Major Dissertation

entitled

COMBUSTION, PERFORMANCE AND EMISSION STUDIES OF A DIESEL ENGINE FUELLED WITH ORANGE PEEL BIODIESEL

Submitted to Delhi Technological University

in partial fulfillment of the requirement for the award of the Degree of

Master of Technology

In

Thermal Engineering

By

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July, 2014

DECLARATION

I, hereby declare that the work embodied in the dissertation entitled **"COMBUSTION, PERFORMANCE AND EMISSION STUDIES OF A DIESEL ENGINE FUELLED WITH ORANGE PEEL BIODIESEL"** in partial fulfillment for the award of degree of MASTER of TECHNOLOGY in "THERMAL ENGINEERING", is an original piece of work carried out by me under the supervision of Prof. Naveen Kumar, Mechanical Engineering Department, Delhi Technological University. The matter either in full or in part have not been submitted to any other institution or University for the award of any other Diploma or Degree or any other purpose what so ever.

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CERTIFICATE

This is to certify that the work embodied in the dissertation entitled **"COMBUSTION, PERFORMANCE AND EMISSION STUDIES OF A DIESEL ENGINE FUELLED WITH ORANGE PEEL BIODIESEL"** by **Mr. AMARDEEP, (**Roll. No.- **2K12/THR/06)** in partial fulfillment of requirements for the award of **Degree of Master of Technology in Thermal Engineering**, is an authentic record of student's own work carried by him under my supervision.

This is also certified that this work has not been submitted to any other Institute or University for the award of any other diploma or degree.

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ABSTRACT

The global petroleum scenario has seen resurgent interest in the field of alternative fuels over the last two decades due to over-exploitation of fossil fuels and environmental degradation.

Various alternate fuels are being explored around the world by researchers to substitute diesel in transportation driven economy. The ease of utilization of non-edible vegetable oil due to its renewable and environment friendly characteristics without affecting food security has attracted various research endeavours. Orange peel biodiesel (OPB) has the potential to serve as a viable substitute due to its decent oxidation stability, low viscosity, density and superior cold flow properties thereby increasing its suitability for high pressure injection system. In the present investigation, an exhaustive range of 5-20% by volume of oil blends were taken; OPB5D95 (5% Orange peel biodiesel with 95% diesel), OPB10D90 (10% Orange peel biodiesel with 90% diesel), OPB15D85 (15% Orange peel biodiesel with 85% diesel) and OPB20D80 (20% Orange peel biodiesel with 80% diesel). The blends thus prepared were found to have properties analogous to conventional diesel besides being homogenous and stable in nature.

The physical properties (calorific value, kinematic viscosity, density and specific gravity) of Orange peel biodiesel-diesel blends were found to be comparable with D100 (neat diesel). Kinematic viscosity and Calorific value is found to decrease with increase in the percentage of Orange peel biodiesel in the blend. However, density was found to increase with concentration of biodiesel in tested blends.

All blends were tested in a single cylinder conventional water cooled diesel engine and the results show an increment in the brake thermal efficiency for 15% and 20% OPB blends. However, the brake specific fuel consumption at full load condition is found to decrease from 0.48 kg/kWh (D100) to 0.40 kg/kWh (OPB20D80) with increase in the

concentration of Orange peel biodiesel in the blends. At full load condition, it was observed that the maximum thermal efficiency of OPB5D95, OPB20D80 and D100 blends are 21.7%, 24.54% and 25.02%, respectively. The HC emissions were found to decrease considerably whereas CO emission was found to decrease for higher concentration of orange peel oil biodiesel in the test fuel samples. Smoke was found to decrease while NOx emission increased considerably for blends with higher concentration of orange peel oil biodiesel. With increase in the volume fraction of OPB in the blend, ignition delay was reduced. The peak pressure for diesel fuel is 62.5 bar whereas it is 66.3, 65, 64.4 and 63.6 bar for 5-20% blends respectively. A notable observation from the combustion studies was the increased trend of percentage heat release in the diffusion phase with increase in OPB volume fraction that leads to smoother engine operation. The overall analysis of the present study suggests that Orange peel biodiesel is a viable unconventional alternative because of its better combustion, performance and emission characteristics and also it does not requires any significant engine modifications.

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NOMENCLATURE

Symbols/ abbreviations

OPB100	Orange peel biodiesel (100% by vol)
OPB5D95	Blend of 5% OPB and 95% diesel
OPB10D90	Blend of 10% OPB and 90% diesel
OPB15D85	Blend of 15% OPB and 85% diesel
OPB20D80	Blend of 20% OPB and 80% diesel
D100	Neat diesel
^{0}CA	Degrees of crank angle rotations.
BMEP	Brake mean effective pressure
CO	Carbon monoxide
CO_2	Carbon dioxide
UBHC	Unburnt hydrocarbons
NO_X	Oxides of nitrogen
BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
ppm	Part per million
H_2	Hydrogen gas
^{0}C	Degree Celsius
K	Kelvin
cSt	Centi-Stoke
DI	Direct injection
MJ/Kg	Mega joules per kilogram
kWh	Kilo-watt-hour
RPM	Rotations per minute
BTDC	Before top dead center
MFB	Mass fraction burnt
ATDC	After top dead center
cc	Centimeter cube
wt. %	Percentage by weight
HRR	Heat release rate

$dQ_C/d\theta$	Net HRR per ^{0}CA
P	In-cylinder pressure
V	Volume
M	Mass
R	Universal gas constant
T	Temperature
C_p	Specific heat at constant pressure
C_v	Specific heat at constant volume
H	Convective heat transfer co-efficient
A	Piston wall area
γ	Specific heat ratio
v/v	Volume wise substitution
Ft	Feet
IMEP	Indicated mean effective pressure
BSEC	Brake specific fuel consumption

CHAPTER 1

INTRODUCTION

1.1 ENERGY CRISIS

Economic growth is one of the most important factor to be considered while projecting changes in world energy consumption. In this regard, the analysis of the relationship between energy consumption and economic growth has received a great deal of attention during the past few decades and there has been a large bulk of published research investigating the causality links between energy consumption and economic growth. This is because the direction of causality has significant policy implications. The issue of fate between energy and GDP has been an interesting matter concerning energy economists' for a number of years given the results have important implications for policy. The empirical literature has been focusing on four hypotheses with the fundamental relationship between energy consumption and economic growth [1, 2].

The "growth hypothesis" emphasizes that energy consumption has an important role in economic growth, and the causality of relationship is from energy consumption to economic growth. In other words, a decrease in energy consumption causes a reduction in economic growth. Second, the "conservation hypothesis" is supported that the causality of relationship is from economic growth to energy consumption, an increase in economic growth causes an increase in energy consumption or a decrease in energy consumption not have a negative impact on economic growth. The other hypothesis, the "neutrality" asserts that energy consumption should not have a significant impact on economic growth and support no causality between economic growth and energy consumption. The last is "feedback hypothesis" suggests that bidirectional causality for energy consumption and economic growth relationship, in this case, energy consumption increases (decreases) result in economic growth increases (decreases) and adverse. Therefore the growth hypothesis is treated as the major factor for the economic growth and is mainly depends on the energy consumption.

Depletion of energy related to the insufficient energy resources leading to the shortage in supply which in turn is not able to meet growing demand of energy in the rapidly expanding industrial, transport, agricultural and urban sectors. Oil, coal and natural gas cover most of the world energy needs and notwithstanding the many and varied projections as to probable time scales, it must be conceded that present sources of such fossil-derived materials are finite and that whatever quantities remain must become increasingly more difficult (costly) to win.

Nevertheless, fossil fuels are not considered sustainable and are also questionable from an economic, ecological and environmental point of view. It should also be realized that, as the more accessible deposits become depleted, the global distribution of those remaining will attract progressively heightened political attention, since not all nations can assume proportional future supplies. The recent increase in petroleum prices and the growing awareness related to the environmental consequences of the fuel over-dependency have stimulated the recent interest in alternative energy sources [3, 4]. Also, alternative fuel source are considered very promising to play an important role in meeting the world's energy requirement [5, 6].

1.2 ENERGY SCENARIO

1.2.1 World Energy Scenario

World is naturally anxious to think about future, because knowing the bitter truth that a day will ultimately come when no more coal or oil will available and it will surely mean energy crisis. People who have made careful calculation feel that at present level of exploitation, the worldwide coal deposits will last till year 2080 and it is also true that poor quality coal with the carbon content of 40 percent only is not conducive for electricity generation and other important implications [7].

As already discussed, energy is one of the most important factors concerned for socio-economic development of any country. Many developing countries are not able to fulfil their energy demand from the resources available in their own country and are majorly depends on other countries for accomplishing their energy requirement. Fig. 1.1 shows the total primary energy supply from the various sources available worldwide.

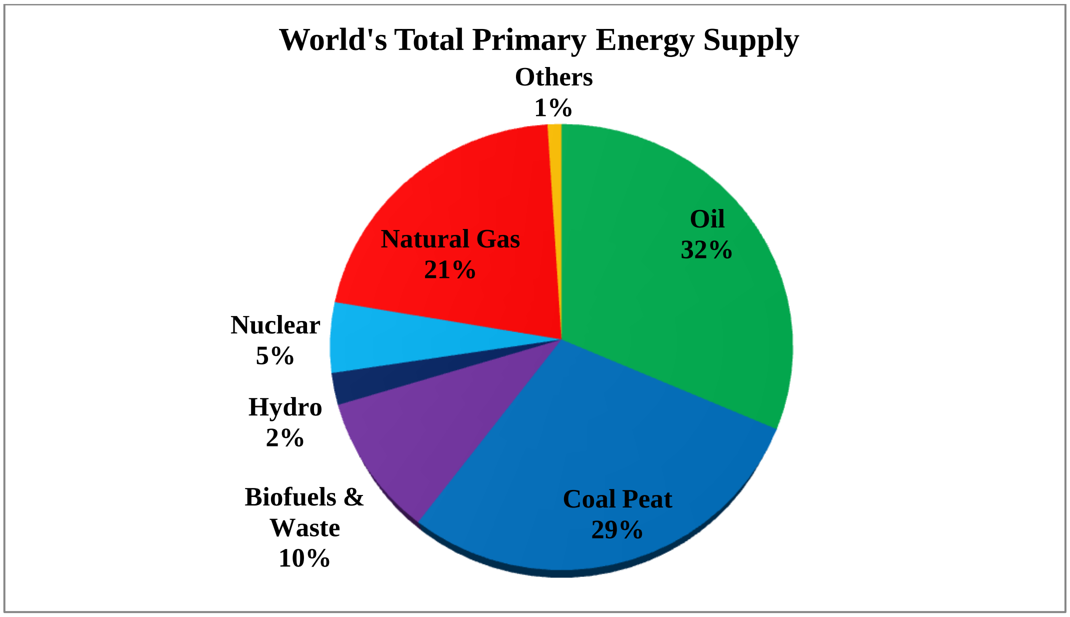


Fig. 1.1: Worlds total primary energy supply (13113 Mtoe) [8].

It explains that out of the total primary energy delivered in the world 32% is supplied by oil, 29% from coal, 21% from natural gas, 10% from biofuels & waste and rest is supplied by hydro, nuclear and other sources. In this, major portion is delivered by non-renewable fossil fuels to meet the demand of the rapid modernization and industrialization of world. Therefore, global world has become more conscious about the growing demand and depletion of oil reserves.

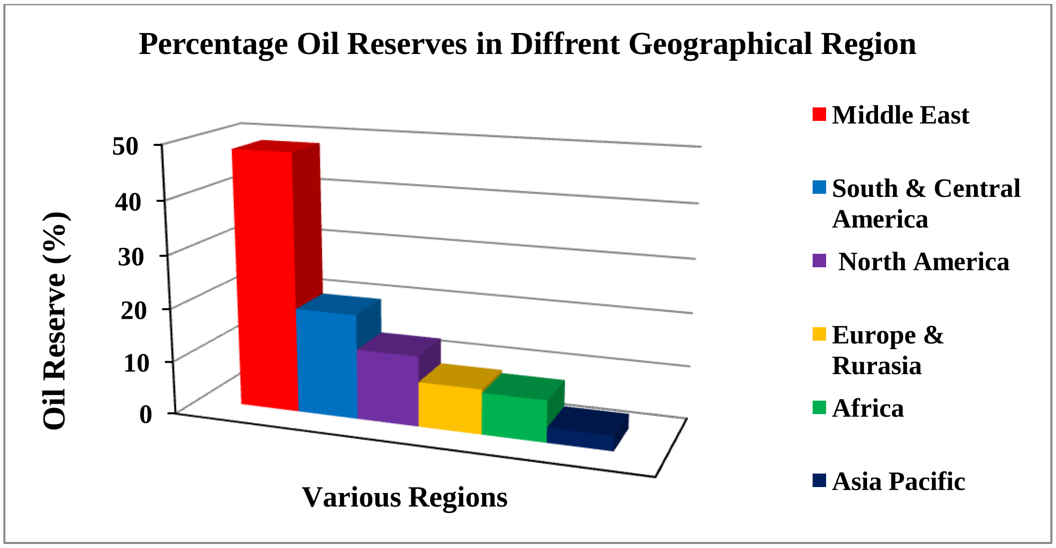


Fig. 1.2: Oil reserves in different geographical regions (1668.9 thousands million barrels) [8].

Figure 1.2 & 1.3 shows the statistics of the production and consumption of oil in different geographical regions. And it can be seen that Middle East dominates in the production while Asia pacific dominates in the consumption followed by the North America and South & Central America.

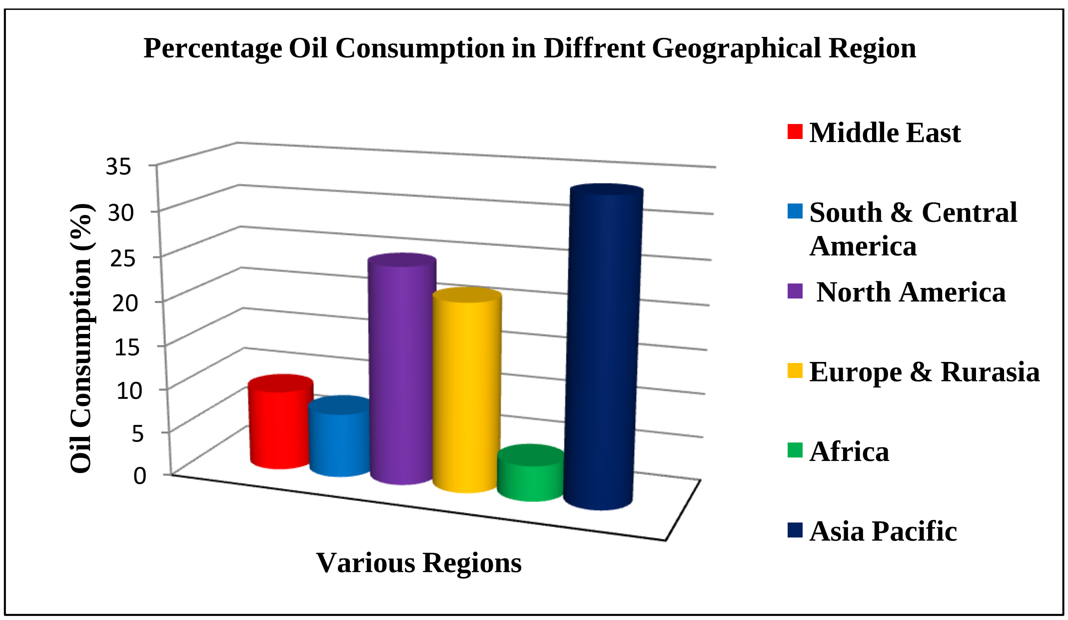


Figure 1.3: Oil Consumption in different geographical regions (89774 thousand barrels) [8].

1.2.2 Oil scenario in India

India is growing at a faster rate and consuming more energy than it ever did in her long millennia old civilization. India needs an abundant and sustainable energy supply in the foreseeable future to maintain the economic growth momentum and progressive social transformation without jeopardizing environment. But unfortunately, it is not able to diversify its sources of energy whose sustainability as well as environmental effect are the factors of great concern. This can be explained by the heavy reliability of Indian energy sector on exhaustible energy resources such as fossil fuels.

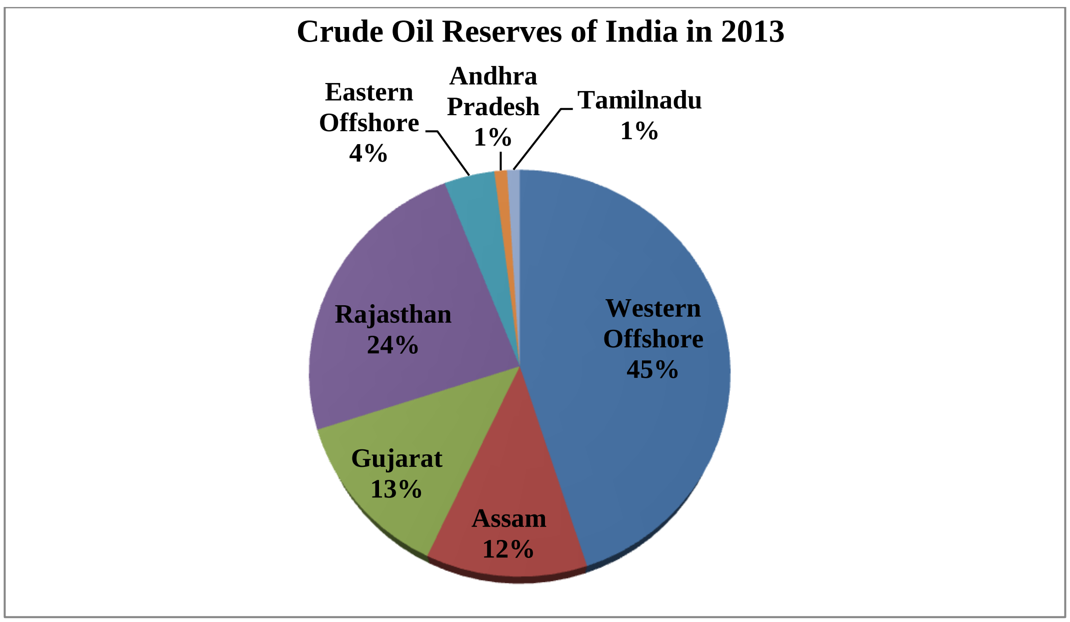


Fig. 1.4: Oil reserves in different regions of India (Total oil reserve 758.27 Million Tonne) [9].

Fig. shows the crude oil reserves in different geographical regions in India in which Western Offshore has the maximum reserve followed by Rajasthan, Gujarat and Assam. However, India is also a great consumer of petroleum products and consumes around four times of its production. Fig. 1.5 below shows the relationship between the production and import of crude oil in India.

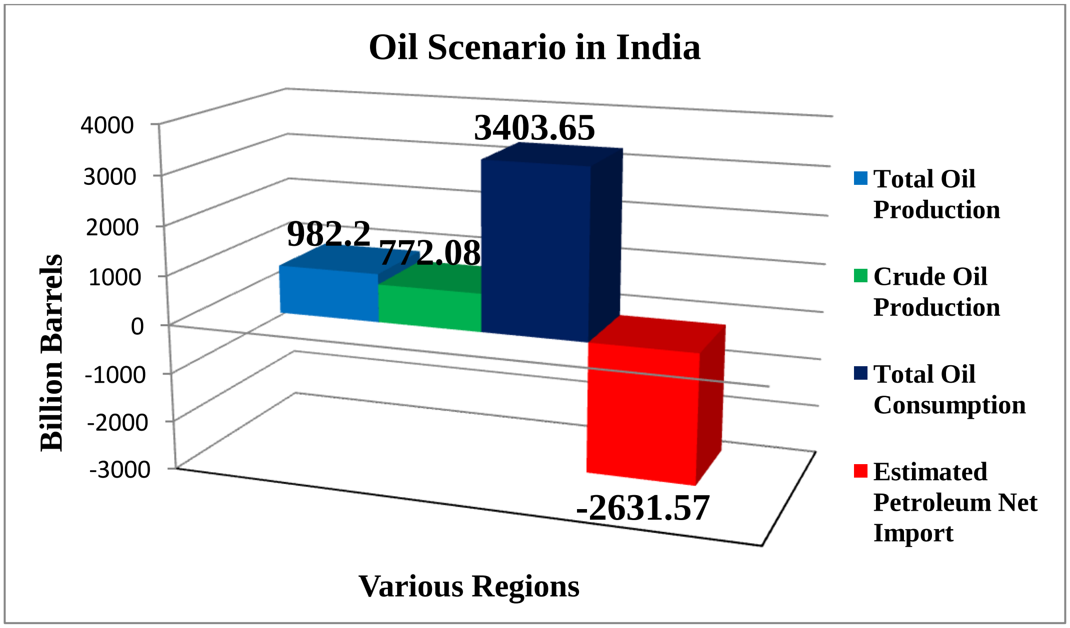


Fig. 1.5: Oil scenario in India [10].

This heavy dependence of India on non-renewable resources results in faster resource depletion, environmental degradation and a huge economic burden for import of expensive fossil fuels resulting in widening trade deficit [11].

In the light of the above facts and discussions, the following conclusions can be made:

- India is an energy starving nation.
- Due to rapid economic growth of the last decade and projected high growth rate in the coming couple of decades at least, it will continue to consume more and more energy.
- Present energy sources are mostly non-renewable and increasingly import driven.
- Self-reliability in energy front and rapid exploration of renewable sources of energy is the pre-requisite for a sustainable, inclusive and vibrant India in the years to come.

1.3 FUTURE ENERGY OUTLOOK

For instance, energy consumption is a vital component in economic growth, and hence it may adversely affect real GDP (Gross Domestic Product). However, a unidirectional causality running from economic growth to energy consumption signifies a less energy dependent economy, so energy conservation policies may be implemented with little or no adverse effect on economic growth [12].

For better economic growth, the major challenges on the rate of energy consumption are industrial and transportation sector. These sectors have been allocated a remarkable proportion of their energy consumption in the form of petroleum products; mainly by the developing countries. Globally, transportation is the second largest energy consuming sector after the industrial sector and accounts 26% of the world's total delivered energy. Since, this sector has experienced steady growth in the past 30 years, it is believed that it is currently responsible for nearly 60% of total world oil demand and will be the strongest growing energy demand sector in the future [13].

So, the energy conservation and emissions are the rising concerns for a large number of countries around the world. Therefore, from last two decades automotive manufacturers are trying to find ways to reduce pollutant emissions and improve fuel conversion efficiency of internal combustion engines. As these engines are basic need for the transportation, so the emissions that come out from the engines are point of concern. Hence, in the development of transport sector, diesel engines occupy a very important position due to their high thermal efficiency and high power to weight ratio. However, in recent times diesel engine powered vehicles have come under heavy attack due to various problems created by them and air pollution being the most serious of these problems. Air pollution can be defined as addition of any material to our atmosphere which will have a deleterious effect on life upon our planet [14].

The main pollutants contributed by automobiles are carbon monoxide (CO), unburned hydrocarbons (UBHC), oxides of nitrogen (NOx), smoke, and particulate matter (PM). Researchers all over the world have evaluated the health risks associated with the exposure to automobile emissions [15-17].

At the same time when it comes to energy security, resources are used to generate energy; their scarcity and the rising impact of those resources on the global environment have made energy conservation a top agenda on the tables of high government officials around the world. Global demand for transportation appears unlikely to decrease in the foreseeable future as the World Energy Outlook projects that it will grow 40% by 2035 [13]. Therefore, in order to minimize the oil consumption and emissions from transportation sector, the policy makers are seeking for the improved vehicle efficiency along with limiting the emissions by promoting the development of alternative fuels.

As already discussed, transportation sector mainly depends on the diesel engines due to their high thermal efficiency and high torque at low rpm. Hence, for the reduction in the oil consumption, various researchers are gearing towards the implementation of fuels which can substitute diesel without major engine modifications or significant emission increments while sustaining the desired petroleum demand. Such kinds of fuels mainly include the vegetable oil and the other oil emulsions like ethanol-diesel and diesel water emulsion. These new technologies are mainly developed in pursuit of fuels having low emissions.

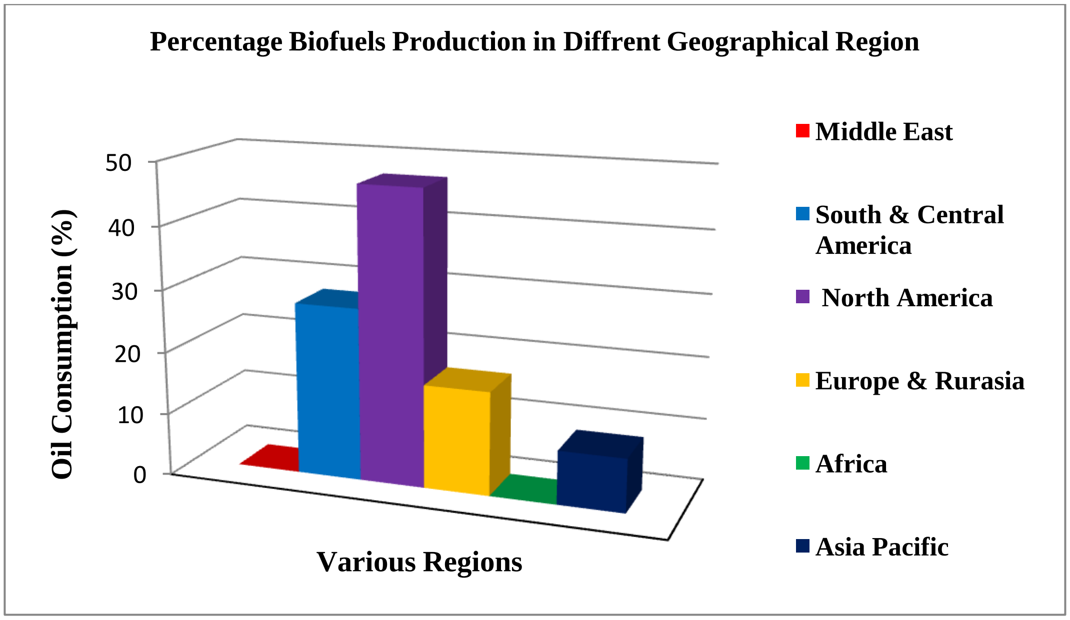


Fig. 1.6: Biofuels Production in different geographical regions [8].

1.4 ENVIROMENTAL DEGRADATION AND ITS GLOBAL EFFECT

The global energy requirements and environmental degradation due to accelerated use of fossil fuels have raised significant concerns worldwide. Current patterns of production and consumption of both fossil fuels and food are draining freshwater supplies; triggering losses of economically-important ecosystems such as forests; intensifying disease and death rates and raising levels of pollution to unsustainable levels. The in-efficient use of energy has strained the global environment to its limits as it can be seen from the unprecedented and hostile responses of the nature in the recent few years. Greenhouse effect, global warming, acid rain, smog, deforestation, shift in climatic conditions etc. are some of the indications over usage of fossil fuels which seriously affect nature.

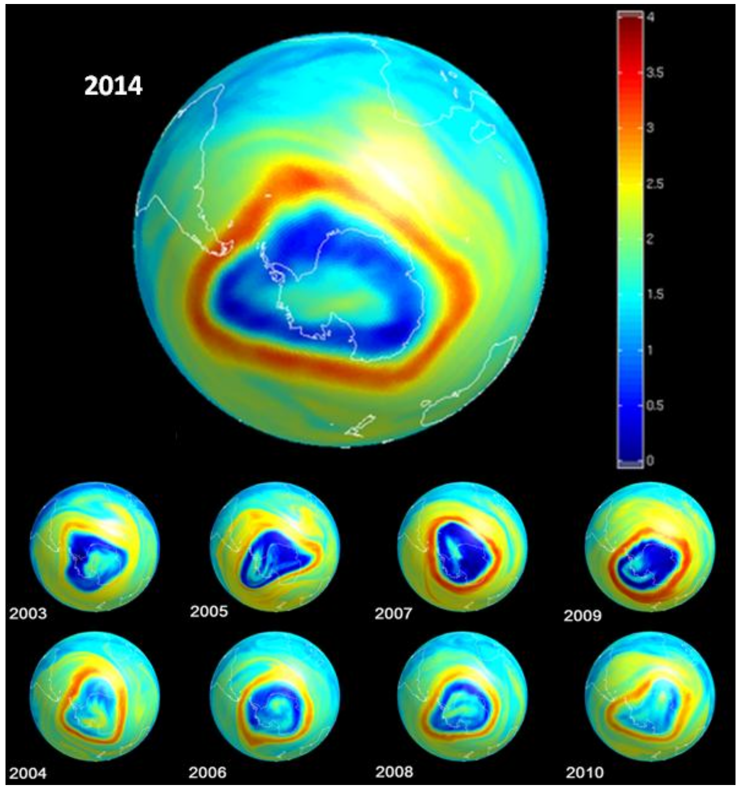


Plate 1.1: Ozone layer depletions over Antarctica from 2003 to 2014.

The ozone layer is a layer in Earth's atmosphere which contains relatively high concentrations of ozone (O_3). The distribution of ozone in the stratosphere is a function of altitude, latitude and season. It is determined by photochemical and transport processes. The ozone layer is located between 10 and 50 km above the Earth's surface and contains 90% of all stratospheric ozone, though the thickness varies seasonally and geographically. This layer absorbs 97–99% of the Sun's high frequency ultraviolet light, which potentially damages the life forms on Earth. Measurements carried out in the Antarctic have shown that at certain times, more than 95% of the ozone concentrations found at altitudes of between 15 - 20 km and more than 50% of total ozone are destroyed. The ozone layer can be depleted by free radical catalysts, including nitric oxide (NO), nitrous oxide (N_2O), hydroxyl (OH), atomic chlorine (Cl), and atomic bromine (Br) [18, 19].

The main potential consequences of this ozone depletion are:

- ❖ Increase in UV-B radiation at ground level: a one percent loss of ozone leads to a two percent increase in UV radiation. Continuous exposure to UV radiation affects humans, animals and plants, and can lead to skin problems (ageing, cancer), depression of the immune system, and corneal cataracts (an eye disease that often leads to blindness). Increased UV radiation may also lead to a massive die-off of photo plankton (a CO_2 "sink") and therefore to increased global warming.
- ❖ Disturbance of the thermal structure of the atmosphere, probably resulting in changes in atmospheric circulation.
- ❖ Reduction of the ozone greenhouse effect: ozone is considered to be a greenhouse gas. A depleted ozone layer may partially dampen the greenhouse effect. Therefore efforts to tackle ozone depletion may result in increased global warming.

Usage of renewable fuels, strict government regulations and global policies has certainly reduced the depletion of ozone layer. A study has revealed that Antarctica ozone levels have already recovered by an amount of 15% since the late 1990s [20].

