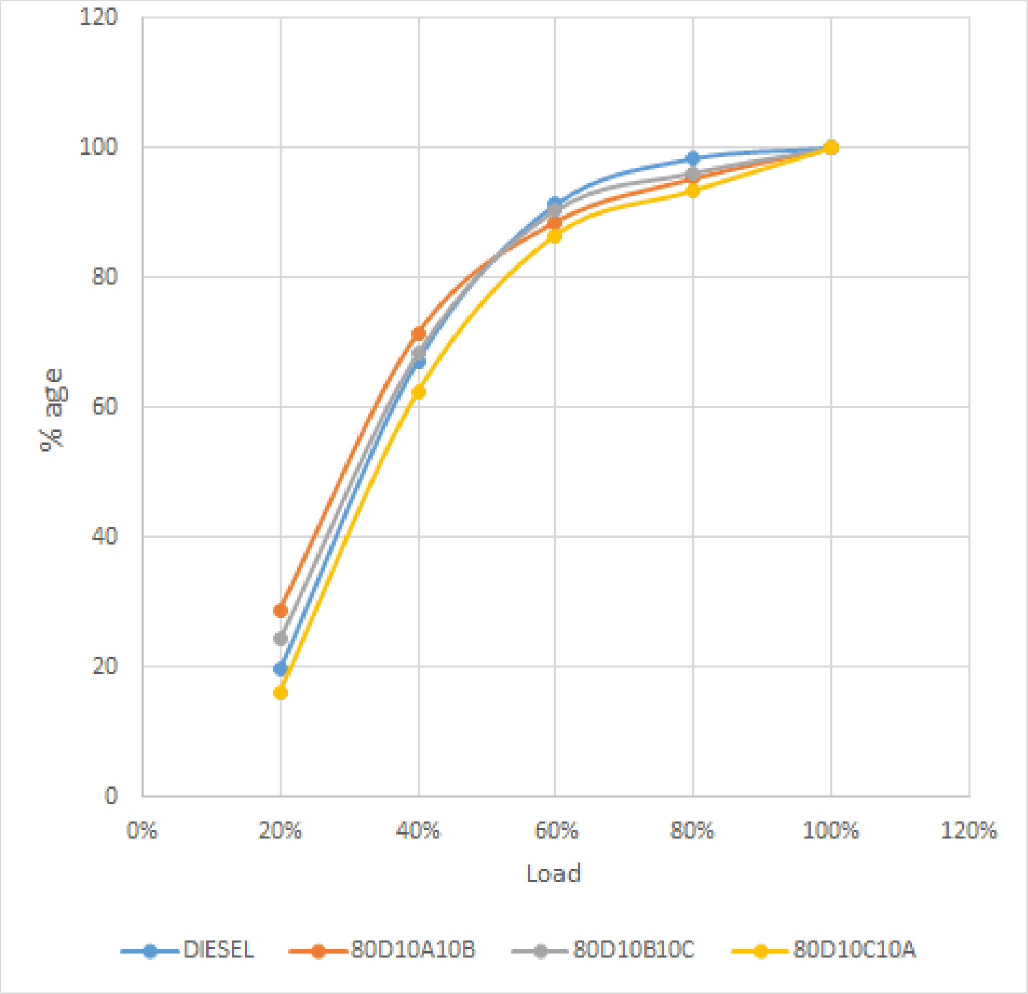

Fig. 4.16: Comparison of Smoke emissions from engine exhaust

CHAPTER-5

CONCLUSION AND SCOPE FOR FUTURE WORK

5.1 CONCLUSION:

Cetane additives such as dipropylene glycol are very effective substances in order to improve the CN of the diesel fuel. Either ‘nitrogen class’ or ‘oxygen class’ additive can be used in order to enhance the ignition quality and performance of diesel.

In this experimental work, ethyl decaneperoxoate, DPG and butyl cellosolve used in mixing with diesel fuel in 10% concentration, gave good results. CO and CO_2 emissions as well as UHC emissions lower as compared to diesel emissions. The smoke opacity and NO_x emissions increased in some cases but in most of cases, these emissions were also lower as compared to diesel.

The performance of engine improved however, BTE, BSEC and power of the engine reduced slightly so as the calorific value but BSFC, density, cetane number, SG and viscosity of the fuel increased. Due to the increase in the cetane number (improved upto 3 number), the burning of the fuel became better and more fraction of the fuel was burnt. This reduced the UHC emissions. Similarly, other type of emissions also reduced.

From the results and calculations, it may be concluded that with the use of these cetane additives, despite increase in BSFC and decrease in BSFC, the performance of the engine improved and emissions from exhaust of the engine reduced which is very important from environmental aspects.

5.2 SCOPE FOR FUTURE WORK:

Since research in the field of modifications in IC engines and its fuels is a major area for improvement, many researchers are already working on it. As concluded from the results, the cetane improving additives used in this experimental work enhanced the performance of the engine and reduced overall emissions from the engine exhaust.

Some other cetane additives can also be used in mixing with the diesel fuel and can be practically and theoretically checked for the performance and emissions. In this experimental study, some of the oxygenative additives were used and analysed for results. In future, some other oxygenative additives such as DEE, DTBE etc. or nitrogen class additives such as EHN or CHN can be utilized to improve the CN of the fuel. Because using these ethers or esters will increase the oxygen content of the fuel and that will improve the burning quality of the fuel.

CHAPTER-6

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