MAJOR PROJECT-II

EVALUATION OF PERFORMANCE AND EMISSION CHARACTERISTICS OF A UNMODIFIED CI ENGINE WITH BLENDS OF DIESEL, BIODIESEL AND DECANOL

Submitted in partial fulfilment of the requirement for the award of degree of

Master of Technology

In

Renewable Energy Technology

Submitted by

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DECLARATION

I, hereby declare that the work which is being presented in this dissertation, titled **"EVALUATION OF PERFORMANCE AND EMISSION CHARACTERISTICS OF A UNMODIFIED CI ENGINE WITH BLENDS OF DIESEL, BIODIESEL AND DECANOL"** towards the partial fulfillment of the requirements for the award of degree of **Master of Technology** with specialization in RENEWABLE ENERGY TECHNOLOGY from Delhi Technological University Delhi, is an authentic record of my own work carried out under the supervision of **Dr. Naveen Kumar**, Professor, Mechanical Engineering Department, Delhi Technological University, Delhi.

The matter embodied in this dissertation record has not been submitted by me for the award of any other degree.

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CERTIFICATE

This is to certify that the work embodied in the dissertation entitled **"EVALUATION OF PERFORMANCE AND EMISSION CHARACTERISTICS OF A UNMODIFIED CI ENGINE WITH BLENDS OF DIESEL, BIODIESEL AND DECANOL"** by Swapnil Anand (2K15/RET/15) in partial fulfilment for the award of degree of Master of Technology in Thermal Engineering, is an authentic record of student's own work carried out under my guidance and supervision.

It is also certified that the report has not been submitted to any other institute/university for the award of any degree.

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ABSTRACT

Biodiesel is a potential alternative fuel for CI engines as it has the potential to reduce dependence on diesel as well as it reduces emission significantly. Out of many biodiesels derived from various resources, Biodiesel from Waste Cooking Oil (WCO) can be prepared economically using transesterification process. In context to present work, the biodiesel is manufactured in two stages due to high free fatty acid (FFA) of waste cooking oil. The blends of diesel, waste cooking oil methyl ester (WCOME) and Decanol are studied and performed experimentally in CI engine. The physico-chemical properties of test fuels are found different than vegetable oils due to which the performance of theengine is improved. In past few years, high wastage of cooking oil is produced by fast food chains and five-star hotels especially in developed countries and metro cities.

Alcohol is also one of the potentialbiofuels which can be used in IC engine. The properties of Decanol is compared with primary alcohols and found that the performance characteristics are comparable with baseline diesel fuel. Due to high carbon rating of decanol, it shows properties similar to petroleum products.Most of the researchers haveinvestigated the performance and emission characteristics in CI engine by using alcohols up to 6 carbon chain blended with diesel. A little quantum of work has been done on higher alcohols and their blends. The physico-chemical properties of test fuels are found satisfactorily within the limits of ASTM and other standards. The research was comprised of fuel blend development and a set of exhaustive engine trail for performance and emission studies. Various test fuels for the engine trial were W5D5, W5D10, W10D10, W15D10 and W15D15 with 10%, 15%, 20%, 25% and 30% volume wise substitution of mineral diesel by Waste cooking oil methyl ester and decanol. The results indicated higher engine performance for all test fuels except W15D15. The emission of carbon monoxide, total hydrocarbon emission and smoke of test fuels were lower than mineral diesel. However, emission of oxides of nitrogen (NO_x) was increased with increase in WCOME volume fraction in the test fuel.

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NOMENCLATURE

Symbol	**Description**
Baseline	Neat diesel
BMEP	Brake mean effective pressure
BSEC	Brake specific energy consumption
BTE	Brake thermal efficiency
CA	Crank angle
CI	Compression Ignition
CAGR	Compound Annual Growth Rate
CO	Carbon monoxide
CO_2	Carbon Dioxide
CR	Compression ratio
cst	Centistokes
Kg	Kilogram
kWh	Kilo-watt-hour
l	Length of connecting rod
LHV	Latent Heat Value
m	Mass of fuel/air

MJ/Kg	Megajoules per kilogram
MTPA	Million Tonnes Per Annum
NaOH	Potassium Hydroxide
NO_x	Oxides of nitrogen
p	Pressure
ppm	Parts per million
H_2	Hydrogen gas
^oC	Degree Celsius
^oK	Degree Kelvin
RPM	Rotations per minute
WCOME	Waste cooking oil methyl ester
Decanol	N-Decanol
THC	Total Unburnt Hydrocarbon
W5D5	5% wcome + 5% decanol + 90% diesel
W10D5	10% WCOME +5% Decanol + 85% Diesel
W10D10	10% WCOME +10% Decanol + 80% Diesel
W10D15	10%WCOME + 15% Decanol +75% Diesel
W15D15	15%WCOME + 15% Decanol + 70% Diesel

CHAPTER 1

INTRODUCTION

1.1 ENERGY CRISIS

The word energy has a root word that is ***"energeia"*** in the Greek language which means "work capacity". In fourth century BC, Aristotle used this word for the very first time [1]. Energy is the key parameter of remarkable economic growth and essential to the existence of current economy. Long-term accessibility of energy is the indicator of economic growth and dependent on the sources which are easily available and environmentally friendly. Global warming, acid rain, and ozone layer depletion have become a serious problem in past few decades. To reduce these unwanted environmental effects, some rigorous actions have been taken in terms of worldwide protocols and conventions.[2]

There is much need of huge investments to fulfill the energy demand especially in the case of developing countries because energy sector has become the crucial parameter for development of any country. The IC engines have bestowed the world with industrialization but also promoted the cause of environmental degradation.[3]

There are a lot of conventions are going on to produce the non-conventional source of energy to beat the energy crisis as soon as possible. The high efficiency of diesel engine played a very important role in Indian economy because they are used in agriculture, power, industry and transport sector. Environmental pollution and harmful emissions from CI engines raised the point to protect the environment globally. The concern for saving of diesel too leads the necessity of alternative fuel which equalizes the property of diesel to meet the same result. [4]

In the present scenario, non-edible oils and its derivative-biodiesel promote the efficient solution of the problem. By using a limited quantity of oxygenated fuel in place of diesel, there could be some significant reduction in emissions achieved without any major modification in CI engine. [5]

1.2 ENERGY SCENARIO: INDIAN PERSPECTIVE

India is a nation with more than 1.27 billion individuals representing more than 17% of world's populace. India is categorized as 7th rank in terms of area whereas fourth highest in the world in terms of energy utilization. There are alot of energy issues faced by Indian power sector and industries due to which Indian government now focuses on various initiatives to promote "make energy from renewable sources". The capacity of power plants has been multiplied like megawatt to gigawatt to save the country from energy crunch. Lack of electricity and energy poverty are one of the major problems faced by Indians. In past few years, energy consumption in India has increased at a generally quicker rate due to population extension and monetary advancement, despite the fact that the base rate might be to some degree low. [6]

According to total energy consumption, India holds 3rd position; almost 70% of the total energy consumption is from coal and crude oil. Power generation in India has been increased from 1.3 GW to 314 GW since independence and helped in enlighten up around 5 lakh villages.[7]

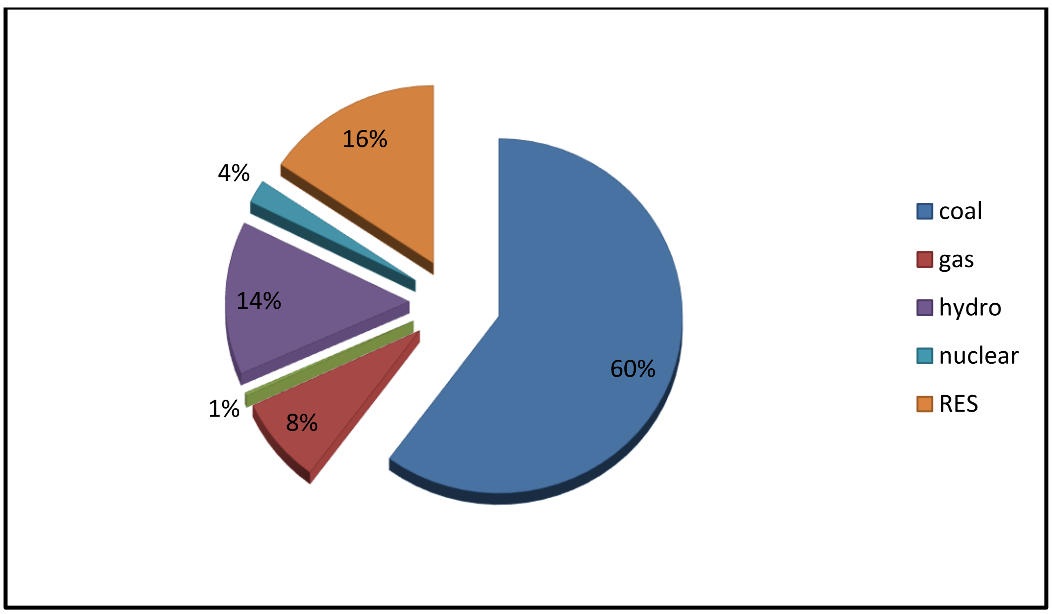


Fig 1.1: Percentage share of different fuels in primary energy consumptions[7]

Fig 1.1 explains the total energy consumption of India in which 60% is just from the coal followed by 14% from hydro and 16% from other renewable energy sources. In India, coal is indigenous and its use has alarmingly increased in last decade due to the establishment of industries and new power plant projects of high capacity and boom in automobile fleet that helped to project billion plus market. Without any significant increase in crude oil production and lack of other energy sources over the years push India in a position to import the crude oil from topmost reserved oil countries.

Today India is one of the topmost leading countries in terms of energy production. According to the data published by Indian power sector as on 31 Jan 2017 (Table 1.1), the private sector has shown a remarkable change as it contributed almost 40% of the total power generation. As compared to the previous data state government also presented an appreciable change because it contributed around 35% of the total production and also reduced the load on the central government in terms of power distribution and other financial facts.[8]

Table 1.1: Total sector wise power generation as on 31 JAN 2017 (MW) [8]

Sector	Coal	Gas	Diesel	Nuclear	Hydro	Res	Total in (MW)
Central	51930	7490	0	5780	11651.43	0	76852.16
State	64195.5	7257.95	363.93	0	29418	1976.67	103212
Private	72362.38	10580	473	0	3120	48041	134577.81
AllIndia	188487	25329.15	837	5780	44189.43	35776.96	314642.17

Last century was the era of consuming conventional power sources for power generation in order to fulfill the energy demand which arises due to industrialization. Some countries like USA and other European countries consume more than their share of conventional energy in order to become developed as a result of which the developing countries of the present world has to bear the load. This process continues till now only the energy consumers have changed. At present, the total energy demand of world has risen to 13147.3 mtoe (according to the table 1.2As given below) but this demand does not have an equal share of all countries in the world. During the second half of 20th century USA was the main consumer of conventional sources but today China has surpassed the USA energy demand and consuming around 1.5 times of USA present demand as shown in above table 1.2 India is at the third position with the total energy demand of about 700.5 mtoe[9].

Table 1.2:Primary energy requirement of different countries(in mtoe) [9]

Country	**Oil**	**Natural gas**	**Coal**	**Nuclear energy**	**Hydro-electric**	**Renewable**	**total**
USA	851.6	713.6	396.3	189.9	57.4	71.7	2280.6
China	559.7	177.6	1920.4	38.6	254.9	62.7	3014.0
India	195.5	45.5	407.2	8.6	28.1	15.5	700.5
Japan	189.6	102.1	119.4	1.0	21.9	14.5	448.5
Saudi Arabia	168.1	95.8	0.1	-	-	-	264.0
Brazil	137.3	36.8	17.4	3.3	81.7	16.3	292.8
Russia	143.0	352.3	88.7	44.2	38.5	0.1	666.8
South Korea	113.7	39.2	84.5	37.3	0.7	1.6	276.9
Germany	110.2	67.2	78.3	20.7	4.4	40.0	320.6
Canada	100.3	92.2	19.8	93.6	86.7	7.3	329.9
World	4331.3	3135.2	3839.9	583.1	892.9	364.9	13147.3

Till 2015 oil and coal plays the lead role as primary fuel for power generation with a share of about 70 percent. But as these fuels prove to be the main cause of degradation of our environment, various countries have shown their concern in renewable energy sources. Presently around 364.9 mtoe of power is being generated from RES. Hydro and nuclear power also have their contribution in world energy generation but it is not comparable to conventional energy sources with both have a combined contribution of 3135 mtoe. Natural gas with a part of 3135 mtoe is at the third place in world energy generation. [10]

1.3 FUTURE OUTLOOK:

World energy demand is expected to increase by 1.3% per annum from in next 20 years. For the development of each and every sector, most of the improvement begins from rising economies. The oil and gas sector is one of the six core industries in India. It plays important role in influencing decisions across other fundamental pillars of the economy. Oil and gas contribute 39.2% to primary energy consumption in India and the demand for primary energy of the country is expected to increase threefold by 2035 to 1,516 Million Tones of Oil Equivalent from 563 Million Tonnes of Oil Equivalent in 2012 as represented in figure 1.2

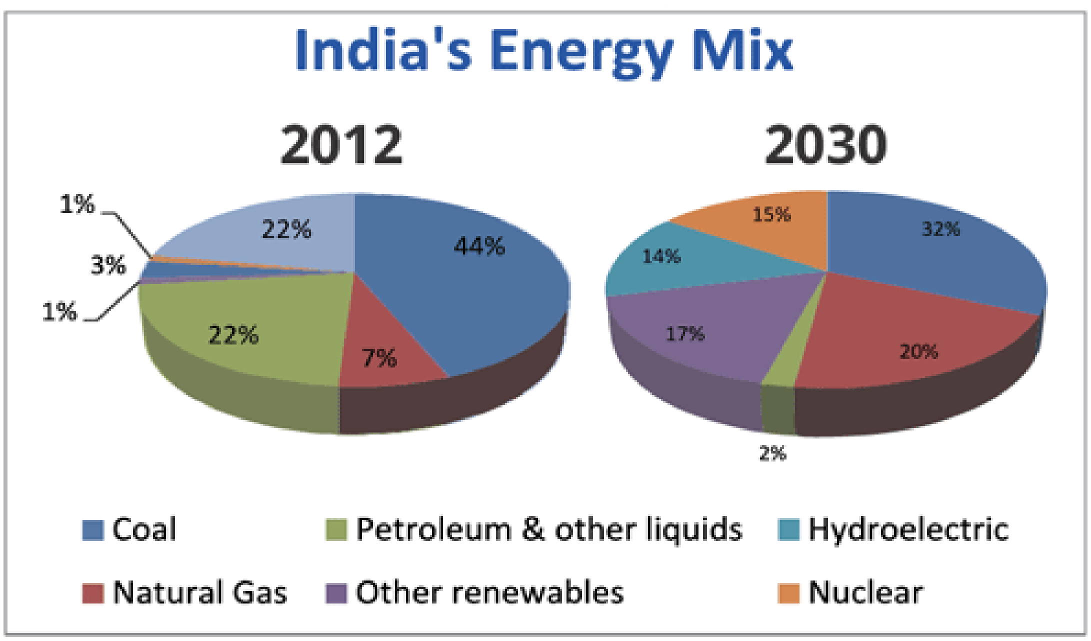


Fig 1.2: India's Energy Future outlook [11]

Backed by new oil fields, domestic oil output is anticipated to grow to 1 MBPD by FY16, and gas consumption is likely to expand at a CAGR of 21 per cent during FY08-17.By 2015-16, India's demand for gas is set to touch 124 MTPA against a domestic supply of 33 MTPA and higher imports of 47.2 MTPA, leaving a shortage of 44 MTPA. India increasingly relies on imported LNG; the country was the fourth largest LNG importer in 2013, accounting for 5.5 percent of global imports. India's LNG imports are forecasted to increase at a CAGR of 33 percent during 2012–17.India has 215.066 MMTPA of refining capacity, making it the second largest refiner in Asia. India projects an increase of the country's refining capacity to 307.366 MMTPA by 2017 based on its current Five Year Plan (2012-17) to meet rising domestic demands and export markets. [11]

1.4ALCOHOL BLENDED FUEL

In compression ignition engine, there are a lot of difficulties were faced when blends of primary alcohols were used because of their low cetane number, high LHV, and long ignition delay. But in past few years, researchers had a focus on higher alcohols then it was found that higher alcohols had a higher value of cetane number and also the most of the propertiesmatch with the property of diesel like in Decanol.[12].