1.5 GLOBAL WARMING

Global Warming is the increase of Earth's average surface temperature due to effect of greenhouse gases, such as carbon dioxide emissions from burning of fossil fuels or from deforestation, which trap heat that would otherwise escape from earth. There are many causes of Global Warming. The destruction and burning down of tropical forests, traffic clogging up the city streets , rapid growth of unplanned industries, the use of CFCs in packaging and manufacturing products, the use of detergents etc. cause global warming. Besides all theses, overpopulation, deforestation is the causative factors of global warming. The setting up of mills and factories in an unplanned way has a great effect on environment. These mills and factories produce black smoke which gets mixed with air and increases the amount of CO_2 [21].

For last few decades, its effect has increased mainly due to industrialization and modernization. From the three main greenhouse gases liberated in the atmosphere i.e. CO_2, NO_X and methane; CO_2 is produced in abundance and it plays a major role in causing global warming [22]. Raising sea levels, glacier retreat, Arctic shrinkage, and altered patterns of agriculture are cited as direct consequences, but predictions for secondary and regional effects include extreme weather events, an expansion of tropical diseases, changes in the timing of seasonal patterns in ecosystems, and drastic economic impact. Concerns have led to political activism advocating proposals to mitigate, eliminate, or adapt to it [23].

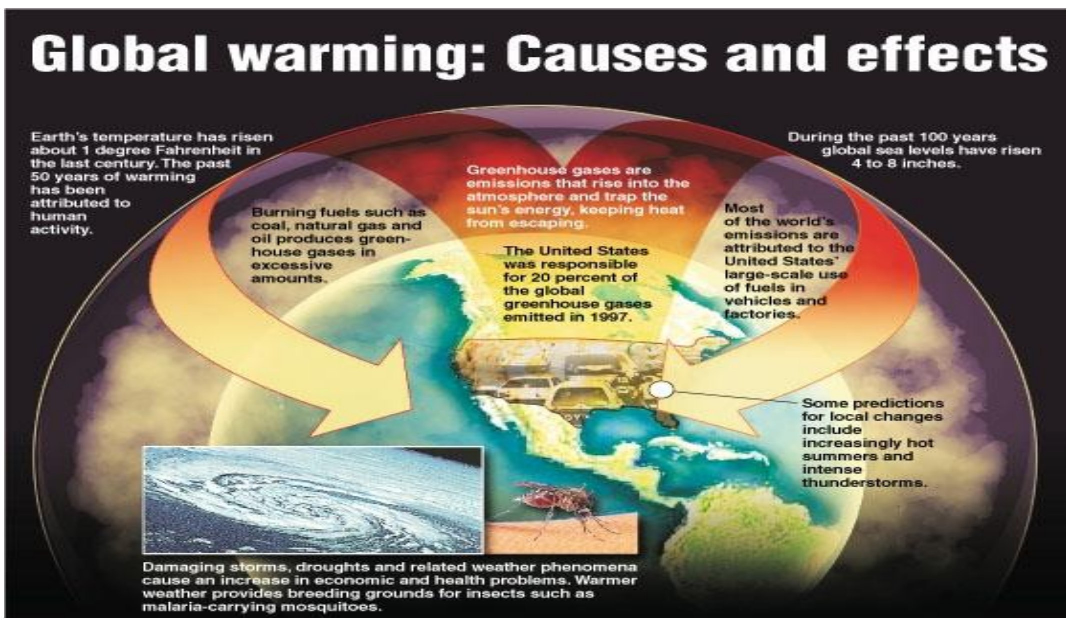


Plate 1.2: Cause and effects of CO_2 on global warming.

Although, being a greenhouse gas CO_2 has adverse effects on environment these are the possible consequences of global warming. The greenhouse effect refers to the interaction between the Earth's atmosphere and surface to absorb, transfer, and emit energy as heat, cycling it through the atmosphere and back to the surface. The natural greenhouse effect is necessary for life as it exists on Earth today.

1.6 DIESEL ENGINE AND INDIAN ECONOMY

Diesel Engine plays a crucial role in Indian economy but also contributes to a significant pollution. During April-May 2013, diesel consumption grew 5.9% compared to period 2012. The overall diesel consumption growth for 2012-13 was 6.8%, compared to 7.8% during 2011-12 [24].

According to the data provided by the Petroleum Planning and Analysis Cell, petrol consumption in India during April-January fiscal was 12.35 million tonnes. India is expected to end up consuming 14.82 million tonnes of petrol in the year, registering growth of 4.41% in FY12. Consumption of diesel is expected to be 63.91 million tonnes, registering, growth of 6.4% [25]. Diesel engine is typically more efficient than the gasoline engine due to higher compression ratio. It also do not suffer from size and power limitations, which the SI engine is prone to. In India, diesel engines are used in heavy trucks, city transport buses, locomotives, electric generators, farm equipment, underground mine equipment etc. The dual problem of fast depletion of petroleum based fuels and air pollution can be judiously handled by switching from fossil fuel based economy to renewable source of energy.

Indian economy is agriculture based economy and agriculture is an energy transformation process as energy is produced and consumed in it. The production of energy is carried through process of photosynthesis in which solar energy is converted into biomass. Agriculture in India is heavily based upon petroleum and its derived products such as fertilizers and pesticides. Energy sources used in agriculture are oil and electricity whereas indirect energy sources are chemical fertilizers and pesticides.

Oil and electricity are two major energy suppliers which are used in agriculture sector. Because of mechanized farming the amount of energy consumed has increased multi-fold since independence in terms of oil and electricity.

1.7 NEED OF ALTERNATIVE FUEL

Projections for the 30-year period from 1990 to 2020 indicate that vehicle travel, and consequently fossil-fuel demand, will almost triple and the resulting emissions will pose a serious problem. The main reason for increased pollution levels, in spite of the stringent emission standards that have been enforced, is the increased demand for energy in all sectors and most significantly the increased use of internal combustion engines for mobility and power sectors [26, 27]. As elaborated in the previous sections, a major chunk of imported crude oil derivatives are used as fuel in internal combustion engines. The most popular petroleum fuels are gasoline and diesel which are used as motor fuels in spark ignition and compression ignition engines respectively. Amongst them, diesel engines have proven their utility in the transportation and power sectors due to their higher efficiency and ruggedness therefore these engines play a pivotal role in rural as well as urban Indian economy [28].

Diesel engines are largely favoured across a wide spectrum of activities like automotive application, small and decentralized power generation, prime mover for farm and agricultural machineries, small scale industrial prime mover and so on. Therefore, in Indian context, diesel consumption is always disproportionately higher than gasoline. Fig.1.7 shows the consumption of motor gasoline and high speed diesel oil during the period 2005 to 2012. It may be observed that diesel to gasoline consumption ratio was 4.80 in 2005 which was dropped to 4.31 in 2012. This indicated that the consumption of diesel is increasing at a faster rate than the consumption of gasoline, still diesel consumption in India is nearly four and half times higher than gasoline

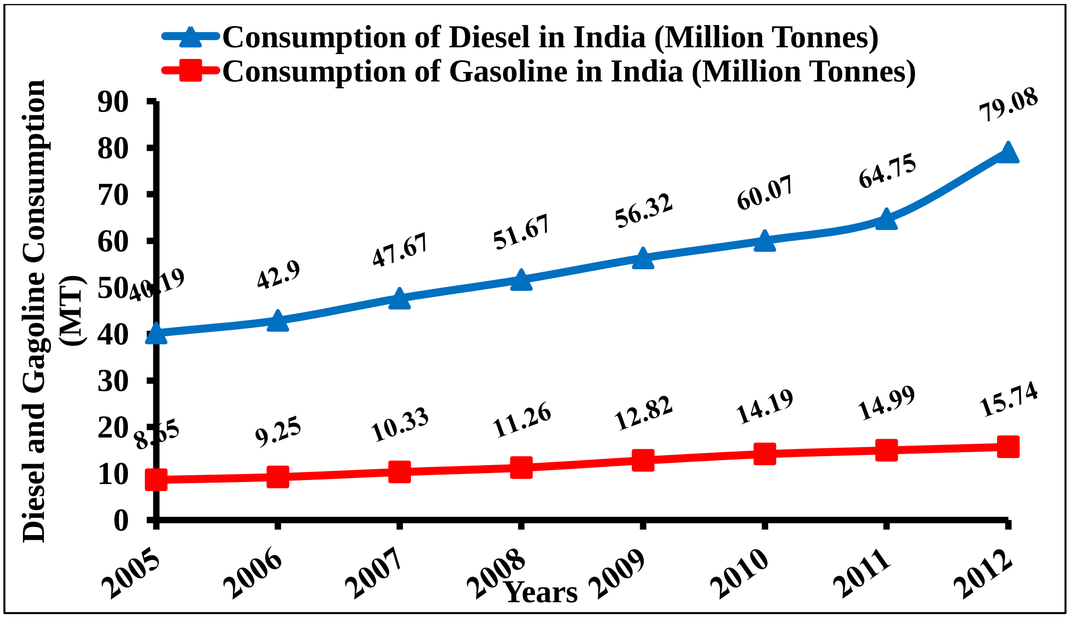


Fig.1.7: Consumption of diesel and gasoline during the period 2005-2006 to 2012-2013 [8, 9].

Therefore, even a partial substitution of mineral diesel by any renewable and carbon neutral alternative fuel can have significant positive effect on economy and environment in terms of reduction in carbon footprints and dependence on imported crude oil. In the light of the apprehensions about long-term availability of petroleum diesel, stringent environmental norms and environmental impacts due to extensive use in fast growing Indian economy have mandated the search for a renewable alternative of diesel fuel [29].

1.8 VEGETABLE OIL: AN ALTERNATIVE FUEL FOR DIESEL ENGINES

Vegetable oils are the plant origin biofuels generally obtained from resins and plant seeds. Being a part of carbon cycle, the vegetable oils are carbon neutral. Moreover, these oils are extensively found all over the country with special penetration in rural areas. Characteristics like renewable background, higher lubricity, high cetane rating, low sulfur content, non-toxic nature, bio-degradability, superior anti-corrosion properties etc. make these fuels a promising alternative one for diesel engine application [30-33]. However, there are certain constraints regarding usage of vegetable oils in diesel engines as well.

The major problem with vegetable oils is their higher viscosity than diesel. The higher viscosity is attributed towards the high molar masses of oils and the presence of unsaturated fatty acids. At elevated engine temperatures the polymerization of unsaturated fatty acids followed by cross-linking leads to formation of very large agglomerations and consequent gumming. When direct injection engines are allowed to run with vegetable oils, injectors normally choked after a few hours. The higher viscosities cause poor fuel atomization which leads to incomplete combustion and carbon deposition on the injector and valve seat, resulting in serious engine fouling. Due to incomplete combustion, partially burnt vegetable oil runs down the cylinder walls and dilutes the lubricating oil and thickens the lubricating oil [30]. Therefore, vegetable oils are not recommended for direct diesel engine application. However, there are several methods like dilution, pyrolysis, transesterification and engine hardware modification in which vegetable oil can be used in diesel engines. Amongst these methods, transesterification has been established as the best method to use vegetable oils in diesel engines. Transesterification is a chemical process in which the triglycerides of the vegetable oil are converted in to mono- alkyl esters and glycerol in presence of a catalyst. The vegetable oil alkyl esters are popularly known as biodiesel and have properties very similar to mineral diesel. Transesterification process in details is discussed in the subsequent sections.

1.9 BIOFUEL POLICY: GOVERNMENT OF INDIA

In the light of the need regarding diversification in energy supply as discussed earlier, Indian Government has taken a lot of initiative in the front of wind and solar energy harnessing projects. However, the formal National Policy on Biofuels to explore the non-edible vegetable oils and other bio-origin oils as alternative fuels was approved by Government of India in December 2009. It encouraged the use of alternative fuels to supplement transport fuels (petrol and diesel for vehicles) and proposed a target of 20 percent biofuels blending (both bio-diesel and bio-ethanol) by 2017. In this context, the government launched the National Bio-diesel Mission (NBM), identifying Jatropha curcas as the most suitable tree-borne oilseed for bio-diesel production. The Planning Commission of India had set an ambitious target of covering 11.2 to 13.4 million hectares of land under Jatropha cultivation by the end of the 11th five-year plan [33]. The central government and several state governments are providing fiscal incentives for supporting plantations of Jatropha and other non-edible oilseeds. Several public institutions, state biofuels boards, state agricultural universities and cooperative sectors are also supporting the biofuels mission in different capacities [34]. However, Government of India had two major constraints in its biofuels policy. Firstly, only non-edible vegetable oils were allowed to be used as fuel crops as India is not self-sufficient in edible oil production, rather it imported 40% of its totally edible oil requirements in 2012 [35]. Secondly, only those non-edible oil species which can grow in waste and barren lands with drought conditions are preferred as diversion of arable lands for energy crop production may impinge food production.

On the lines of the above constraints, government's ambitious plan of producing sufficient biodiesel to meet its mandate of 20% diesel blending by the year of 2012 was not realized. Excessive dependence on Jatropha curcas to produce biodiesel, lack of sufficient feed stocks, absence of exploration of other suitable oilseeds for biodiesel production and lack of comprehensive research and development activities have been some of the major stumbling blocks cited officially by Government agencies for the above mentioned failure [36-38].

As cited in the previous paragraph, lack of sufficient feed stocks and excessive dependence on Jatropha curcas were some of the reasons for the initial set back of National Bio-diesel Mission. Therefore, exploration of other potential non-edible oil feed stocks for biodiesel production and an integrated research and development approach to address the multifaceted dimensions of biodiesel production and usage may supplement

Government's biofuels policy and also it has increase the feedstock availability substantially. In this context, the present research work deals with one such less popular non-edible and pure waste vegetable oil feedstock known as "Orange peel" to evaluate its potential as an alternative diesel engine fuel.

1.10 ORANGE PEEL OIL: AN ALTERNATIVE DIESELFUEL

An Orange is a type of citrus fruit which people often eat. The orange (specifically, the sweet orange) is the fruit of the citrus species, Citrus sinensis in the family Rutaceae [39]. Citrus is one of the most important fruit crops grown throughout the world. Further, it is made up of many species that vary in importance due to different climatic zones. Citrus fruits belong to the plant family Rutaceae sub family Aurantiodeae which comprises 33 well-known genera and 203 species. Orange is unknown in the wild state; is assumed to have originated in southern China, north-eastern India, and perhaps south-eastern Asia and that they were first cultivated in China around 2500 BC [40, 41]. In Europe, citrus fruits among them the bitter orange, introduced to Italy by the crusaders in the 11^{th} century were grown widely in the south for medicinal purposes but the sweet orange was unknown until the late 15^{th} century or the beginnings of the 16^{th} century, when Italian and Portuguese merchants brought orange trees into the Mediterranean area. Shortly afterward, the sweet orange quickly was adopted as an edible fruit. It also was considered a luxury item and wealthy people grew oranges in private conservatories, called orangeries. By 1646, the sweet orange was well known throughout Europe [40].

Plate 1.3: (a) Orange tree with fruits, (b) navel-orange, (c)-orange fruits, (d) orange peels.

Like most citrus plants, oranges do well under moderate temperatures between 15.5°C and 29°C (59.9 & 84.2 °F) and require considerable amounts of sunshine and water. It has been suggested that the use of water resources by the citrus industry in the Middle East is a contributing factor to the desiccation of the region. Another significant element in the full development of the fruit is the temperature variation between summer and winter and, between day and night. In cooler climates, oranges can be grown indoors. Different names have been given to the many varieties of the genus. Orange applies primarily to the sweet orange. The orange tree is an evergreen, flowering tree, with an average height of 9 to 10 meter (30 to 33 ft), although some very old specimens can reach 15 meter (49 ft) [42]. Its oval leaves normally alternately arranged, are of 4 to 10 cm (1.6 to 3.9 inch) long and have crenulated margins. Although the sweet orange presents different sizes and shapes varying from spherical to oblong, it generally has ten segments (carpels) inside, and contains up to 6 seeds (or pips) [43] and a porous white tissue called pith or, more properly, mesocarp or albedo lines its rind. When unripe, the fruit is green.

The grainy irregular rind of the ripe fruit can range from bright orange to yellow orange, but frequently retains green patches or, under warm climate conditions, remains entirely green. Like all other citrus fruits, the sweet orange is non-climacteric. The Citrus sinensis is subdivided into four classes with distinct characteristics: common oranges, blood or pigmented oranges, navel oranges, and acid less orange [42, 44, 45].

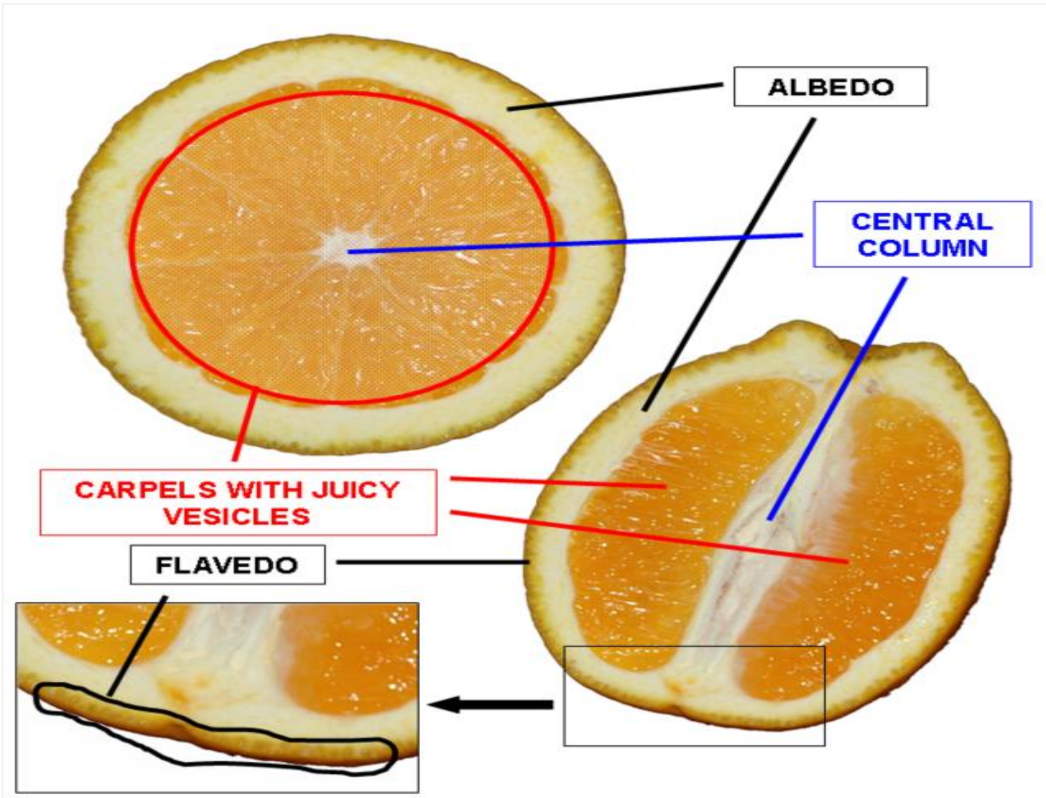


Plate 1.4: Orange fruit cross-section.

Global Orange production for 2013/14 is forecast to rise 5 percent from the previous year to 68.7 million metric tons as increases in Brazil, China, and the European Union (EU) more than offset the continued drop in the United States. Brazil is the largest producer of Orange followed by USA and China is forecast to remain the largest fresh consumer accounting for over 20 percent of global consumption while South Africa, the world's largest exporter of Orange's accounts for over 25 percent of world trade and is forecast at a record 1.2 million tons. Oranges are the second largest fruit grown and processed in the world after grapes [46]. Orange is the 3rd largest producing fruit in India. The major Orange producing states of India are Andhra Pradesh, Maharashtra, Karnataka, Punjab and Rajasthan. In 2012, the Orange production was 51.8 million metric tons, which was higher by 15% compared with that of 1997-1999 [47]. Orange peel is one of the most underutilized and geographically diverse bio-waste residues on the planet. Table 1.1 shows the rank of Top ten countries with the largest production of orange in 2012 [48].

Table 1.1: Top ten countries with the largest production of orange in 2012 [48].

Rank	Country	Production **(million tonnes)**
1	Brazil	18.0
2	United States	8.1
3	China	6.5
4	India	5.0
5	Mexico	3.6
6	Spain	2.9
7	Egypt	2.7
8	Italy	1.7
9	Turkey	1.6
10	South Africa	1.6

India has a huge potential for producing Orange peel oil of 27,600 ton (based on 0.5% recovery of oil from 46 lakhs ton fruits by cold press process) from the Orange fruits.

Table 1.2: Physical characteristics of sweet Orange [51].

Characteristics	**Value**
Color	Greenish yellow
Weight of fruits (gram)	199.00
Diameter (mm)	84.06
Thickness of peel (mm)	2.34
Weight. of peel (gram)	47.10
Weight of albedo (gram)	31.69
Weight of Flavedo (gram)	15.39
Weight of fruit without peel (gram)	167.25
Weight of juice (gram)	77.65
Weight of Pomace (gram)	66.00
Weight. of seeds (gram)	12.60
No. of seeds	17
Peel (%)	23.6
Oil from peel (%)	0.5

Presently, 2–3 tons of Orange peel oil is produced for food and cosmetic industries. There is no other demand for Orange peel oil. As the demand increases for large quantity of Orange peel oil for fuelling in internal combustion engines, the requirement for Orange peel collection would increase drastically [49, 50]. Orange peel oil is a biomass-derived fuel obtained from Orange skin, which has 90% D-limonene and can be used for many applications. Physical characteristic of Orange peel oil is mentioned in table 1.2.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

As discussed in the earlier section, an integrated research and development approach has to be implemented to assess the potential of "Orange peel oil" as alternative diesel fuel. Therefore, the existing quantum of research work in the domains like optimization of biodiesel production from vegetable oil sources, physico-chemical and fuel property characterisation, application in engines to evaluate performance, emission and combustion, numerical studies using computational fluid dynamics and model validation etc. need to be studied as review of literature. In this context, a comprehensive literature review of various national and International journals was carried out. Some of the important outcomes are summarized below.

2.2 REVIEW OF AVAILABLE LITERATURE

2.2.1 Biodiesel Production from Vegetable oils, Characterisation and Optimization

Atadashi et.al. [52] explored the production of fatty acid methyl esters or biodiesel from high free fatty acid containing feed stocks like some non-edible vegetable oils, animal fats etc. to bring their properties close to mineral diesel. The results concluded that the properties of the biodiesel produced closely matched the corresponding ASTM standards and cost of production was reported to be 25% less compared to refined low FFA feed stocks.

Chen et. al. [53] studied the feasibility of biodiesel production from "Tung" (Vernicia montana) oil with respect to the transesterification yield and biodiesel properties. The findings indicated high cold filter plugging point of 11^{O}C, 94.9 wt.% of ester content and oxidation stability of 0.3 hours at 110^{O}C for the biodiesel sample produced. Moreover, the tung oil biodiesel exhibited high density of 903 kg/m3at 15 ^{O}C, kinematic viscosity of 7.84 mm^2/s at 40 ^{o}C and iodine value of 161.1 g I_2/100 g. The properties of the tung oil biodiesel were found to be improved by blending with canola and palm oil biodiesels to satisfy the biodiesel specifications.

Usta et. al. [54] evaluated tobacco seed oil as a feedstock for biodiesel production. Various physicochemical and fuel properties of the tobacco biodiesel were examined and compared with European Biodiesel Standard EN14214. The results showed oxidation stability and iodine number of the biodiesel were not within the standards limit. Oxidation stability was improved by six different anti-oxidants, out of which “pyrogallol” was found to be the most effective. Poor iodine number was improved by blending it with biodiesel containing more unsaturated fatty acids. The resultant reduction in cold flow plugging point was addressed by adding “octadecene-1-maleic anhydride copolymer” as cold flow property improver.

Salles et.al. [55] studied the production and physico- chemical characterisation of biodiesel from the fruits of the Syagrus coronate (Mart.) Becc., popularly known in Brazil as “licuri” or “ouricuri”. The oil was transesterified using conventional catalysts and methanol, to obtain biodiesel. The properties of the biodiesel produced were comparable with standards.

Silitonga et. al. [56] investigated biodiesel characterization and production from Ceiba pentandra seed oil. The production was conducted by two step acid–base transesterification. The results found that properties of C. pentandra methyl ester fall within the recommended biodiesel standards (ASTM D6751and EN 14214). Beside, this study also suggested biodiesel–diesel blending to improve the properties such as viscosity, density, flash point, calorific value and oxidation stability.

Lin et. al. [57] carried out a three stage transesterification process to produce biodiesel from crude rice bran oil (RBO) The influence of variables on conversion efficiency to methyl ester, i.e., methanol/RBO molar ratio, catalyst amount, reaction temperature and reaction time, was studied. The content of methyl ester was analysed by chromatographic analysis. Through orthogonal analysis of parameters in a four-factor and three-level test, the optimum reaction conditions for the transesterification were obtained: methanol/ RBO molar ratio 6:1, usage amount of KOH 0.9% w/w, reaction temperature 60 ^{O}C and reaction time 60 minutes. Fuel properties of RBO biodiesel were studied and compared according to ASTM D6751-02 and DIN V51606 standards for biodiesel. Most fuel properties complied with the limits prescribed in the aforementioned standards.

Benjumea et. al. [58] measured some basic properties of several palm oil biodiesel–diesel fuel blends according to the corresponding ASTM standards. In order to predict these properties, mixing rules were evaluated as a function of the volume fraction of biodiesel in the blend. Kay's mixing rule was 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 was used for viscosity. The absolute average deviations (AAD) obtained was 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 was in better agreement with the reported cetane number than the one corresponding to the ASTM D976.

Berman et.al. [59] investigated 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 petro-diesel in a 10% vol ratio (B10). Kinematic viscosity and distillation temperature of B100 (15.17 mm^2/s 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 required that the pure biodiesel meets the requirements of ASTM D6751. This can limit the use of a wide range of feed stocks, including castor, as alternative fuel, especially due to the fact that in practice vehicles normally use low level blends of biodiesel and petrodiesel.

Harrison et. al. [60] examined the effect of varying levels of eicosapentaenoic acid(EPA) and docosahexaenoic acid (DHA) on algal methyl ester fuel properties. Oxidative stability, Cetane Number, density, viscosity, bulk modulus, cloud point and cold filter plugging point were measured for algal methyl esters produced from various microalgae feedstocks as well as model algal methyl ester compounds formulated to match the fatty acid composition of Nannochloropsis species, Nannochloropsis oculata and Isochrysis galbana subjected to varying levels of removal of EPA and DHA. The results suggest that removal of 50 to 80% of the long chain-polyunsaturated fatty acids (LC-PUFA) from Nannochloropsis- based methyl esters would be sufficient for meeting existing specifications for oxidative stability. However, higher levels of LC-PUFA removal from Nannochloropsis-based methyl esters would be required to produce fuels with acceptable Cetane Number. The removal of EPA and DHA was shown to have a detrimental effect on cold flow properties since the algal methyl esters are also high in fully saturated fatty acid content.

Chakraborty et. al. [61] carried out an investigation to evaluate the prospect of terminalia oil for biodiesel production with reference to some relevant properties. The fatty acid profile of oil extracted from terminalia was found comparable with similar seed oils attempted for biodiesel production in this region. Terminalia oil contained 32.8% palmitic acid, 31.3% oleic acid, and 28.8% linoleic acid. The calorific value and kinematic viscosity of terminalia oil were 37.50 MJ/kg and 25.60 cSt, respectively. The calorific value and cetane number of terminalia FAME were within the acceptable limit of the EN 14214 standard. However, the flashpoint of terminalia FAME (90 °C) was relatively lower than the minimum required standard. Overall, the properties of biodiesel obtained from terminalia seed conform to the existing biodiesel standard.

Chammoun et. al. [62] identified Oilseed radish (Raphanus sativus) as a potential cool season cover and energy crop for the southern United States. The fatty acid profile of this oil showed high levels of erucic acid (C22:1), which has been linked to health issues. The extracted oil was converted to fatty acid methyl esters (biodiesel) via transesterification. Fuel properties were analysed including fatty acid profile, free and total glycerol, acid number, sulphur content, water content and cold filter plugging point (CFPP). Fuel properties of the biodiesel were found to meet or exceed ASTM standards for use in on-road vehicles.

Chu et.al. [63] produced biodiesel from A. pedunculata conformed to EN14214, ASTM D6751, and GB/T20828 standards, except for those cetane number and oxidative stability. Cold flow and transportation safety properties were excellent (cold filter plugging point 11°C, flashpoint 169°C). Additives and antioxidants would be required to meet cetane number and oxidative stability specifications. The addition of 500 ppm tert- butyl hydroquinone resulted in a higher induction period (6.7 h), bringing oxidative stability into compliance with all three biodiesel standards.

Wang et. al. [64] investigated Siberian apricot (Prunus sibirica L.) seed kernel oil as a promising non-conventional feedstock for preparation of biodiesel. The oil has high oil content (50.18 ± 3.92%), low acid value (0.46 mg/g), low water content (0.17%) and high percentage of oleic acid (65.23 ± 4.97%) and linoleic acid (28.92 ± 4.62%). The measured fuel properties of the Siberian apricot biodiesel, except cetane number and oxidative stability, were conformed to EN 14214-08, ASTM D6751-10 and GB/T 20828-07 standards, especially the cold flow properties were excellent (Cold filter plugging point -14°C).

Wang et. al. [65] studied feasibility of biodiesel production from Datura stramonium L. oil (DSO). The research work explored an optimum yield of 87% using a two-step catalysed reaction conditions. 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 mm^2/s) and cold filter plug point (-5°C).

Omar et. al. [66] investigated heterogeneous transesterification of waste cooking palm oil (WCPO) to biodiesel over Sr/ZrO_2 catalyst and the process optimization. Response surface methodology (RSM) was employed to study the relationships of methanol to oil molar ratio, catalyst loading, reaction time, and reaction temperature on methyl ester yield and free fatty acid conversion. The experiments were designed using central composite by applying24 full factorial designs with two centre points. Transesterification of WCPO produced79.7% maximum methyl ester yield at the optimum methanol to oil molar ratio ¼ 29:1, catalyst loading ¼ 2.7 wt.%, reaction time ¼ 87 min and reaction temperature ¼ 115.5°C.

Yun et. al. [67] simulated a continuous enzyme-catalysed biodiesel pilot plant using waste cooking oil, with production capacity of 6482 ton/yr, by Aspen Plus. Detailed operating conditions and equipment designs were obtained. Five reactions were applied to represent the transesterification of the biodiesel production. The simulation results were in good agreement with the real data. Based on the simulation of the original process, five optimization processes, was proposed focusing on energy saving and methanol recovery Pinch technology was also used to develop heat exchange networks. Throughout the different optimizations, the quality of biodiesel was still kept at a high purity (>98.5%).