The first alcohol developed that is methyl alcohol has the lowest value of combustion energy of all the fuels listed. However, it has correct air fuel ratio chemically that signifies the production of most power. Because of its high burning rate of alcohols compared to diesel the combustion efficiency also results in a high value. Alcohol is used in CI engine so it is blended with CI engine fuel to produce diesohol or added to the air intake of the engine. Commercial availability of CI engine is also there for adding a mixture of the second category of alcohol (ethanol) and water. The fundamental role of the system is to lower the temperature of turbocharged air (with the help of latent heat) and thus have gain in volumetric efficiency as well as in o/p power. The intercooler can also be used to get same results. There is a difficulty in controlling the amount of alcohol that caused some unwanted engine operation if the huge quantity of alcohol were added.[13]

With the ssaddition of ethanol in CI engine, the basic role of ethanol was to dilute the fuel-air mixture that results in more efficient combustion. There is a problem of mixing of methanol with CI engine fuel due to its high polarity nature whereas ethanol can be mixed easily with the diesel with the condition of a little quantity of water.

1.5RATIONALE OF ALCOHOL BLENDED FUELS IN INDIA

The production of alcohol fuels for utilization of IC engine in India is essential in the context of following points:

- Utilization of alcohol blended fuel is essential with respect to strict emission norms and court interventions.
- Provision of energy security especially in villages.
- Need to create employment in poor living areas having high chance of land destruction
- Increasing self-reliance in terms of oil imports.
- The high efficiency of present engines without any significant modification when using alcohol blended fuel.
- Alcohol blended fuel does not demand time-consuming research or study.
- Superior fuel as per the environmental point of view.

1.6 BINARY FUEL AND TERTIARY FUEL

There are a lot of experiments have been performed in CI engine based on binary blended fuel but as it comes in the context of tertiary blend, there if very restricted numbers of papers available in well-reputed journals and that too with low carbon containing alcohols. In Table1.3 there is basic comparison has been presented between binary and tertiary fuel. For the current work, the tertiary blend has been used that comprises of decanol, waste cooking oil biodiesel, and diesel.

Table 1.3: Comparison of binary and tertiary blend

Binary blend	Tertiary Blend
1.Binary blend consists of two compounds 2. The properties of binary blend have significant difference than the corresponding engine fuel. 3. Diesel + Biodiesel Biodiesel+ Ethanol	1.Tertiary blend consists of two or more compounds 2. The properties of tertiaryblend have almost equal to corresponding engine fuel. 3. Diesel + Biodiesel + Ethanol Diesel + Butanol + Jatropha oil

1.7 WASTE VEGETABLE OIL AS A FUEL FOR BIODIESEL

The diminishing of fossil fuel reserves in all over world and dependence on petroleum fuels has intimated the world to think of an alternative source of energy to beat the present energy crisis as well as in future. In the context of this concern, WCOME has certified as a viable option for use in CI engine due to its low cost, non-toxicity, and environment-friendly nature. The contribution of low emission and other sustainable properties of WCOME is the driving force to use it in research work.[9]

There are almost 9000 fast food chains and restaurants including 3 star, 4 star and 5 star in Delhi and NCR region. On an average, every restaurantproduces around 50-60 L of oil which is not used repeatedly in a day. Every fast food outlets produce around 25-30L of oil in a day. The quantity of waste cooking oil is around 35-40 thousand liters per day which is an enormous figure. This much amount of WCO can be converted into biodiesel to get a neat and clean fuel

1.8 OBJECTIVE

Biodiesel is a potential alternative fuel for CI engines as it has the potential to reduce dependence on diesel as well as it reduces emission significantly. Out of many biodiesels derived from various resources, Biodiesel from Waste Cooking Oil (WCO) can be prepared economically using transesterification process. In context to present work, the biodiesel is manufactured in two stages due to high free fatty acid (FFA) of waste cooking oil. The blends of diesel, waste cooking oil methyl ester (WCOME) and Decanol are studied and performed experimentally in CI engine. The physico-chemical properties of test fuels are found different than vegetable oils due to which the performance of the engine is improved. In past few years, high wastage of cooking oil is produced by fast food chains and five-star hotels especially in developed countries and metro cities.

Alcohol is also one of the potential biofuels which can be used in IC engine. The properties of Decanol is compared with primary alcohols and found that the performance characteristics are comparable with baseline diesel fuel. Due to high carbon rating of decanol, it shows properties similar to petroleum products. Most of the researchers have investigated the performance and emission characteristics in CI engine by using alcohols up to 6 carbon chain blended with diesel. A little quantum of work has been done on higher alcohols and their blends. The physico-chemical properties of test fuels are found satisfactorily within the limits of ASTM and other standards. The research was comprised of fuel blend development and a set of exhaustive engine trail for performance and emission studies. Various test fuels for the engine trial were W5D5, W5D10, W10D10, W15D10 and W15D15 with 10%, 15%, 20%, 25% and 30% volume wise substitution of mineral diesel by Waste cooking oil methyl ester and decanol. The results indicated higher engine performance for all test fuels except W15D15. The emission of carbon monoxide, total hydrocarbon emission and smoke of test fuels were lower than mineral diesel. However, emission of oxides of nitrogen (NO_x) was increased with increase in WCOME volume fraction in the test fuel.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The literature based on WCOME has been wisely assessed as an alternative fuel. Therefore the pile of research has been categorized in several sections like waste cooking oil, production of biodiesel from a different type of vegetable oils followed by physico-chemical properties and application in CI engine to analyze the behavior of performance parameters and emission parameters. In this context, categorized review has been presented with the help of a number of national and international journals. To fulfill the desired objective, possible outcomes of the literature review are summarized below:

2.2 REVIEW OF AVAILABLE LITERATURE

2.2.1 Biodiesel Production

Kathirvel et. al. [13] reported that waste cooking Biodiesel or Waste cooking oil Methyl Ester (WCOME) has all the making of a viable alternate for use in CI engines due to its characteristic to reduce emissions and the scope it extends to alleviate the overdependence on fossil fuels. The physiochemical properties of WCOME are tabulated in Table 2.1 for comparison:

Table 2.1: Comparison of WCOME properties with diesel

Sl no.	Fuel properties	Diesel	Biodiesel
1	Fuel standard	ASTM D 975	ASTM D 6751
2	Fuel composition	C10-21 HC	C12-22FAME
3	Lower heating value (MJ/kg)	42.49	39.6
4	Kinematic viscosity(CST) at 30 °C	4.59	1.9–6.0
5	Density at 15 °C (kg/m3)	840	880
6	Flashpoint (°C)	52–96	273
7	Cetane number	45	37
8	Auto ignition temperature (°C)	260	300

Amani et. al. [14] investigated the potential of using Cesium impregnated silica as the heterogeneous catalyst for the transesterification reaction of waste cooking palm oil (WCPO) and palm oil (PO). The author used various combinations of Cesium loadings, the methanol-to-oil molar ratios, catalyst loading, reaction time and water content to study their influence on the process variables of the reaction. Detailed characterization of the catalyst was carried out by the authors and 25% of cesium on silica was reported to result in a maximum yield of 90% within a short reaction time of 3 hours at 65 °C with 3 wt % of catalyst loading.

Chuah et. al. [15] examined the conversion of methyl esters from waste cooking oil from palm olein and refined cooking oil using hydrodynamic cavitation technology. The author studied the impact of the inlet pressure and the geometry of the orifice plate on the yield % and the reaction time of the conversion process. It was reported that 8 times more energy efficiency and 6 times less reaction time were achieved with the optimized orifice plate geometry that had 21 holes for each 1 mm diameter

Chuah et. al. [16] analyzed the effect of the major operating parameters in methyl ester conversion with hydrodynamic cavitation. Oil to methanol molar ratio, catalyst loading, and reaction temperature were varied, and the role of their variations on yield efficiency was studied. The Higher molar ratio of 1:6, optimum catalyst loading of 1% KOH and an optimum reaction temperature of 60 °C were proven to exhibit good results.

Sneha et. al. [17] synthesized a heterogeneous catalyst of 25% Potassium Bromide impregnated in CaO using wet impregnation method for the transesterification process. Fourier Transform Infrared spectrometry (FTIR), X-ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) techniques were used for the characterization of the catalyst, and Gas Chromatography–Mass Spectrometry (GC–MS) was used to ascertain the composition of the methyl esters formed. The author varied the process parameters of the transesterification method like catalyst loading, reaction time, and methanol to oil molar ratio to analyze their effect on the yield of the methyl esters with the help of Response Surface Modeling (RSM). The transesterified biodiesel was used in a four stroke, direct injection diesel engine with different blends. Less emission was observed for B10 and B20 blends while the brake thermal efficiency increased compared to the pure diesel.

Gupta et. al. [18] explored the impact of the process parameters of the transesterification reaction using calcium diglyceroxide (CaDG) as a heterogeneous catalyst. The ultrasonic irradiation was used to intensify the reaction, and the parameters like reaction temperature, catalyst loading, methanol to oil molar ratio, ultrasonic and duty cycle on the progress of the reaction were varied to determine the optimum set of variables. Methanol to oil molar ratio of 9:1, catalyst loading of 1% (w/w) of waste cooking oil, reaction temperature of 60 °C, low-intensity ultrasonic power of 120 W and 50% duty cycle were found as optimal conditions for the reaction and a maximum biodiesel yield of 93.5% was reported. The conventional stirring method was also compared with the ultrasonic assisted reaction process, and the improvement of the resultant biodiesel properties was highlighted.

Berman et. al. [19] the specifications in ASTM D6751 and D7467 which are related to the fatty acid composition of pure castor methyl esters (B100) and its blend with petrodiesel in a 10% vol ratio (B10) were investigated. Kinematic viscosity and a distillation temperature of B100 (15.17 mm2 s−1 and 398.7 °C respectively) were the only two properties which did not meet the appropriate standard limits. In contrast, B10 met all the specifications. Still, ASTM D7467 requires that the pure biodiesel meets the requirements of ASTM D6751. This can limit the use of a wide range of feedstocks, including castor, as an alternative fuel, especially due to the fact that in practice vehicles normally use low-level blends of biodiesel and petrodiesel.

Benjumea et.al. [20] basic properties of several palm oil biodiesel–diesel fuel blends were measured according to the corresponding ASTM standards. In order to predict these properties, mixing rules are evaluated as a function of the volume fraction of biodiesel in the blend. Kay's mixing rule is used for predicting density, heating value, three different points of the distillation curve (T10, T50, and T90), cloud point and calculated cetane index, while an Arrhenius mixing rule is used for viscosity. The absolute average deviations (AAD) obtained were low, demonstrating the suitability of the used mixing rules. It was found that the calculated cetane index of palm oil biodiesel obtained using ASTM D4737 is in better agreement with the reported cetane number than the one corresponding to the ASTM D976.

Wang et. al. [21] studies the feasibility of biodiesel preparation from a new and promising non-edible feedstock, Datura stramonium L. Oil (DSO). First, important physical–chemical properties, such as oil content of seed (21.4 wt%), acid value (7.93 mg KOH/g) and fatty acid composition of expressed oil, were determined. Second, under the optimal two-step catalyzed reaction conditions, the maximum fatty acid methyl ester (FAME) yield (87%) and FAME content of more than 98 wt% were obtained. Furthermore, the fuel properties of DSO biodiesel were determined and evaluated. Compared with Jatropha curcas L. (JC) and beef tallow (BT) biodiesel, DSO biodiesel possessed the best kinematic viscosity (4.33 mm2/s) and cold filter plug point (−5 °C). Based on the results, D. stramonium L. was identified as a promising species for biodiesel feedstock.

Uzun et. al. [22] Alkali-catalyzed transesterification of waste frying oils (WFO) was carried out in various conditions to investigate the effects of catalyst concentration, reaction time, methanol/oil molar ratio, reaction temperature, catalyst type (hydroxides, methoxides and ethoxides), and purification type (such as washing with hot water, purification with silica gel and dowex) on the biodiesel yields. The optimum conditions were 0.5% wt. of NaOH, 30 min reaction time, 50 °C reaction temperature, 7.5 methanol to oil ratio and purification with hot distilled water. 96% biodiesel yield with ~97% ester content was obtained within in these conditions, and the activation energy was found to be as 11741 J mol−1. The determined specifications of obtained biodiesel according to ASTM D 6751 and EN 14214 standards were in accordance with the required limits. As a conclusion, the present study indicates that WFO derived fuel promises being an alternative for petrodiesel, and could be used in engines without a major modification due to its qualifications.

Kafuku et. al. [23] Croton megalocarpus oil as a non-edible feedstock. C. megalocarpus oil was obtained from north Tanzania. This study aimed at optimizing the biodiesel production process parameters experimentally. The parameters involved in the optimization process were the amount of the catalyst, of alcohol, temperature, agitation speed and reaction time. The optimum biodiesel conversion efficiency obtained was 88% at the optimal conditions of 1.0 wt.% amount of potassium hydroxide catalyst, 30 wt.% amount of methanol, 60 °C reaction temperature, 400 rpm agitation rate and 60 min reaction time. The properties of Croton biodiesel which were determined fell within the recommended biodiesel standards. Croton oil was found with a free fatty acid content of 1.68% which is below the 2% recommended for the application of the one step alkaline transesterification method. The most remarkable feature of Croton biodiesel is its cold flow properties. This biodiesel yielded a cloud and pour point of −4 °C and −9 °C, respectively, while its kinematic viscosity lay within the recommended standard value. This points to the viability of using croton biodiesel in cold regions.

As an outcome of the exhaustive review of available literature in the field of biodiesel production from vegetable oils, physico-chemical characterization and process optimization major finding are obtained which will be discussed later at the end of this chapter.

2.2.2 Utilization of alcohol in CI engine

Joshi et. al. [24] alcohols as alternate fuels in internal combustion engines (ICE) has been accelerating since the middle of 1970 and reached its peak by the middle of 1980. This was due to the serious effect of the exhaust emissions from automotive engines powered with oil-derived fuels coupled with a market rise in the cost of oil-derived fuels. This project leads to the idea of using alcohol in the internal combustion engine such that it reduces the demand for the petroleum products that are going to be extinct in near future. It includes the emissions of harmful gases that can be reduced by the use of alcohol instead of petroleum products. Various fuels have been tested on IC engines for their suitability as alternate fuels. Expect few alcohols, CNG and LPG, not many fuels have been found to be matched with IC Engines requirements.Thus this project is an attempt for the use of an alternative resource such that it can prove to be useful for the peoples in near future.

Srinivasnaik et. al. [25] reviewed the physical and the combustion characteristics of alcohols have been discussed briefly after comparing with the diesel. The production methods of alcohols have been discussed. The safety aspects of alcohols have also been discussed. The fuel which is used in Internal Combustion engines meant for transportation applications will satisfy all the requirements of cost-effectiveness, maximum thermal efficiency, excellent engine performance, and still remain clean enough to protect the environment. Alcohol fuels such as methanol (CH3OH), Ethanol (C2H5OH) are favorable for IC Engines because of their high octane rating, burning velocities, and wider flammability limits. Alcohols can be considered as attractive alternative fuels because they can be obtained from both natural and manufactured sources. The air quality deterioration is a vital issue that needs to be seriously monitored and limited. The transportation system is a major air pollution contributor due to the exhaust emissions such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxide (NOx), carbon dioxide (CO2), and particulate matter (PM). Extensive research and development is difficult to justify until the fuels are accepted as viable for large numbers of engines. Liquid fuels are preferred for Internal Combustion Engines because they are easy to store and have reasonably good calorific value. The main alternative is the alcohol. Methanol and ethanol are two kinds of alcohols that seem most promising fuels and will likely play an increasingly important role in the future.

Udayakumar et. al. [26] conducted experiments on two cylinders, four stroke diesel engine with use of standard Diesel and Alcohol (Butanol and Diethyl ether) on the engine. The study has shown that with the use of these alternate fuels, combustion was found satisfactory when Butanol was injected with Diesel and Diethyl ether was mixed with Diesel in the existing engine. It was found that the Brake Mean Effective Pressure (BMEP) and Brake thermal efficiency (BTE%) were higher when 0.06ml./sec. of butanol was injected into the intake air, whereas Brake Specific Energy Consumption (BSEC) was lower. For other flow rates, the results are similar that of pure diesel. So it is concluded that 0.06 ml./sec. seems to be the optimum rate of butanol to be supplied with diesel. On the other hand, when Diethyl ether was mixed with diesel and tested in the engine, it gives an almost similar performance that of the diesel and it is giving slightly less efficiency and more energy consumption.