As an outcome of exhaustive review of available literatures in the field of biodiesel production from vegetable oils, physico-chemical characterization and process optimization the following major findings are obtained:

- 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.
- 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.

- Response surface methodology using central composite design method was followed by many researchers as an effective process optimization technique in biodiesel production from a wide range of feed stocks.
- However, most of the process optimization was confined to the final stage only with % yield as the response and not both the stages of transesterification.
- In many reported cases the final biodiesel sample produced did not comply with the designated standards of ASTM/EN/ISO etc. resulting in further addition of additives and post-processing.

2.2.2 Diesel Engine Trials and analysis of Results using Biodiesel as a fuel

Purushothaman.K et. al [68] have studied the performance, emission and combustion characteristics of a single cylinder compression ignition engine operating on neat Orange peel oil, and their results showed that the oil exhibits a longer ignition delay as well as higher combustion duration compared to diesel. It was found during the investigation that heat release rate and brake thermal efficiency (BTE) (at full load) for Orange peel oil is higher than diesel. HC and CO emissions were found to be reduced for Orange peel oil when compared to diesel. Smoke emissions are reduced marginally for Orange peel oil than diesel fuel. NOx emissions are higher for Orange peel oil than diesel

Kumar et.al. [69] used Karanja oil blends with diesel as inducted fuel in a direct injection compression ignition (DICI) engine for experimental investigations on performance, emission and combustion characteristics of the fuel. They found that the thermal efficiency and fuel consumption was relatively lower for all Karanja oil blends as compared to mineral diesel. The HC emissions were found to be lower for the whole operating range across all Karanja oil blend concentrations than mineral diesel. NOx and CO emissions were considerably higher for higher Karanja oil blends. On decreasing the concentration of Karanja oil blends, Smoke opacity was found to decrease in comparison to mineral diesel.

Purushothaman.K et. al. [70] observed that the heat release rate increases with longer ignition delay when up to 30% of Orange oil is used and slightly decreases for higher concentration of Orange oil. The maximum in-cylinder pressure and brake thermal efficiency was achieved at 30% Orange oil blend than fossil diesel. It was also found that the use of Orange oil resulted in reduced HC, CO and smoke emissions in comparison to diesel, although the NOx emission increased significantly.

Deep. A. et. al. [71] has performed experimental investigation of Orange peel oil methyl ester on a single cylinder diesel engine. They found that the brake thermal efficiency improved as the concentration of Orange peel oil methyl ester was increased in the blend with diesel over baseline data of diesel. The emissions of HC and CO were found to decrease with increase in the amount of Orange peel oil methyl ester in diesel blends. Overall, they concluded that 20% blend of Orange peel oil methyl ester with neat diesel has high potential for running the diesel engine.

Buyukkaya et. al. [72] investigated experimental tests to evaluate the performance, emission and combustion of a diesel engine using neat rapeseed oil and its blends of 5%, 20% and 70%, and standard diesel fuel separately. The results indicated that the use of biodiesel produced lower smoke opacity (up to 60%), and higher brake specific fuel consumption (BSFC) (up to 11%) compared to diesel fuel. The measured CO emissions of B5 andB100 fuels were found to be 9% and 32% lower than that of the diesel fuel, respectively. The BSFC of biodiesel at the maximum torque and rated power conditions were found to be 8.5% and 8% higher than that of the diesel fuel, respectively. From the combustion analysis, it was found that ignition delay was shorter for neat rapeseed oil and its blends tested compared to that of standard diesel. The combustion characteristics of rapeseed oil and its diesel blends closely followed those of standard diesel.

Rehman et. al. [73] carried out investigation in studying the fuel properties of karanja methyl ester (KME) and its blend with diesel from 20% to 80% by volume and in running a diesel engine with these fuels. Engine tests have been carried out with the aim of obtaining comparative measures of torque, power, specific fuel consumption and emissions such as CO, smoke density and NO_x to evaluate and compute the behaviour of the diesel engine running on the above-mentioned fuels. The reduction in exhaust emissions together with increase in torque, brake power, brake thermal e:ciency and reduction in brake-speci4c fuel consumption made the blends of karanja esteri4ed oil (B20 and B40) a suitable alternative fuel for diesel and could help in controlling air pollution.

Godiganur et. al. [74] ran a Cummins 6BTA 5.9 G2- 1,158 HP rated power, turbocharged, DI, water cooled diesel engine on diesel, methyl ester of mahua oil and its blends at constant speed of 1500 rpm under variable load conditions. The volumetric blending ratios of biodiesel with conventional diesel fuel were set at 0, 20, 40, 60, and 100. Engine performance (brake specific fuel consumption, brake specific energy consumption, thermal efficiency and exhaust gas temperature) and emissions (CO, HC and NO_x) were measured to evaluate and compute the behaviour of the diesel engine running on biodiesel. The results indicated that with the increase of biodiesel in the blends CO, HC reduced significantly, fuel consumption and NO_x emission of biodiesel increased slightly compared with diesel. Brake specific energy consumption decreased and thermal efficiency of engine slightly increased when operating on 20% biodiesel than that operating on diesel.

Raheman et. al. [75] presented the performance of biodiesel obtained from mahua oil and its blend with high speed diesel in a Ricardo E6 in this paper together with some of its fuel properties. These properties were found to be comparable to diesel and confirming to both the American and European standards. Engine performance (brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature) and emissions (CO, smoke density and NO_x) were measured to evaluate and compute the behaviour of the diesel engine running on biodiesel. The reductions in exhaust emissions and brake specific fuel consumption together with increase brake power, brake thermal efficiency made the blend of biodiesel (B20) a suitable alternative fuel for diesel and thus could help in controlling air pollution.

Sahoo et. al. [76] filtered high viscous (72 cSt at 40°C) and high acid value (44 mg KOH/gm) polanga (Calophyllum Inophyllum) oil based mono esters (biodiesel) produced by triple stage transesterification process and blended with high speed diesel (HSD) and tested for their use as a substitute fuel of diesel in a single cylinder diesel engine. HSD and polanga oil methyl ester (POME) fuel blends (20%, 40%, 60%, 80%, and 100%) were used for conducting the short-term engine performance tests at varying loads (0%, 20%, 40%, 60%, 80% and 100%). Tests were carried out over entire range of engine operation at varying conditions of speed and load. The brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE) were calculated from the recorded data. The engine performance parameters such as fuel consumption, thermal efficiency, exhaust gas temperature and exhaust emissions (CO, CO2, HC, NO_x, and O_2) were recorded. The optimum engine operating condition based on lower brake specific fuel consumption and higher brake thermal efficiency was observed at 100% load for neat biodiesel. From emission point of view the neat POME was found to be the best fuel as it showed lesser exhaust emission as compared to HSD.

Liaqat et. al. [77] used a total of three fuel samples, such as DF (100% diesel fuel), CB5 (5% coconut biodiesel and95% DF), and CB15 (15% CB and 85% DF). 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, engine emission tests were carried out at 2200 rpm at 100% and 80% throttle position.

As results of investigations, there was a reduction in torque and brake power, while increase in specific fuel consumption observed for biodiesel blended fuels over the entire speed range compared to net diesel fuel. In case of engine exhaust gas emissions, lower HC, CO and, higher CO_2 and NOx emissions was found for biodiesel blended fuels compared to diesel fuel. Moreover, reduction in sound level for both biodiesel blended fuels was observed when compared to diesel fuel.

Chauhan et. al. [78] transesterified Karanja oil and found the properties within acceptable limits of relevant standards. The performance parameters evaluated in the present study included brake thermal efficiency of Karanja biodiesel with different compositions at 5%, 10%, 20%,30% and 100% with mineral Diesel BTE was about 3-5% lower with Karanja biodiesel and its blends with respect to diesel. Also, emissions parameters such as carbon monoxide, carbon dioxide, UBHC (unburnt hydrocarbon), oxides of nitrogen and smoke opacity for different test fuels were also measured. UBHC, CO, CO_2 and smoke were lower with Karanja biodiesel fuel. However, NO_x emissions of Karanja biodiesel and its blend were higher than Diesel. The combustion analysis was done using peak cylinder pressure and heat release rate with respect to crank angle. The peak cylinder pressure and heat release rate was lower for Karanja biodiesel. The results from the experiments suggested that biodiesel from non-edible oil like Karanja and its blends with diesel could be a potential fuel for diesel engine and play a vital role in the near future especially for small and medium energy production.

Chen et. al. [79] blended Jatropha oil methyl esters (JMEs) produced from jatropha (Jatropha curcas) oil with diesel at various volumetric percentages to evaluate the variations in the fuel properties. Correlations between fuel properties, including the calorific heat, cold filter plugging point, density, kinematic viscosity, and oxidation stability of the JMEs–diesel blends, and the blending ratio of the JMEs was established.

As a result, a blending ratio of the JME with diesel was recommended up to 40 vol. % in comparison with the relevant specifications for biodiesel–diesel blends. The combustion tests of the JME–diesel blends were performed in a diesel generator. Higher brake thermal efficiency and lower brake specific fuel consumption were clearly observed with higher output loading. The concentration of carbon dioxide and nitrogen monoxide in the exhaust gas increased with higher output loading while the concentration of oxygen and carbon monoxide decreased. The concentration of nitrogen oxide decreased with the addition of pyrogallol. Multiple linear correlations for combustion performance and pollutant emissions was established that were associated with system parameters, including output loading, the blending ratio, and the pyrogallol addition.

Lapureta et. al. [80] collected and analysed the body of work written mainly in scientific journals about diesel engine emissions when using biodiesel fuels as opposed to conventional diesel fuels. Since the basis for comparison was to maintain engine performance, the first section was dedicated to the effect of biodiesel fuel on engine power, fuel consumption and thermal efficiency. The highest consensus was found to lie in an increase in fuel consumption in approximate proportion to the loss of heating value. In the subsequent sections, the engine emissions from biodiesel and diesel fuels were compared, paying special attention to the most concerning emissions: nitric oxides and particulate matter, the latter not only in mass and composition but also in size distributions. In this case the highest consensus was found in the sharp reduction in particulate emissions.

Nabi et. al. [81] produced karanja methyl ester (KME), which was termed as BD by well-known transesterification process. The properties of B100 (B100) and its blends were determined mainly according to ASTM standard and some of them were as per EN14214 standard. The Fourier transform infrared (FTIR) analysis showed that the DF fuel contained mainly alkanes and alkens, while the B100 contained mainly esters. The gas chromatography (GC) of B100 revealed that a maximum of 97% methyl ester was produced from karanja oil. Engine experiment result showed that all BD blends reduced engine emissions including carbon monoxide (CO), smoke and engine noise, but increased oxides of nitrogen (NOx). Compared to DF, B100 reduced CO, and smoke emissions by 50 and 43%, while a 15% increase in NOx emission was observed with the B100. Compared to DF, engine noise with B100 was reduced by 2.5 dB.

Shivalakshmi et.al. [82] carried out an experimental investigation to evaluate the effect of using diethyl ether as additive to biodiesel on the combustion, performance and emission characteristics in an unmodified diesel engine at different loads and constant engine speed. The results indicated that peak cylinder pressure and heat release rate was higher for BD5 (5% (v/v) diethyl ether blended biodiesel) than those of neat biodiesel. The carbon monoxide emissions especially at full load and smoke emissions at almost all engine loads decreased while oxides of nitrogen and hydrocarbon emissions increased for BD5 than those of neat biodiesel at almost all engine loads. The brake thermal efficiency of BD5 was higher as compared to biodiesel.

Das et. al.[83] has investigated on filtered Jatropha (Jatropha curcas), Karanja (Pongamia pinnata) and Polanga (Calophyllum inophyllum) oil based mono esters (biodiesel) tested for their use as substitute fuels of diesel engines. Diesel, neat biodiesel from Jatropha, Karanja and Polanga; and their blends (20% and 50% by v/v) were used for conducting combustion tests at varying loads (0, 50 and 100%). Combustion analysis revealed that neat Polanga biodiesel that results in maximum peak cylinder pressure was the optimum fuel blend as far as the peak cylinder pressure was concerned. The ignition delays were consistently shorter for neat Jatropha biodiesel neat Karanja and Polanga biodiesel and found lower than diesel with the difference increasing with the load.

Labecki et. al. [84] found combustion and emission characteristics of rapeseed plant oil (RSO) and its blends with diesel fuel in a multi-cylinder direct injection diesel engine. An attempt had been made to reduce soot emissions from the combustion of RSO to exploit the advantage of its low NOx emissions. Variation in injection parameters such as injection pressures and injection timings had been used in this work to reduce the soot emissions for blends of 50% and 30% RSO in diesel fuel. Under diesel equivalent soot emission levels, it was also possible to achieve a further reduction in NOx emissions by up to 22% for 30% RSO blend, this was achieved at the expense of THC, CO and BSFC. However, when compared to diesel, the exhaust soot particle number concentration for 30% RSO blend was still higher, even after diesel equivalent level of soot emission was achieved. The heat release shapes are almost the same for all cases, except for a shift towards the expansion stroke for 30% RSO case under diesel equivalent soot operating condition.

Qi et. al. [85] examined the performance, emissions and combustion characteristics of diesel and biodiesel as fuels in the compression ignition engine. The power output of biodiesel was almost identical with that of diesel. The brake specific fuel consumption was higher for biodiesel due to its lower heating value. Biodiesel provided significant reduction in CO, HC, NOx and smoke under speed characteristic at full engine load. Based on this study, biodiesel can be used as a substitute for diesel in diesel engine.

Adailehet et. al. [86] presented the combustion and emissions characteristics of waste vegetable oil biodiesel at variable engine speed between 1200-2600 rpm. The results showed significant reductions in CO, and unburned HC, but the NOx was increased. Biodiesel has 5.95 % increases in brake-specific fuel consumption. The fuel consumption rate, brake thermal efficiency, and exhaust gas temperature increased while the BSFC, emission indices of CO_2, CO decreased with an increase of engine speed.

As an outcome of the elaborative review of existing technical literatures regarding the engine trial results of biodiesels derived from a wide range of vegetable oil feed stocks and its blends, the following conclusions are made:

1. Depending upon the feed stocks, some of the biodiesels showed improved brake thermal efficiency and reduced brake specific fuel consumption with increased biodiesel volume fraction in the test fuel where as some others exhibited exactly opposite trend. Therefore engine performance using biodiesel directly depends upon the property of corresponding feedstock and transesterification process.
2. Most of the literatures agreed on the common denominator that emissions of carbon monoxide and unburnt hydro carbons were reduced with biodiesel, whereas that of oxides of nitrogen increased. However, the same was not linear. In many cases even, reduction in oxides of nitrogen was reported.
3. All most all of the literatures indicated increased in-cylinder pressure for lower volume fraction of biodiesel in the test fuels irrespective of the feed stocks. This led to shorter combustion duration, increased in-cylinder temperature and lower exhausts temperatures reported in many cases. However, at higher volume fractions of biodiesel some literatures indicated reduction in peak in-cylinder pressure where some indicated minimal change in the peak in-cylinder pressure. Therefore, the combustion phenomena using biodiesel is highly sensitive to the nature of the feedstock and transesterification process which actually determines the fuel properties.
4. With increase in volume fraction of biodiesel, reduction in combustion heat release was reported in major cases. However, in some cases a marginal increase was reported at lower blends.
5. Increased heat release in the diffusion phase, smoother engine operation etc. are some of the major conclusions in most of the literatures.

2.3 LITERATURE GAP

Orange peel biodiesel was chosen for this study because the quantum of available research work pertains to the utilization of straight vegetable oil in a diesel engine. The following points justify the selection of orange peel biodiesel for combustion, performance and emission studies on a conventional diesel engine;

1. The research work on Orange peel oil has been largely restricted to its utilization as a straight vegetable oil in a diesel engine. Hence, there was a need to explore the potential of Orange peel biodiesel as a fuel substitute in a diesel engine.
2. Orange peel oil has one of the least FFA (Free fatty acid), i.e. less than 1% thereby its biodiesel can be obtained by a single step transesterification process.
3. Orange peel biodiesel has a viscosity which is one of the lowest among all other biodiesel produced from various feedstocks thus reducing the problem of higher viscosity.
4. Orange peel is a non-edible feedstock for biodiesel production, which is also a waste material, produced in large quantities across the world, hence a viable alternative for sustainable production.
5. Orange peel biodiesel has a very favourable oxidation stability and cold flow property.

2.4 STATEMENT OF THE PROBLEM

In the light of the exhaustive literature review and the subsequent analysis on the basis of it, 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 popularly known as transesterification may be a single step or two step processes depending upon the FFA of vegetable oil. Most of the non-edible vegetable oils have high FFA content i.e. >2% therefore for these oils an acid catalysed esterification followed by a base catalysed transesterification process. As two steps transesterification is energy intensive, therefore optimization of various process parameters like catalyst concentration, reaction time, reaction temperature, molar ratio are essential for commercially competitive production. The biodiesel so obtained should be thoroughly characterised as per the various ASTM/EN standards. If some of the properties are not consistent with standards as reported in many literatures, some additives may be added to improve theses essential standard properties. Then the final biodiesel so prepared would be used as a fuel in diesel engines in neat form as well as various proportional blends with diesel. The performance, emissions and combustion behaviour of diesel engine fuelled with all set of test fuels validate their suitability. On the basis of this valuable information, the following objectives were envisaged for the present research work:

1. Looking towards the low FFA of Orange peel vegetable oil, the one stage transesterification process is to be done with process optimization stages. The parameters like catalyst concentration, reaction time and reaction temperature to be taken as factors in the experimental design for the acid catalysed stage, %FFA and for the base catalysed stage, %yield of biodiesel were to be considered as the response.
2. Bulk quantity Orange peel biodiesel will be produced using the optimized parameters obtained in the transesterification stage. Various physico-chemical and fuel properties of OPB would be evaluated and compared with various standards like ASTM/EN etc.
3. A comprehensive engine trial will be carried out to assess the performance, emissions and combustion behaviours of actual diesel engine fuelled with OPB and its blends. Also, its comparison will be done with the baseline diesel operation.

CHAPTER 3

SYSTEM DEVELOPMENT & EXPERIEMENTAL PROCEDURE

3.1 INTRODUCTION

Diesel engines are amongst the most useful and efficient prime movers amongst all power producing machines. Due to this reason it has becomes necessary to develop alternative fuels with properties comparable to petroleum based diesel fuels with the view of protecting global environment and concerns for long-term energy security. For countries like India and many other developing countries; fuels of bio-origin provide a feasible solution to the above twin crisis. Bio-fuels are getting a worldwide attention because of global stress on reduction of greenhouse gases (GHGs) and clean development mechanism (CDM).

The fuels of bio-origin may be alcohol, vegetable oils, biodiesel, biomass, and biogas. Biodiesel have comparable physico-chemical properties with mineral diesel and they are biodegradable, non-toxic, and have a potential to significantly reduce pollution. Due to these reasons many countries including the developing one has started investing generously into the projects which will provide some useful fuel. Each country can move ahead in the production of fuel depending upon its climatic conditions as well as its economy. Various blend of biodiesel with alcohols prove to work as a promising fuel as already seen in the Literature Review in terms of reduction in harmful emissions in the environment and decreasing the dependency on fossil diesel to some extent.

The qualities of this fuel, environmentally as well as technically, have pushed this fuel close to the final stages of commercialization in many countries. Each country can proceed in the production of particular fuel, depending upon the climate and economy.

Different countries have taken initiatives in this field and re-forestation has a very important role to play in meeting the challenge of climate change. Several initiatives have been taken in recent years in different parts of the country to promote large scale cultivation of oilseed bearing plants. Amongst the various plant species, oil extracted from peel of orange to produce biodiesel has been found very suitable as a substitute to diesel fuel.

This chapter deals with the systematic execution of the four steps mentioned in the problem statement section. It includes the production of biodiesel from Orange peel oil and preparation of various blends of OPB (Orange peel biodiesel) and diesel, comprehensive physico-chemical characterisation, development of engine test rig, development of heat release model and other engine parameters like performance and emission, procedures for engine trial.

3.2 PRODUCTION OF ORANGE PEEL BIODIESEL

3.2.1 Conventional Two Step Process

Biodiesel is normally produced by the transesterification of the waste vegetable oil, algal oil or animal fat as a feedstock. The most commonly used alcohol is methanol or ethanol to produce methyl esters or ethyl esters. It is generally referred as fatty acid methyl esters (FAME) or fatty acid ethyl esters (FAEE) [87].

As already seen in literatures, the viscosity, volatility and exhaust emissions of vegetable oils deviate far away from properties of diesel. To make use of vegetable oils in an effective way it should be converted into biodiesel using a single or a two step conversion process.

Nowadays, there are four different methods available to reduce the viscosity of vegetable oil, which is detrimental to engine hardware, such as blending of oil with petroleum diesel, pyrolysis (Thermal Cracking), emulsification and transesterification as discussed earlier [88]. The diesel combustion engines to be modified to avoid carbon deposition, when the vegetable oil is used directly or mixed along with petroleum diesel [89, 90].

The pyrolysis and emulsification methods are producing heavy carbon deposits, in complete combustion, increase of lubricating oil viscosity and undesirable side-products such as aliphatic and aromatic compounds and carboxylic acids. Recently, transesterification has been reported as the most common way to produce biodiesel from vegetable with alcohol, in presence of an acid or base catalyst [91].

For that a two step transesterification process is discussed by Karmakar et. al. [92] and its flow chart are shown in Fig. 3.1 to make biodiesel from raw oil.

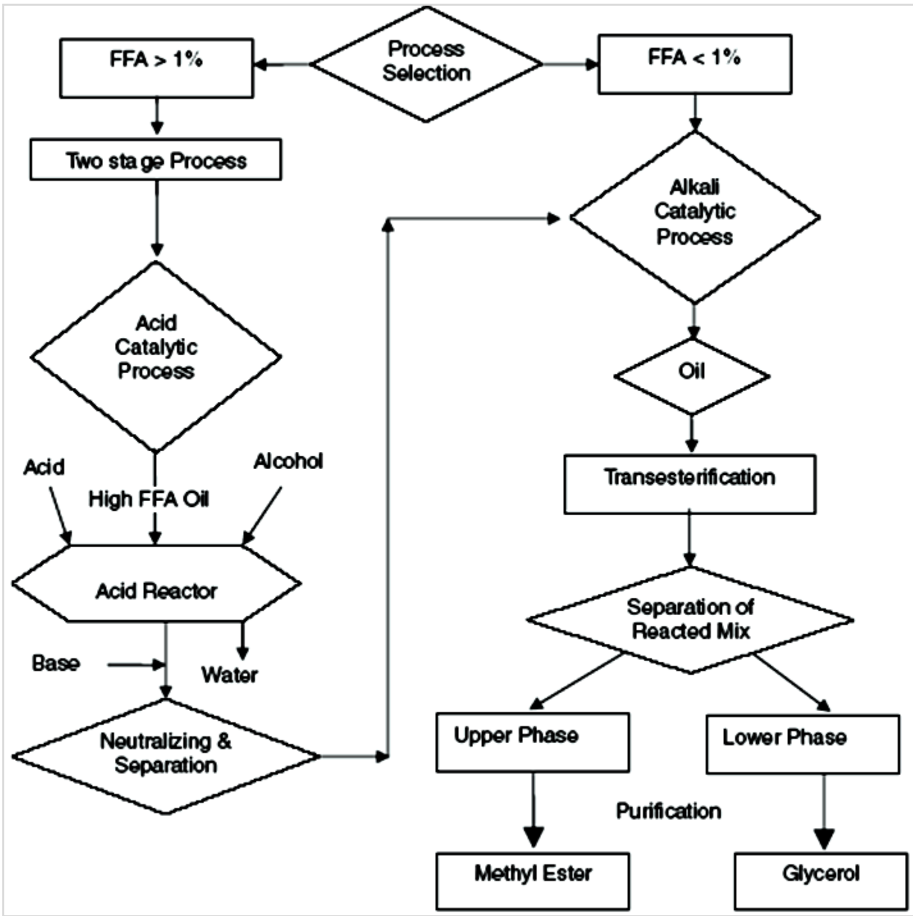
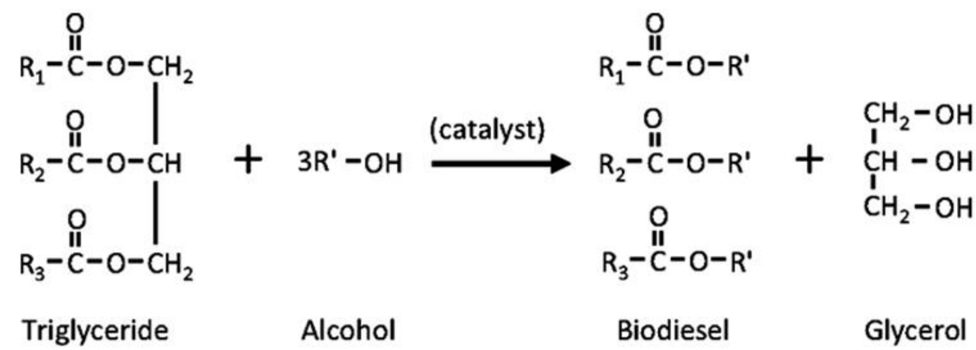


Fig. 3.1 Two step transesterification process.

Also the transesterification reaction for FAME is presented in equation (3.1), where R is a mixture of fatty acid chains [93].



...(3.1)

However, the feed stocks having high content of free fatty acids in the vegetable oil require a different procedure to follow. That is because the free fatty acids do not react with methanol in presence of an alkaline catalyst. However, the FFA can react with alcohol to form ester (biodiesel) by an acid-catalysed esterification reaction [94]. This reaction is very useful for handling oils or fats with high FFA, as shown in the equation (3.2) below:

$$\underset{\text{(FFA)}}{R_1{-}COOH} + \underset{\text{(alcohol)}}{ROH} \overset{H^+}{\rightarrow} \underset{\text{(fatty acid ester)}}{R{-}O{-}CO{-}R_1} + \underset{\text{(water)}}{H_2O} \quad ...(3.2)$$

Normally, sulphuric acid is considered as the suitable catalyst for this reaction, however a good range of acids may be considered for the same purpose. Therefore, vegetable oil feed stocks have more than 2% free fatty acid contents are generally transesterified in two stages. In the first stage the FFA is reacted with the alcohol in presence of acid catalyst and when the FFA is reduced below 2%, then it is transesterified in presence of alkaline catalyst.

3.2.2 Single Step Transesterification for Production of Biodiesel

Orange oil was extracted from good quality peel oil expeller. The oil so obtained was pressure filtered and heated at 120°C for 20 minutes to remove moisture. The oil was then preserved in an airtight screw cap bottle. Plate 3.1 shows Orange peel, extracted oil and the transesterification process.

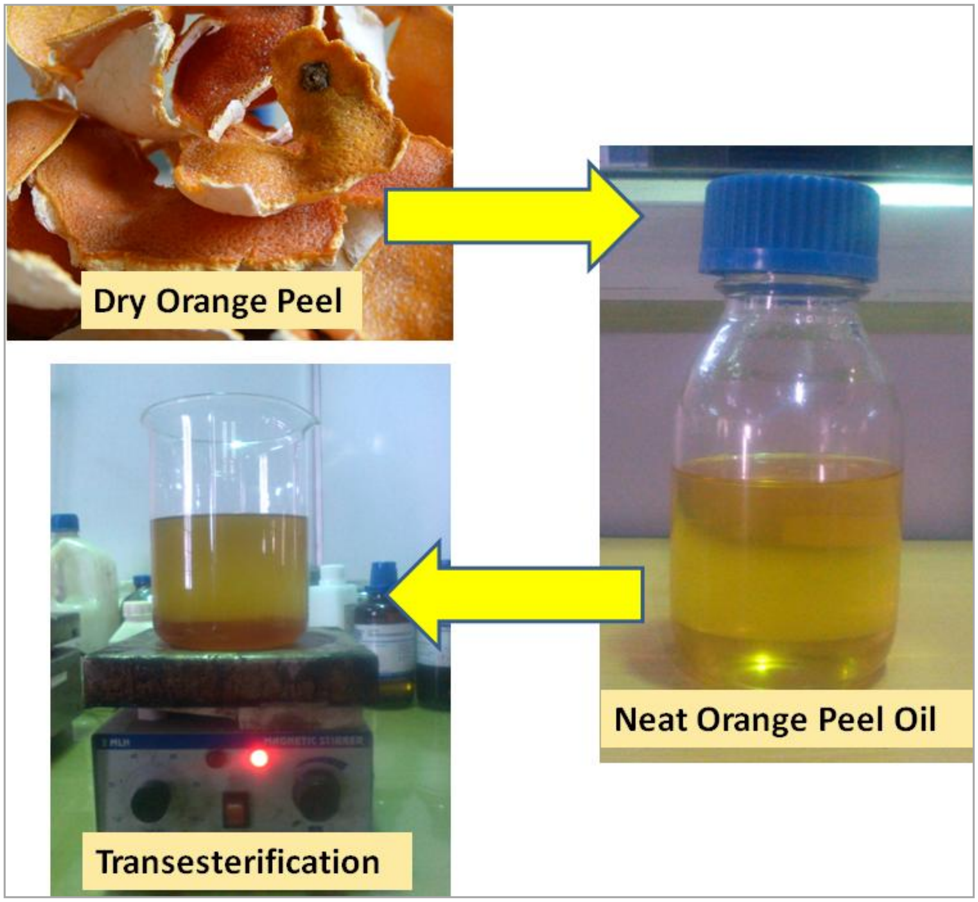


Plate 3.1: Shows Orange Peel, Oil and Transesterification process.

As already discussed in the literature review the free fatty acid (FFA) of Orange peel oil is very low i.e. less than 1% therefore we need to undergo only the transesterification process with the help of alcohol and base catalyst like NaOH and KOH to obtain biodiesel. Reaction 3.3 explains the process of production of Orange peel Biodiesel.

Orange Peel Oil + Methanol + KOH ⟶ Orange Peel Biodiesel + Glycerin ...(3.3)

After this reaction fatty acid methyl ester is ready however glycerine is still remained in the prepared sample which is first separated by gravimetric separation in a separating funnel followed by the centrifuge separation by the action of centrifugal force for the complete extraction of pure biodiesel. At the same time to ensure the biodiesel methanol free the sample was run on rotary evaporator for 45 min at 53ºC.

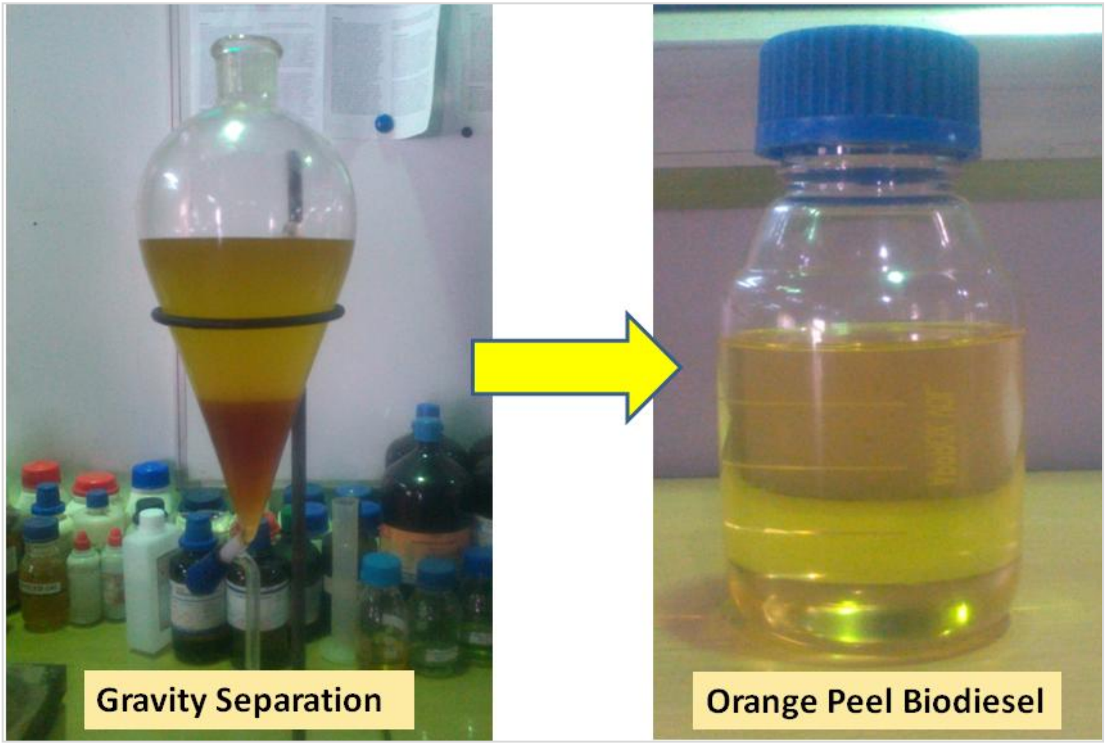


Plate 3.2: Gravity Separation and final produced Orange peel biodiesel.

The biodiesel so obtained was pure and was found completely miscible with mineral diesel. To check the miscibility various proportions of biodiesel was added to mineral diesel and monitored for 15 days. No signs of separation were observed. Therefore, the methyl ester of Orange peel oil is concluded to be completely miscible with mineral diesel.

3.3 EQUIPMENTS USED FOR THE DETERMINATION OF PHYSICO-CHEMICAL PROPERTIES

Determination of various physico-chemical and fuel properties of the Orange oil biodiesel was essential for its standardisation as well as various calculations for engine trials. At the same time properties of the various blends are also equally important. Therefore, after production of Orange peel oil biodiesel, various blends i.e. 5%, 10%, 15% and 20% (v/v) of Orange peel oil biodiesel with mineral diesel were prepared and all five test fuel samples including diesel were tested for the complete characterization of fuel. The entire tests conducted were in accordance with their respective standard suggested by the regulating authorities. Plate 3.3 shows various blends of Orange peel biodiesel and diesel.

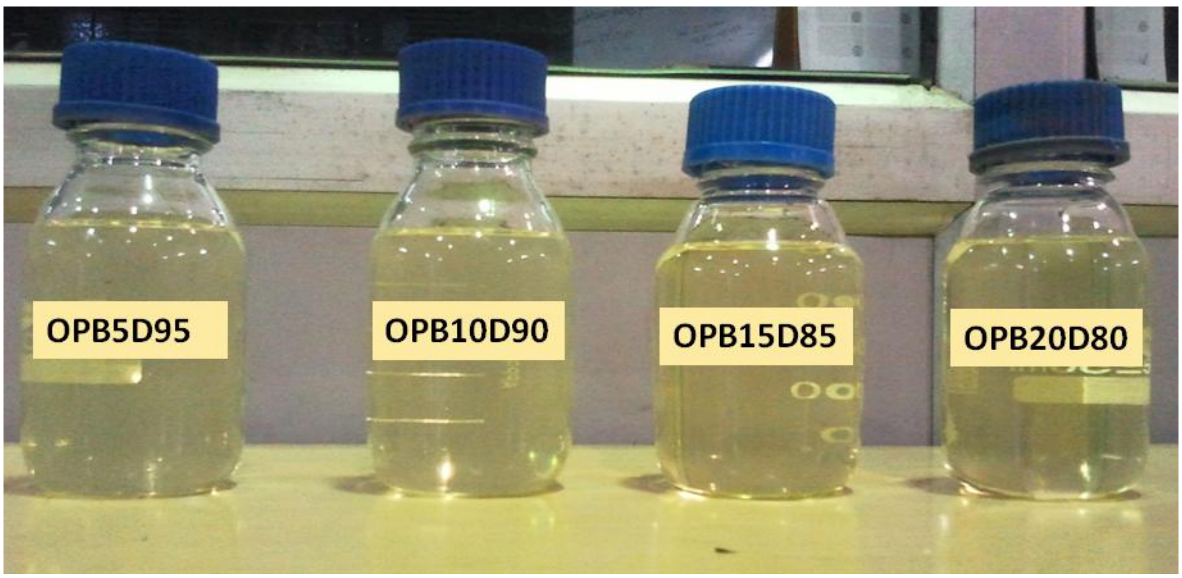


Plate 3.3: Various blends of Orange peel biodiesel and Diesel.

The following equipment's were used in the laboratory for determination of Physico-chemical properties of all test fuel samples specified in the project. All these equipment's were used at Centre for Advanced Studies and Research in Automotive Engineering (CASRAE), Delhi Technological University. The equipment's used were of standard quality and the error within permissible range. Also, all these equipment's were first calibrated before their use.

3.3.1 Rotary Evaporator

Rotary evaporator is a device used in chemical laboratories for the efficient and gentle removal of solvents from samples by evaporation. The equipment used was Heidolph Laborota 4003Control rotary evaporator. Rotating flask dipped in hot water creates greater surface area of thin film facilitating rapid evaporation of methanol. Distilled water was used and temperature was maintained at 53ºC for the complete evaporation of methanol. Then methanol vapors were condensed by coils cooled by a recirculating chiller and collected in a receiving flask.

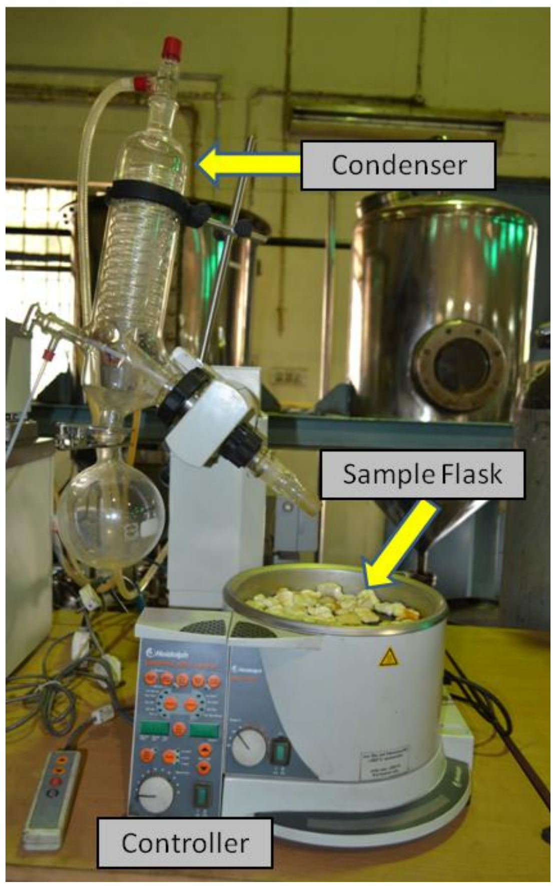


Plate 3.4: Rotary Evaporator.

3.3.2 Centrifuge

The Seta Oil Test Centrifuge incorporated with isothermal heaters which are fitted internally to the centrifuge chamber giving precise temperature control to within ± 1ºC as required by the test methods. A brushless asynchronous motor ensures high reliability with low maintenance and the centrifuge has in-built error messaging diagnostics. Speed can be specified and measured in either RPM (rotational speed) or RCF (relative centrifugal force) mode. The run duration can be set between 10 seconds and 100 hours in 10 second and one-minute increments, or set for continuous operation. Acceleration and braking time are adjustable and can be store up to 99 run profiles in the memory. In this investigation the sample was run at 3000rpm, 40ºC and run for 10min.

Plate 3.5: Centrifuge.

3.3.3 Density meter

A simple U tube oscillating true density meter is one of the simplest methods for the determination of density and specific gravity. The equipment used was "Anton Par Density Meter, Model DMA 4500 shown in Plate 3.6. In the present investigation the specific gravity of the test fuel samples was measured at a temperature of 15ºC in accordance with ASTM D-4052. Subsequently the temperature was varied from 30°C to 80°C with 10°C increment in each step and the density was measured for individual test fuels separately to evaluate the effect of temperature on density. The procedure for measurement of density and specific gravity was very simple. Initially the equipment was switched on by supplying electrical power. Then the test fuel pipeline was rinsed by injecting 10cc of toluene through the sample injection port. Subsequently 10cc of actual sample was fed to the injection port. It took approximately 5-7 minutes to give a precise value of density and specific gravity of the test fuel. The repeatability of the measurement was checked thrice and found satisfactory. Moreover, the average of the three measurements was taken as the final value for each sample.

Plate 3.6: Density Meter.

3.3.4 Kinematic Viscometer

Viscosity is an important property of fuel and it can be defined as measure of the resistance of a fluid which is being deformed by either shear stress or tensile stress. Viscosity describes a fluid's internal resistance to flow and may be thought of as a measure of fluid friction. In general too viscous fuel tends to form scum and deposits on cylinder walls, piston head etc., and cause atomization problems. So it is desirable that viscosity of fuel should be low. The different blend samples are prepared are investigated for viscosity at 40°C using a kinematic viscometer as per the specification given in ASTM D445. It consists of a capillary tube in which sample to be test is filled. The capillary tube has two marks engraved on it. The time for flow of fuel sample from upper mark to lower mark is measured and kinematic viscosity is calculated using time taken by each sample. The plate of the kinematic viscometer apparatus is shown below.

The kinematic viscosity of different fuel blends can be calculated as:

$$\upsilon = k \times t$$

Where,

υ= kinematic viscosity of sample;

k = constant for viscometer;

t = time taken by the fluid to flow through capillary tube.

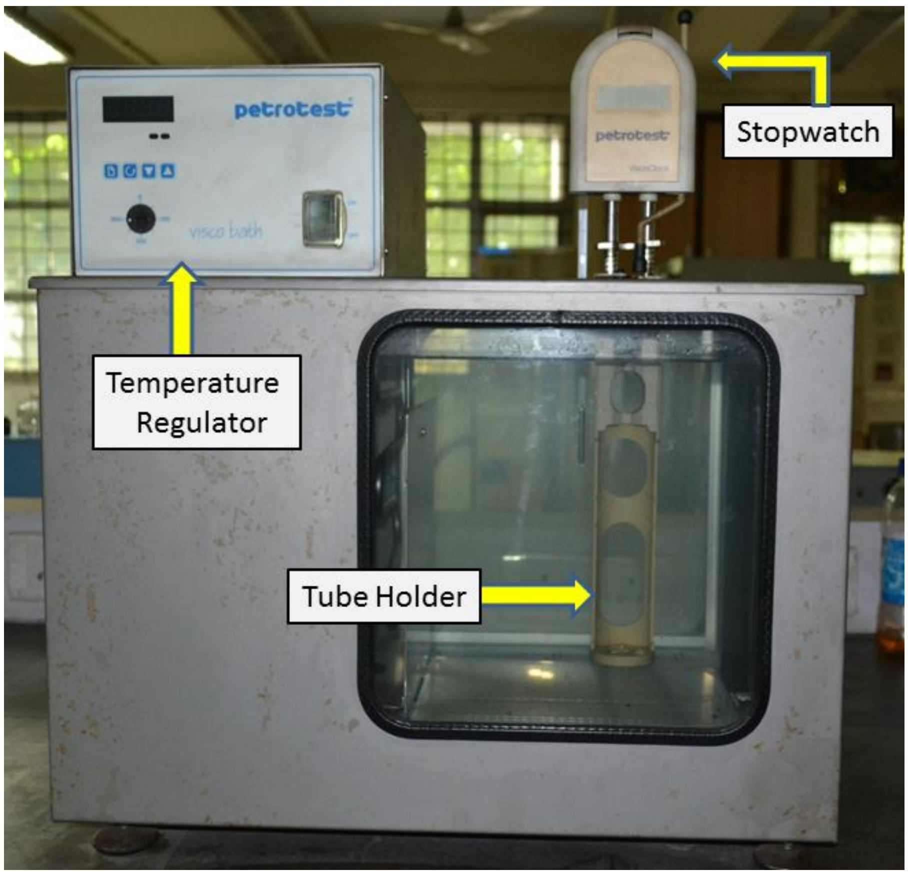


Plate 3.7: Kinematic Viscometer.

3.3.5 Bomb Calorimeter

The calorific value is defined in terms of the number of heat units liberated when unit mass of fuel is completely burnt in a calorimeter under specified conditions. Higher calorific value of fuel is the total heat liberated in kJ per kg or m^3. All fuels containing hydrogen in the available form will combine with oxygen and form steam during the process of combustion. If the products of combustion are cooled to it initial temperature, the steam formed as a result will condense. Thus maximum heat is abstracted. This heat value is called the higher calorific value. The calorific value of the fuel was determined with the Isothermal Bomb Calorimeter as per the specification given in ASTM D240. The combustion of fuel takes place at constant volume in a totally enclosed vessel in the presence of oxygen. The sample of fuel was ignited electrically. Then the fuel samples were burnt in bomb calorimeter and the calorific value of all samples were calculated. Parr Model 6100EF was used in laboratory for measuring calorific value of biodiesel.

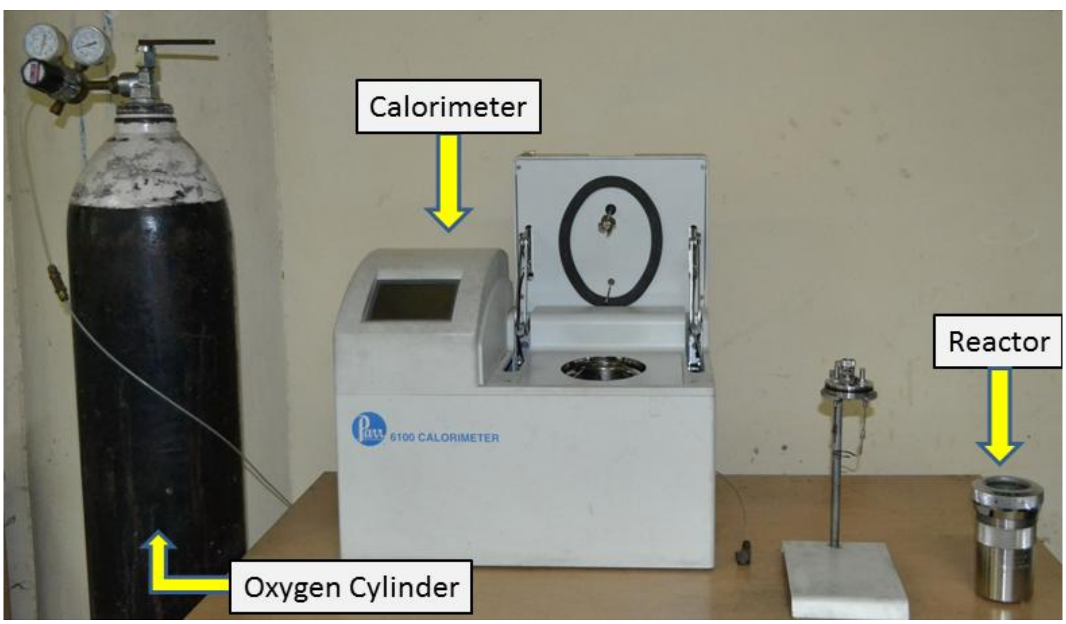


Plate 3.8: Bomb Calorimeter.

3.3.6 Oxygen Stability (Rancimat)

Oxygen in the surrounding atmosphere causes a chemical reaction to take place within fuels overtime particularly biodiesel. This reaction, known as auto-oxidation, causes a fuel's composition to change, which in turn affects how a fuel is burned during combustion. During auto-oxidation, unsaturated fatty acids undergo radical reactions in which decomposition products are formed such as peroxides as the primary oxidation products and alcohols, carboxylic acids, and aldehydes as the secondary oxidation products. The time until occurrence of these secondary reaction products is referred to as the induction time or induction period, which is a good indicator for the fuel's oxidation stability. Biodiesel is known to oxidize faster than conventional diesel because it already contains a percentage of oxygen within itself. In the present investigation, the oxidation stability index (hours) was measured by the induction period of the sample due to electric conductance of the peroxides formed by bubbling oxygen from the water source system flowing at 10L/hour in the Metrohm biodiesel Rancimat 873 shown in the Plate 3.9. The standard for the measurement was EN14112. The bath temperatures considered for the individual measurements was 110°C.

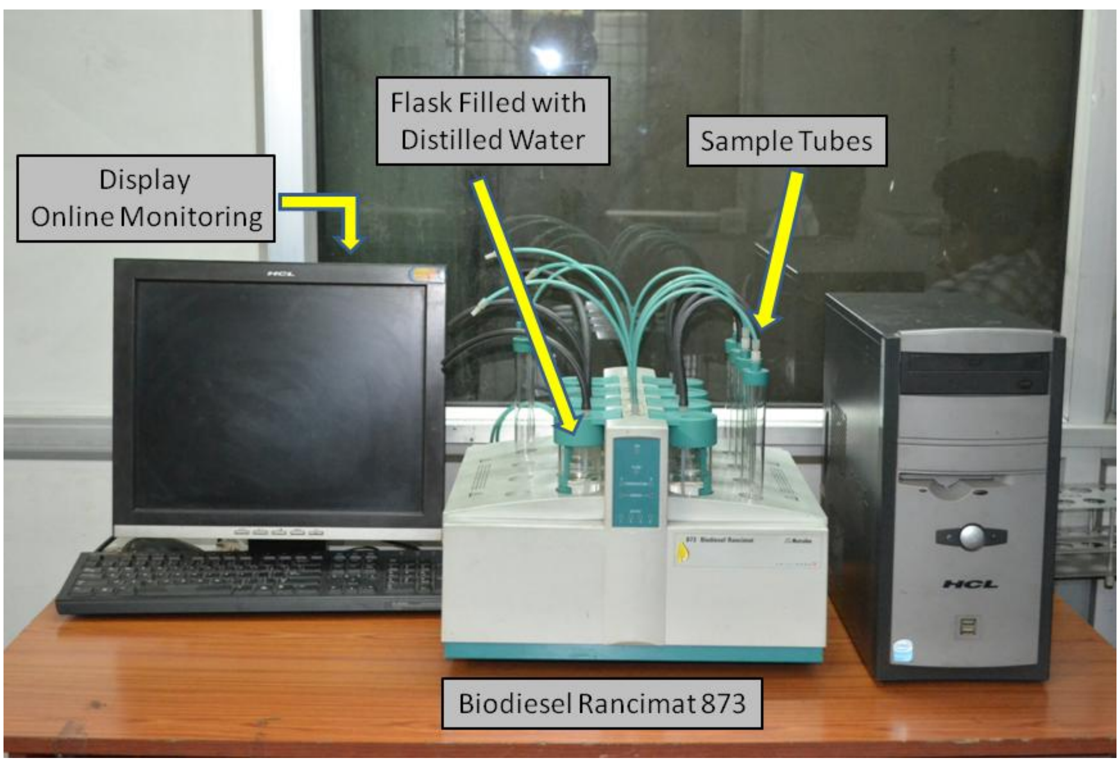


Plate 3.9: Biodiesel Rancimat.

3.3.7 Carbon Residue

Ash generated after the complete combustion of any biofuels is a major issue since it generally causes the engine deposits. Therefore tests were conducted on the Alcor Micro Carbon Residue tester to find the carbon residue of Orange oil biodiesel. The tests were conducted in accordance with the ASTM D4530 standard with on a fully automatic heating & pyrolysis in a closed system. Twelve samples can be simultaneously test with Automatic, constant flow of nitrogen according to low flow (150mL/min) and high flow (600mL/min) test.

Plate 3.10: Carbon Residue.

3.3.8 Cold Filter Plugging Point (CFPP)

Cold Filter Plugging Point (CFPP) is defined as the minimum temperature at which the fuel filter does not allow the fuel to pass through it. At low operating temperature fuel may thicken and does not flow properly affecting the performance of fuel lines, fuel pumps and injectors. Cold filter plugging point of biodiesel reflects its cold weather performance. It defines the fuel's limit of filterability. The apparatus for CFPP measurement is shown in plate 3.11. The measurements were carried out as per the ASTM D6371 05(2010) standards. All the test samples were subjected to the CFPP test to evaluate the effect of increasing volume fractions of OPB in the blend on the cold flow properties.

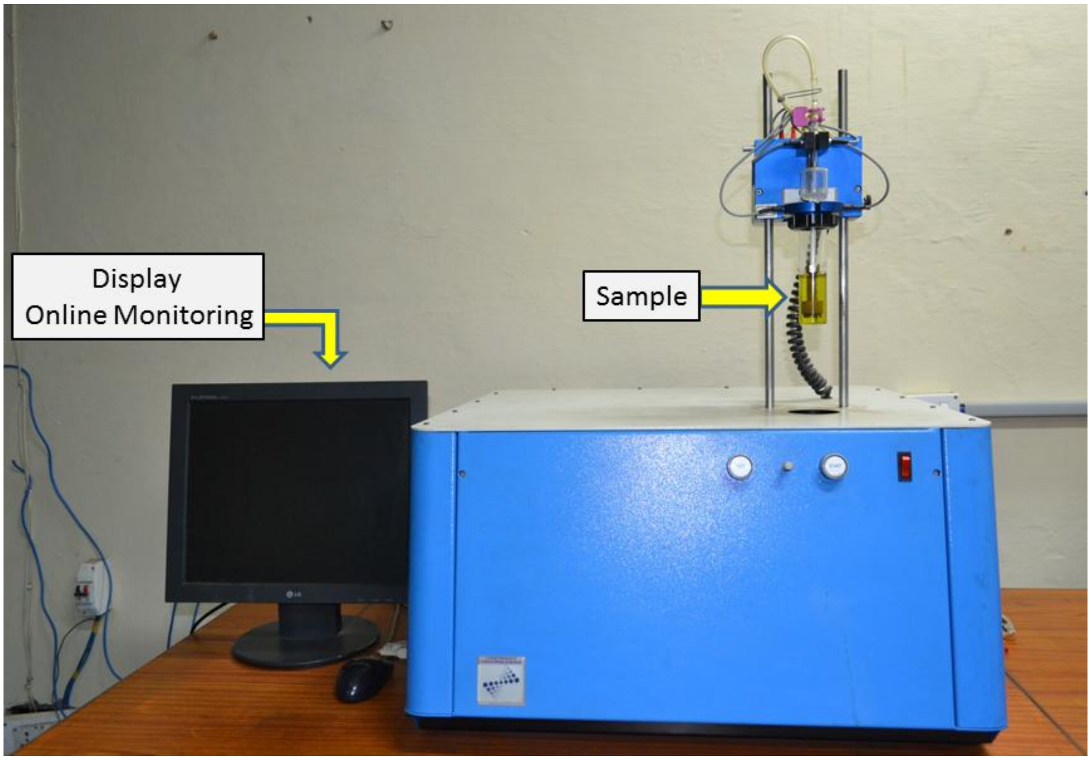


Plate 3.11: Cold Flow Point Tester.

3.3.9 Gas Chromatograph

The chromatography was conducted by injection of 20 µg of the OPB into the equipment with a split/split-less injection port using flame ionization detector and N_2 as the carrier gas flowing at a rate of 8ml/min. The split ratio was 50:1 while the injection temperature was kept at 350^{o}C and sample elusion time of 45 minutes. This equipment was highly precise and provided the composition in terms of peaks on a chart paper. From the area of the individual peaks, the composition of OPB was determined. Dilution of OPB with methanol in 1:10 ratio provided better visibility of the peaks. The chromatography equipment is shown in the Plate 3.12.

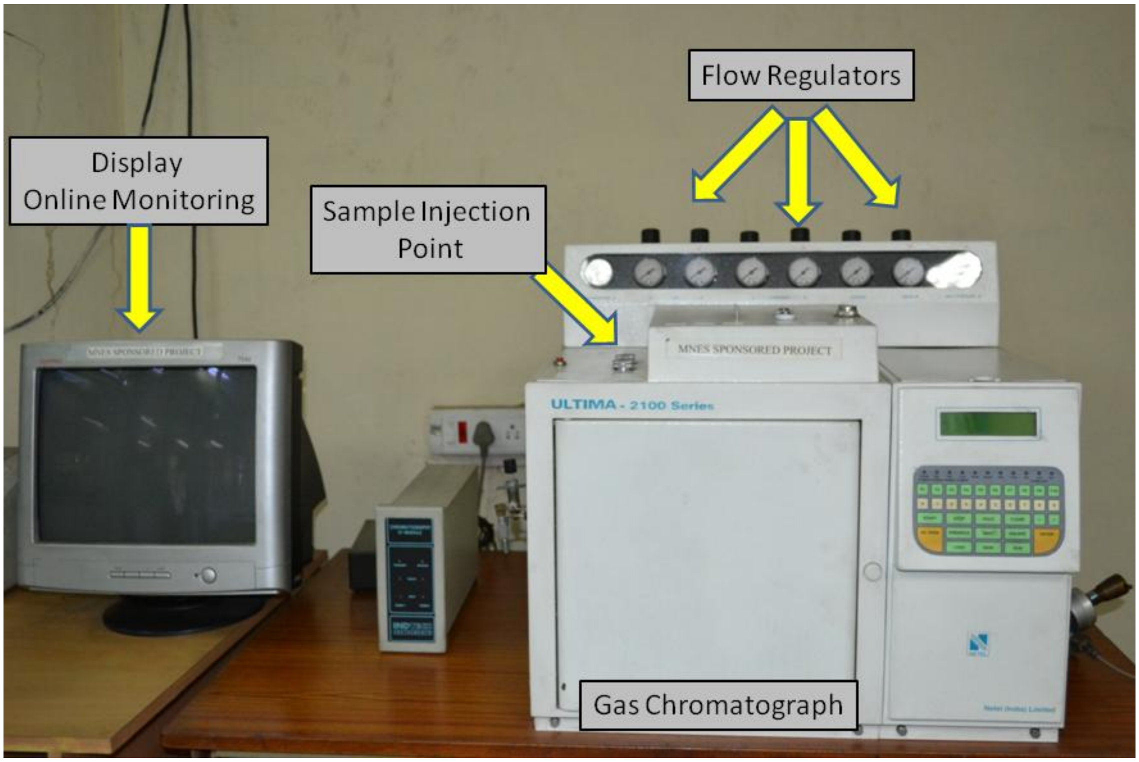


Plate 3.12: Gas Chromatography Setup.

3.4 SELECTION OF DIESEL ENGINE AND TEST RIG DEVELOPMENT

Due to robustness and high load carrying capacity of diesel engine, they are preferred more than the gasoline engine in almost every sector like agriculture, marine, and other load carrying locomotives. Also due to economic point of view diesel engine are always preferred due to its high brake thermal efficiency (BTE) for a same capacity petrol engine.

Air pollution created by diesel engine is also more severe than the petrol engine. Also due to bulkiness in terms of more storage capacity of engine for moving more goods at same time they consume more fuel and so create more air pollution. Due to this reason by changing some trends to reduce the air pollution or harmful emissions by changing the fuel may bring considerable changes in the environment. Keeping all these specific features of diesel in mind, a typical engine system has been selected for present experimental investigations. Moreover, a research engine was used to carry out all OPB-diesel blend tests which include combustion and performance evaluation for the optimization of fuel samples.

3.4.1 Selection of Diesel Engine for Experimental trial

As indicated earlier, diesel engines play a vital role in Indian economy. Starting from small capacity single cylinder agricultural engines to heavy duty multi-cylinder railway locomotive and marine engines, they are widely used. However, in the present study a single cylinder and light duty diesel engine was chosen for experimental trials because of a number of reasons. Firstly, such types of engines are portable and hence can be used almost anywhere even in the remotest parts of the country where the conventional energy modes are not accessible. Secondly, these engines are an integral part of rural agrarian economy of India and thirdly there are at least two million such engines that actively running across the country making it one of the largest sources of decentralised power.

3.4.2 Development of Engine Test Rig

The experiments were conducted in a single cylinder, four strokes, direct injection variable compression ratio (VCR) diesel engine (Kirloskar make, India). The engine is connected to a water cooled eddy current type dynamometer for loading. A tilting cylinder block arrangement is used to vary the Compression Ratio (CR) without stopping the engine and altering the combustion chamber geometry. The engine can be hand started using decompression lever and was provided with centrifugal speed governor. The cylinder was made of cast iron and fitted with a hardened high-phosphorus cast iron liner. The lubrication system used in this engine was of wet sump type, and oil was delivered to the crankshaft and the big end by means of a pump mounted on the front cover of the engine and driven from the crankshaft. The inlet and exhaust valves were operated by an overhead camshaft driven from the crankshaft through two pairs of bevel gears. The fuel pump was driven from the end of camshaft. The brief engine specifications are given in the table 3.1:

Table 3.1: Specifications of Engine.

Make	Kirloskar
Model	VCR test setup 234
Rated Brake Power (kW)	5.2
Rated Speed (rpm)	1500
Number of Cylinder	One
Bore X Stroke (mm)	87.5 x 110
Compression Ratio	17.5:1
Variable compression ratio	12 to 18
Cooling System	Water Cooled
Dynamometer	Eddy current
Piezo sensor	Range 5000 PSI, with low noise cable
Crank angle sensor	Resolution 1 Degree, Speed 5500 RPM with TDC pulse
Load sensor	type strain gauge, range 0-50 Kg
Cubic Capacity	661cc
Air flow transmitter	Pressure transmitter, Range (-) 250 mm WC
Inlet Valve Open (°)	4.5 BTDC
Inlet Valve Closed (°)	35.5 ABDC
Exhaust Valve Open (°)	35.5 BBDC
Exhaust Valve Closed (°)	4.5 ATDC
Fuel Injection Timing (°)	26 BTDC

The specification of the fuel injector is shown in table 3.2 and the injector with the spray cone is shown in figure 3.2. Valve lift profile of the engine was essential for numerical studies to be discussed in the subsequent sections. Therefore, valve lift at each crank angle was generated for both inlet and exhaust valves. For this a scale was generated at the periphery of the dynamometer. The lift was measured by using a magnetic base dial gauge.