2.2.3 Engine Trials and Analysis of Results using Alcohol-Biodiesel Diesel blend as a fuel

Muralidharan et. al. [27] conducted experiments on a single cylinder four strokes variable compression ratio CI Engine fueled by waste cooking oil and its blends with standard diesel to evaluate the performance, emission and combustion characteristics. Fuel blends of 20%, 40%, 60% and 80% were used at a compression ratio of 21 with an engine speed of 1500 rpm for different loading conditions. It was observed that the brake thermal efficiency of the blend B40 increased with the increase in applied load but the exhaust gas temperature decreased with the increase in load. At higher loads, the HC emission was also increased. Biodiesel from different origins has some common properties like lower heating value and high viscosity and density. This can be reflected while measuring the core parameters.

Ozsezen et. al. [28] highlighted two different varieties of biodiesel, namely, Canola Oil Methyl Esters (COME) and Waste Palm Oil Methyl Esters (WPOME) and carried out experiments on a 6 cylinder, water cooled, naturally aspirated, direct ignition Diesel Engine to analyze the performance, combustion and emission characteristics of the engine working at full load conditions with constant speeds of 1000, 1250, 1500, 1750 and 2000 rpm. It is concluded that due to the lower heating value of the BD, the brake power achieved using COME and WPOME was less than that of Petroleum-Based Diesel Fuel (PBDF). The HC, CO, CO2 and smoke opacity got reduced for both the kinds of biodiesel while NOx emissions increased due to higher cylinder temperatures caused by shorter Ignition Delay.

Yilmaz et. al. [29] studied the performance and emission characteristics of two compressions ignited engines of different compression ratios, the number of cylinders, cooling system, and power output are studied. Waste vegetable oil-derived biofuel is used. Engines are fueled with B0, B20 and B100 mixtures. Thermal efficiency, brake specific consumption and engine emissions (CO, Unburned HC, O_2

and NO) are reported and comparisons are made for fuel mixtures running on both engines. Trends of emissions and performance curves are compared to the literature of the available data. It is noted that the biofuel certainly affects unburned HC emissions regardless of engine specifications and/or operating conditions. However, the type of fuel or adding biofuel to diesel may not affect parameters such as exhaust gas temperature and emissions (CO, Unburned HC, O_2, NO). These parameters may change as functions of engine specifications and operating conditions regardless of biofuel or diesel being used. These findings are supported by separate investigations using different biofuels in literature.

Yamin et. al. [30] The results were compared with the characteristics with ordinary diesel. Because of the advanced injection timing caused by the higher bulk modulus of the TWCO (Treated Waste Cooking Oil) blend, the NOx emissions increased whereas the same got reduced when EGR is employed in the engine set up. The reduction in oxygen content due to EGR was quoted as the reason for the above phenomena. One of the major findings in the emission analysis of WCOME fueled CI engines for many researchers is that the harmful NOx emissions normally increased compared with Petro diesel as fuel. There are several methods to offset this characteristic that is commonly referred to as biodiesel NOx effect. Exhaust Gas Recirculation (EGR) is one of the useful modifications that are meant to reduce the NOx emissions of a biodiesel driven CI engine. The combustion and emission characteristics of a four-cylinder direct injection diesel engine with treated waste cooking oil blended with ordinary diesel as the fuel were analyzed employing an external EGR system.

Lin et. al. [31] tested Ultra Low Sulfur Diesel (ULSD) with WCOME on the Heavy Duty Diesel Engine (HDDE) under the US-HDD transient cycle. The authors analyzed the complete emission profile of a heavy duty Diesel engine and reported that due to better combustion efficiency of the WCOB blends, PAH emissions were decreased by 7.53%–37.5% while HC emissions were reduced by 10.5%–36.0%. Particulate Matter (PM) emissions registered a decrease of 5.29%–8.32% and the reduction in CO emissions was recorded as 3.33%–13.1%.

Kalam et. al. [32] used waste cooking oil derived from palm oil and coconut oil was blended with pure diesel in the proportion of 5% WCOME and 95% pure diesel in a multi-cylinder vertical diesel engine. The lower heating values of palm oil and coconut oil reduce the brake power by 0.7% for C5 and 1.2% for P5 blends as compared to pure diesel. Due to the presence of 92% of highly saturated fatty acids in coconut oil compared with that of 50% of palm oil, the exhaust temperature is 1.12% higher for P5 while it is 1.58% for C5. Further, lower Co emission and higher CO2 emissions were recorded for P5 blends whereas lower HC emissions were registered for C5. NOx emissions were reduced by 1% for C5 blend and increased by 2% for P5 blend.

Hirkude et. al. [33] thoroughly investigated the same, working on a single cylinder four-stroke DI diesel engine with blends of Waste Fried Oil Methyl Esters (WFOME) and comparing the performance and emission characteristics with that of mineral diesel. An increase in BSFC of 6.89% and a decrease in BTE of 6.5% were observed by the authors for B50 blend at rated output. With reference to the emissions, 21%–45% reductions in CO emissions 23%–47% reduction in the particulate matter were also found for different blends.

An et. al. [34] conducted Experiments for different loading conditions such as 25%, 50% and 100% at different speeds of 800 rpm, 1200 rpm, 2400 rpm and 3600 rpm on a EURO IV Diesel Engine with pure diesel and WCO biodiesel blends and analyzed the variation of performance, emission and combustion characteristics of the above tests and reported lower HC as well as lower NOx emissions for the biodiesel blends. The BSFC was recorded as higher at partial loads and at low speeds. BTE was recorded as higher at 50% and 100% loads while it was less for 25% load condition.

Koul et.al. [35] conducted an experiment on a single cylinder, direct injection diesel engine and tested blends of octanol in diesel fuel. They replaced up to 20% (v/v) of diesel fuel with octanol and found 10% octanol blend to be an optimum blend in terms of performance and exhaust emissions. It was also concluded that octanol can be used as a blend with diesel fuel in CI engine without any major modification and found 10 % octanol blend to be an optimum blend in terms of performance and exhaust emissions. The experimental engine trial results showed an increase in brake thermal efficiency (BTE) and reduction in brake specific fuel consumption (BSFC) and increased exhaust temperature.

Can et. al. [36] studied the effects of ethanol addition (10% and 15% in volume) to Diesel No. 2 on the performance and emissions of a four stroke cycle, four cylinder turbocharged indirect injection Diesel engine having different fuel injection pressures (150, 200 and 250 bar) at full load were investigated. 1% isopropanol was added to the mixtures to satisfy homogeneity and prevent phase separation. Experimental results showed that the ethanol addition reduces CO, soot and SO2 emissions, although it caused an increase in NOx emission and approximately 12.5% (for 10% ethanol addition) and 20% (for 15% ethanol addition) power reductions. It was also found that increasing the injection pressure of the engine running with ethanol–Diesel fuel decreased CO and smoke emissions, especially between 1500 and 2500 rpm, with respect to Diesel fuel, while it caused some reduction in power.

Dubay et. al. [37] new combination of bio-fuels. For this rationale; the diesel engine operated with blends of Jatropha biodiesel and turpentine oil with a view to completely eliminate dependency on fossil fuel. Jatropha biodiesel (methyl ester) and turpentine oil is a high and low viscosity fuels combination with comparable heating values to that of diesel; this makes conducive for its use in a diesel engine. Extensive experimental work is carried out on a Kirloskar make the single cylinder, naturally aspired diesel engine to examine combustion performance and emission characteristics using Jatropha methyl ester with turpentine oil blends (dual fuel blends) and conventional diesel. Dual fuel blends are found to be the best substitute to conventional diesel fuel in all aspects such as performance and emissions. Further, BT 50 resulted at full load condition, reduction of 2.9%, 4.72%, 4.56%, 42.5% and 29.16% in the brake thermal efficiency, NOx, HC, CO, and smoke respectively while CO2 emissions increased 10.7%.

Rakopoulos et. al.[38] evaluated the effects of using blends of n-butanol (normal butanol) with conventional diesel fuel, with 8%, 16% and 24% (by volume) n-butanol, on the performance and exhaust emissions of a standard, fully instrumented, four-stroke, high-speed, direct injection (DI), Ricardo/Cussons 'Hydra' diesel engine located at the authors' laboratory. The tests are conducted using each of the above fuel blends or neat diesel fuel, with the engine working at a speed of 2000 rpm and at three different loads. In each test, fuel consumption, exhaust smokiness, and exhaust regulated gas emissions such as nitrogen oxides, carbon monoxide and total unburned hydrocarbons are measured. The differences in the measured performance and exhaust emission parameters of the three butanol–diesel fuel blends from the baseline operation of the diesel engine, i.e., when working with neat diesel fuel, are determined and compared. It is revealed that this fuel, which can be produced from biomass (biobutanol), forms a challenging and promising bio-fuel for diesel engines. The differing physical and chemical properties of butanol against those for the diesel fuel are used to aid the correct interpretation of the observed engine behavior.

Li li et. al. [39] revealed the effects of pentanol addition to diesel and biodiesel fuels in different ratios on the combustion and emission of a single-cylinder direct-injection diesel engine. The tests were conducted at a constant speed (1600 r/min) under different engine loads without exhaust gas recirculation. The indicated thermal efficiency using pentanol blends was found to be higher than that of using pure diesel for all of the tested loads from 0.5 to 1.0 MPa indicated mean effective pressure at the test conditions, which is due to its higher maximum heat release rate and shorter combustion duration. An obvious decrease in soot emissions was attained with the addition of pentanol. Moreover, emissions of nitrogen oxides (NOx) were simultaneously reduced compared with using pure diesel fuel at low to middle loads. Furthermore, diesel engine fueled with oxygenated fuel blends can reduce the carbon monoxide and unburnt total hydrocarbons emissions except for the diesel–pentanol blends at low engine load. Finally, the strategy with 40% diesel–30% biodiesel–30% pentanol showed better combustion, emission characteristics as well as economy performance among all the fuels.

Pours et. al. [40] studied the utilization of three blends of 1-hexanol viz., HEX10, HEX20 and HEX30 obtained by mixing 10, 20 and 30% by vol. as a blend component with diesel respectively. Engine tests were carried out at all loads to study the effects of 1-hexanol addition on combustion and emission characteristics of a direct injection diesel engine. Results indicated that addition of 1-hexanol to fossil diesel resulted in longer ignition delays with enhanced premixed combustion phase characterized by higher peaks of pressures and heat release rates (HRR) at the engines standard injection timing without exhaust gas recirculation (EGR). NOx emissions increased at high loads while smoke density reduced at all loads with increasing 1-hexanol content in the blends. Later tests were extended to investigate the effects of injection timing (21, 23 and 25 CA bTDC) and EGR rates (10, 20 and 30%) on engine characteristics for all blends at high engine loads. HEX30 injected at 25CA bTDC under 30% EGR presented the longest ignition delay with 2% increase in peak pressure and peak HRRs when compared to baseline diesel operation. HEX30 at similar conditions was also beneficial in terms of reduced smoke density by 35.9% with a slight penalty in NOx emissions by 3%. Biomass-derived 1-hexanol could be a promising and viable biofuel for existing diesel engines with some modifications.

Liaquata et. al. [41] analyzed engine performance and emissions characteristics of diesel engine using different blend fuels without any engine modifications. A total of four fuel samples, such as DF (100% diesel fuel), JB5 (5% jatropha biodiesel and 95% DF), JB10 (10% JB and 90% DF) and J5W5 (5% JB, 5% waste cooking oil and 90% DF) respectively were used in this study. Engine performance test was carried out at 100% load keeping throttle 100% wide open with variable speeds of 1500 to 2400 rpm at an interval of 100 rpm. Whereas, emission tests were carried out at 2300 rpm at 100% and 80% throttle position. As results of investigations, the average torque reduction compared to DF for JB5, JB10 and J5W5 was found as 0.63%, 1.63% and 1.44% and average power reduction was found as 0.67%, 1.66% and 1.54% respectively. The average increase in bsfc compared to DF was observed as 0.54%, 1.0% JB10 and 1.14% for JB5, JB10 and J5W5 respectively. In case of engine exhaust gas emissions, compared to DF average reduction in HC for JB5, JB10 and J5W5 at 2300 rpm and 100% throttle position found as 8.96%, 11.25% and 12.50%, whereas, at 2300 and 80% throttle position, reduction was 16.28%, 30.23%, and 31.98% respectively. Average reduction in CO at 2300 rpm and 100%

throttle position for JB5, JB10 and J5W5 was found as 17.26%, 25.92%, and 26.87%, whereas, at 80% throttle position, the reduction was observed as 20.70%, 33.24%, and 35.57%. Similarly, the reduction in CO2 compared to DF for JB5, JB10, and J5W5 at 2300 rpm and 100% throttle position was as 12.10%, 20.51%, and 24.91%, whereas, at 80% throttle position, reductions were observed as 5.98%, 10.38% and 18.49% respectively. However, some NOx emissions were increased for all blend fuels compared to DF. In the case of noise emission, sound level for all blend fuels was reduced compared to DF. It can be concluded that JB5, JB10, and J5W5 can be used in diesel engines without any engine modifications, However, W5B5 produced some better results when compared to JB10.

Choia et. al. [42] investigated the effect of diesel fuel blend with biobutanol on the emission of turbocharged CRDI(common rail direct injection) diesel engine. The blends considered here were blends of diesel fuels with 10 and 20% (by vol.) n-butanol. Engine performance and emission characteristics were measured by the ESC(European Stationary Cycle) test. Emissions of HCs, CO, NOx, HCHO, HCOOH, and NH3 were measured by the FTIR. Size and number distribution of particulate matter were measured by the SMPS. From the results, for the butanol blend, NOx emission increased compared with the neat diesel fuel case. At the case of 20% butanol, both THC and CO emissions increased significantly, and both HCHO and HCOOH increased modestly in the low loading of ESC 7, 9, 11 and 13 mode compared with the neat diesel fuel case. While n-butanol blending with diesel fuel reduced the mass of PM by 50~73%, it emitted ultrafine particles (Dp<200nm) slightly more.

Pethkar et. al. [43] reported the effect of biodiesel on diesel engine performances, lubricants, and emissions, published by highly rated journals in scientific indexes, were cited. From these reports, the effect of biodiesel on engine power, durability and emissions and the corresponding effect factors are surveyed and analyzed in detail. The use of biodiesel leads to the substantial reduction in PM, HC and CO emissions accompanying with the imperceptible power loss, the increase in fuel consumption and the increase in NOX emission on conventional diesel engines with no or fewer modification. And it favors to reduce carbon deposit and wear of the key engine parts. Therefore, the blends of biodiesel with small content in place of petroleum diesel can help in controlling air pollution and easing the pressure on scarce resources without significantly sacrificing engine power and economy. However, many further types of research about optimization and modification on the engine, low-temperature performances of the engine, new instrumentation, and methodology for measurements, etc., should be performed when petroleum diesel is substituted completely by biodiesel.

Kumar et. al. [44] explored simultaneous reduction of smoke and NOx emissions using a combination of low EGR, retarded injection timing and diesel fuel reformulation (with low cetane number alcohols) to enable a partially premixed low-temperature combustion (LTC) mode in DI diesel engine. Two higher alcohol/diesel blends, B40 (40% iso-butanol–60% diesel) and P40 (40% n-pentanol–60% diesel) blends were prepared and tested under the combination of three EGR rates (10%, 20% and 30%) and two injection timings (23 and 21 CA bTDC) at high loads and constant engine speed. The performance and emission characteristics of the engine under these conditions are investigated. Results indicate that B40 gives a longer ignition delay, higher peak pressure and higher premixed heat release rate than P40. B40 has superior EGR tolerance and better influence on NOx-smoke trade-off when compared to P40. At retarded injection timing (21 CA bTDC) and 30% EGR, B40 presented simultaneous reduction of NOx (; 41.7%) and smoke (; 90.8%) emissions with diesel-like performance while P40 presented simultaneous reduction of NOx (; 39.3%) and smoke (; 15%) emissions with a small drop in performance. It was found that B40 presented better smoke suppression characteristics than P40. Smoke emissions of both blends increased drastically beyond 30% EGR. HC emissions increased and CO emissions remained low for both blends at all EGR rates. The combination of low EGR, late injection and higher alcohol/diesel blends can achieve partially premixed LTC and reduce smoke and NOx emissions simultaneously.