Table 3.2: Injector Specification

Type	**Bosch**
No. of injector holes	3
Full load diesel injection per cycle	32.8mg
Injection duration	18ºCA
Nozzle diameter	0.148 mm
Spray orientation angle	55ºCA

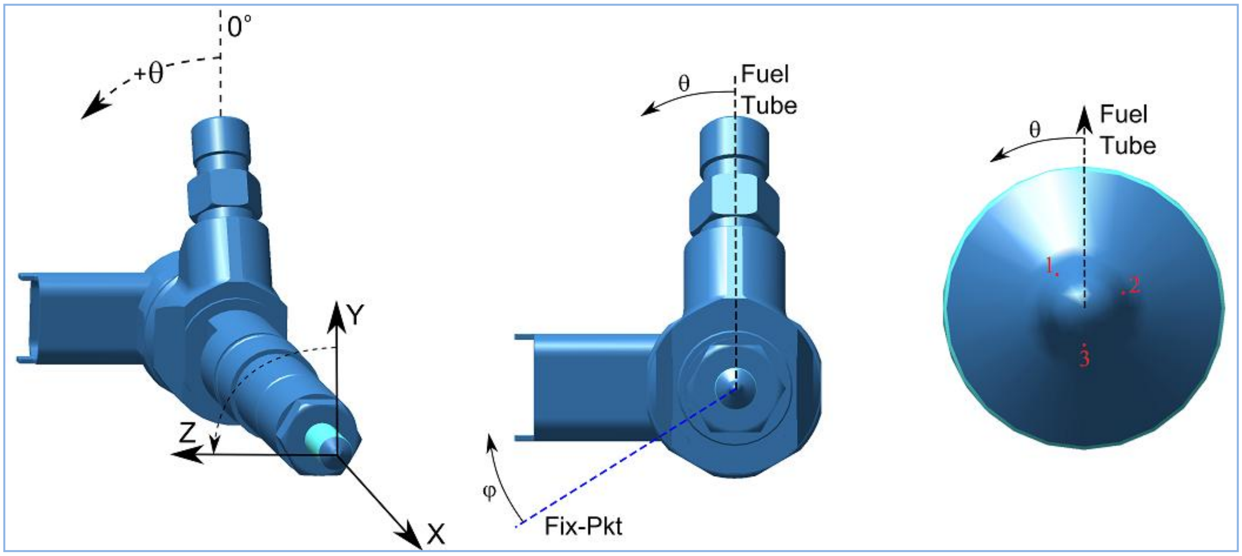


Fig.3.2: Fuel Injector Geometry.

For the provision of loading, a water cooled eddy current dynamometer was coupled with the engine shaft. A high precision stain gauge type load cell was attached to the dynamometer to accurately transmit the engine loading. A magnetic pick up type rpm sensor was attached at the end of the dynamometer to measure rpm. The eddy current type dynamometer, the magnetic pick up type rpm sensor and the strain gauge type load cell are shown in Plate 3.14. The cooling water flow for the engine was 350 Liters/hour and that of the dynamometer was 75 Liters/hour. The flow of the cooling water was controlled by two numbers of rotameters, one for the engine and other for the dynamometer. Setup is provided with necessary instruments for combustion pressure and crank-angle measurements. Two PCB make piezo type sensors are mounted on the cylinder head and fuel injector for combustion pressure and fuel line pressure measurement. The optical crank-angle sensor delivers a signal for each degree rotation of crank shaft. These signals are then interfaced to computer through engine indicator to measure rpm of the engine.

A total of six thermocouples (Type K–Chromel (Nickel–Chromium Alloy)/ Alumel (Nickel–Aluminum Alloy)) are installed at various locations of the setup for measurement of water and exhaust gas temperature.

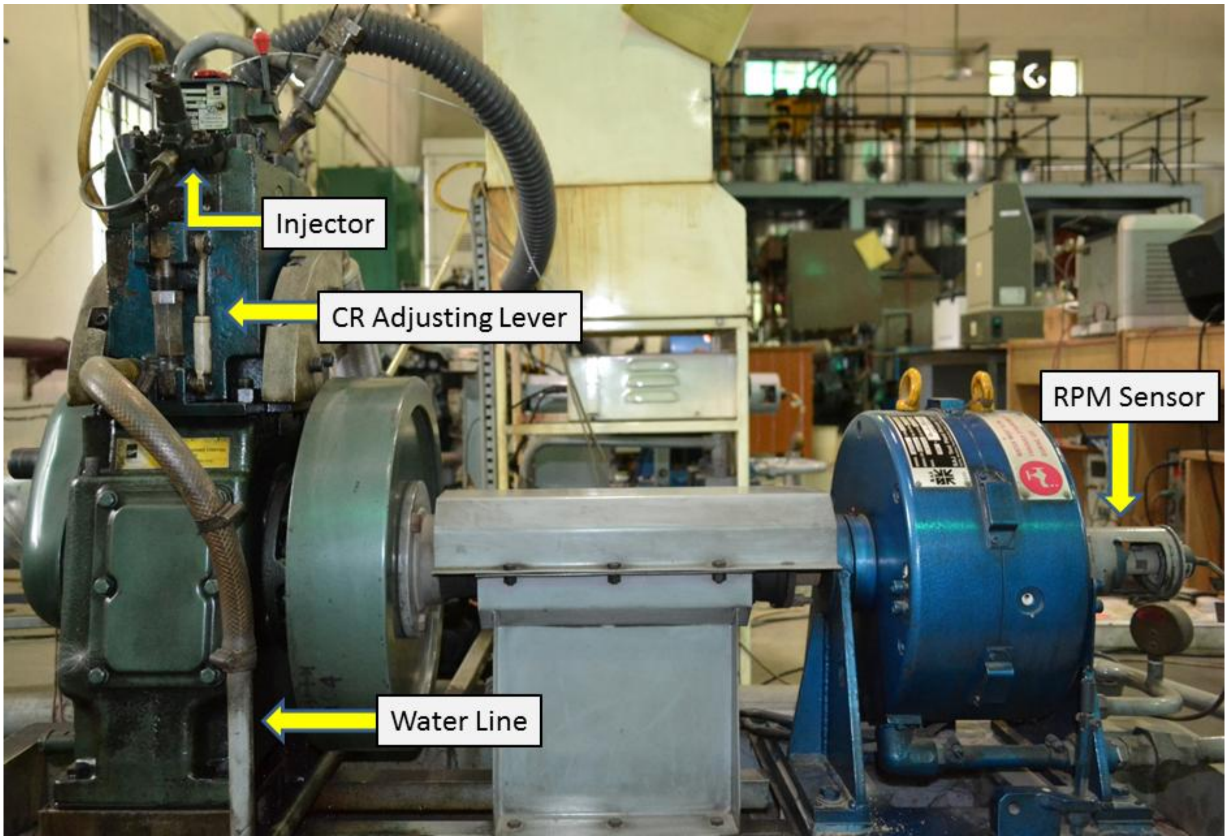


Plate 3.13: Engine Setup.

The setup has a stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring burette. The fuel measurement is performed by differential pressure transducer (Yokogawa make, Model No: EJA110A-DMS5A-92NN). It is connected through a fuel line and the signal of flow rate is transferred to the National Instrument made data acquisition device (DAD). Also the fuel consumption measurement is compared with the measured by the use of 20 cc burette and stopwatch with level sensors.

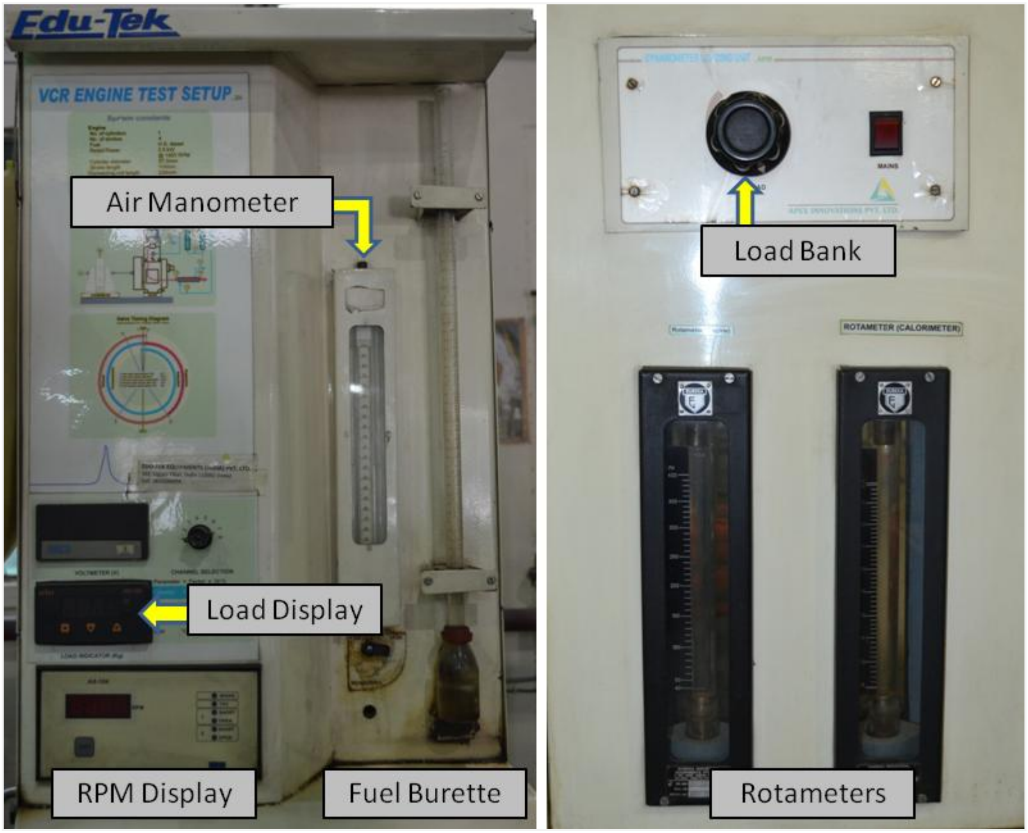


Plate 3.14: Engine Control Panel and Water Flow Meters.

This DAD is connected to the computer with USB port and measurement of fuel flow is stored in computer in kg/h. Rotameters are used for cooling water flow measurement through the jackets of engine block, cylinder head and calorimeter. All the analog signals recorded from different locations of the test rig are supplied to the 'Enginesoft' software for performance analysis. The schematic diagram of the VCR diesel engine setup is shown in the Fig. 3.3.

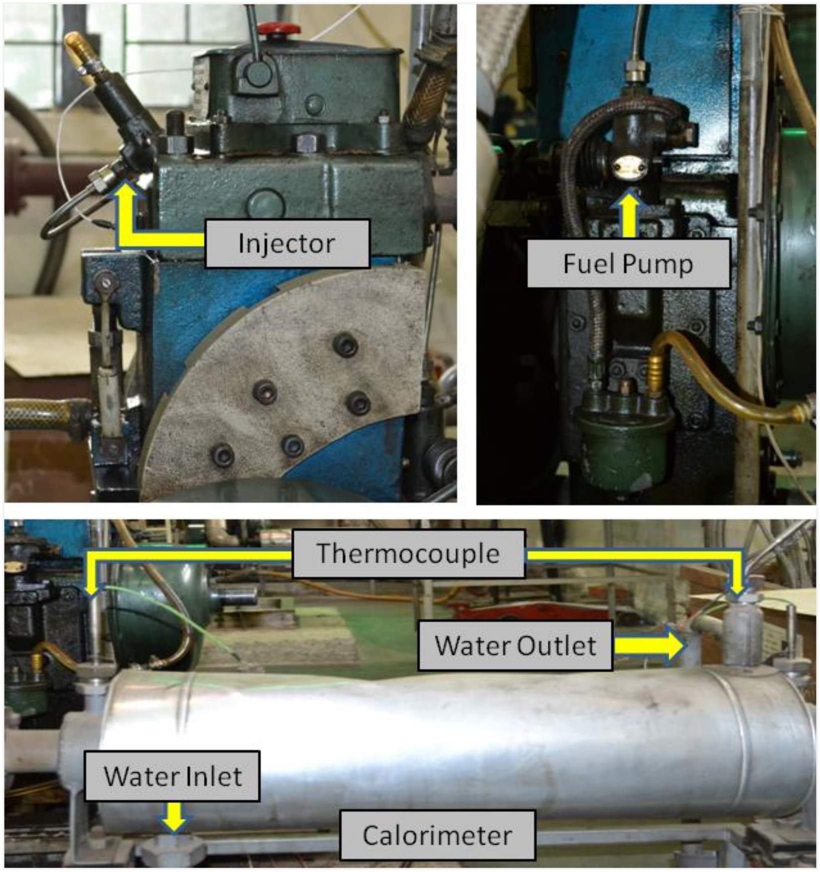


Plate 3.15: Injector, Fuel Pump and Calorimeter.

The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, Indicated mean effective pressure (IMEP), brake thermal efficiency, indicated thermal efficiency, mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance. Lab view based Engine Performance Analysis software package "Enginesoft” is provided for on line performance evaluation.

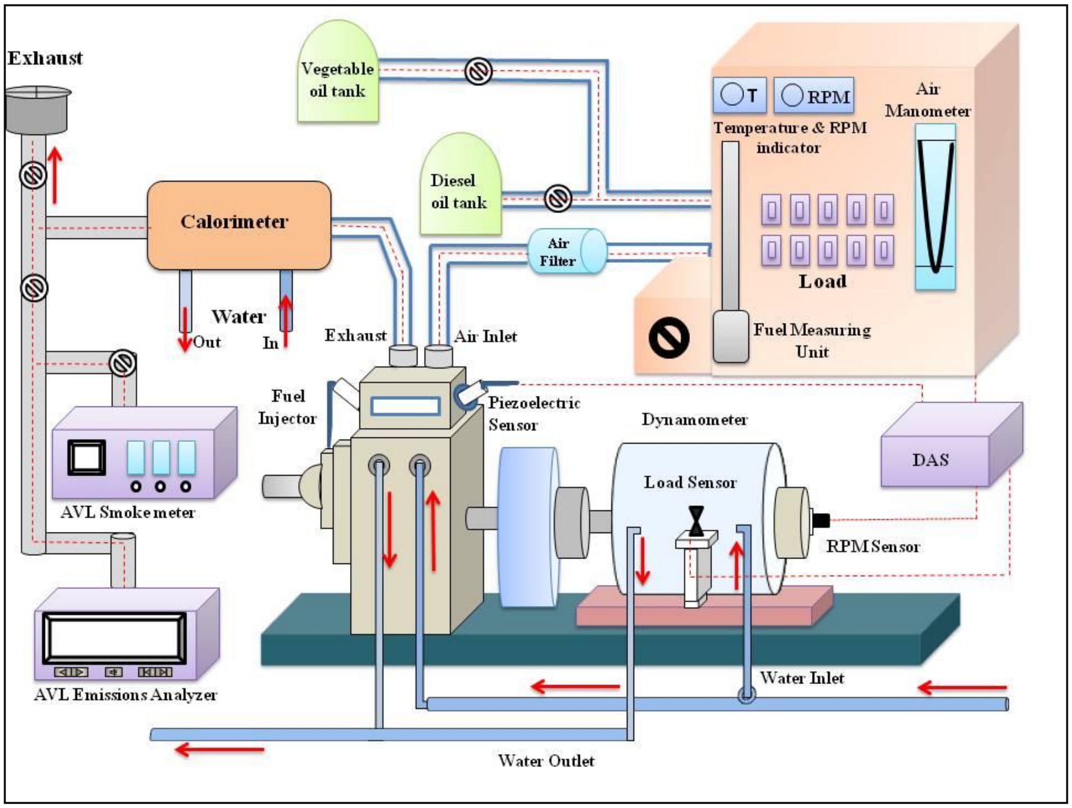


Fig. 3.3: Engine Setup Layout.

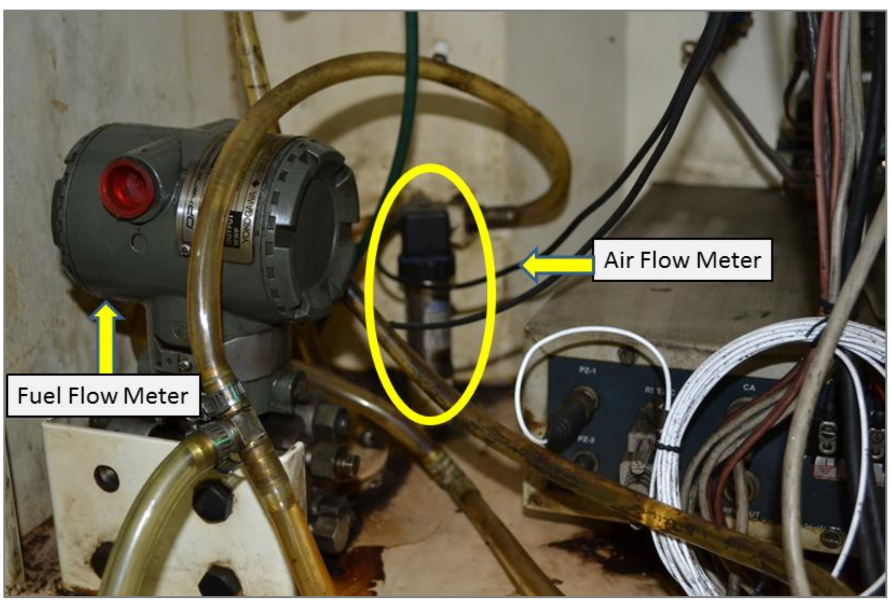


Plate 3.16: Fuel and Air Flow Meters.

The VCR engine is first run using diesel at standard diesel specification; CR of 18 and injection timing of 23˚BTDC. As the load is increased, the engine speed reduces. Therefore, in order to maintain a constant BP, the engine consumes more fuel resulting a higher heat release, and hence, a higher temperature inside cylinder. This increases temperatures at the outlet of the cooling water and exhaust gas. At full load condition the engine is allowed to run for few minutes and the temperatures at the outlet of cooling water and exhaust gas are monitored closely at the computer display until it reaches a steady state condition. This indicates that the combustion inside the cylinder becomes steady and the engine is ready for data acquisition. The readings of temperatures, air and fuel flow rate, speed, cylinder and fuel pressure variation are automatically recorded by the DAD (data acquisition device). Thereafter, the engine is brought back to no load condition slowly and allowed to run for few minutes.

3.5 EXHAUST EMISSION ANALYSIS

The major pollutants appearing in the exhaust of a diesel engine are the oxides of nitrogen. Exhaust gas analysis was done for exhaust smoke opacity, UBHC, CO, CO_2 and NOx. For measuring the smoke opacity, AVL 437 smoke analyzer was utilized. This instrument gave reading in terms of percentage opacity. Of the light beam projected across a flowing stream of exhaust gases, a certain portion of light is absorbed or scattered by the suspended soot particles in the exhaust.

The remaining portion of the light falls on a photocell, generating a photoelectric current, which is a measure of smoke density. For measurement of UBHC, CO, CO_2 and NOx, AVL 4000 Light Di-Gas Analyzer was used. Both the AVL 437 Smoke meter and AVL Di Gas Analyzer are shown in Plate 3.17. The engine trial was conducted as specified in IS: 10,000. And the accuracy of the all equipment’s are mentioned in annexure –III.

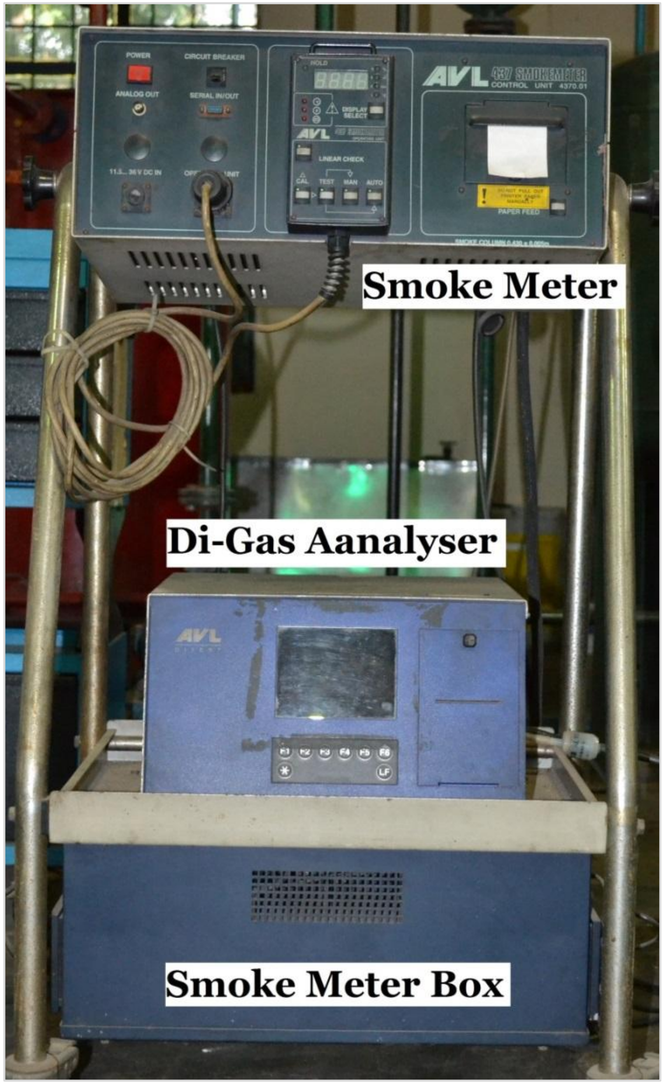


Plate 3.17: AVL Di-Gas Analyzer and Smoke Meter.

3.6 PARAMETERS SELECTION

The selections of appropriate parameters were essential for engine calculations, and parameters were selected very judiciously. The engine test was done as specified by IS: 10000. The main parameters desired from the engine are listed below:

1. Power produced by the engines
2. Brake Specific Energy Consumption
3. Brake Mean Effective Pressure
4. Engine speed (Rev/min)
5. Fuel consumption

6. Temperature

7. Exhaust Gas Emissions

8. Exhaust Gas Temperature

With a view to calculate the parameters mentioned above, it was essential to pick up the following signals from the test bench.

1. RPM of the engine.

2. Fuel consumption rate

3. AVL 437 smoke meter reading

4. AVL Di Gas analyzer reading

Once the parameters were selected, the essential instruments required for sensing these parameters were installed at the appropriate points in the experimental set-up.

3.7 EXPERIMENTAL PROCEDURE

The engine was started at no load by pressing the exhaust valve with decompression lever and it was released suddenly when the engine was hand cranked at sufficient speed. After feed control was adjusted so that engine attains rated speed and was allowed to run (about 30 minutes) till the steady state condition was reached.

With the fuel measuring unit and stop watch, the time elapsed for the consumption of 20cc of fuel was measured twice for every reading and average of them was taken. Fuel Consumption, RPM, exhaust temperature, smoke density, CO, NOx, HC , CO_2 and power output were also measured. The engine was loaded gradually keeping the speed with in the permissible range and the observations of different parameters were evaluated. The performance and emission characteristics of various OPB blends and diesel were evaluated and compared with baseline diesel fuel. The engine was always started with diesel and was run for 20-25 minutes, before switching to the different fuels and again run for 20 minutes to achieve stability.

3.7.1 Measurement of Engine Power and Mean Effective Pressure

The brake power at the engine shaft was calculated by the formula in equation 3.4.

$$BP\ (kW) = \frac{2 \times \pi \times RPM \times Load(kg) \times 9.81 \times Dynamometer\ arm\ length\ (m)}{60 \times 1000} \quad \text{.......... (3.4)}$$

Similarly, the brake mean effective pressure was calculated using the formula in equation 3.5.

$$BMEP\ (bar) = \frac{120 \times BP\ (kW)}{L \times A \times N \times 101.325} \quad \text{.......... (3.5)}$$

Where, L = Stroke length in meter.

A = Piston area in m^2

N = Engine rpm

3.7.2 Measurement of Fuel Flow

The fuel consumption of an engine is measured by determining the time required for consumption of a given volume of fuel. The mass of fuel consumed can be determined by multiplication of the volumetric fuel consumption to its density. In the present set up volumetric fuel consumption was measured using a fuel flow sensor inserted inside the control panel. The sensor signal was fed to the data acquisition system. The same data was available in “MSEXCEL” format from the “Enginesoft” software in the computer for offline analysis. Moreover, the data was also available at the sensor indicator with the fourth channel slot. The sensor data in many cases was validated by manually taking the time for 20cc fuel consumptions in the burette by blocking the fuel cock. However, it was observed that the sensor data was more precise.

Two important engine performance parameters i.e. Brake thermal efficiency (BTE) and brake specific energy consumption (BSEC) were determined from the rate of fuel flow as shown below. Brake thermal efficiency is the ratio of brake power to the product of mass flow rate of fuel and its heating value. The BTE is calculated by the formula mentioned in equation 3.6.

$$\text{BTE (\%)} = \frac{\text{BP (kW)}}{\text{mf}\times\text{Qcv}} \quad (3.6)$$

Where, mf = Mass flow rate of fuel in (Kg/s)

Qcv = Calorific value of fuel (kJ/Kg)

Brake specific energy consumption is the amount of fuel energy consumed in order to generate one unit of shaft power. It is calculated by the standard formula mentioned in equation 3.7.

$$\text{BSEC (MJ/kW-h)} = \frac{\text{mf}\times\text{Qcv}\times 3600}{\text{BP (kW)}} \quad (3.7)$$

3.7.3 Measurement of RPM

A magnetic pick up type rpm sensor was attached to the end of the dynamometer shaft which was toothed. This type of sensor consists of a permanent magnet, yoke, and coil. This sensor was mounted close to a toothed gear. As each tooth moved by the sensor, an AC voltage pulse was induced in the coil. Each tooth produced a pulse. As the gear rotated faster more pulses were produced. These impulse signals were fed digitally to the data acquisition system. The engine control module of the data acquisition system calculated the engine rpm which was subsequently displayed both in the control panel and the enginesoft database in the computer.

3.7.4 Exhaust Temperature and Emission Measurement

Chromel-Alumel K-type thermocouples were connected to a 6 channel digital panel meter to measure temperatures of exhaust gas. The meter was calibrated by a milli-volt source up to 800^{o}C. The sensor was placed close to the exhaust manifold of the engine. The temperature data was observed both at the sensor indicator in the control panel as well as the engine-soft database.

As discussed above the gaseous pollutant emissions were measured using the gas analyzer and the smoke meter. The emission data was collected manually from the printed results of the analyzers as well as the engine-soft database from the computer.

3.7.5 Measurement of Air Flow

The air flow was measured using a turbine type flow meter installed inside the control panel. In principle, the turbine flow meters use the mechanical energy of the fluid to rotate a "pinwheel" (rotor) in the flow stream. Blades on the rotor are angled to transform energy from the flow stream into rotational energy. The rotor shaft spins on bearings. When the fluid moves faster, the rotor spins proportionally faster. Blade movement is often detected magnetically, with each blade or embedded piece of metal generating a pulse. The transmitter processes the pulse signal to the data acquisition system that determines the flow of the fluid. The air flow data was available in the sensor indicator of the control panel and the enginesoft database. Moreover, there was another method available to validate the sensor data. It was based on the orifice and the air box method. The differential pressure across the orifice inserted in the air flow channel provides the air flow rate using the formula in equation 3.8.

Mass of air (m) = $C_d \times A \times \sqrt{(2gh_w\rho_w\rho_a)}$……..….(3.8)

Where, C_d = Co-efficient of discharge of orifice (0.6 in the present case).

A = Orifice area

g = Acceleration due to gravity

h_w = Height of water column

ρ_w/ρ_a = Density of water/air

However, it was observed that the sensor data were more precise

3.7.6 In-cylinder Pressure

As discussed in the earlier sections, the "Kubeler" piezoelectric transducer was used for in-cylinder pressure measurement. The signals from the charge amplifier were fed to the data acquisition system where the engine control module converted the signals into digital data. The in-cylinder pressure data in terms of pressure crank angle history was only obtained in the engine-soft database.

3.7.7 Characterisation of Heat Release Rate

Evaluation of cyclic heat release is very much significant for combustion study. Various heat release models have been proposed by researchers for determining critical combustion parameters like heat release rate, pressure rise rate etc. In the present investigation, the heat release calculations described by Sorenson et al. [95] and Hanson et.al. [96] was referred. Although combustion in a CI, DI (compression-ignition, direct-injection) engine is quite heterogeneous, the contents of the combustion chamber are assumed to be homogeneous in the method suggested by Sorenson et.al. This type of heat release model is generally termed as zero-dimensional model in the literature. In contrast to the model proposed by Sorenson et. al., Hanson, have developed more complex, quasi-dimensional models, but it was only slightly more accurate than the zero-dimensional model. In the light of the above fact, the zero dimensional models proposed by Sorenson were considered for combustion characterisation.

The Sorenson's model is a thermodynamic model based upon energy conservation principle. Neglecting the heat loss through piston rings [97] the energy balance inside the engine may be written as:

$$\frac{dQc}{d\theta} - \frac{dQw}{d\theta} = \frac{d(\mathrm{mu})}{d\theta} + P\,\frac{dV}{d\theta} = mC_v\frac{dT}{d\theta} + P\frac{dV}{d\theta} \quad \text{.......... (3.9)}$$

Where, $dQ_c/d\theta$ = Rate of net heat release inside the engine cylinder (J/°CA)

$dQ_w/d\theta$ = Rate of heat transfer from the wall (J/°CA)

m = Mass flow of the gas (Kg)

u = Internal energy of the gas (J/Kg)

P = Cylinder pressure (bar)

V = Gas volume (m^3)

θ = Crank angle (°)

T = Gas temperature (°K)

C_v = Specific heat at constant volume (J/Kg°K)

Now the universal gas equation is given by

$PV = mRT$…………………………………………………………………………… (3.10)

The derivative of universal gas equation with respect to crank angle is given by

$P\frac{dV}{d\theta} + V\frac{dP}{d\theta} = mR\frac{dT}{d\theta}$…………………………………………………………….. (3.11)

Putting equation (3.11) in equation (3.1), the heat release rate is derived as follows.

$\frac{dQc}{d\theta} = P\frac{Cp}{R}\frac{dV}{d\theta} + V.\frac{Cv}{R}\frac{dP}{d\theta} + mT\frac{dCv}{d\theta} + \frac{dQw}{d\theta}$…………………………………………………….(3.12)

Where, C_p = Specific heat at constant pressure (J/Kg°K)

Equation (3.12) is further simplified for actual heat release calculation and is given below

$\frac{dQc}{d\theta} = \frac{1}{\gamma-1}V\frac{dP}{d\theta} + \frac{\gamma}{\gamma-1}P\frac{dV}{d\theta} + \frac{dQw}{d\theta}$……………………………………………………… (3.13)

Where, $\frac{dQw}{d\theta} = h.A\,(T_w - T_j)$………………………………………………………... (3.14)

γ= Ratio of specific heats

In a four-stroke engine, crank angles are typically given with zero values at the TDC, (top dead center) between intakes and exhaust strokes. However, the important heat release events occur between SOI (start of injection, typically about 337°) and EVO (exhaust valve opening, typically about 500°). The trigonometric functions require their arguments in radians that are essential for gas volume calculations. The formula for calculating the arguments for the trigonometric functions, equation 3.15 was used.