Prabakaran et. al. [45] performed An Experimental Investigation of diesel-butanol blends in various proportions is conducted in a diesel engine. Nitrogen oxides and smoke emission are the most significant emissions for the diesel engines. Especially, fuels containing high levels oxygen content can have potential to reduce smoke emission significantly. The aim of the present study is to evaluate the influence of n-butanol/diesel fuel blends of higher n-butanol content (as an oxygenation additive for the diesel fuel) on engine performance and exhaust emissions in a diesel engine. Blends take for this study are 30% and 45% of n-butanol along with diesel. Properties of the two blends are determined as per ASTM standards and tested in a diesel engine. The results are compared with diesel as base fuel. The results showed that for both blends there are a decrease NOx emissions for both blends at all loads compared to diesel and decrease of CO emissions at higher loads. However, there is a decrease of BTE and increase of BSFC, emissions of HC.

Sahityaganam et. al. [46] added hexanol in ethanol – diesel fuel to prevent separation of ethanol from diesel in this study. The ethanol blend proportion can be increased up to 45% in volume by adding the Hexanol. Engine performance and emissions characteristics of the fuel blends were investigated on a diesel engine and compared with diesel fuel. Experimental results show smoke emission decreases significantly with the increase of oxygen content in the fuel. When blended fuels are used, nitrogen oxides (NOx) emission is almost the same as or slightly higher than the NOx emission when diesel fuel is used. Cylinder pressure and Heat release are slightly increased when the engine was fueled with ethanol – Hexanol – diesel blends. Hexanol-ethanol diesel blended fuel slightly improves the performance of the engine.

Paula et. al. [47] studied the effect of the addition of jatropha biodiesel to mineral diesel on the performance and emission characteristics of a conventional compression ignition engine have been experimentally investigated and compared with simulated data using the Diesel-RK software. The experiments were carried out using pure diesel (B0) and pure jatropha biodiesel (JB100) as fuels. The performance characteristics show that brake specific fuel consumption (BSFC) increases and brake thermal efficiency decreases with the use of jatropha biodiesel. Experimentally, pure diesel has maximum efficiency 29.6%, whereas pure biodiesel has a maximum efficiency of 21.2%. In the simulation, the pure diesel has maximum efficiency 30.3%

where as pure jatropha biodiesel has the maximum efficiency of 27.5%. In respect of emission characteristics, NOx emission is found to increase with load as well as the use of biodiesel in both experimental and simulation study. After the successful validation of the numerical study with the experimental, another simulation was done, where the performance, combustion and emission characteristics of the same engine fueled with pure diesel (B0), pure jatropha biodiesel (JB100) and 50% jatropha blend (JB50) were derived. In the numerical study, it is found that with the use of jatropha biodiesel the BSFC increases whereas brake thermal efficiency decreases. Combustion characteristics show an increase in peak cylinder pressure and a decrease in ignition delay period with the increase in biodiesel share in the blends; whereas the emission of NOx and CO2 increases; smoke and PM emission decreases for the same.

Kwona et. al. [48] measured the flash point of decanol by using a Tagclosed tester, a Seta-flash-closed tester, a Pensky–Martens-closed tester and a Cleveland-open tester at the National Research Institute of Fire and Disaster (NRIFD) in Japan and the Korea Fire Equipment Inspection Corporation (KOFEIC) in Korea. The flash points measured were compared to data of the references. The flash points determined at NRIFD were similar to those of KOFEIC. However, the flash points 112 and 115 1C of n-decanol, measured at the NRIFD and 117 and 120 1C at the KOFEIC, respectively, were much different from those in MSDS and literature. Therefore, manufacturers should be more careful when they make MSDS.

Fernandez et. al [49] used straight (in modified engines) or blended alcohols with fossil fuel provide an attractive alternative fuel for internal combustion engines. Moreover, alcohol can be produced by bio refineries, thus reducing the use of fossil resources. However, main achievements in this field correspond to the use of short-chain alcohols, like ethanol, while there is little experience with higher alcohols. In this work, the performance of a direct-injection diesel engine, without any modifications, fueled with 1-pentanol/ diesel fuel blends has been evaluated. Blends with 10% pentanol/90% diesel fuel, 15% pentanol/85% diesel fuel, 20% pentanol/80% diesel fuel and 25% pentanol/75% diesel fuel (v/v) were tested and engine performance results were compared with those provided by neat diesel fuel.

Experimental results showed insignificant engine power, brake thermal efficiency, and brake-specific fuel consumption variations when the engine was fueled with the majority of the blends instead of straight diesel fuel. Moreover, statistical analysis showed no significant differences between the blends and diesel fuel (EN 590) tests. During engine starting, no difficulties were experienced and the engine performed satisfactorily on the blends throughout the entire test. On the basis of this study, pentanol/diesel fuel blends can be considered acceptable diesel fuel alternatives if exhaust emissions and long-term engine tests show acceptable results.

Armas et. al. [50] worked on a turbocharged, direct injection (DI), diesel engine equipped with common rail injection system and EGR strategy was tested during the starting. The engine was tested at relatively cold and warm start. Pollutant emissions (HC, NOx, smoke opacity and particle size distributions), in-cylinder pressure and operating parameters such as rotation speed, relative fuel–air ratio and EGR valve position were registered during the tests. The engine was fueled with a pure low sulfur diesel fuel and blended with ethanol and butanol. Fuel blends were prepared with the same oxygen content (~3.3% in mass). The results show that alcohol diesel blends lead to a positive effect on the reduction in the smoke opacity and particle concentration during warm engine start with similar nitrogen oxide (NOx) emissions. At cold start, blends tested produced combustion instabilities. This fact, jointly with the inefficient operation of the diesel oxidation catalyst, produced an increase of all regulated pollutant emissions.

Gopal et. al. [51] identified Biodiesel as a potential alternative fuel for CI engines because the use of biodiesel can reduce petroleum diesel consumption as well as engine out emissions. Out of many biodiesels derived from various resources, Biodiesel from Waste Cooking Oil (WCO) can be prepared economically using usual transesterification process. In the present study, in-depth research and comparative study of blends of biodiesel made from WCO and diesel are carried out to bring out the benefits of its extensive usage in CI engines. The experimental results of the study reveal that the WCO biodiesel has similar characteristics to that of diesel. The brake thermal efficiency, carbon monoxide, unburned hydrocarbon and smoke opacity are observed to be lower in the case of WCO biodiesel blends than diesel. On the other hand, specific energy consumption and oxides of nitrogen of WCO biodiesel blends are found to be higher than diesel. In addition, combustion characteristics of all biodiesel blends showed similar trends when compared to that of conventional diesel.

2.3 LITERATURE OUTCOME

2.3.1 Biodiesel production

As an outcome of the exhaustive review of available literature in the field of biodiesel production from vegetable oils, physicochemical characterization and process optimization the following major finding are obtained:

1. with some exceptions, most of the non-edible oils have high free fatty acid contents leading to a two-stage transesterification process to produce biodiesel.
2. The energy consumption in two-stage transesterification is higher. Therefore, optimization of process parameters is must in high FFA non-edible oil seeds for commercial scale production.
3. In many reported cases the final biodiesel sample produced did not comply with the designated standards of ASTM/EN/ISO etc. resulting in the further addition of additives and post processing.

In the light of above review, it may be stated that the production of biodiesel from waste cooking oil with optimized parameters and the subsequent compliance with the corresponding international may prove the suitability of this vegetable oil as a true alternative to mineral diesel.

2.3.2 Engine trials

As an outcome of the elaborative review of existing technical literature regarding the engine trial results of biodiesel from a wide range of vegetable oil feedstocks and its blends, the following conclusion is made**.**

1. Depending upon the feedstocks, some of the biodiesels showed improved brake thermal efficiency and reduced brake specific fuel consumption with increased biodiesel volume fraction in the test fuel drt6whereas some others exhibited exactly opposite trend. Therefore, engine performance using biodiesel depends upon the property of the corresponding feedstock and transesterification process.
2. Most of the literature reported that the oxides of nitrogen increased with the addition of biodiesel whereas CO and unburnt hydrocarbon were reduced. However, in many cases reduction in oxides of nitrogen was reported.

In the light of above reviews and outcomes, it may be concluded that comprehensive engine trials to evaluate the performance, emission, and combustion on diesel engine fuelled with blends of decanol and biodiesel are about in the literature. Therefore, exhaustive engine trials using decanol biodiesel blend at various proportions and the subsequent analysis may provide a clear picture regarding this blend as an alternative fuel to diesel.

2.3 PROBLEM STATEMENT

In the context of detailed and valuable literature review, the problem statement for the present research was devised. It was clear that the most popular usage of vegetable oils in diesel engine was the conversion to methyl esters or biodiesel to address the high viscosity of vegetable oils. The conversion generally is known as transesterification that may be a single or double step process based on the FFA content of the vegetable oils. If some of the properties of biodiesel after transesterification is not matched with the ASTM standards then some additives may be added to make it useful in a diesel engine as a blend. The performance and emission behavior of a diesel engine fuelled with these set of test fuels will validate the suitability of these fuels. Looking at the FFA of waste cooking oil, the two-stage transesterification was to be done with some optimization process like catalyst concentration, reaction time and reaction temperature. Measurement of all the physico-chemical properties of test fuels by corresponding instruments was done properly. A comprehensive engine trial will be carried out to assess the performance, emissions behavior of an actual diesel engine fuelled with WCOME and its blends and its comparison with the baseline diesel operation.

CHAPTER3

SYSTEM DEVELOPMENT & METHODOLOGY

3.1 INTRODUCTION

This section comprises of execution of the three steps described in the problem statement i.e. is mentioned in literature review section. It introduces the production of biodiesel from waste cooking oil, preparation of various blends by mixing Decanol and prepared biodiesel, measurement of physic-chemical properties, development and experiment procedure of engine test rig. They all are explained briefly as follows.

3.2 WASTE COOKING OIL AVAILIBILTY

There are almost 9000 fast food chains and restaurants including 3 star, 4 star and 5 star in Delhi and NCR region. On an average, every restaurant produces around 50-60 L of oil which is not used repeatedly in a day. Every fast food outlets produce around 25-30L of oil in a day. The quantity of waste cooking oil is around 35-40 thousand liters per day which is an enormous figure. This much amount of WCO can be converted into biodiesel to get a neat and clean fuel. In context of the present study, WCO is collected from DTU canteen.

3.3 PREPARATION OF BIODIESEL

3.3.1 Determination of FFA content in the WCO

Determining the FFA content is essential because it helps in deciding the type of transesterification process will be used. If FFA content is found to be less than 2.5 weight% then transesterification process will be alkali based else it will be acid based. Titration is performed to determine the FFA content of the feedstock oil. Under this, phenolphthalein indicator solution was prepared in which mixing of 0.05g phenolphthalein was done with 50ml ethanol and 50ml of distilled water. After this, stirring of the solution was done for few seconds and hence phenolphthalein indicator solution is prepared. Another solution is prepared which contains 1g of NaOH is mixed with 100ml of distilled water and then we dilute it by adding 900ml of distilled water. This solution is poured into the burette.

In another beaker, mix 1ml of sesame oil with 10ml of methanol. Mix two or three drops of phenolphthalein indicator in the oil and alcohol solution. After this, 0.1% NaOH solution is added into oil-alcohol-phenolphthalein solution using burette till the solution in the beaker appears pink. As soon as pink color appears in a beaker, titration is assumed to be completed. The FFA content is calculated according to the amount of 0.1% NaOH solution used in titration.

3.3.2 Preparation of sample

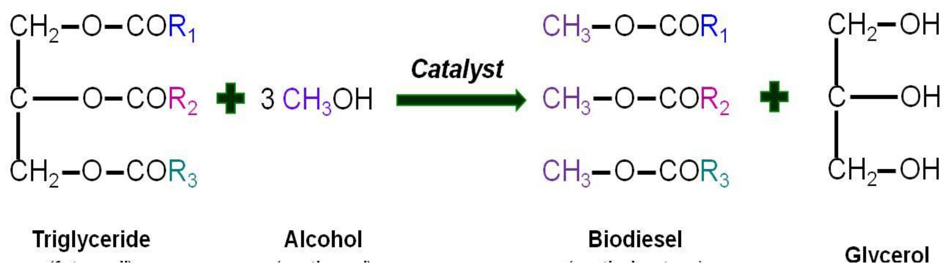
a.) Heat the oil up to 100^0C so that if there is any moisture content in the raw oil, it gets flashed off into vapors and our oil remains moisture free.

b.) In the second step, we prepare catalyst solution till our oil temperature reaches the temperature of about 60^0C. Depending upon the molar ratio, we choose the amount of KOH and methanol to prepare the catalyst. There are following steps will be performed:-

1. Take the specific amount of oil by weighing it on digital weight balance. On the filter paper followed by heating the oil up to 100^0C to remove any probable moisture.

2. Take 5% of WCO as potassium hydroxide (KOH) and 20% of WCO as methanol and stir it well so that KOH gets completely dissolved in the methanol. This was carried out manually by using glass rod and it took about 5 minutes to dissolve it completely. If it is to be produced on large scale we can use mechanical stirrer.

3. As soon as mixing is done and oil temperature reaches 60^0C, pour the catalyst solution in the beaker containing oil. Don’t mix the solution when the oil is at high temperature as methanol will evaporate. The corresponding reaction is shown in following in equation 3.1:



(3.1)

4. It will take approximately 2-2:15 hours to form biodiesel. Because of mechanical stirring followed by regular measurement of the temperature of the sample the formation of biodiesel will start. To check the formation of biodiesel, glycerin deposition will be seen at the base of the container.

After this procedure, pour the content into separating flask, so that glycerin gets settled down at the base of the flask. Allow glycerin to settle down properly for a day. Then after separate the oil from glycerin.

3.3.3 Water washing

1. For water wash process, take water 35% of the weight of the oil and heat it till it reaches 40^0C. Pour that water into the flask containing biodiesel so that catalyst can be separated by dissolving it in water. And remove water after 1 hour. Repeat this step 4-5 times until we start getting clear water.

2. Heat the oil depending on its weight so that water get off into vapors and to get the clear biodiesel.

3.4 DECANOL

Decanol is a tenth member of alcohol family contains straight alcohol and ten carbon atoms with the chemical formula $C_{10}H_{22}O$. In context to its physico-chemical property, it has a light yellow thick liquid that is not soluble in water and also has an aromatic odor. The surface tension with respect to water is 8.97 mN/m at 20°C which signifies its molecular forces. The chemical structure of Decanol is represented in plate 3.1:

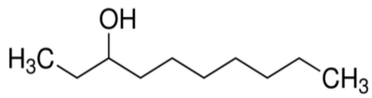


Plate 3.1: Chemical formula of Decanol

Decanol is prepared by decanoic acid by hydrogenation. Decanoic acid can be obtained in coconut oil approx. 10% and palm kernel oil approx 6%. Ziegler process is the method of production too. Manufacturing of plastics, lubricants, surfactants, and solvents can be done by Decanol that is also beneficial for industries. The physical properties of Decanol is represented in Table 3.1

Table 3.1 Physical properties of decanol [62]

Property	**Value**
Boiling point	230°C
Melting point	7°C
Density	0.83 g/cm³
Flashpoint	108°C
Auto-ignition temperature	255°C
Relative vapor density (air = 1)	5.5
Solubility in water, g/100ml at 20°C	0.37
Vapour pressure, Pa at 20°C	1
Relative density of the vapor /air mixture at 20°C	1.01

3.5 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 a homogenous solution.

WCOME signifies waste cooking oil methyl ester. All blends are formed by fixing the amount of diesel at 80% and varying the amount of decanol and biodiesel within the range of 0-30%. All the nomenclature is represented in Table 3.2. W5D5 refers to the blend formed by mixing 5% volume of waste cooking oil biodiesel, 5% volume of decanol and 90% volume of diesel fuel.W10D5 refers to the blend formed by mixing 10% volume of waste cooking oil biodiesel, 5% volume of decanol and 85% volume of diesel fuel. W10D10 refers to the blend formed by mixing 10% volume of waste cooking oil biodiesel, 10% volume of decanol and 80% volume of diesel fuel. Similarly, for W10D15 and W15D15 blends are formed by mixing 75%, 70% by volume of diesel, 15% by volume of decanol and 10%, 15% by volume of waste cooking oil biodiesel respectively. The different blend formed are shown in plate 3.2.