$\theta rad = \frac{\pi(\theta - 360 + Phase)}{180}$…………………………………………(3.15)

Where, θ_{rad} = argument of trigonometric functions (radians)

Phase = phase shift angle (°CA)

The piston displacement was needed in calculating the gas volume. It is provided in equation 3.16.

$\frac{S}{R} = [1 - Cos\,(\theta rad)] + \frac{L}{R}\{1 - [\sqrt{1 - \frac{Sin\,(\theta rad)}{L/R}}]^2\}$…………………………… (3.16)

Where, S = piston displacement from TDC (m)

R = radius to crank pin (m)

L = connecting rod length (m)

Then the gas volume was calculated as in the equation 3.17

$$V = V_{cl} + S\,A_p \quad \text{...}(3.17)$$

Where, A_p = top area of piston (m^2) = $\pi(\text{bore})^2/4$

bore = cylinder bore (m)

V_{cl} = clearance volume (m^3)

r = compression ratio

Stroke = piston stroke (m)

The combustion chamber wall area, needed for heat transfer calculations, was given in the equation 3.18.

$$A_{wall} = 2A_p + \pi\,(\text{bore})\,S \quad \text{...}(3.18)$$

Equation 3.18 ignores the area associated with the piston cup, but the approximation has little effect on the heat release results. The heat release equation (3.14) requires the calculation of $dP/d\theta$. It can be shown that the slope at the j^{th} point of the curve defined by n sequential points is as shown in equation 3.18.

$$\frac{S}{R} = \frac{n\sum(Pi\theta i) - \sum Pi \times \sum \theta i}{n\sum(\theta i)2 - (\sum \theta i)2} \quad \text{...}(3.19)$$

Where n is an odd number and each summation is from [j – (n – 1)/2] to [j + (n – 1)/2]. When a shaft encoder is used to trigger pressure measurements, the points are equally spaced along the θ axis at spacing $\Delta\theta$. The choice of n is a compromise; a larger n helps to combat noise in the pressure data, but may also obscure real changes in the heat release curve. In the present case with $\Delta\theta = 1°$, choice of $n = 7$ was found to fit the equation 3.14 over 4° of the pressure trace and was a suitable compromise. Equation 3.20 shows the pressure smoothing technique applied to the noise in pressure data.

$$P_{j+1} = P_j + \frac{dPj}{d\theta}\,\Delta\theta \quad \text{......(3.20)}$$

Calculation of $dV/d\theta$ was accomplished as per the equation 3.21.

$$\frac{dVj}{d\theta} = V_j - V_{j-1} \quad \text{......(3.21)}$$

In-cylinder gas temperature varies rapidly throughout the cycle. Consequently the value of γ varies with temperature. The ideal gas law was used to calculate the spatially averaged temperature in the combustion chamber as mentioned in the equation 3.22.

$$T_j = \frac{Pj \times Vj}{MRg} \quad \text{......(3.22)}$$

Where, T_j = bulk gas temperature at point j (°K) R_g = idea gas constant = 8.314/29 = 0.287

M = mass of charge, g = (1 + AF) mf

AF = air/fuel ratio of engine

m_f = mass of fuel injected into each engine cycle (g)

The value of γ varies with temperature and the calculation of γ from the bulk gas temperature is shown in equation 3.23.

$$\gamma = \left(1 - \frac{Rj}{Cp}\right)^{-1} \quad \text{......(3.23)}$$

According to Crowell [98], the value of C_p/R_g can be calculated from the equation 3.24

$$\frac{Cp}{Rg} = A_0 + A_1 T_j + A_2 T_j^2 + A_3 T_j^3 + A_4 T_j^4 \quad \text{......(3.24)}$$

Where, A_0 = 3.04473

A_1 = 1.33805e^{-3}

A_2 = –4.88256e^{-7}

A_3 = 8.55475e^{-11}

A_4 = –5.70132e^{-15}

Final term in equation 3.14 was $dQ_w/d\theta$, the term was calculated using the equation 3.25.

$$\frac{dQw}{d\theta} = \frac{h \times Awall\ (Tw - Tj)}{24N} \qquad (3.25)$$

Where, $dQ_w/d\theta$= rate of wall heat transfer (J/°CA)

T_w = Effective wall temperature (°K)

h = Convective heat transfer coefficient ($J/s \cdot m^2 \cdot °K$)

N = Engine speed (rpm)

The heat transfer calculations are not very sensitive to the wall temperature, T_w; a wall temperature of T_w = 475°K has been found to give satisfactory results. Eichelberg [99] developed the following equation for convective heat transfer:

$$h = 0.00767\ S_p^{0.333}\ (P_j T_j)^{0.5} \qquad (3.26)$$

Where, S_p = mean piston speed, m/s = 2 R ω/π = 2 (stroke) N/60

ω = crankshaft speed (rad/s)

3.7.8 Calculation of Mass Fraction Burnt

Mass fraction burned (MFB) in each individual engine cycle is a normalized quantity with a scale of 0 to 1, describing the process of chemical energy release as a function of crank angle. The determination of MBF is commonly based on burn rate analysis a procedure developed by Rassweiler and Withrow (published in 1938). It is still widely used because of its relative simplicity and computational efficiency, despite the approximate nature of this method [100].

The Rassweiler and Withrow procedure is based on the assumption that, during engine combustion, the pressure rise Δp_j (at crank angle increment) consists of two parts: pressure rise due combustion (Δpc_j) and pressure change due to volume change (Δpv_j).

$$\text{Therefore, } \Delta p_j = \Delta pc_j + \Delta pv_j \qquad (3.27)$$

Assuming that the pressure rise Δpc_j is proportional to the heat added to the in- cylinder medium during the crank angle interval, the mass fraction burned at the end of the considered j^{th} interval may be calculated as [100].

$$MFB = \frac{mb\ (i)}{mb\ (Total)} = \frac{\sum_{O}^{i} \Delta Pc}{\sum_{O}^{N} \Delta Pc} \qquad (3.28)$$

Where, N is the total number of crank angles in the in-cylinder pressure crank angle data.

3.7.9 Calculation of Other Combustion Parameters

A comprehensive spreadsheet in “MSEXCEL” was prepared using the concepts of section 3.7.7 and section 3.7.8. The rate of heat release for the test fuels were calculated using equation (3.14). The cumulative heat release was calculated by summing up the heat release per crank angle data throughout the cycle. The pressure rise rate for various test fuels were calculated from the spread sheet data base using equation (3.19) and (3.20). The bulk gas temperature was calculated using equation (3.21) and the mass fraction burnt was calculated from equation (3.28). Calculation of wall heat transfer was based on equation (3.25) and the subsequent mathematical operations in the spreadsheet.

Ignition delay for the test fuels were calculated as the difference between the fuel injection angle and the crank angle corresponding to the MFB of 0.05. Similarly the total combustion duration for the test fuels was calculated as the difference between the crank angles corresponding to MFB of 0.10 to MFB of 0.95.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

Various results obtained in the present investigation were categorized as the physico-chemical characterization of Orange peel biodiesel and its blends. The main objective of the study was to evaluate the performance; emission and combustion characteristics of unmodified water cooled diesel engine fuelled with Orange peel biodiesel and diesel. The results obtained with the use of different blends were compared treating diesel as reference fuel.

4.2 RESULTS OF PHYSICO-CHEMICAL CHARACTERISATION

4.2.1 Oxidative stability

As describe earlier, the biodiesel rancimat method was used for oxidation stability study. The EN14112 standard was followed with 10 liter/h air flow and 110°C bath temperature. The total induction time showed by the all Orange peel biodiesel sample was 6.00 hours as against the standard of three hours. Therefore, the oxidation stability of OPB was found to be within the limits of European biodiesel standard. However, the stability of the oil was found to be excellent over the prescribed limit. Therefore, addition of oxidation stability improvers to the OPB may be studied before commercial scale production or usage. Fig. 4.1 shows the conductivity and induction time curve for oxidation stability study using biodiesel rancimat.

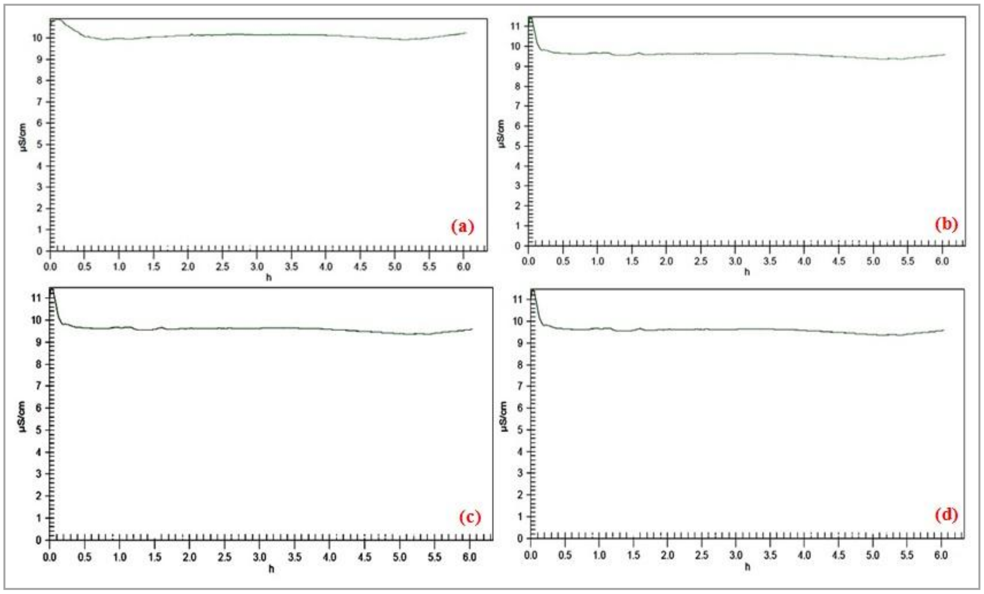


Fig. 4.1: Oxidation stability of all four blends (a) 5% Orange peel biodiesel, (b) 10% Orange peel biodiesel, (c) 15% biodiesel and (d) 20% biodiesel.

4.2.2 Fatty Acid Profile

The fatty acids profile of the Orange peel biodiesel was obtained using the gas chromatography equipment as discussed d in the earlier sections. The scanned copy of the peaks obtained during the chromatography test is shown in Fig. 4.2. Each fatty acid corresponds to one peak. The area of that peak to the summation of the area under all other peaks provided the % composition of the respective fatty acid.

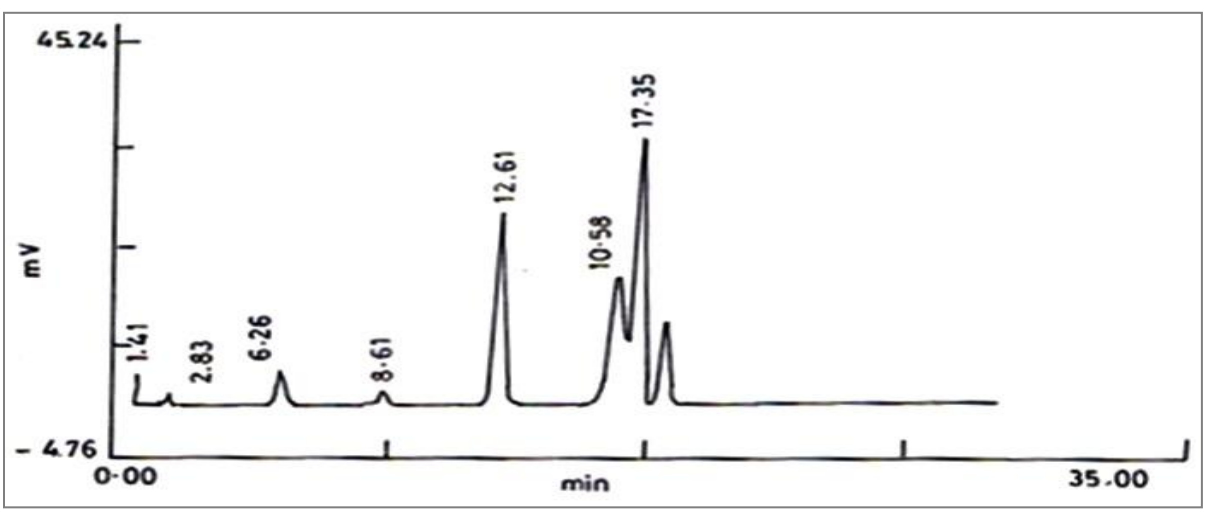


Fig. 4.2: Graph obtained from Gas Chromatograph for Orange peel biodiesel.

Various equipments used for determination of physico-chemical and fuel properties and the corresponding standards are provided in table 4.1. A comparative assessment of various physico-chemical properties of OPB was carried out with diesel fuel in table 4.2.

Table 4.1: List of equipments used for property measurements and the standards

Property	Equipment	ASTMD6751	ASTMD6751 LIMITS
Kinematic viscosity	Petrotest cometer	D445	1.9-6 cSt
Oxidative stability	873 Rancimat	D675	3 hours
Density	U tube density meter	D1298/ISO12185	0.86-0.9g/cc
CFPP	Automatic NTL 450	D6371	Not specified
Calorific value	Parr 6100 Bomb	Not specified	Not specified

Table 4.2: Physico-chemical Properties of Fuels

Properties	ASTM Method	OPB100	D100
Density (Kg/m^3, at 15ºC)	D-4052	849	820
Boiling Point Temperature (ºC)	D-5399	176 [101]	215-376 [102]
Flash Point (ºC)	D-93	60.5	53
Cetane Number	D-613	47[103]	49[103]
Viscosity (cSt at 40 ºC)	D-445	0.96	2.65
Calorific Value (KJ/kg)	D-4809	41673	43226
Carbon residue (%)	D-524	1.86	0.29
CFPP (ºC)	D-6371	< -50	6

On the basis of the data provided in the table 4.1 and 4.2, it may be concluded that Orange peel biodiesel was well within the limits of international biodiesel standards.

Physico-chemical properties of Orange peel biodiesel and its blends (in different volumetric proportion) with mineral diesel were evaluated using standard test facilities Neat Orange peel biodiesel has lower calorific value and viscosity than that of mineral diesel but having high density. The different blends prepared are as follows: D 100(mineral diesel), OPB5D95 (5 % Orange peel biodiesel and 95 % pure diesel), OPB10D90 (10% Orange peel biodiesel and 90 % pure diesel), OPB15D85 (15% Orange peel biodiesel and 85 % pure diesel), OPB20D80 (20% Orange peel biodiesel and 80 % pure diesel).

Kinematic viscosity and Calorific value decreases with increase in percentage of Orange peel biodiesel. But density was found to be increase with concentration of biodiesel increases in tested blends. The Physico-chemical properties evaluated in respect of different blends are summarized in Table 4.3

Table 4.3: Physico-chemical Properties of Test Samples

Property	**OPB5D95**	**OPB10D90**	**OPB15D85**	**OPB20D80**
Density (Kg/m^3)	821	824	825	826
Viscosity (cSt)	2.57	2.48	2.41	2.33
Calorific Value (KJ/kg)	43148	43070	42993	42915
Specific gravity	0.8482	0.8451	0.8421	0.8396
Flash Point ($^{\circ}$C)	59.1	57.1	53.8	50.3
Carbon residue (%)	0.366	0.441	.517	0.592

4.3 RESULTS OF ENGINE TRIALS

4.3.1 Engine Performance Results

Various performance characteristics were analyzed for different test fuels and they are summarized in this section. The results obtained for different blends of Orange peel biodiesel and diesel are compared with baseline diesel fuel.

4.3.1.1 Brake thermal efficiency (BTE)

Brake thermal efficiency is a vital engine performance parameter. It is the ratio between useful mechanical work obtained at the engine shaft and the energy of the injected fuel, the latter being the product of mass flow rate and heating value of the fuel [104]. Variation of brake thermal efficiency with brake mean effective pressure for the test fuels is shown in Fig. 4.3.

It was observed that with increase in load, brake thermal efficiency of the engine was increased for all test fuels. This was attributed to the fact that at higher loads more power was generated and heat loss was reduced [57, 76,105]. It was observed that the maximum thermal efficiency for different blends in the engine trial i.e. for OPB5D95, OPB10D0, OPB15D85, OPB20D80 and D100 were 21.7%, 22.75%, 22.85%, 24.54% and 25.02%, respectively. As a nutshell, it may be stated that thermal efficiency of the diesel engine was increased with increase in the volume fraction of Orange peel biodiesel up to 20%. Firstly, this may be attributed to the biodiesel is an oxygenated fuel that leads to better combustion even at lower equivalence ratio zones [75]. Secondly, the lower flame temperature of the blends than diesel leads towards a reduction in heat loss [72]. All these factors contribute towards improved combustion, reduced losses and higher thermal efficiency. The results are in accordance to the results proposed by Vibhanshu V.et. al., and Rao Nand kishore. et. al. [106, 107].

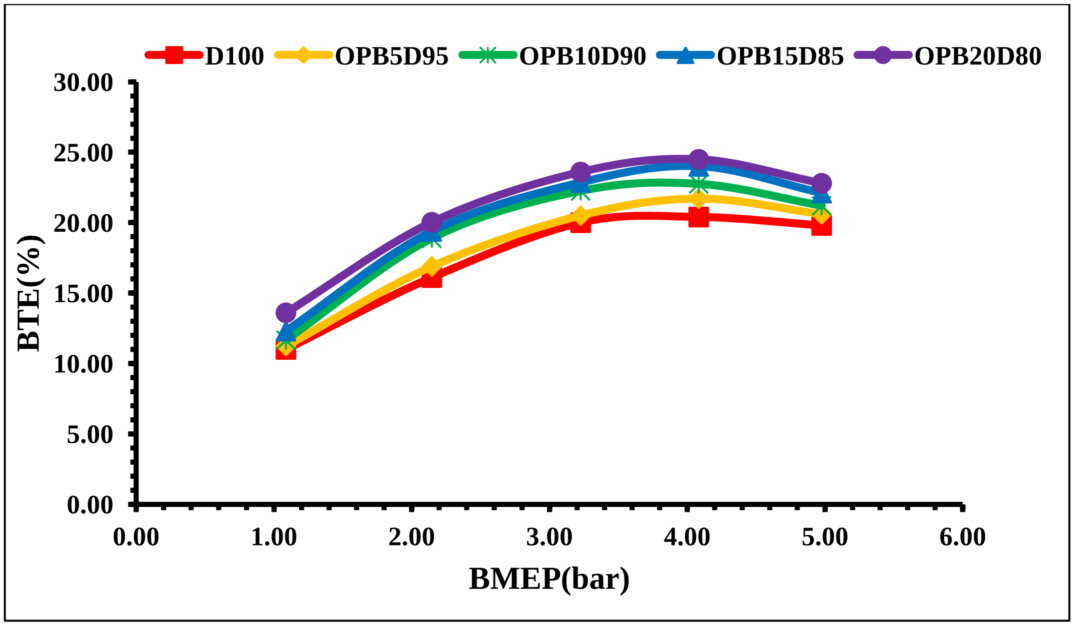


Fig.4.3: Variations of brake thermal efficiency with brake mean effective pressure.

4.3.1.2 Brake Specific Fuel Consumption (BSFC)

Comparative assessment of volumetric consumption of fuel is an important parameter to explain the engine performance exhibited by various test fuels. In this context, brake specific fuel consumption which is a ratio between fuel mass flow rates to the brake power has been used as a conventional parameter. However, BSFC has not been considered as a reliable parameter when the calorific values and densities of test fuels vary considerably [76].

Fig.4.4 shows the variation of BSFC with BMEP for various test fuels. It may be observed that BSFC was found to reduce with increases in BMEP to some extent. BSFC was found to get increased considerably with the increase in volume fraction of Orange peel biodiesel due to its less viscosity; in the test fuel. It is observed that BSFC for OPB20D80 at full load were found to be 0.40 kg/kWh as compared to 0.48kg/kWh neat diesel fuel operation. The primary reason may be due to the higher volatility of Orange peel biodiesel which speeds up the mixing velocity of air/fuel mixture, improves the combustion process and increases the combustion efficiency by burning fuels at locations with lower equivalence ratios. The experimental results come in accordance to the conclusion proposed by Qi et. al. [108], Shadidi B. et. al. [109].

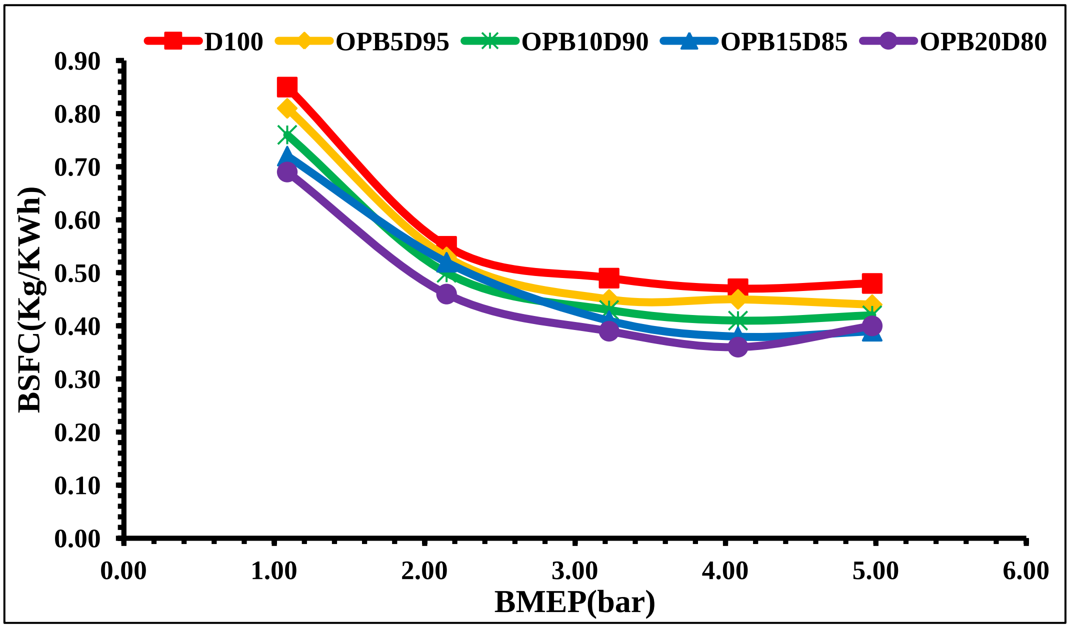


Fig. 4.4: Variations of brake specific fuel consumption with brake mean effective pressure

4.3.2 Engine Emissions Results

The emission characteristics of the test engine on Orange peel biodiesel-diesel blends are summarized in this section. Main exhaust emissions considered are CO, UBHC, NO_X and smoke density.

4.3.2.1 Carbon monoxide (CO)

Carbon monoxide is considered as a major diesel engine pollutant. The formation of CO during combustion in diesel engines is primarily attributed to lower fuel-air equivalence ratios of combustible mixtures [110]. However, factors like combustion chamber design, atomization rate, start of injection timing, fuel injection pressure, engine load, speed etc. may affect formation of CO at varied influences [111]. Volumetric emissions of CO with brake mean effective pressure for various test fuels is shown in Fig.4.5.

CO emission patterns exhibited by various test fuels at different loading conditions and observed 0.09%, 0.18% and 0.88% for D100, OPB20D80 and OPB5D95 respectively. It indicates that by increasing the percentage of Orange peel biodiesel in the blends, there is an appreciable reduction of 80% in emission at high loads over the baseline data of diesel. The increase in CO emission is due to the fact that the test fuels have poor atomization characteristics and lower volatility. Higher amount of fuel injection in to the engine leads to incomplete combustion and steep increase in CO emissions is another reason. These results are found to be consistent with the studies carried out by Singh et al. [112], Chauhan BS. et al. [113] and Zhu et al. [114].

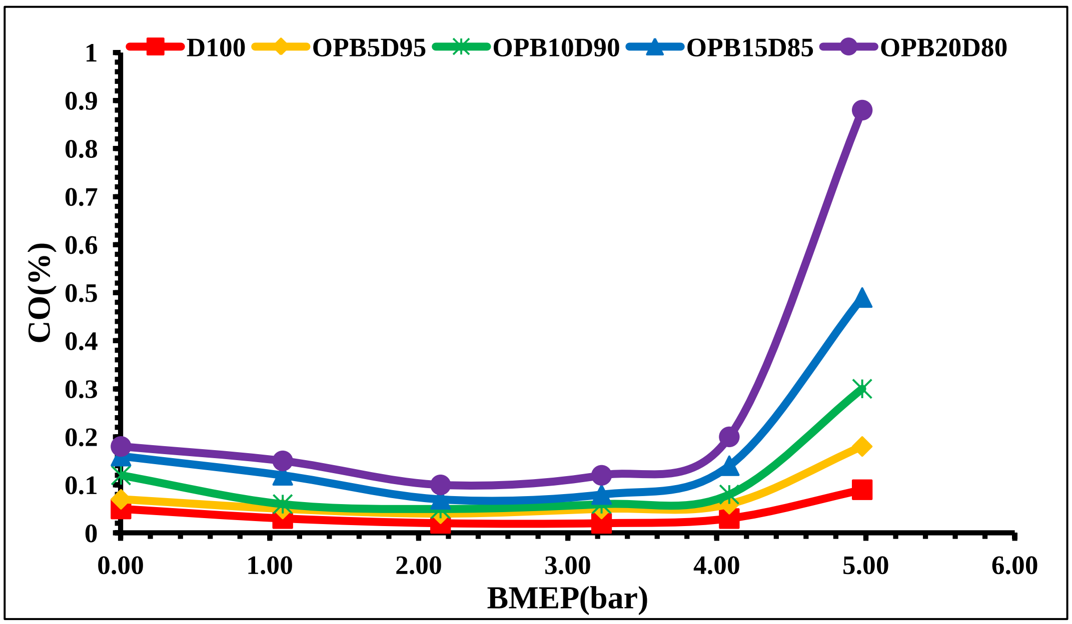


Fig. 4.5: Volumetric emissions of carbon monoxide with brake mean effective pressure.

4.3.2.2 Unburnt hydrocarbon emissions (UBHC)

Emission of total hydrocarbons with brake mean effective pressure is shown in Fig. 4.6. The detail mechanism of formation of hydrocarbons inside engine cylinder during combustion and its theoretical study is still at infancy and elusive [114]. However, certain factors like in engine cylinder crevices, engine configuration, fuel structure, combustion temperature, oxygen availability, residence time etc. are presumed to affect the hydrocarbon emissions in compression ignition engines [115,116].

In the present investigation reduction in emissions of hydrocarbons was reported with increase Orange peel biodiesel volume fractions in the blends. At full load, OPB5D95, OPB10D90, OPB15D85 and OPB20D80 demonstrated volumetric emissions of 89, 85, 71 and 67 ppm respectively as compared to 92 ppm illustrated by the baseline data of diesel.

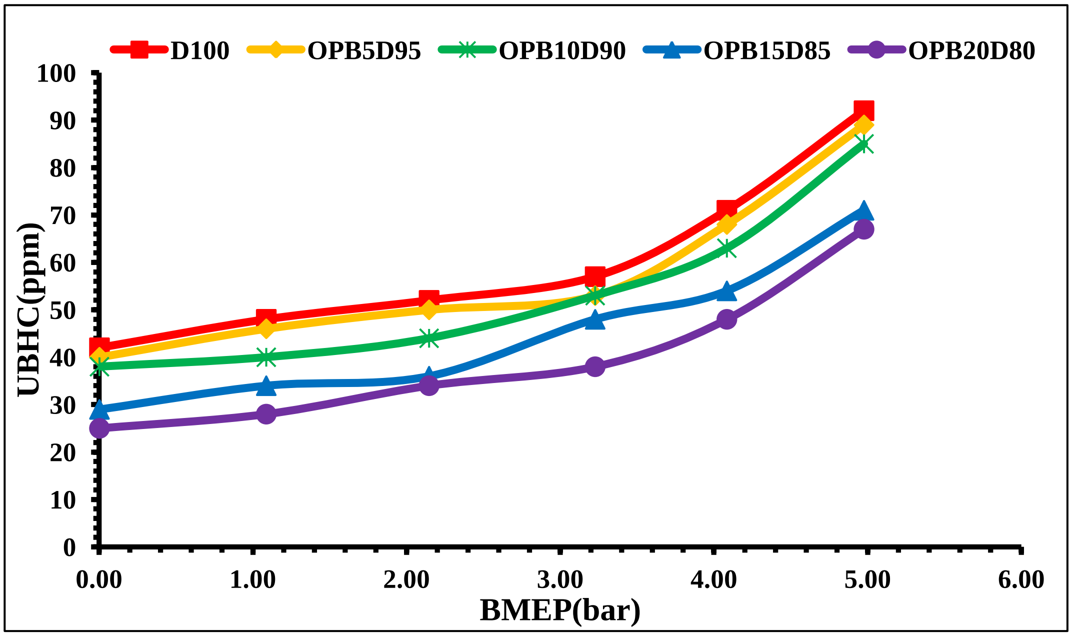


Fig. 4.6: Volumetric emissions of unburnt hydrocarbons with brake mean effective pressure.

4.3.2.3 Oxides of nitrogen emissions (NO_x)

Oxides of nitrogen popularly referred as NO_x are the critical diesel engine emissions of major concern. It mostly comprises of nitric oxide (NO) and nitrogen dioxide (NO_2), formed by "Zeldovich Mechanism". Combustion flame temperature, availability of oxygen and time for oxygen-nitrogen reaction are the major factors controlling NO_x formation in diesel engines [117-119]. Fig.4.7 shows the volumetric emissions of NO_x demonstrated by various test fuels under the designated operating loads. It may be observed that NO_x emissions increased with increase in engine load for all test fuels. The increase in NOx emission may be attributed to the fact that ethanol is rich in oxygen and possess a lower cetane rating leading to an increased heat release in the uncontrolled phase of the combustion which in turn rises the in-cylinder pressure and temperature leading to higher emissions of NOx. The results suggested that OPB5D95, OPB15D85 and OPB20D80 exhibited 1685, 1755 and 1870 ppm volumetric emissions of NOx at full load which was higher than 1628 ppm showed by the baseline data of diesel.

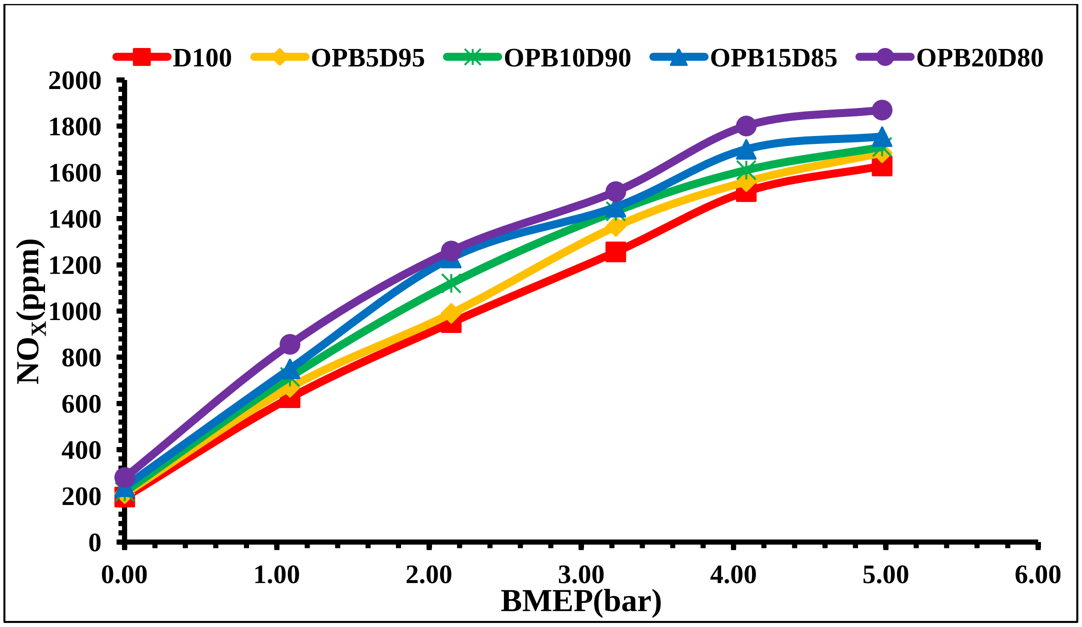


Fig. 4.7: Volumetric emissions of oxides of nitrogen with brake mean effective pressure.

4.3.2.4 Smoke opacity

Smoke is one of the most unpleasant emissions in diesel engines. It can be seen from Fig. 4.8 that smoke level decreased sharply with increase in load for all fuels tested. At full load OPB5D95, OPB10D90, OPB15D85 and OPB20D80 showed smoke opacities of 80%, 75.3%, 60% and 57% as compared to 82% exhibited by baseline diesel. The reduction in smoke opacity at full loads with increase in OPB volume fraction may be attributed to a number of factors such as higher oxygen content in Orange peel biodiesel that contributes towards better fuel oxidation even at locally rich zones [104], lower C/H ratio and absence of aromatic compounds. Higher number of carbon atoms in a fuel molecule leads towards higher smoke and soot formations where as higher number oxygen and hydrogen atoms leads to lower smoke and soot [122]. These results are in agreement with the results of Senthil et al. [120] and Kumar et al. [121].

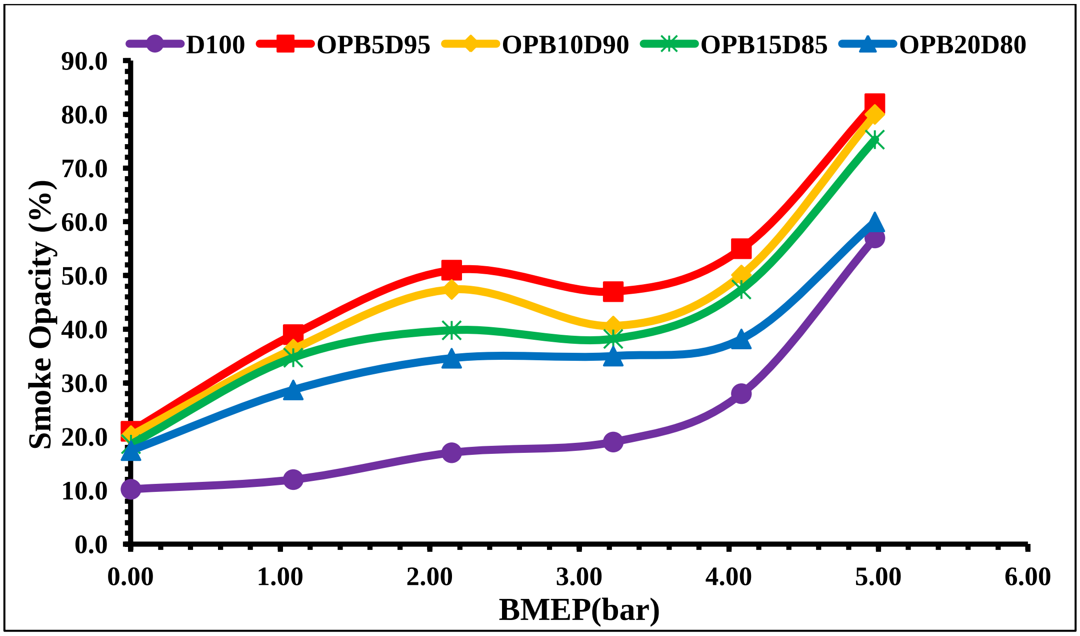


Fig. 4.8: Smoke opacity variation with brake mean effective pressure.

4.3.3 Engine Combustion Results

For combustion analysis, the cylinder pressure histories are measured for all the fuel blends and the peak cylinder pressure, pressure rise rate, instantaneous energy release rate, phase-wise percentage combustion energy release and mass fraction burnt are deduced from the measured cylinder pressures.

4.3.3.1 In-cylinder pressure and pressure rise rate

The variation of full load in-cylinder pressure with crank angle is shown in Fig. 4.9 for the test fuels. For the purpose of clarity, in visualisation of firing pressure for different test fuels, the pressure data between 337°CA and 407°CA was taken for in-cylinder pressure. The peak pressure is 66.3, 65, 64.4, 63.6 and 62.5 bar for diesel fuel, OPB5D95, OPB10D90, OPB15D85 and OPB20D80 respectively.

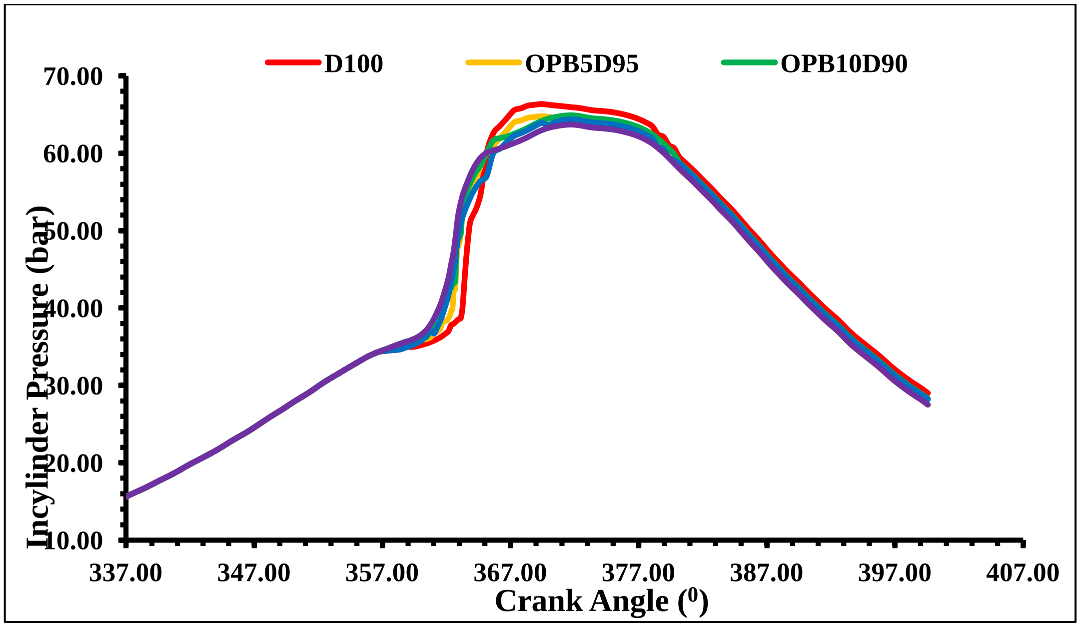


Fig. 4.9: In-cylinder Pressure Variation with Crank Angle.

In a compression ignition engine, the peak cylinder pressure depends on the burned fuel fraction during the premixed burning phase, i.e. the initial stage of combustion. It can be seen that peak cylinder pressure occurs later for all blends of Orange peel biodiesel due to slightly poor atomization but the start of combustion is significantly earlier for orange peel biodiesel and its blends as these fuels are more on oxygen content when compared to fossil diesel.

The variations of peak pressures and maximum rate of pressure rise for different blends are shown in fig. 4.10. The differences in peak pressure between the biodiesel blended fuels are negligible for full load condition. The pressure rise rate for OPB20D80 is moderately less than that of diesel at 4.7 bar/ºCA while, suffering a total reduction of about 10% than diesel.

The rate of pressure rise is the first derivative of cylinder pressure that relates to the smoothness of engine operation. The maximum rate of pressure rise increases initially with load and then decreases due to the prominent influence of premixed phase at lower loads while role of diffusion phase of combustion remains significant at higher loads. The maximum rate of pressure rise is higher for diesel than the Orange peel biodiesel-diesel blends as cetane number of Orange peel biodiesel is slightly less than that of diesel fuel. Similar types of results were obtained by Sahoo et.al. [76] and Shivalakshmi et.al.[82].

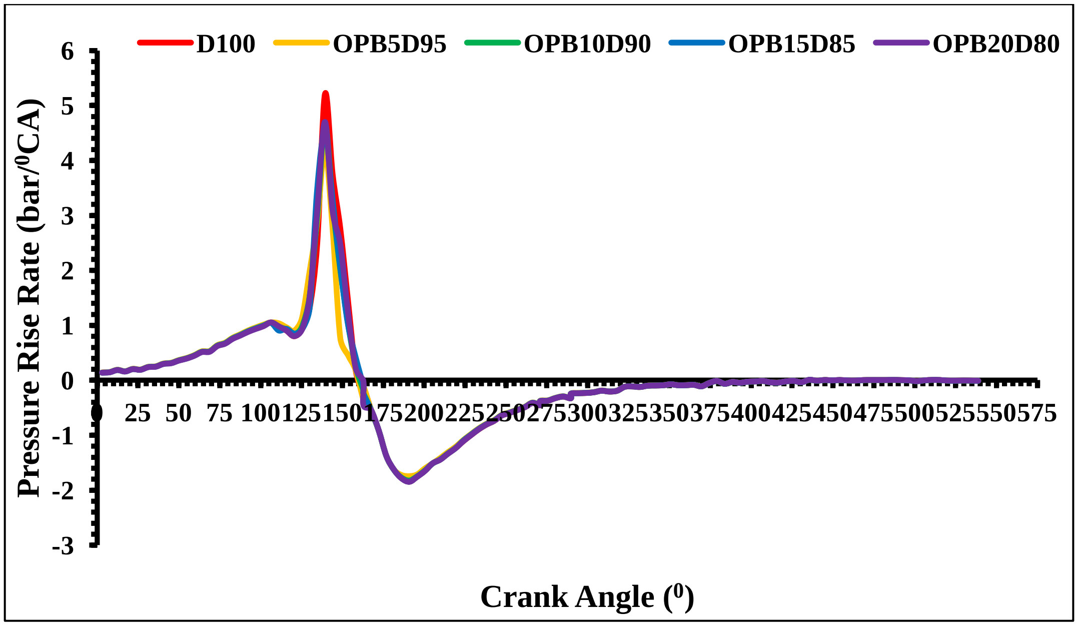


Fig. 4.10: Pressure Rise Rate Variation with Crank Angle.

4.3.3.2 Heat release rate

The rate of heat release was calculated from the pressure crank angle data using the Sorenson's heat release model elaborately discussed in the section 3.7.7. Heat release per crank angle was calculated using the equation. The heat release curve for various test fuels is shown in Fig. 4.11. It may be observed that the peak heat release rate of diesel was 62 J/°CA. E5OPO95, E10OPO90, E15OPO85 and E20OPO80 exhibited reduced peak heat release rates of 53.40, 54, 56 and 60 J/°CA respectively compared to the diesel baseline. Notably, the crank angle corresponding to the peak heat release was lower for OPB blends except OPB20D80 blend. In this premixed combustion stage, Orange peel biodiesel favours better fuel atomization and mixing to form a fuel air mixture burning rapidly and releasing more heat. Results in the similar spirits were reported by Sahoo et.al. [83], Dhar et. al.[69] and Qi et.al. [108].

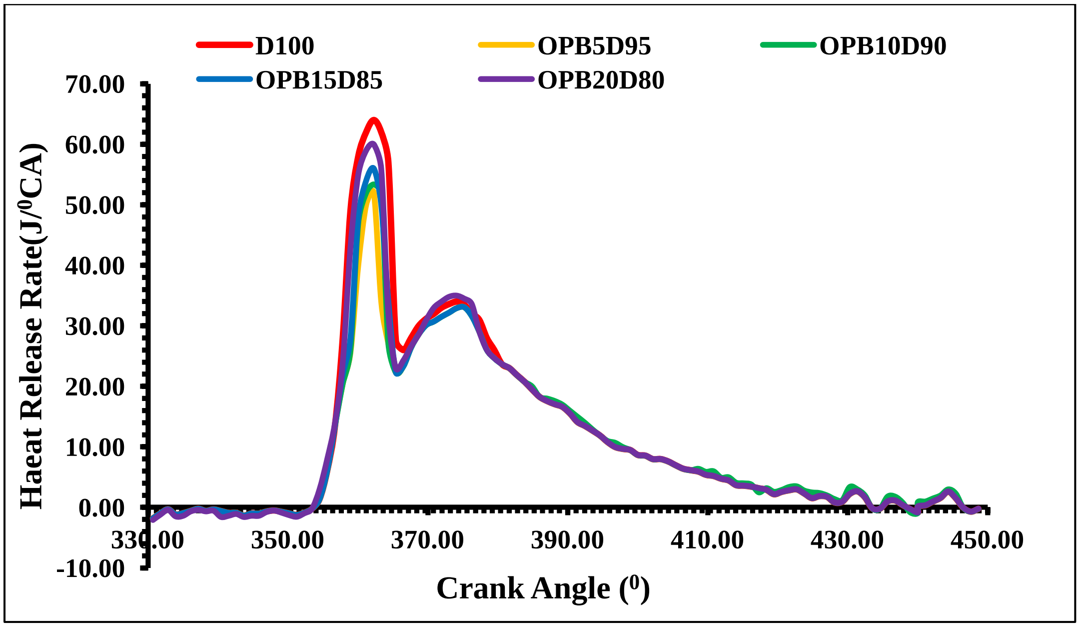


Fig. 4.11: Heat Release Rate Variation with Crank Angle.

4.3.3.3 Mass fraction burnt

Mass fraction burnt was calculated as per the equation discussed in the 3.7.8 section. The ignition delay of individual test fuels and total combustion duration was calculated from the mass fraction burnt. Ignition delay was calculated as the difference between the crank angle corresponding to the beginning of fuel injection and the crank angle.

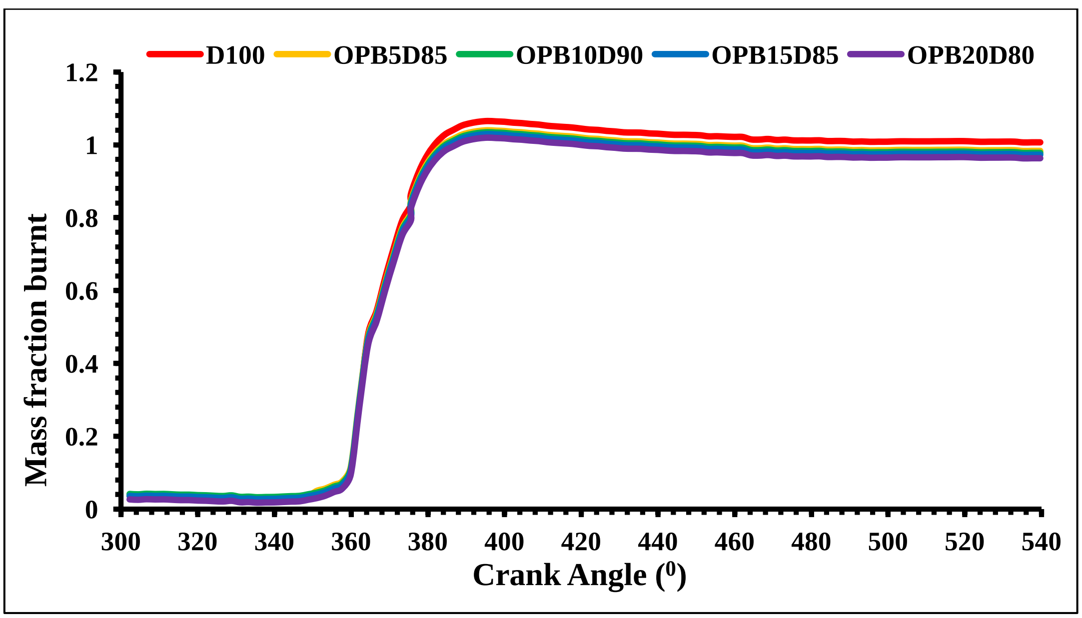


Fig. 4.12: Mass Fraction Burnt Variation with Crank Angle.

4.3.3.4 Combustion Heat Release

The numerical values of phase wise combustion duration were evaluated using the data of heat release rate and mass fraction burnt. It may be observed from fig. 4.13 that the diffusion phase heat release as a fraction of total combustion heat release increased from 53% for D100 to 63% for OPB20D80 confirming low engine noise and smooth combustion for the OPB blends. Apart from this the results also indicated the increase in total combustion duration and reduction in combustion heat release for the blended fuels as compared to the baseline which contributes towards reduced thermal efficiency and high exhaust temperature (not in the scope of present study) which was discussed earlier.

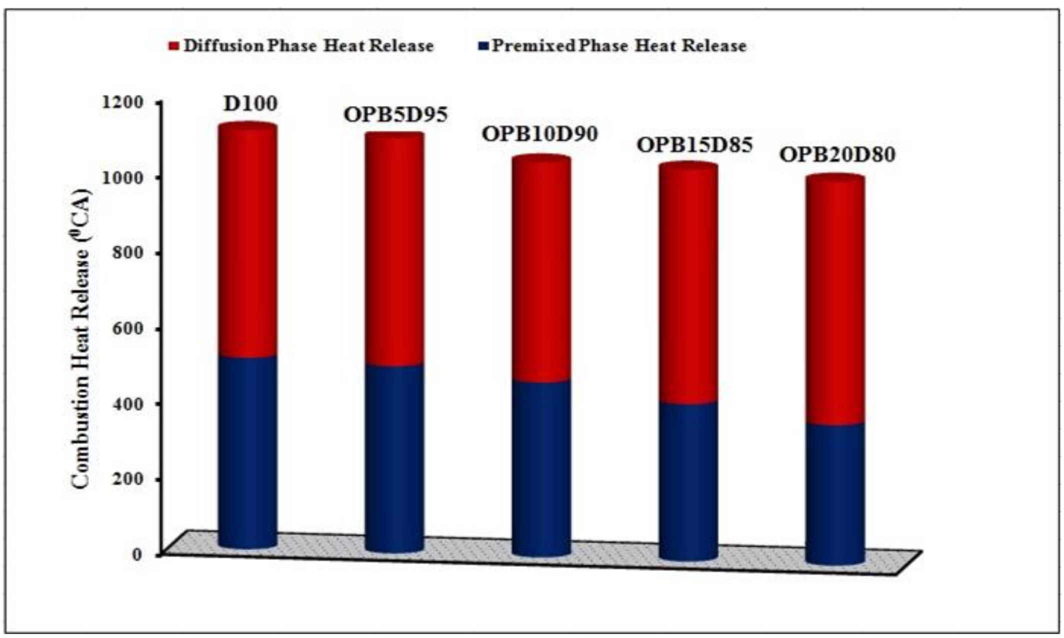


Fig. 4.13: Combustion Heat Release.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

In the present study, all the experiments were conducted using blends of Orange peel biodiesel and diesel. Subsequently combustion, performance, and emission studies were carried out and were compared with diesel .Based on the experimental results; the following major conclusions have been drawn:

1. The physical properties (calorific value, kinematic viscosity, density and specific gravity) of Orange peel biodiesel-diesel blends were found to be comparable with D100. Kinematic viscosity and Calorific value decreases with increase in percentage of Orange peel biodiesel. However, density was found to be increase with concentration of biodiesel increases in tested blends.
2. The brake thermal efficiency of OPB20D80 was marginally less than D100 and was found 24.5% and 25% respectively but it decreases with increase in Orange peel oil content in fuel blend. The brake thermal efficiency which decreases with increase in Orange peel biodiesel content.
3. BSFC was found increased considerably with increase in volume fraction of Orange peel biodiesel in the blends. It is observed that BSFC for OPB20D80 at full load was found 0.40 kg/kWh as compared to 0.36kg/kWh neat diesel fuel operation.
4. For CO emission; by increasing the percentage of Orange peel biodiesel in the blends, there is an appreciable reduction of around 80% in emission at full load was recorded over the baseline data of diesel.

5. At full load, UBHC of OPB5D95, OPB10D90, OPB15D85 and OPB20D80 demonstrated volumetric emissions of 89, 85, 71 and 67 ppm respectively as compared to 92 ppm illustrated by the baseline data of diesel.
6. In present investigation it was observed that NO_x emissions increased with increase in engine load for all test fuels. The samples OPB5D95, OPB15D85 and OPB20D80 exhibited 1685, 1755 and 1870 ppm volumetric emissions of NOx at full load which was higher than 1628 ppm showed by the baseline diesel data.
7. At full load OPB5D95, OPB10D90, OPB15D85 and OPB20D80 blends showed smoke opacities 80%, 75.3%, 60% and 57% as compared to 82% exhibited by baseline diesel.
8. The in-cylinder pressure and pressure rise rate for Orange peel biodiesel-diesel blends were found to be quite similar to D100. However, it slightly reduced by about 5% and 10% respectively. Also, heat release rate increases with increase in OPB content in the test blends as it was found 60 J/°CA and 62 J/°CA correspondingly for OPB20D80 and D100. Conversely, the diffusion phase heat release was better for OPB20D80 than D100.

As a fair conclusion of the exhaustive engine trial, it may be stated that a blending of 20% OPB in diesel will result in better engine performance and emissions of HC, and smoke opacity .However, emission of NOx and CO was found to be enhanced with addition of OPB which may be addressed through adequate catalytic converters. Furthermore Long-term runand wear analysis of biodiesel fueled engine is also necessary along with injection timing and duration for better combustion of biodiesel in diesel engines.

5.2 FUTURE SCOPE

On the basis of the results from the present investigation, the following directions are indicated for further investigation and developments:

1. Utilization of blends of biodiesel-diesel is suggusted for improvement in performance characteristic and NO_x and CO emission.
2. In the present study, an unmodified water cooled diesel engine at constant compression ratio was used however, it is expected that for better engine performance design may be modified specially the injection system, injection angle variation, etc.
3. Comprehensive combustion simulation may be carried out to evaluate the performance, emission and combustion behaviour of the model using various permutation and combination of Orange peel biodiesel and diesel.
4. The short term trial of engine was carried in the present work. Therefore, is an urgent need to carryout long term endurance test to assess the suitability of Orange peel biodiesel-diesel blends on engine hardware is needed.

[1] Yemane Wolde-Rufael, Coal consumption and economic growth revisited, Applied Energy, Volume 87, Issue 1, January 2010, Pages 160-167, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2009.05.001.

[2] Ilhan Ozturk, Ali Acaravci, Electricity consumption and real GDP causality nexus: Evidence from ARDL bounds testing approach for 11 MENA countries, Applied Energy, Volume 88, Issue 8, August 2011, Pages 2885-2892, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2011.01.065.

[3] http://www.preservearticles.com/2011081410495/572-words-sample-essay-on-energy-crisis-worldwide.html accessed on 11 May, 2014.

[4] Bezergianni Stella, DimitriadisAthanasios, KalogianniAggeliki, PilavachiPetros A., Hydrotreating of waste cooking oil for biodiesel production. Part I: Effect of temperature on product yields and heteroatom removal, Bioresource Technology 101 (2010) 6651-6656.

[5] HalimSiti Fatimah Abdul, KamaruddinAzlinaHarun, Fernando W.J.N., Continuous biosynthesis of biodiesel from waste cooking palm oil in a packed bed reactor: Optimization using response surface methodology (RSM) and mass transfer studies, Bio resource Technology 100 (2009) 710-716.

[6] M. Berrios, M.A. Martín, A.F. Chica, A. Martín, Purification of biodiesel from used cooking oils, Applied Energy, Volume 88, Issue 11, November 2011, Pages 3625-3631, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2011.04.060.

[7] http://www.preservearticles.com/2011081410495/572-words-sample-essay-on-energy-crisis-worldwide.html accessed on 11 May 2014.

[8] http://www.bp.com/content/dam/bp/pdf/Energy-economics/statistical-review-2014/BP-statistical-review-of-world-energy-2014-full-report.pdf, accessed on may, 2014.

[9] EIA- U.S. Energy Information admistration, 26 June, 2014, India.

[10] http://www.eia.gov/countries/country-data.cfm?fips=IN, Accessed on 28 June 2014.

[11] S.S. Gill, A. Tsolakis, K.D. Dearn, J. Rodríguez-Fernández, Combustion characteristics and emissions of Fischer–Tropsch diesel fuels in IC engines,

Progress in Energy and Combustion Science, Volume 37, Issue 4, August 2011, Pages 503-523, ISSN 0360-1285, http://dx.doi.org/10.1016/j.pecs.2010.09.001.

[12] Jude C. Eggoh, Chrysost Bangake, Christophe Rault, Energy consumption and economic growth revisited in African countries, Energy Policy, Volume 39, Issue 11, November 2011, Pages 7408-7421, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2011.09.007.

[13] International energy outlook 2014. Paris: International Energy Agency; 2014.

[14] Mathur, M. L., and Sharma, R. P, "A Course in Internal Combustion Engine", Dhanpat Rai Publications, 7th edition pp. 770-774.

[15] Murayama, T., Tsukahara, M., Morishima, Y., and Miyamoto, N., "Experimental Reduction of NOx, Smoke, and BSFC in a Diesel Engine Using Uniquely Produced Water (0 - 80%) to Fuel Emulsion," SAE Technical Paper 780224, 1978, doi:10.4271/780224.

[16] Miyamoto, N., Ogawa, H., Wang, J., and Yamazaki, K., "Simultaneous Reductions in Diesel NOx and Smoke Emissions with Aqueous Metal-Salt Solutions Directly Injected into the Combustion Chamber," SAE Technical Paper 961164, 1996, doi:10.4271/961164.

[17] Sawanth H.N., 1989, “Emission and performance characteristics of a diesel engine using emulsions of diesel fuel with water, methanol and ethanol”, XI National conference on I.C. Engines and Combustion.

[18] Pricing and Resource Allocation to Take Place under Market Forces under an Effective and Credible Regulatory Oversight, as Far as Possible, Integrated energy policy, Govt. of India.

[19] M. Salby, E. Titova, and L. Deschamps; Rebound of Antarctic ozone; Geophysical Research Letters, Vol-38, pp 4, 2011.

[20] M. Salby, E. Titova, and L. Deschamps; Rebound of Antarctic ozone; Geophysical Research Letters, Vol-38, pp 4, 2011.

[21] http://www.nmsea.org/Curriculum/Primer/Global Warming/fossil fuels and global warming.htm Accessed on 15th May, 2014.

[22] http://www.worldbank.org/en/topic/climatechange/overview accessed on 15th May 2014.

[23] http://ralphdeeds.hubpages.com/hub/Global warming where we are now accessed on 15th May 2014.

[24] http://webtv.accuweather.com/en/home-garden-articles/earth-and-you/ozone-hole-shrinks-to-record-l/6058589, accessed on May 15, 2014.

[25] http://www.livemint.com/Politics/F5G9nfaQUUvGvMe5qH3xbM/Petrol-consumption-may-decelerate-in-FY12.html accessed on May 20, 2014.

[26] Libing Wang, Haiyan Yu, Biodiesel from Siberian apricot (Prunus sibirica L.) seed kernel oil, Bioresource Technology, Volume 112, May 2012, Pages 355-358, ISSN 0960-8524, http://dx.doi.org/10.1016/j.biortech.2012.02.120.

[27] Avinash Kumar Agarwal, Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines, Progress in Energy and Combustion Science, Volume 33, Issue 3, June 2007, Pages 233-271, ISSN 0360-1285, http://dx.doi.org/10.1016/j.pecs.2006.08.003.

[28] Chauhan B.S, Kumar N, Cho H.M. Performance and emission studies on an agriculture engine on neat Jatropha oil. Journal of Mechanical Science and Technology 24 (2) (2010), pp: 529-535, DOI 10.1007/s12206-010-0101-5.

[29] Bhupendra Singh Chauhan, Naveen Kumar, Shyam Sunder Pal, Yong Du Jun, Experimental studies on fumigation of ethanol in a small capacity Diesel engine, Energy, Volume 36, Issue 2, February 2011, Pages 1030-1038, ISSN 0360-5442, http://dx.doi.org/10.1016/j.energy.2010.12.005.

[30] R.D. Misra, M.S. Murthy, Straight vegetable oils usage in a compression ignition engine—A review, Renewable and Sustainable Energy Reviews, Volume 14, Issue 9, December 2010, Pages 3005-3013, ISSN 1364-0321, http://dx.doi.org/10.1016/j.rser.2010.06.010.

[31] W.M.J. Achten, L. Verchot, Y.J. Franken, E. Mathijs, V.P. Singh, R. Aerts, B. Muys, Jatropha bio-diesel production and use, Biomass and Bioenergy, Volume 32, Issue 12, December 2008, Pages 1063-1084, ISSN 0961-9534, http://dx.doi.org/10.1016/j.biombioe.2008.03.003.

[32] Lin Lin, Dong Ying, Sumpun Chaitep, Saritporn Vittayapadung, Biodiesel production from crude rice bran oil and properties as fuel, Applied Energy, Volume 86, Issue 5, May 2009, Pages 681-688, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2008.06.002.

[33] B.K. Barnwal, M.P. Sharma, Prospects of biodiesel production from vegetable oils in India, Renewable and Sustainable Energy Reviews, Volume 9, Issue 4, August 2005, Pages 363-378, ISSN 1364-0321, http://dx.doi.org/10.1016/j.rser.2004.05.007.

[34] http://planningcommission.nic.in/plans/planrel/fiveyr/welcome.html. Data taken on 02.06.2014.