Table: 3.2 Nomenclature of various test fuel

S.N.	**Name**	**Composition**
1.	WCOME	Waste Cooking Oil Methyl Ester
2.	Decanol	n-Decanol
3.	W5D5	5% WCOME + 5% Decanol + 90% Diesel
4.	W10D5	10% WCOME +5% Decanol + 85% Diesel
5.	W10D10	10% WCOME +10% Decanol + 80% Diesel
6.	W10D15	10%WCOME + 15% Decanol +75% Diesel
7.	W15D15	15%WCOME + 15% Decanol + 70% Diesel

The prepared samples are shown along with nomenclature:

Plate 3.2: Test fuel samples formed during experiment

3.5 HOMOGENEITY TEST

Homogeneity test is done to analyze the uniformity of the samples. Here, uniformity is defined in terms of phase separation. All the test samples were kept for two months in enclosed bottles and were supervised regularly to find phase separation and homogeneity.

3.6 PHYSIO-CHEMICAL CHARACTERISATION OF TEST FUELS

Physico-chemical properties are very important factor in the context of performance and emission characteristics so the standardization of all the test fuels is necessary including diesel and neat WCOME. Therefore, 7 samples were prepared each contains 250cc consisting of neat diesel and WCOME followed by W5D5, W10D5, W10D10, W10D15 and W15D15 with 10%, 15%, 20%, 25% and 30% volume wise replacement of diesel fuel by varying the content of Decanol and WCO. Baseline was defined by neat diesel. The properties which were evaluated during the present investigation and experimental procedure are mentioned below:

3.6.1 Density

Density is defined as mass per unit volume. This parameter was measured at room temperature with the help of a U-Tube Oscillating True Density meter of make "Anton Paar", model number "DMA 4500". The density of diesel along with all blends was measured and compared with the density of diesel. The instrument (U-Tube Oscillating True Density meter) used for density measurement is represented in plate 3.3. The procedure for measuring the density was very fundamental. First, the electrical power was switched on followed by taking 10cc of toluene in the injection and pushed it into injection port to rinse fuel pipeline. The measurement time was approximately 7-8 minutes to provide a suitable value of specific gravity and density of the test fuel. The same procedure was followed 2-3 times for each sample to have a satisfactory result. Further, the average of all the values was taken to get the final value for every sample. The comparison of the density of every sample is shown in next chapter.

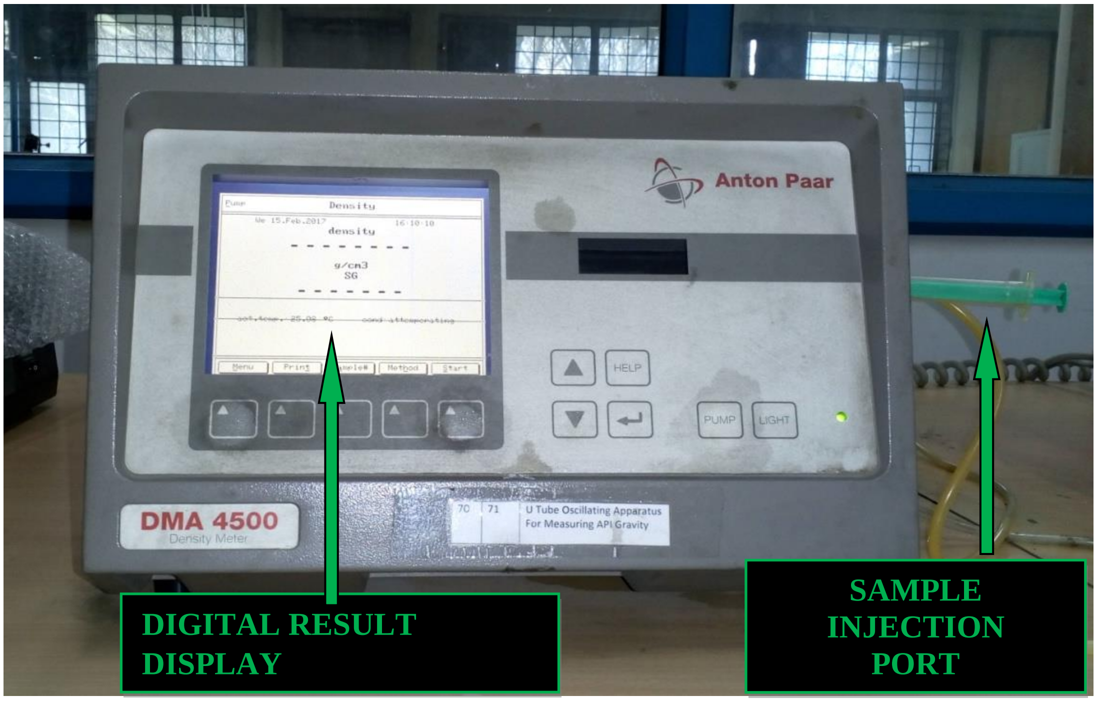


Plate 3.3: U-Tube Oscillating True Density meter

3.6.2 Viscosity

The resistance of flow due to internal friction of fluid which is subjected to external forces is known as viscosity. During injection of fuel, atomization of fuel takes place which is affected by viscosity. If the variation in the value of viscosity is too low or too high then the mixing of air and fuel, as well as atomization of fuel in the combustion chamber, may get affected severely. For different test fuels, the viscosity was measured in terms of kinematic viscosity. The kinematic viscosity of liquid fuels was measured using Kinematics Viscometer of make "Petrostat" as shown in the plate 3.4 at 40^{o}C as per the specification is given in ASTM D445. A standard capillary tube was selected in which a particular amount of fuel is taken that was allowed to flow through the capillary. The procedure was very simple. Firstly a capillary tube was selected followed by taking some amount of the sample and allowed it for free flow through it. Time was recorded by stopwatch in seconds (equation 3.2) as liquid flow through the corresponding marks one on the upper and second id on the lower side of the capillary tube.

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

$$V = c * t \qquad \textbf{\textit{(3.2)}}$$

Where,

V = Kinematic Viscosity

c = constant; mm^2/sec^2 (c = 0.005675 mm^2/sec^2)

t = time, in sec

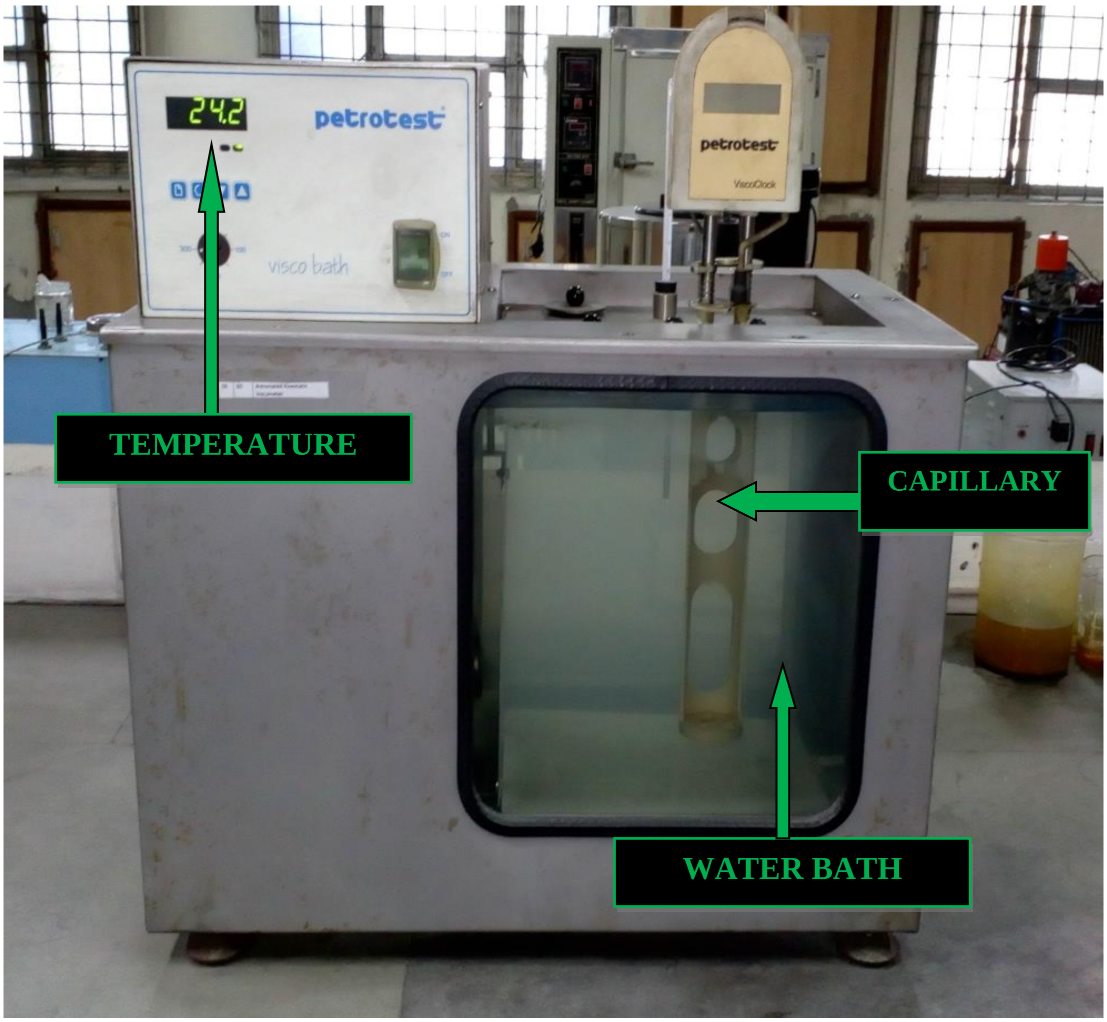


Plate 3.4: Petrotest Viscometer

3.6.3 Calorific Value

The energy contained in a fuel or food, determined by measuring the heat produced by complete combustion of a specified quantity in it which is generally expressed in joules per kilogram. This parameter was determined with the Isothermal Bomb Calorimeter as per the specification given in ASTM D240. The calorimeter model was “Parr 6100 Calorimeter”. At constant volume, the combustion of fuel takes place in the presence of oxygen. The ignition of fuel was done by an electrical method. Oxygen was supplied by a cylinder which had compressed oxygen. After few minutes, the fuel had burnt completely and the results were displayed in the instrument. The schematic diagram of corresponding bomb calorimeter is represented in plate 3.5:

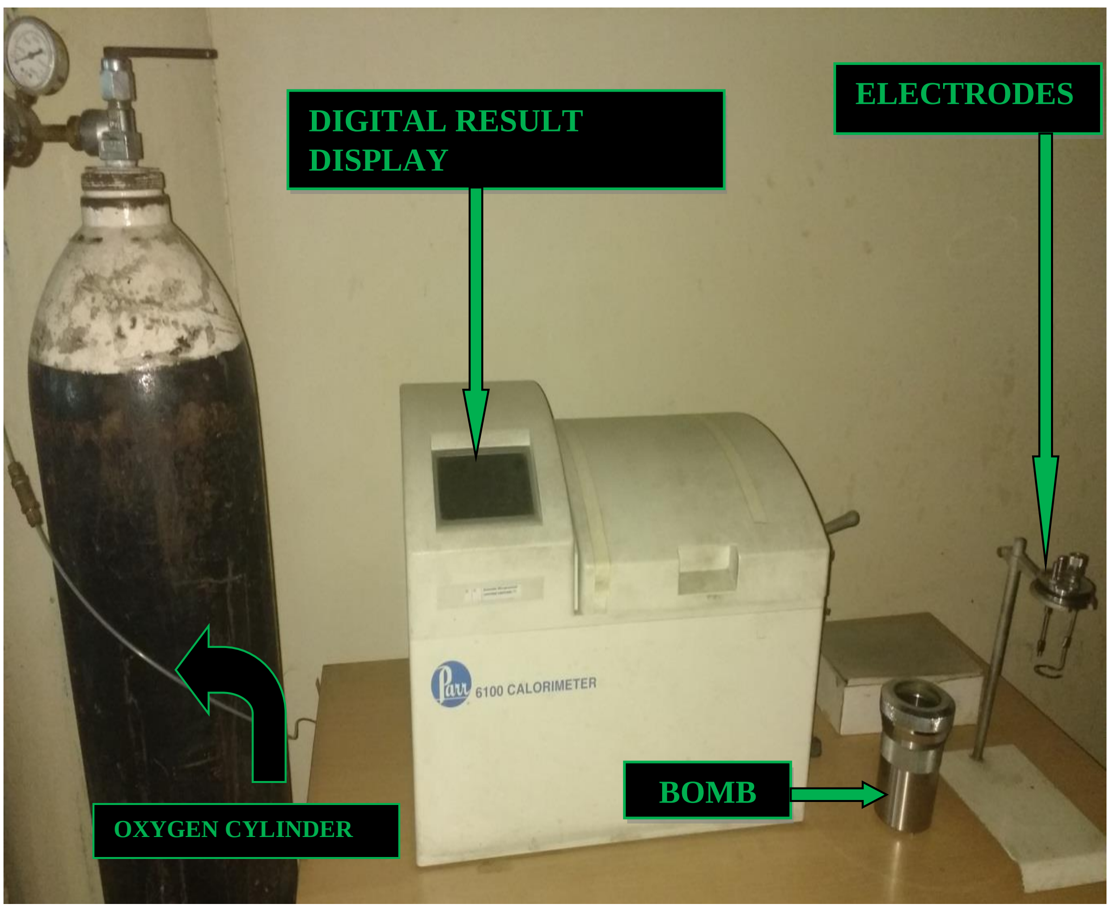


Plate 3.5: Parr 6100 Bomb Calorimeter

3.7 SELECTION OF DIESEL ENGINE

Indian economy is one of the pillars of the development of India. Due to the high efficiency and rough use of diesel engine, they can be easily used in transportation, agriculture and industrial sectors which ultimately lead to the strong Indian economy. On the other hand, they also emit unwanted and harmful emissions leading to a polluted environment. Hence it is essential to regulate the trend of increasing emissions by modifying the fuel in CI engine which is the major parameter to have a considerable change in the atmosphere. Concerning about practical aspects, there are a number of reasons to use a single cylinder and light duty diesel engine is used. Firstly, it is generally operated in the above-mentioned sectors and also they are very portable that can be carried anywhere in the rural areas where renewable energy modes are not available. Secondly, these engines are part of Indian economy especially agrarian economy, that is why it is \chosen for the current experimental procedure.

3.8 DEVELOPMENT OF ENGINE TEST RIG

Setup contains hand cranked, single cylinder, four strokes, air cooled (radial cooled), vertical, totally enclosed, direct injection, cold starting, naturally aspirated , gravity feed fuel system with efficient paper element filter , force feed lubrication to main and large end bearing and camshaft bush diesel engine that is connected to dynamometer (eddy current type loading). The test rig is represented in plate 3.7. There is a provision with necessary instruments for measurement of combustion pressure and crank angle. It is also made for airflow, the flow of fuel, temperature analysis and measurement of the load. There is a panel box contains air box, two fuel tanks for fuel test, manometer, fuel measuring unit. There is a rotameter installed for measurement of flow rate of fuel. The final setup enables the measurements of various important parameters like brake thermal efficiency, indicated mean effective pressure, brake mean effective pressure, frictional power, mechanical efficiency, specific fuel consumption, indicated thermal efficiency, A/F ratio, brake power and indicated power.

The technical specification of the corresponding engine are listed below in Table 3.3

Table 3.3: Technical specification of the diesel engine

Make	**Kirloskar**
No of cylinder	1
Bore x stroke	95 x 110mm
Cubic capacity	0.78 Lit.
Compression ratio	17.5:1
Rated output as per BS514//ISO 1000	5.9 KW at 1500 rpm
Starting	Hand start with cranking handle
SFC at rated hp/1500 rpm	251 g/KWh
Fuel tank capacity	11.5 lit.
Fuel tank refilling time period	Every 6.9 hours engine running at rated o/p
Engine weight w/o flywheel	118 kg
Weight of flywheel	64 kg
Rotation while looking at flywheel	clockwise
Cooling system	Air cooled
Dynamometer	Eddy current

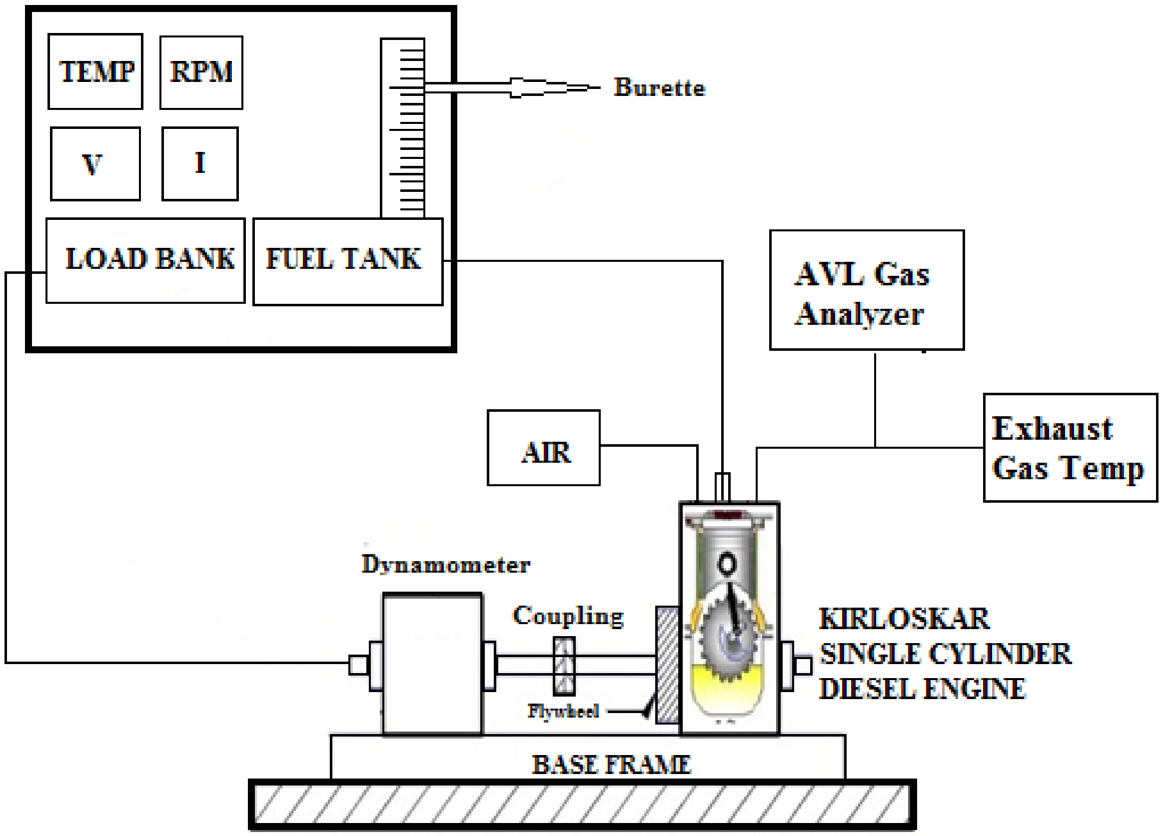


Plate 3.7: Schematic diagram of experimental test rig

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 were installed in the exhaust manifold. The AVL 437 smoke meter and AVL Di gas analyzer were also involved in the nearby region for analysis of temperature of various exhaust gases.

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

3.9 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 rig.

1. Alternator voltage
2. Alternator current
3. RPM sensor
4. Exhaust gas temp at inlet
5. Exhaust gas temp at outlet
6. Fuel inlet and outlet across heat exchanger
7. Fuel consumption rate
8. AVL 437 smoke meter
9. AVL Di gas analyzer

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

3.9.1 RPM of the Engine:

For accurate measurement of speed, the best method is to count the number of revolutions in given time. In this study an ‘MTC’ make digital panel tachometer with proximate/photo reflective sensor was used for measurement of RPM of the engine. The magnetic pickup will produce a pulse for every revolution and a pulse counter will accurately measure the speed of the engine.

This instrument is capable of functioning in the range of 1 to 9.999 rpm with a sampling time of 1 second. A nut was welded on the flywheel face and sensor was mounted on a bracket near the flywheel in such a way that the distance was less than 5mm. A digital display unit is mounted on the panel board. The tachometer used in this study is shown in the plate 3.8:

Plate 3.8: Engine speed measurement

3.9.2 Fuel Consumption Measuring Systems

The fuel consumption of the engine is measured by determining the volume in a given time interval and multiplying it by the specific gravity of the fuel. To get an accurate value it should be measured occasionally. Another method which can be used to measure the time required for consumption of given mass of fuel. The brake specific fuel consumption was calculated by using the following relationships.

BSFC = (Vol. of fuel consumed*density of fuel*3600)/ (bp*t)

Where, BSFC = brake specific fuel consumption, g/Kw-h

BP = brake power, kW

t= time taken to consume cc of fuel, sec

Plate.3.9: Fuel measurement system

3.9.3 Temperature measurement

To measure the exhaust temperature, a socket was welded on the exhaust pipe, before the muffler, and a chromel Almelo K-type thermocouple was mounted on it. Digital temperature display unit was mounted for getting the output of thermocouple attached for the measurement of exhaust gas temperature which is shown in plate 3.10.

Plate.3.10: Temperature Sensor

3.9.4 Load Bank

The engine is loaded using a load bank comprising of two 300 W tungsten electrodes bulbs and Ten 500 W tungsten electrode bulbs. The load on the engine is varied through a series of individual switches. The load bank comprises of a digital ammeter, a digital voltmeter, speed sensor and thermocouple to measure exhaust gas temperature, burette, and manometer. It also houses fuel tanks for the two fuels used- 42 cetane and 91 octane petrol.

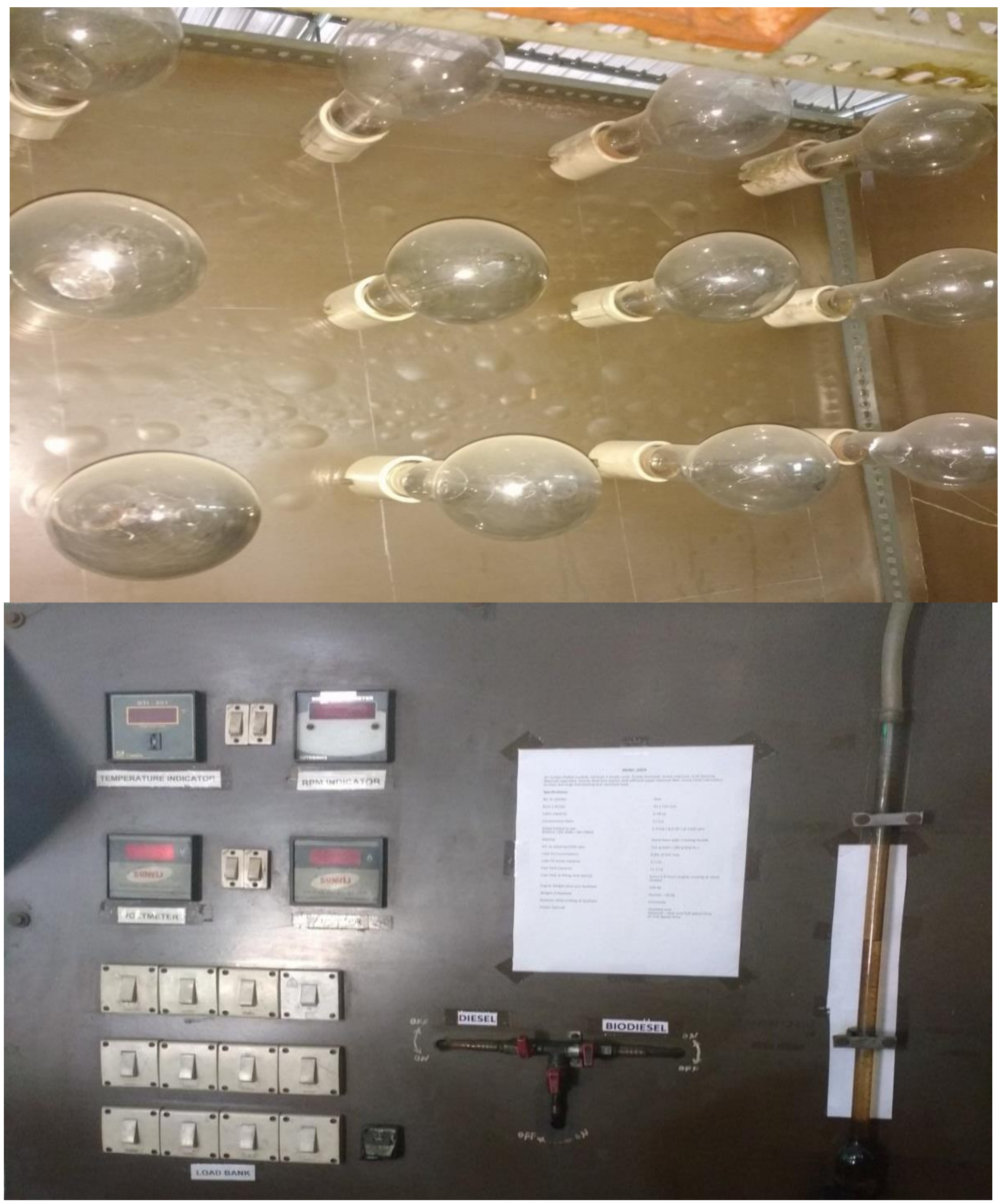


Plate 3.11: Load Bank Control panel

3.10 EXHAUST EMISSION ANALYSIS

3.10.1 AVL 437 Smoke meter

To measure the smoke capacity, AVL 437 smoke analyzer was used. The fundamental measurement of these instruments was recorded in terms of opacity. The light beam was projected across a flowing stream of exhaust gases, suspended soot particles absorbed the definite portion of light. The remaining part of light strikes on the photocell, generating a photoelectric current which defines smoke density.

Plate 3.12: AVL 437 Smokemeter

Table 3.4 Specifications of AVL Di-Gas 4000 light and AVL smoke meter

Emissions sensor	**Measurement range**	**Resolution**
CO	0-10 % vol	.01% vol.
CO_2	0-10 % vol	.1 % vol
NO_X	0-5.000 ppm % vol	1 ppm
HC	0-20.000 ppm % vol	1 ppm
AVL smoke meter	0-100 % vol	1%

3.10.2 *AVL Di Gas 4000 Exhaust Gas Analyser*

There are a lot of emissions produced from 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. These instruments are calibrated regularly using a 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 plate 3.13. Technical specifications of AVL Di-gas 4000 light and smoke meter are outlined in following table 3.4

Plate 3.13: AVL Di Gas 4000 Light Exhaust Gas Analyser

3.11 MEASUREMENT METHODS AND CALCULATIONS

The major components of test rig are measuring unit for fuel consumption, load bank for load variation, thermocouples, and emission measurement equipment. The engine was started with standard fuel that is diesel and allowed to run for almost half an hour to stabilize all the parameters which are represented in control panel. Then the corresponding readings were noted down after prescribed thirty minutes. WCOME and Decanol blends were connected to the engine for observations followed by varying the load by load bank. The performance parameters like brake power, brake thermal efficiency, and brake specific fuel consumption are calculated by theoretical approach. The methodology to find out these parameters are described below

3.11.1 BRAKE POWER

The brake power is calculated by following equation 3.1. The rated power of the engine is 5.5 kW at 1500 rpm but engine hardware was able to operate smoothly up to 5 kW. The dynamometer is connected to the voltmeter and ammeter for measurement of corresponding parameters in control panel.

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

Where,

V = voltage recorded by voltmeter

I= Current recorded by ammeter

3.11.2 BMEP

The BMEP is also calculated by following formula:

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

Where,

L= stroke length(m)

A= piston area (m^2)

N= Engine rpm (rps)

3.11.3 BRAKE THERMAL EFFICIENCY

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

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

Where,

m= mass flow rate of the fuel (kg/s)

CV= calorific value of the fuel (KJ/kg)

3.11.4 BRAKE SPECIFIC ENERGY CONSUMPTION

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

$$BSEC\left(\frac{MJ}{kWh}\right) = \frac{m\ x\ C\dot{V}\ x\ 3600}{brake\ power}$$

Where,

m= mass flow rate of the fuel (kg/s)

CV= calorific value of the fuel (KJ/kg)

3.12 ENGINE TRIAL 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 (approximate 30 minutes) till the steady state condition is reached. Time elapsed for the consumption of 10cc, 20cc, and 30cc of fuel was recorded and an average of them was noted down with the help of fuel measuring unit and stopwatch. Exhaust temperature, smoke density, fuel consumption, RPM, CO, NO_X, HC, CO_2 and power o/p was measured. Leakage of fuel from the injector was also recorded with the help of small measuring cylinder. The engine was loaded with the corresponding loads keeping the speed in the 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, decanol, and biodiesel was tested and compared with the CI engine fuel. Then subsequently all blends were tested followed by the same procedure and their performance and emission characteristics were evaluated. Comparison of this parameter was successfully done with the diesel fuel. The engine was always started with the diesel fuel, run it for 25-30 minutes before switching it on blends to get a steady state. To turn the engine off, each and every blend was replaced with diesel oil and it was run on diesel till all the blend is consumed in the fuel pipe and filter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The experiment was performed on in CI engine without any modification executed in it. The motive of the current study is to operate the diesel engine with the blend of Decanol, waste cooking oil methyl ester and diesel followed by performing the experiment to measure emission and performance parameters. In this chapter, all the physico-chemical properties along with performance and emission parameters have been shown graphically and explained too theoretically.

4.2 PHYSICO-CHEMICAL CHARACTERISATION

Analysis of diesel along with different test fuels was done for corresponding properties physically, chemically and thermally. Some of the properties like viscosity and density of test fuels have a higher value than diesel. Combustion properties and emission have been superior to diesel due to the presence of oxygen in the test fuels. However, the 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 procedure and measurement of physico-chemical properties have been discussed below one by one:

4.2.1 Viscosity

Measurement of viscosity was done by using “Petrotest Viscometer” which is discussed in earlier sections. Figure 4.1 represents the variation of density of WCOME, decanol and corresponding blends. After testing the neat decanol it was found highly viscous but after blending it with diesel that has viscosity 4.59 cSt according to ASTMD6751, then all the blends had viscosity under ASTM standard range. The WCO had viscosity 37.24 cSt which is reduced by transesterification. Further, WCOME had 5.56176 cSt which is also in the desired range.

During measurement and also as per literature review it was reported that the measurement time is directly proportional to the viscosity that is highly viscous liquid will take more time than that of less viscous liquid. According to the graph, the value of W15D15 is maximum that is equal to 5.493 cSt. The viscosity of all the blends have been measured successfully by the corresponding instrument and also compared with the diesel and neat WCOME and Decanol.

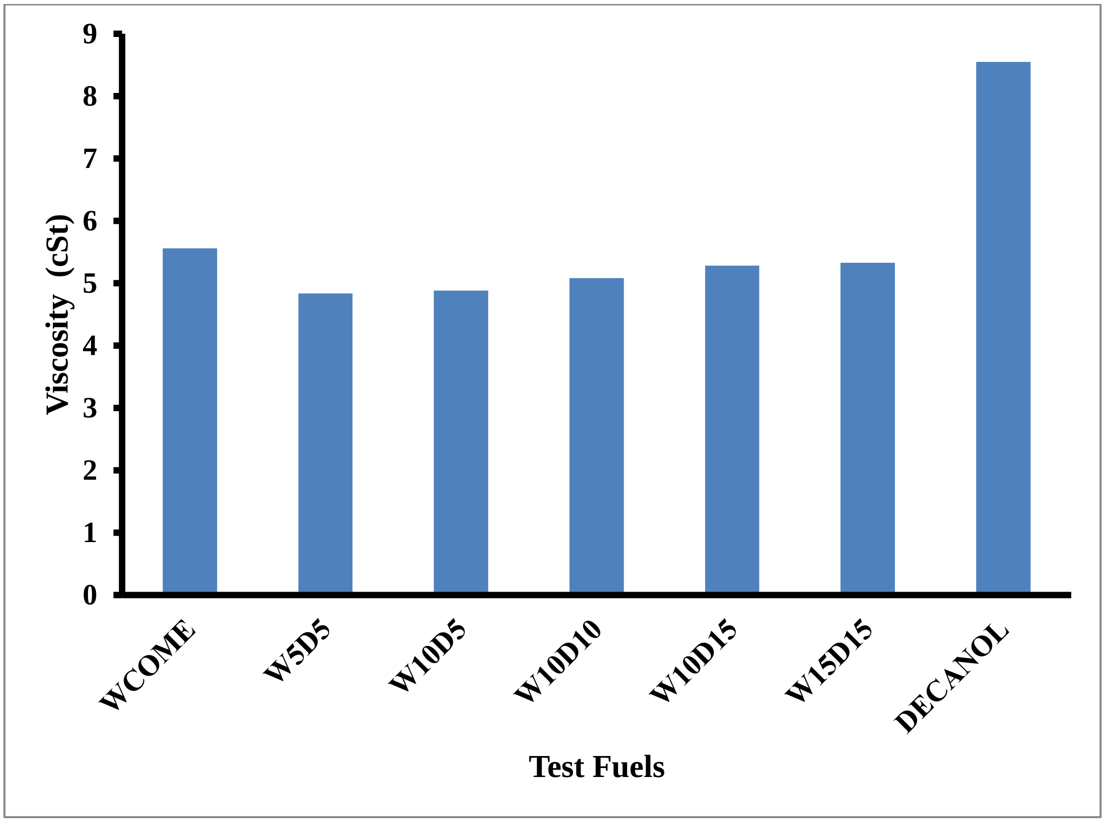


Fig 4.1: Comparison of viscosity of test fuels

4.2.2 Density

Oscillating "U" tube density meter, which is discussed briefly in the previous chapter, was used for measuring the density of test fuels. Density is a key parameter that directly affects the engine performance and emission behavior. Cetane rating of fuels, as well as heating value, are linked to density [52]. Higher density will create a difficulty in the injection of fuel. Density effect is also less sensitive than the viscosity. Fig 4.2 represents the variation of density between various test fuels. The density of diesel along with all blends was measured and compared with the density of diesel.