[35] http://mofpi.nic.in/ContentPage.aspx? CategoryId=687. Data taken on 02.06.2014.

[36] http://www.bioenergyconsult.com/tag/national-biodiesel-mission/. Data taken on 02.06.2014.

[37] http://www.jatrophabiodiesel.org/indianPrograms.php. Data taken on0 2.06.2014.

[38] http://mnre.gov.in/file-manager/UserFiles/biofuelpolicy.pdf. data taken on 02.06.2014.

[39] Citrus ×sinensis (L.) Osbeck (prosp.) (maxima × reticulata) sweet orange". Plants.USDA.gov accessed on 04 April, 2014.

[40] Morton, J., Fruits of Warm Climates (1987) Miami, FL, pp. 134–142, ISBN: 0-9610184-1-0.

[41] Webber, Herbert John (1967–1989). Chapter-I. History and Development of the Citrus Industry in origin of citrus, Vol. 1. University of California.

[42] Webber, Herbert John, rev Walter Reuther and Harry W. Lawton; Willard Hodgson "The Citrus Industry, Horticultural Varieties of Citrus, University of California Division of Agricultural Sciences", 1967–1989, 1943.

[43] Yourdictionary.com, pip definition with thesaurus, examples, audio and more, Retrieved on 2011-10-02, 2011-09-23.

[44] Kimball, Dan A Citrus processing: a complete guide, New York: Springer. p.450. ISBN 0-8342-1258-7, 1999.

[45] horticulture.tamu.edu, Home Fruit Production – Oranges, Julian W. Sauls, Ph.D., Professor & Extension Horticulturist, Texas Cooperative Extension December, 1998

[46] Citrus world market and Trade, USDA FSA, 2014 http://apps.fas.usda.gov/psdonline/circulars/citrus.pdf.

[47] Diomi Mamma, Elisavet Kourtoglou, Paul Christakopoulos, Fungal multienzyme production on industrial by-products of the citrus-processing industry, Bioresource

Technology, Volume 99, Issue 7, May 2008, Pages 2373-2383, ISSN 0960-8524, http://dx.doi.org/10.1016/j.biortech.2007.05.018.

[48] www.faostat.fao.org, Retrieved on 2014-01-26.accessed on 04 April, 2014.

[49] Mishra D, Shukla AK, Dixit AK, Singh K. Aqueous enzymatic extraction of oil from mandrin peels. JST.JSTAGE/jos/54.355, http://dx.doi.org/10.5650/jos.54.355.

[50] Physicochemical properties of citrus essential oils from FloridA, Richard W. Wolford, James W. Kesterson, and John A. Attaway, Journal of Agricultural and Food Chemistry 1971 19 (6), 1097-1105.

[51] Syed HM, Ghatge PU, Machewad G, Pawar S (2012) Studies on Preparation of Squash from Sweet Orange. 1:311. doi:10.4172/scientificreports.311.

[52] A.E. Atabani, A.S. Silitonga, H.C. Ong, T.M.I. Mahlia, H.H. Masjuki, Irfan Anjum Badruddin, H. Fayaz, Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production, Renewable and Sustainable Energy Reviews, Volume 18, February 2013, Pages 211-245, ISSN 1364-0321, http://dx.doi.org/10.1016/j.rser.2012.10.013.

[53] Chen Y.H, Chen J.H, Chang C.Y, Chang C.C. Biodiesel production from tung (Vernicia montana) oil and its blending properties in different fatty acid compositions. Bioresource Technology 2010 Dec;101(24):9521-6. doi: 10.1016/j.biortech.2010.06.117. Epub 2010 August.

[54] N. Usta, B. Aydoğan, A.H. Çon, E. Uğuzdoğan, S.G. Özkal, Properties and quality verification of biodiesel produced from tobacco seed oil, Energy Conversion and Management, Volume 52, Issue 5, May 2011, Pages 2031-2039, ISSN 0196-8904, http://dx.doi.org/10.1016/j.enconman.2010.12.021.

[55] K. Teixeira da Silva de La Salles, S.M.P. Meneghetti, W. Ferreira de La Salles, M.R. Meneghetti, I.C.F. dos Santos, J.P.V. da Silva, S.H.V. de Carvalho, J.I. Soletti, Characterization of Syagrus coronata (Mart.) Becc. oil and properties of methyl esters for use as biodiesel, Industrial Crops and Products, Volume 32, Issue 3, November 2010, Pages 518-521, ISSN 0926-6690, http://dx.doi.org/10.1016/j.indcrop.2010.06.026.

[56] A.S. Silitonga, H.C. Ong, T.M.I. Mahlia, H.H. Masjuki, W.T. Chong, Characterization and production of Ceiba pentandra biodiesel and its blends, Fuel,

Volume 108, June 2013, Pages 855-858, ISSN 0016-2361, http://dx.doi.org/10.1016/j.fuel.2013.02.014.

[57] Lin Lin, Dong Ying, Sumpun Chaitep, Saritporn Vittayapadung, Biodiesel production from crude rice bran oil and properties as fuel, Applied Energy, Volume 86, Issue 5, May 2009, Pages 681-688, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2008.06.002.

[58] Pedro Benjumea, John Agudelo, Andrés Agudelo, Basic properties of palm oil biodiesel–diesel blends, Fuel, Volume 87, Issues 10–11, August 2008, Pages 2069-2075, ISSN 0016-2361, http://dx.doi.org/10.1016/j.fuel.2007.11.004

[59] Paula Berman, Shahar Nizri, Zeev Wiesman, Castor oil biodiesel and its blends as alternative fuel, Biomass and Bioenergy, Volume 35, Issue 7, July 2011, Pages 2861-2866, ISSN 0961-9534, http://dx.doi.org/10.1016/j.biombioe.2011.03.024.

[60] Harrison B. Bucy, Marc E. Baumgardner, Anthony J. Marchese, Chemical and physical properties of algal methyl ester biodiesel containing varying levels of methyl eicosapentaenoate and methyl docosahexaenoate, Algal Research, Volume 1, Issue 1, May 2012, Pages 57-69, ISSN 2211-9264, http://dx.doi.org/10.1016/j.algal.2012.02.001.

[61] Maumita Chakraborty, D.C. Baruah, D. Konwer, Investigation of terminalia (Terminalia belerica Robx.) seed oil as prospective biodiesel source for North-East India, Fuel Processing Technology, Volume 90, Issue 12, December 2009, Pages 1435-1441, ISSN 0378-3820, http://dx.doi.org/10.1016/j.fuproc.2009.06.023.

[62] Nicholas Chammoun, Daniel P. Geller, K.C. Das, Fuel properties, performance testing and economic feasibility of Raphanus sativus (oilseed radish) biodiesel, Industrial Crops and Products, Volume 45, February 2013, Pages 155-159, ISSN 0926-6690, http://dx.doi.org/10.1016/j.indcrop.2012.11.029.

[63] Jianmin Chu, Xinqiao Xu, Yinglong Zhang, Production and properties of biodiesel produced from Amygdalus pedunculata Pall, Bioresource Technology, Volume 134, April 2013, Pages 374-376, ISSN 0960-8524, http://dx.doi.org/10.1016/j.biortech.2012.12.089.

[64] Libing Wang, Haiyan Yu, Biodiesel from Siberian apricot (Prunus sibirica L.) seed kernel oil, Bioresource Technology, Volume 112, May 2012, Pages 355-358, ISSN 0960-8524, http://dx.doi.org/10.1016/j.biortech.2012.02.120.

[65] Rui Wang, Wan-Wei Zhou, Milford A. Hanna, Yu-Ping Zhang, Pinaki S. Bhadury, Yan Wang, Bao-An Song, Song Yang, Biodiesel preparation, optimization, and fuel properties from non-edible feedstock, Datura stramonium L., Fuel, Volume 91, Issue 1, January 2012, Pages 182-186, ISSN 0016-2361, http://dx.doi.org/10.1016/j.fuel.2011.07.001.

[66] Wan Nor Nadyaini Wan Omar, Nor Aishah Saidina Amin, Optimization of heterogeneous biodiesel production from waste cooking palm oil via response surface methodology, Biomass and Bioenergy, Volume 35, Issue 3, March 2011, Pages 1329-1338, ISSN 0961-9534, http://dx.doi.org/10.1016/j.biombioe.2010.12.049.

[67] Huimin Yun, Meng Wang, Wei Feng, Tianwei Tan, Process simulation and energy optimization of the enzyme-catalyzed biodiesel production, Energy, Volume 54, 1 June 2013, Pages 84-96, ISSN 0360-5442, http://dx.doi.org/10.1016/j.energy.2013.01.002.

[68] K. Purushothaman, G. Nagarajan, Performance, emission and combustion characteristics of a compression ignition engine operating on neat orange oil, Renewable Energy, Volume 34, Issue 1, January 2009, Pages 242-245, ISSN 0960-1481, http://dx.doi.org/10.1016/j.renene.2008.03.012.

[69] Avinash Kumar Agarwal, Atul Dhar, Experimental investigations of performance, emission and combustion characteristics of Karanja oil blends fuelled DICI engine, Renewable Energy, Volume 52, 2013,283-291, ISSN 0960 1481,http://dx.doi.org/10.1016/j.renene.2012.10.015.

[70] K. Purushothaman, G. Nagarajan, Study of Combustion, Performance and Emission Characteristics of a Compression Ignition Engine Operating on a Diesel – Orange oil Blended with Lower Concentrations, International Conference on Mechanical, Automobile and Robotics Engineering.

[71] Deep, A., Singh, A., Vibhanshu, V., Khandelwal, A. et al., "Experimental Investigation of Orange Peel Oil Methyl Ester on Single Cylinder Diesel Engine," SAE Technical Paper 2013-24-0171, 2013, doi: 10.4271/2013-24-0171.

[72] Ekrem Buyukkaya, Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics, Fuel, Volume 89, Issue 10, October 2010, Pages 3099-3105, ISSN 0016-2361, http://dx.doi.org/10.1016/j.fuel.2010.05.034.

[73] H. Raheman, A.G. Phadatare, Diesel engine emissions and performance from blends of karanja methyl ester and diesel, Biomass and Bioenergy, Volume 27, Issue 4, October 2004, Pages 393-397, ISSN 0961-9534, http://dx.doi.org/10.1016/j.biombioe.2004.03.002.

[74] Sharanappa Godiganur, C.H. Suryanarayana Murthy, Rana Prathap Reddy, 6BTA 5.9 G2-1 Cummins engine performance and emission tests using methyl ester mahua (Madhuca indica) oil/diesel blends, Renewable Energy, Volume 34, Issue 10, October 2009, Pages 2172-2177, ISSN 0960-1481, http://dx.doi.org/10.1016/j.renene.2008.12.035.

[75] H. Raheman, S.V. Ghadge, Performance of compression ignition engine with mahua (Madhuca indica) biodiesel, Fuel, Volume 86, Issue 16, November 2007, Pages 2568-2573, ISSN 0016-2361, http://dx.doi.org/10.1016/j.fuel.2007.02.019.

[76] P.K. Sahoo, L.M. Das, M.K.G. Babu, S.N. Naik, Biodiesel development from high acid value polanga seed oil and performance evaluation in a CI engine, Fuel, Volume 86, Issue 3, February 2007, Pages 448-454, ISSN 0016-2361, http://dx.doi.org/10.1016/j.fuel.2006.07.025.

[77] A.M. Liaquat, H.H. Masjuki, M.A. Kalam, I.M. Rizwanul Fattah, M.A. Hazrat, M. Varman, M. Mofijur, M. Shahabuddin, Effect of Coconut Biodiesel Blended Fuels on Engine Performance and Emission Characteristics, Procedia Engineering, Volume 56, 2013, Pages 583-590, ISSN 1877-7058, http://dx.doi.org/10.1016/j.proeng.2013.03.163.

[78] Mustafa Canakci, Ahmet Necati Ozsezen, Erol Arcaklioglu, Ahmet Erdil, Prediction of performance and exhaust emissions of a diesel engine fueled with biodiesel produced from waste frying palm oil, Expert Systems with Applications, Volume 36, Issue 5, July 2009, Pages 9268-9280, ISSN 0957-4174, http://dx.doi.org/10.1016/j.eswa.2008.12.005.

[79] Lu-Yen Chen, Yi-Hung Chen, Yi-Shun Hung, Tsung-Han Chiang, Cheng-Hsien Tsai, Fuel properties and combustion characteristics of jatropha oil biodiesel–diesel blends, Journal of the Taiwan Institute of Chemical Engineers, Volume 44, Issue 2, March 2013, Pages 214-220, ISSN 1876-1070, http://dx.doi.org/10.1016/j.jtice.2012.09.011.

[80] Magín Lapuerta, Octavio Armas, José Rodríguez-Fernández, Effect of biodiesel fuels on diesel engine emissions, Progress in Energy and Combustion Science, Volume 34, Issue 2, April 2008, Pages 198-223, ISSN 0360-1285, http://dx.doi.org/10.1016/j.pecs.2007.07.001.

[81] Md. Nurun Nabi, S.M. Najmul Hoque, Md. Shamim Akhter, Karanja (Pongamia Pinnata) biodiesel production in Bangladesh, characterization of karanja biodiesel and its effect on diesel emissions, Fuel Processing Technology, Volume 90, Issue 9, September 2009, Pages 1080-1086, ISSN 0378-3820.

[82] S. Sivalakshmi, T. Balusamy, Effect of biodiesel and its blends with diethyl ether on the combustion, performance and emissions from a diesel engine, Fuel, Volume 106, April 2013, Pages 106-110, ISSN 0016-2361, http://dx.doi.org/10.1016/j.fuel.2012.12.033.

[83] P.K. Sahoo, L.M. Das, Combustion analysis of Jatropha, Karanja and Polanga based biodiesel as fuel in a diesel engine, Fuel, Volume 88, Issue 6, June 2009, Pages 994-999, ISSN 0016-2361, http://dx.doi.org/10.1016/j.fuel.2008.11.012.

[84] L. Labecki, A. Cairns, J. Xia, A. Megaritis, H. Zhao, L.C. Ganippa, Combustion and emission of rapeseed oil blends in diesel engine, Applied Energy, Volume 95, July 2012, Pages 139-146, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2012.02.026.

[85] D.H. Qi, L.M. Geng, H. Chen, Y.ZH. Bian, J. Liu, X.CH. Ren, Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crude oil, Renewable Energy, Volume 34, Issue 12, December 2009, Pages 2706-2713, ISSN 0960-1481, http://dx.doi.org/10.1016/j.renene.2009.05.004.

[86] Wail M. Adaileh, Khaled S. AlQdah, Performance of Diesel Engine Fuelled by a Biodiesel Extracted From A Waste Cocking Oil, Energy Procedia, Volume 18, 2012, Pages 1317-1334, ISSN 1876-6102, http://dx.doi.org/10.1016/j.egypro.2012.05.14.

[87] Chopade G, Kulkarni K.S, Kulkarni A.D, Topare S. Solid heterogeneous catalysts for production of biodiesel from trans-esterification of triglycerides with methanol : a review. Acta Chimica & Pharmaceutica Indica (2012) ; 2(1):8–14.

[88] Strayer R.C, Blake J.A, Craig W.K. Canola and higher ucicrape seed oil as substitutes for diesel fuel: preliminary tests. Journal of the American Oil Chemists' Society (1983);60:1587–92.

[89] N.N.A.N. Yusuf, S.K. Kamarudin, Z. Yaakub, Overview on the current trends in biodiesel production, Energy Conversion and Management, Volume 52, Issue 7, July 2011, Pages 2741-2751, ISSN 0196-8904, http://dx.doi.org/10.1016/j.enconman.2010.12.004.

[90] Parawira W. Biodiesel production from Jatropha curcas: a review. Scientific Research and Essays (2010) ;5(14):1796–808.

[91] Dennis Y.C. Leung, Xuan Wu, M.K.H. Leung, A review on biodiesel production using catalyzed transesterification, Applied Energy, Volume 87, Issue 4, April 2010, Pages 1083-1095, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2009.10.006.

[92] Aninidita Karmakar, Subrata Karmakar, Souti Mukherjee, Properties of various plants and animals feedstocks for biodiesel production, Bioresource Technology, Volume 101, Issue 19, October 2010, Pages 7201-7210, ISSN 0960-8524, http://dx.doi.org/10.1016/j.biortech.2010.04.079.

[93] Young-Moo Park, Joon Yeob Lee, Sang-Ho Chung, In Seon Park, Seung-Yeon Lee, Deog-Keun Kim, Jin-Suk Lee, Kwan-Young Lee, Esterification of used vegetable oils using the heterogeneous WO3/ZrO2 catalyst for production of biodiesel, Bioresource Technology, Volume 101, Issue 1, Supplement, January 2010, Pages S59-S61, ISSN 0960-8524, http://dx.doi.org/10.1016/j.biortech.2009.04.025.

[94] Dennis Y.C. Leung, Xuan Wu, M.K.H. Leung, A review on biodiesel production using catalyzed transesterification, Applied Energy, Volume 87, Issue 4, April 2010, Pages 1083-1095, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2009.10.006.

[95] Faletti, J. J., S. C. Sorenson, and C. E. Goering. 1984. Energy release rates from hybrid fu Transactions of the ASABE. 27 (2): 0322-0325. (doi: 10.13031/2013.32783), 1984.

[96] Hanson, A. C. 1989. A diagnostic quasi-dimensional model of heat transfer and combustion in compression-ignition engines. Unpublished. Ph.D. thesis.

Pietermaritzburg, South Africa: Dept. of Agricultural Engineering, University of Natal.

[97] Huang Z.H, Jiang D.M, Zeng K, Liu B, Yang Z.L. “Combustion characteristics and heat release analysis of a DI compression ignition engine fuelled with diesel-dimethyl carbonate blends”. Proc Inst Mech Eng, Part D, J Automobile Eng (2003); 217(D7):595– 606, DOI: 10.1243/095440703322114979.

[98] Crowell, T. J. Evaluation of enhanced ethanol with fumigation as a diesel fuel replacement. Unpublished. M.S. thesis (1989). Urbana, Ill.: University of Illinois.

[99] Eichelberg, G. Some new investigations on old combustion engine problems. Engineering (1939) ; 148: 463-464, 547-560.

[100] Heywood J.B. Internal Combustion Engine Fundamentals. McGraw-Hill. 1988, ISBN 0- 07-100499-8.

[101] Purushothaman K., Nagarajan G.,“The Effect of Orange Oil-diesel Fuel Blends on Direct Injection Diesel Engine Performance Exhaust Emissions and Combustion” Thammasat lnt. J. Sc. Tech., Vol. 13, No.4, October-December 2008.

[102] Material Safety Datasheet of HP Diesel http://www.hindustanpetroleum.com/documents/pdf/MSDSHSD.pdf.

[103] K. Purushothaman, G. Nagarajan, Experimental investigation on a C.I. engine using orange oil and orange oil with DEE, Fuel, Volume 88, Issue 9, September 2009, Pages 1732-1740, ISSN 0016-2361, http://dx.doi.org/10.1016/j.fuel.2009.03.032.

[104] Magín Lapuerta, Octavio Armas, José Rodríguez-Fernández, Effect of biodiesel fuels on diesel engine emissions, Progress in Energy and Combustion Science, Volume 34, Issue 2, April 2008, Pages 198-223, ISSN 0360-1285, http://dx.doi.org/10.1016/j.pecs.2007.07.001.

[105] Bhupendra Singh Chauhan, Naveen Kumar, Haeng Muk Cho, A study on the performance and emission of a diesel engine fueled with Jatropha biodiesel oil and its blends, Energy, Volume 37, Issue 1, January 2012, Pages 616-622, ISSN 0360-5442, http://dx.doi.org/10.1016/j.energy.2011.10.043.

[106] Vibhanshu, V., Kumar, N., Mishra, C., Sinha, S. et al., "Experimental Investigation of Diesel Engine Fuelled with Jatropha Oil Blend with Ethanol," SAE Int. J. Fuels Lubr. 6(3):951-958, 2013, doi:10.4271/2013-24-0105.

[107] Rao Nandkishore R., D. Premkumar, B. Sudheer and Yohan M., “Performance and emission characteristics of straight vegetable oil ethanol emulsion in a compression ignition engine”, ARPN Journal of Engineering and Applied Sciences , ISSN:1819-6608, 2012.

[108] Qi D.H., Chen H.a, Matthews R.D.b, Bian Y.ZH., “Combustion and emission characteristics of ethanol-biodiesel-water micro-emulsions used in a direct injection compression ignition engine” Fuel 89 (2010) 958-964.

[109] Shadidi B., Yusaf T., Alizadeh H., Ghobadian B., “Experimental investigation of the tractor engine performance using diesohol fuel” Applied Energy 114:874–879, 2014, doi.org/10.1016/j.apenergy.2013.06.011.

[110] C.H. Cheng, C.S. Cheung, T.L. Chan, S.C. Lee, C.D. Yao, Experimental investigation on the performance, gaseous and particulate emissions of a methanol fumigated diesel engine, Science of The Total Environment, Volume 389, Issue 1, 15 January 2008, Pages 115-124, ISSN 0048-9697, http://dx.doi.org/10.1016/j.scitotenv.2007.08.041.

[111] Cenk Sayin, Ahmet Necati Ozsezen, Mustafa Canakci, The influence of operating parameters on the performance and emissions of a DI diesel engine using methanol-blended-diesel fuel, Fuel, Volume 89, Issue 7, July 2010, Pages 1407-1414, ISSN 0016-2361, http://dx.doi.org/10.1016/j.fuel.2009.10.035.

[112] Singh, Pranil J. and Khurma, Jagjit R. and Singh, Anirudh., “Preparation, characterisation, engine performance and emission characteristics of coconut oil based hybrid fuels” Renewable Energy, 35 (9). pp. 2065-2070., doi:10.1016/j.renene.2010.02.007.

[113] Chauhan BS, Kumar N, Pal SS, Du Jun Y. Experimental studies on fumigation of ethanol in a small capacity diesel engine. Energy; 36:1030–8, 2011.

[114] Zhu L., Cheung., Zhang W., Huang Z., “Effect of charge dilution on gaseous and particulate emissions from a diesel engine fuelled with biodiesel and biodiesel blended with methanol and ethanol”, Applied Thermal Engineering 31:2271e2278, 2011, doi: 10.1016/j.applthermaleng.2011.03.023.

[115] Cenk Sayin, Engine performance and exhaust gas emissions of methanol and ethanol–diesel blends, Fuel, Volume 89, Issue 11, November 2010, Pages 3410-3415, ISSN 0016-2361, http://dx.doi.org/10.1016/j.fuel.2010.02.017.

[116] Challen B, Baranescu R. Diesel engine reference book. 2nd edition. Woburn, MA: SAE and Butterworth Heinemann; (1999).

[117] D.H. Qi, H. Chen, L.M. Geng, Y. ZH. Bian, Experimental studies on the combustion characteristics and performance of a direct injection engine fueled with iodiesel/diesel blends, Energy Conversion and Management, Volume 51, Issue 12, December 2010, Pages 2985-2992, ISSN 0196-8904, http://dx.doi.org/10.1016/j.enconman.2010.06.042.

[118] Mu-Rong Chao, Ta-Chang Lin, How-Ran Chao, Feng-Hsiang Chang, Chung-Bang Chen, Effects of methanol-containing additive on emission characteristics from a heavy-duty diesel engine, Science of The Total Environment, Volume 279, Issues 1–3, 12 November 2001, Pages 167-179, ISSN 0048-9697, http://dx.doi.org/10.1016/S0048-9697(01)00764-1.

[119] Stone R. Introduction to internal combustion engines. 3rd edition. Warrendale: SAE Inc.; (1999).

[120] Kumar M. Senthil, Kerihuel A., Bellettre J., Tazerout M. "Ethanol animal fat emulsions as a diesel engine fuel - Part 2: Engine test analysis", Fuel 85:2646-2652, 2006.

[121] Kumar, N., Bansal, S., Vibhanshu, V., and Singh, A., "Utilization of Blends of Jatropha Oil and N-Butanol in a Naturally Aspirated Compression Ignition Engine," SAE Technical Paper 2013-01-2684, 2013, doi: 10.4271/2013-01-2684.

[122] Dale R. Tree, Kenth I. Svensson, Soot processes in compression ignition engines, Progress in Energy and Combustion Science, Volume 33, Issue 3, June 2007, Pages 272-309, ISSN 0360-1285, http://dx.doi.org/10.1016/j.pecs.2006.03.002.

APPENDIX-I

Technical Specifications of AVL Di-Gas Analyser

Measurement principle	CO, HC, CO_2	Infrared measurement
	O_2	Electrochemical measurement
	NO (option)	Electrochemical measurement
Operating temperature	+5 to +45ºC	Keeping measurement accuracy
	+1 to +50ºC	Ready for measurement
	+5 to +35ºC	with integral NO sensor (+40ºC)
Storage temperature	-20 to +60ºC	
	-20 to +50ºC	With integrated O_2 sensor
	-10 to. +45ºC	With integrated NO sensor
	0 to +50ºC	With water in filter or pump
Air humidity	90% max,	non-condensing
Power drawn	150 VA	
Dimensions	432 x 230 x 470 mm	(w x h x l)
Weight	16 Kg	

Measurement Ranges of AVL Di-Gas Analyser

Parameter	**Measurement Range**	**Resolution**
CO	0-10% vol	0.01% vol
CO_2	0-20% vol	0.1% vol
HC	0-20000 ppm vol	1 ppm
NOx	0-5000 ppm vol	1 ppm
O_2	0-25% vol	0.01% vol

APPENDIX-II

Technical Specifications of AVL 437 Smoke Meter

Accuracy and Reproducibility	± 1% full scale reading
Heating Time	Approx. 20 min
Light source	Halogen bulb 12 V / 5W
Colour temperature	3000 K ± 150 K
Detector	Selenium photocell dia. 45 mm, Max. Sensitivity in light In Frequency range: 550 to 570 nm. Below 430 nm and above 680 nm sensitivity is less than 4% related to the maximum sensitivity
Maximum Smoke	250ºC Temperature at entrance

APPENDIX-III

Accuracies and uncertainties of measurements

S.N.	Measurements	Measurement Principle	Range	Accuracy
1	Engine load	Strain gauge type load cell	0-25 Kg	±0.1Kg
2	Speed	Magnetic pick up type	0-2000 rpm	±20 rpm
3	Time	Stop watch	--	±0.5%
4	Exhaust Temperature	K-type thermocouple	0-1000°C	±1^{0}C
5	Carbon monoxide	Non-dispersive infrared	0-10% vol.	±0.2%
6	Carbon dioxide	Non-dispersive infrared	0-20% vol.	±0.2%
7	Total hydrocarbons	Non-dispersive infrared	0-20,000 ppm	±2 ppm
8	Oxides of nitrogen	Electrochemical	0-4000 ppm	±15ppm
9	Smoke	Photochemical	0-100%	± 2%
10	Crank angle encoder	Optical	0-720 °CA	± 0.2^{0}CA
11	Pressure	Piezoelectric	0-200 bar	± 1 bar
	Calculated results			**Uncertainty**
12	Engine power	--	0-8 kW	±1.0%
13	Fuel consumption	Level sensor	--	±2.0%
14	Air consumption	Turbine flow type	--	±1.0%
15	BTE	--	--	±1.0%
16	BSEC	--	--	±1.5%
17	Heat release	Sorenson model	--	±5.0%
18	In-cylinder temp.	Ideal gas equation	Up to 3000°K	±5.0%

APPENDIX-IV

List of publications in International, National Conferences and Journals

- **Deep, A.,** Singh, A**,** Vibhanshu, V., Khandelwal, A., and Kumar, N., "Experimental Investigation of Orange Peel Oil Methyl Ester on Single Cylinder Diesel Engine" SAE Technical Paper 2013-24-0171, 2013, **doi:** 10.4271/2013-24-0171.
- **Deep, A.,** Singh, A., and Pali, H, "Orange Peel Oil- An alternative fuel in single cylinder diesel engine" **Mangalmay Journal of Management & Technology', Print ISSN: 0973-7251, Online ISSN: 2230-729X**.
- **Deep, A.,** Singh, A., and Pali, H.,"Orange Peel Oil- An alternative fuel in single cylinder diesel engine" ISBN: 978-93-5156-340-2 **2nd International Conference on 'Technology and Management Advances in the new age economy: An Industry Perspective.' MIET, Greater Noida, 01 March, 2014.**
- **Deep, A,** Kumar, N., Sharma, A., Patel, J., "Biodiesel Production and Physico-Chemical Properties of Orange Peel Oil Methyl Ester" ISTE 181, Proceedings of national conference on **Technological Universities and Institutions in New Knowledge Age: Future Perspectives and Action Plan" DTU, September 5-6, 2013.**
- Singh, A., **Deep, A.,** and Pali, H.," "Performance and emission analysis of CI engine in dual mode with CNG and Jatropha oil methyl ester" **Mangalmay Journal of Management & Technology', Print ISSN: 0973-7251, Online ISSN: 2230-729X.**
- Gupta, D., **Deep, A,** Kumar, N., Khandelwal, A., and Pathak, V., "Production of bio diesel using super critical method" ISTE 182, Proceedings of national conference on **Technological Universities and Institutions in New Knowledge Age: Future Perspectives and Action Plan" DTU, September 5-6, 2013.**
- Patel, J., Kumar, N., **Deep, A.,** Sharma, A. et al., "Evaluation of Emission Characteristics of Blend of Algae Oil Methyl Ester with Diesel in a Medium Capacity Diesel Engine," SAE Technical Paper 2014-01-1378, 2014, **doi:** 10.4271/2014-01-1378.
- Tomar, V., Gupta, D., **Deep, A.,** Kumar, N., "Evaluation of Oxidation Stability of Fish Oil Biodiesel" ISTE 184, Proceedings of national conference on **Technological**

Universities and Institutions in New Knowledge Age: Future Perspectives and Action Plan" DTU, September 5-6, 2013.

- Sinha, S., Vibhanshu, V., Kumar,N.,and **Deep, A,** **"**Experimental Investigation of Performance and Emission Characteristics of Blends of Jatropha Oil Methyl Ester and Ethanol in Light Duty Diesel Vehicle", **Journal of Engineering Research and Applications ISSN : 2248-9622, Vol. 4, Issue 2(Version 1), February 2014, pp.374-383.**
- Sharma, A., Kumar, N., Vibhanshu, V., and **Deep, A.,** "Emission Studies on a VCR Engine Using Stable Diesel Water Emulsion," SAE Technical Paper 2013-01-2665, 2013, **doi:** 10.4271/2013-01-2665.
- Singh, A., **Deep, A.,** and Pali, H.," "Performance and emission analysis of CI engine in dual mode with CNG and Jatropha oil methyl ester" ISBN: 978-93-5156-340-2, **2nd International Conference on 'Technology and Management Advances in the new age economy: An Industry Perspective.' MIET, Greater Noida, 01 March, 2014**.