The density of corresponding waste cooking oil was found 0.93394 g/cc. According to the graph, as shown in fig 4.2, it was found that W15D15 had a higher density than all the test fuels. High density signifies poor atomization of fuel when it is discussed in the context of CI engine injection procedure. On the other hand, W5D5 had less viscosity than all of the test fuel and that is equal to 0.841 g/cc.

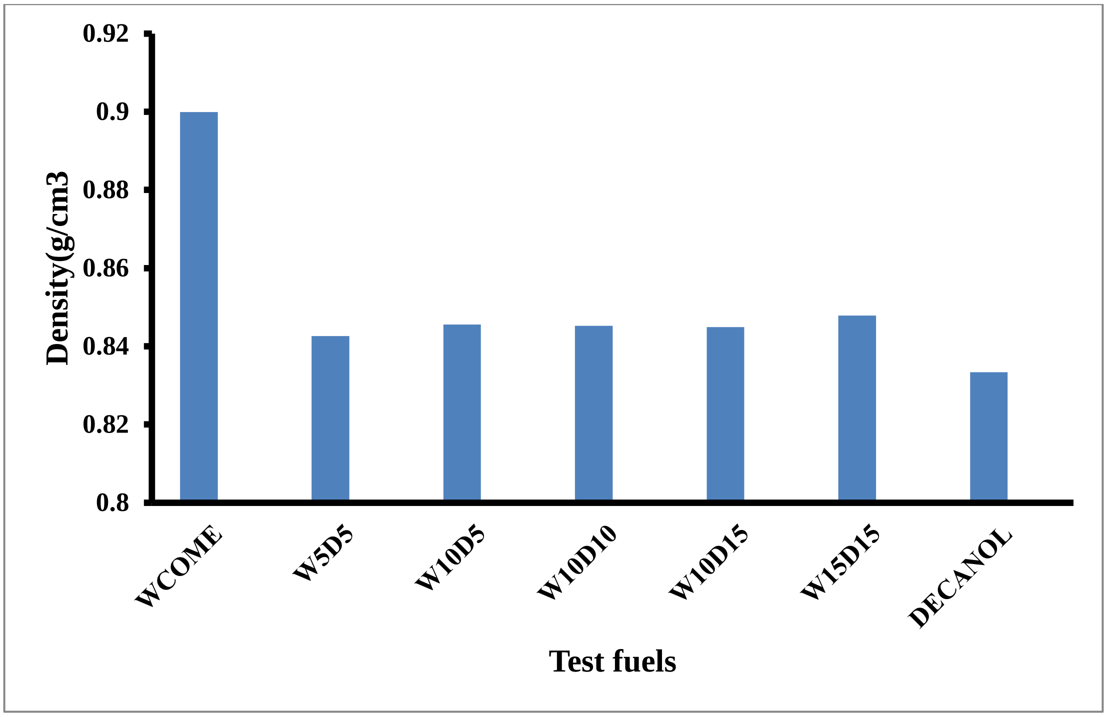


Fig 4.2: Comparison of density of test fuels

4.2.3 Calorific value

This is an important parameter regarding engine performance. Calorific value directly affects the BSEC of the test fuels. A bomb calorimeter was used to measure the calorific value of the test fuels. A bomb calorimeter is described in the previous section. Figure 4.3 shows the values of calorific value for different test fuels. The calorific value of the blends was less than that of diesel fuel that will definitely affect the engine performance.

The calorific value of corresponding Waste cooking oil was found 37.942 MJ/kg. According to the graph, as shown in fig 4.3, W5D5 had higher calorific value in comparison of all the test fuels and that is equal to 44.8 MJ/kg. On the other hand, W15D15 had less value than all other test fuels that is equal to 44.2 MJ/kg. Calorific value plays its role in the calculation of brake specific energy consumption and also in combustion behavior which directly affects the engine performance and emissions too. The heating value of all the test values is almost equal to the diesel due to the high calorific value of Decanol.

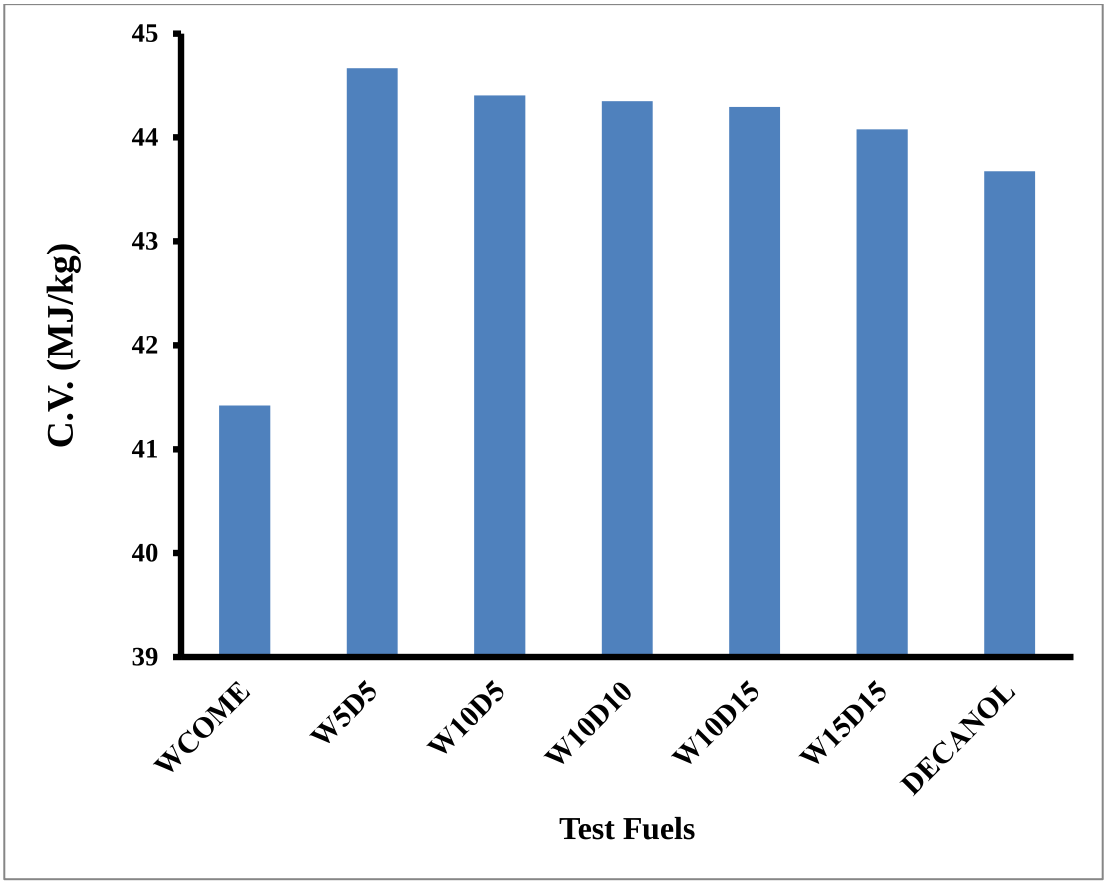


Fig 4.3: Comparison of calorific value of test fuels

4.3 ENGINE PERFORMANCE

The performance parameters were analyzed by measuring the basic data and calculated by applying theoretical analysis. The known values were compared with the results of CI engine fuel. In the context of performance parameters, brake thermal efficiency and brake specific fuel consumption has been measured by earlier discussed the theoretical approach and also presented in following diagrams:

4.3.1. Brake Thermal Efficiency (BTE)

Brake thermal efficiency is a key parameter to analyze the engine performance. Brake thermal efficiency is the ratio of productive mechanical work gained at the shaft of the engine to the injected fuel energy. This energy is equal to the product of calorific value and mass flow rate of the fuel [53]. The relationship between brake thermal efficiency with brake mean effective pressure for the test fuels is represented in Fig 4.5:

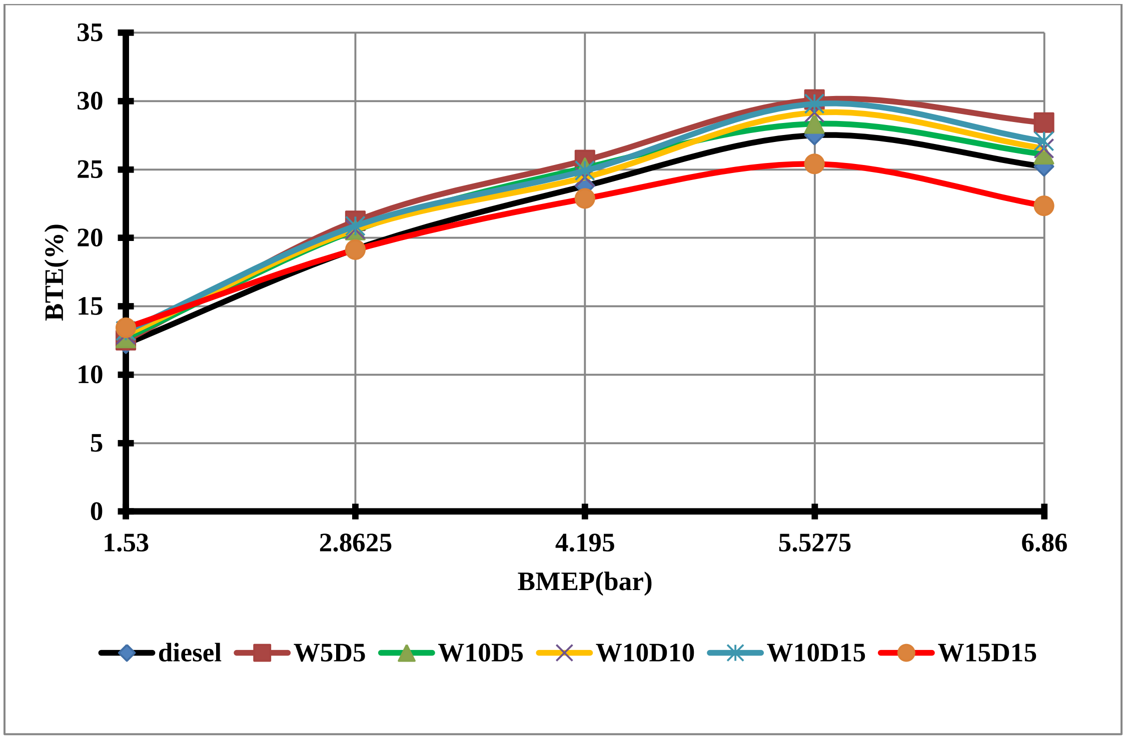


Fig. 4.5 Variation of brake thermal efficiency with brake mean effective pressure

It is found that brake thermal efficiency was increased for all test fuels with the increment in load. In the context of Fig 4.5, it was found that W5D5 had a maximum efficiency that is equal to 30.09% as compared to the diesel fuel i.e. 27.5%. It is also observed that as the content of decanol was increased, BTE also had improved. According to the above Fig 4.5, during higher load condition, W10D5, W10D10 and W15D10 had 28.34%, 29.15%, and 29.29% respectively. On the other hand, W15D15 had only 22.34% BTE which was very less than the baseline fuel that is equal to 25.2%. In brief, it may be concluded that the brake thermal efficiency is increased with the increment in a mixture of WCOME and Decanol up to 25%. After that, the inflection point was observed beyond which drop in the thermal efficiency was reported. Up to 25% the improvement in efficiency and then subsequent drop lead to some conclusion that the WCOME is an oxygenated fuel that helps in combustion at lower equivalence ratio. However, beyond 25% higher viscosity of Decanol and high density of WCOME may lead to the poor atomization of fuel that resulted into increase in fuel consumption rate followed by a drop in BTE.

4.3.2 Brake Specific Energy Consumption

A detailed assessment of consumption of fuel is also an important factor to describe the performance of engine associated with several test fuels. In the light of this parameter, BSFC which is the ratio of mass flow rate of fuel to the brake power is found as an irrelevant parameter that does not signify the exact reason of variation in consumption of fuel [54]. When the density and calorific value vary significantly then BSEC has been considered as a reliable parameter instead to BSFC. When talking about neat WCOME that has 7.5% and higher density and 10.13% less CV than diesel. Thus BSEC has been depicted as a relevant parameter to measure the fuel consumption rate. [55]

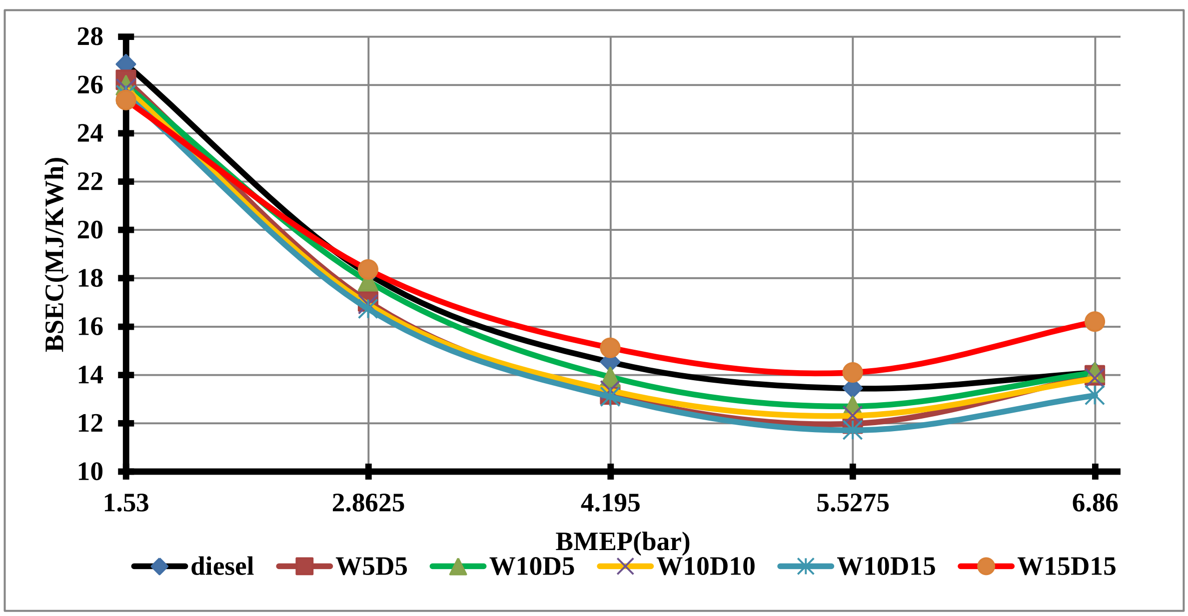


Fig. 4.6: Variation of brake specific energy consumption with brake mean effective press.

The relationship between BSEC and BMEP has been presented in fig 4.6.It may be found that the BSEC is decreased up to 25% blending of WCOME (10%) and Decanol (15%) at full load and just below than that. It may be also observed that as the percentage of Decanol is increased keeping WCOME amount as constant, the BSEC was decreased slightly. Beyond 25% blending as in the case of W15D15, almost 15% rise in BSEC was reported as compared to diesel. Thus it may be concluded that the presence of Decanol has improved this parameter and hence engine performance too.

4.4 EMISSION CHARACTERISTICS

4.4.1 CO Emissions

CO is known as an important environmental pollutant mainly produced by CI engine that should be reduced as soon as possible. During incomplete combustion formation of CO occurs that is due to higher air-fuel equivalence ratio.[56]

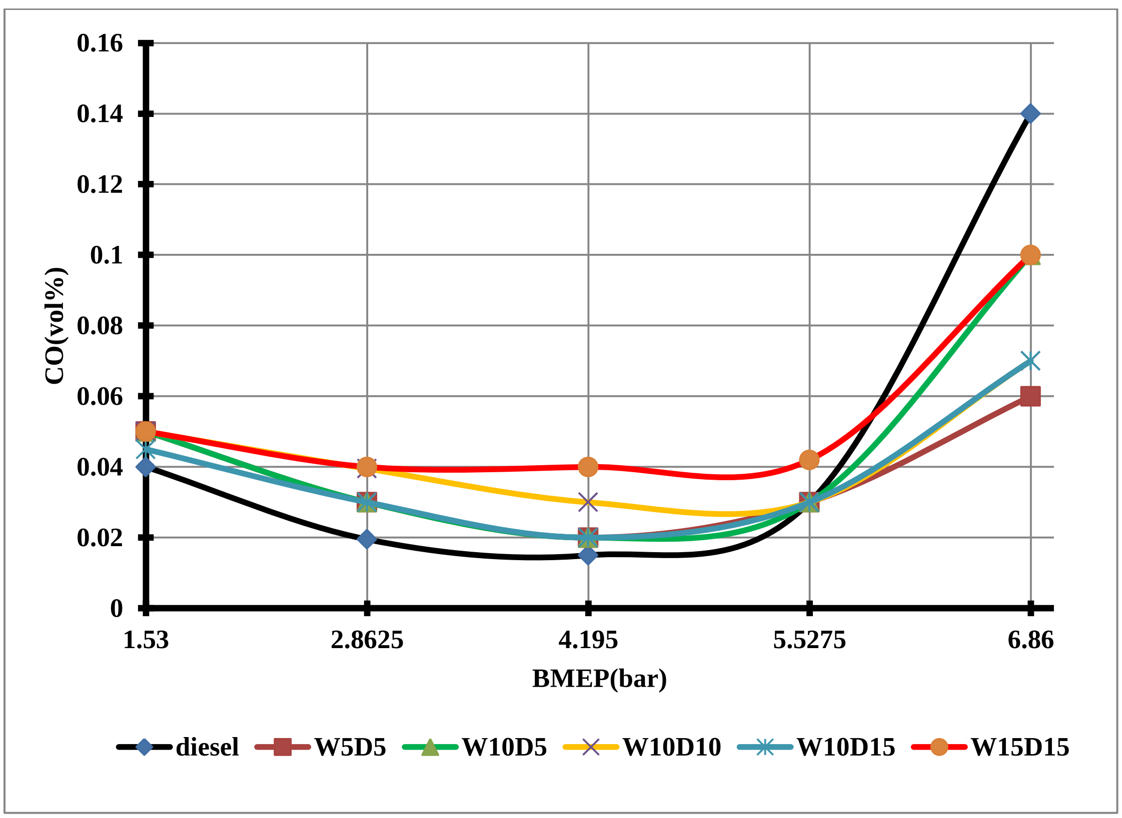


Fig. 4.7: Variation of CO with brake mean effective pressure

There are a lot of factors affect the formation of CO like engine chamber design, injection procedure, load on the engine and speed etc.[57] Relationship between the volumetric emission of CO and BMEP is shown in figure 4.7. It may be observed that for all test fuels the formation of CO was reduced up to 40% but after 50-60% load, there is a sudden rise in CO emissions irrespective of the blends. Little bit high CO may be due to a low in-cylinder temperature that leads to incomplete combustion at no load condition. When an increase in load temperature gets higher due to the burning of fuel that resulted in a reduction of CO emissions due to improved combustion. Beyond 60% load, the steep hike in CO emission was due to a higher amount of fuel injected and less air that resulted into incomplete combustion. At higher load, blends of WCOME and Decanol had shown high CO emission than that of the baseline fuel.

4.4.2 Total Hydrocarbon Emissions

The mechanism of formation of HC is still unclear but certain factors like engine condition and configuration, combustion temperature etc are likely to affect this parameter. In the current study, there is not a particular pattern was observed but the reduction in emissions was reported with the increase in blending. At partial loads, no significant pattern was observed but at full load condition, all test fuels had lower emission than the baseline fuel that was equal to 43, 40, 38, 34 and 37 ppm corresponding to W5D5, W10D5, W10D10, W10D15, and W15D15 respectively. The relationship between the total hydrocarbon emission and brake mean effective pressure is represented in fig 4.8.

As per the literature review, it was found that the cetane rating of decanol was almost equal to baseline fuel and also lower ignition delay than diesel. Thus, in brief, it may be concluded that the overall effect of higher in-cylinder temperature, high cetane rating, and reduced ignition delay produced low HC by WCOME and Decanol blends.

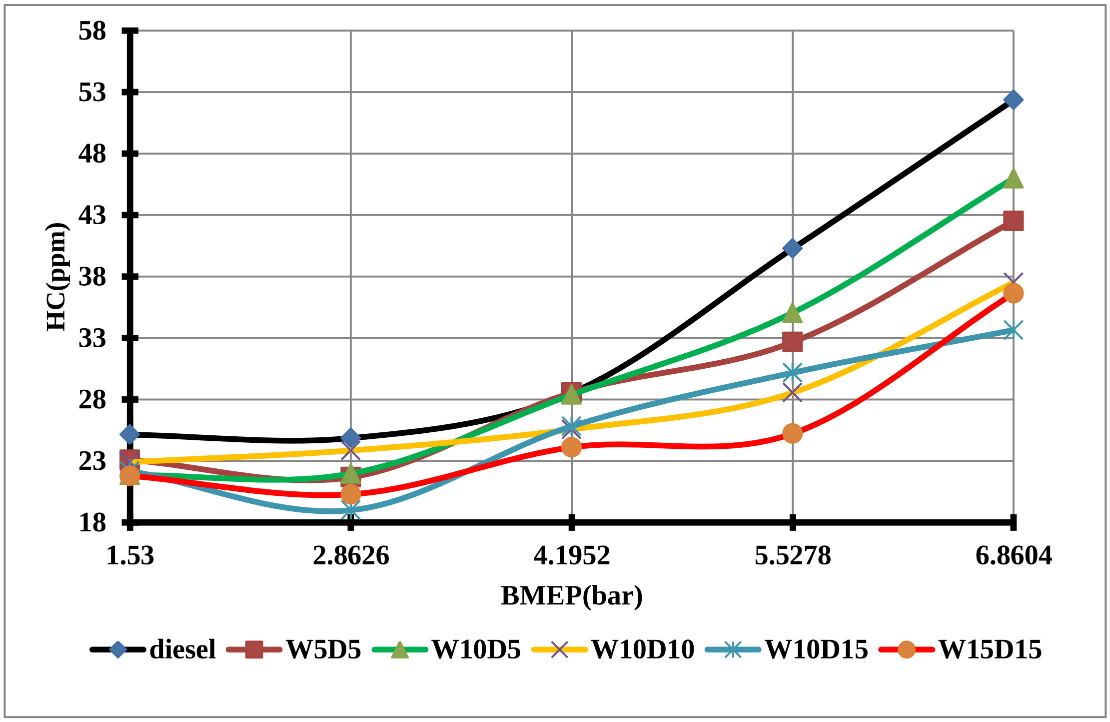


Fig. 4.8: Variation of total HC with brake mean effective pressure

4.4.3 NO_x Emissions

NOx emissions are the major environmental pollutant and formed by "Zeldovich mechanism". It comprises of nitric oxide and nitrogen dioxide which has chemical formula NO and NO_2 respectively. The temperature of combustion flame and oxygen availability effects the formation of NOx. The relationship between the volumetric emission of oxides of nitrogen and brake mean effective pressure is represented in fig 4.9. It was found that the NOx emission was increased for all test fuels as the increment in load due to the elevated in-cylinder temp and exhaust gas temperature. According to the literature review, it was reported that the NOx formation is highly dependent on temperature.

The experimental results depicted that the W5D5, W10D5 and W15D15 had 870, 885 and 876 ppm respectively which was slightly higher than the diesel fuel. However, the maximum difference was less than 75ppm. On the other hand, W10D10, W10 D15 had less NOx emission than the diesel fuel. In brief, it may be concluded that all test fuels had an almost same value of NOx emissions irrespective of load.

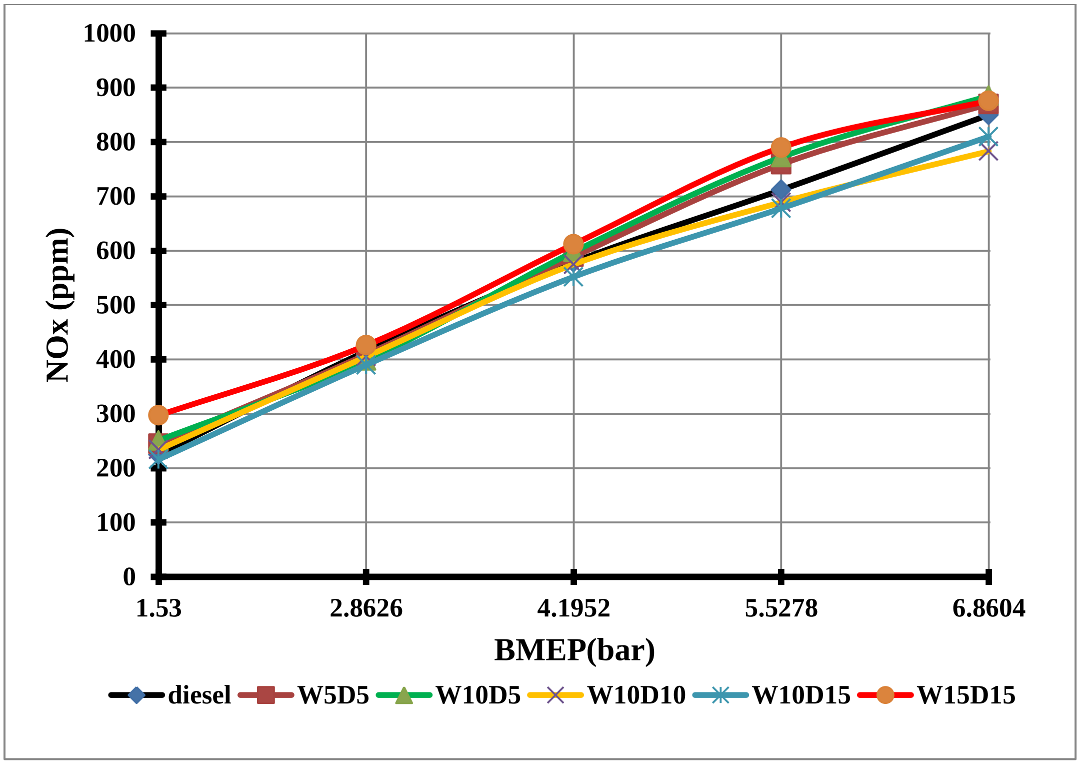
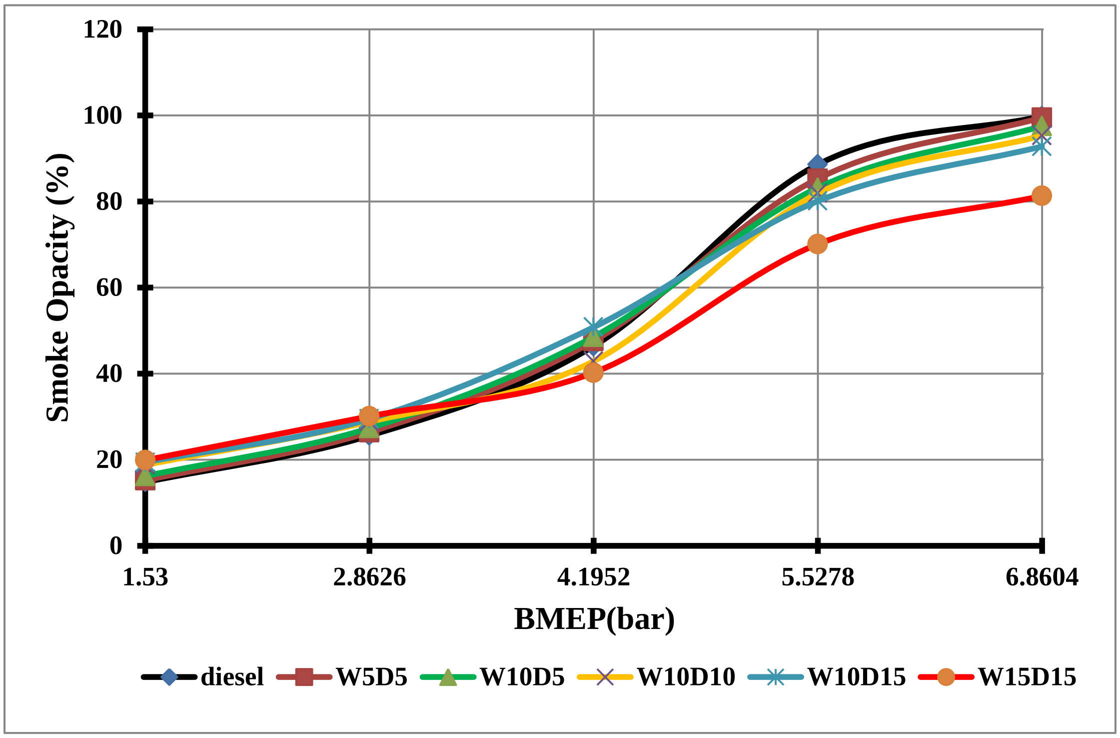


Fig. 4.9: Variation of NOx with brake mean effective pressure

4.4.4 Smoke Opacity

The relationship between smoke opacity and brake mean effective pressure is represented in fig 4.10. Smoke is a very unpleasant phenomenon that occurs due to some unwanted activities that are improper fuel burning, poor engine conditions etc. Up to 40 % load the smoke opacity of test fuels were higher than diesel because of the high viscosity of Decanol, lower in-cylinder temp leads to the poor atomization of the fuel.

The smoke opacity variation is almost unpredictable in context of blends at high load. It was found that the smoke opacity at full load for W5D5, W10D5, W10D10, W10D15, W15D15 was 99.5, 97.5, 95.3, 92.8 and 81.3 respectively as compared to 99.8% presented by diesel. The oxygenated fuel that is WCOME was the major factor behind low smoke opacity than diesel at higher load because the presence of oxygen resulted towards perfect fuel oxidation.



F*ig 4.10: Variation of Smoke opacity with brake mean effective pressure*

CONCLUSION

5.1 CONCLUSION

In the context of present work, the investigation in CI engine was performed followed by detailed discussion. The whole study includes the production of biodiesel from waste cooking oil, characterization of physic-thermal properties, extensive diesel engine trials using blends of diesel, Decanol, and biodiesel to evaluate the various parameters like performance and emission characteristics. The outcomes of the current study are presented below:

5.1.1 Biodiesel production

1. The statistically considerable model for the first step that is transesterification was defined as a quadratic model.

2. The précised condition depicted in the first stage was 2.2 FFA and temperature of reaction was achieved at 65°C for a reaction time of 80 minutes.

5.1.2 Physico-chemical and fuel characterization

1. The density of WCOME was found 0.8999 g/cc at 15°C whereas viscosity was noted down as 5.56 cSt which was quite higher than diesel and lower than Decanol. All the parameters were noted down within the range of prescribed ASTM regulations.

5.1.3 Engine trials

1. W5D5, W10D5, W10D15 and W10D15 reported 28.41%, 26.10%, 26.53% and 27.05% respectively whereas diesel engine reported only 25.2% at full load. W15D15 exhibited less BTE than diesel at full load.

2.W5D5, W10D5, W10D10, W10D15 and W15D15 illustrated full load BSEC of 13.22 MJ/kWh, 13.97MJ/kWh, 14.10 MJ/kWh, 13.85 MJ/kWh and 16.2 MJ/kWh respectively as compared to 14.10 MJ/kWh illustrated by the baseline diesel operation.

3. Total hydrocarbon emissions, smoke opacity and carbon monoxide of test fuels were less than the baseline data.

4. WCO and its blends showed the excess amount of oxide of Nitrogen emissions than mineral diesel almost at all loads.

5.2 Future Scope

The knowledge so gained during the present research work may be extended in the following directions for further work:

1. The performance parameters could be improved more with help of higher alcohols above than decanol
2. The emission parameters could also be improved with higher alcohols along with some modification in a diesel engine.

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