

**Major Project -II**  
**SOME EXPERIMENTAL STUDIES ON BIODIESEL**  
**BLENDED WITH LOWER ALCOHOLS**

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**Master of Technology**

**In**

**Thermal Engineering**

**By**

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**July-2013**

## **DECLARATION**

I, hereby declare that the work embodied in the dissertation entitled “*SOME EXPERIMENTAL STUDIES ON BIODIESEL BLENDED WITH LOWER ALCOHOLS*” 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 of this work either 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 “*SOME EXPERIMENTAL STUDIES ON BIODIESEL BLENDED WITH LOWER ALCOHOLS*” by **ASHUTOSH KUMAR RAI**, (Roll No.-**2K11/THE/26**) in partial fulfillment of requirements for the award of **Degree of Master of Technology (M.Tech) 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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**ASHUTOSH KUMAR RAI**

Date: 30 July 2013

M.TECH (Thermal Engineering)

## ABSTRACT

Today world is moving towards the sustainable energy sources which are renewable in nature and biodegradable. There are several resources and several means to convert these resources in useful form of energy. But majority of the world energy demand dependent upon the fossil fuel either they are power sector, agricultural sector or transportation sector. Diesel engine is one among the several energy conversion mechanisms which uses fossil fuels for the useful energy need. These Engines have proved their utility in transportation, agriculture and power sector of India. These engines have also proved their utilization for the remote areas which are beyond the reach of grid connectivity. Diesel engine has highest thermal efficiency among internal combustion engines. Nowadays society is concerned for clean and green environment. As a social responsibility biofuels are better alternative to petroleum fuels which are available for limited period. Rules and norms for environmental pollution limit is a better way to protect the environment. Promotion to biofuels such as biodiesel, ethanol etc. as a transportation fuel is a better way in this direction.

Vegetable oils have always been considered as a good alternative. The transesterified vegetable oils, popularly known as biodiesel are one of the popular modes of usage in diesel engines. However, one of the major outcomes of biodiesel usage in diesel engines is the increased emissions of oxides of nitrogen ( $\text{NO}_x$ ) as documented by numerous research articles. This problem can be sort-out by blending of ethanol in biodiesel due to cooling action of ethanol during combustion.

Biodiesel derived from Linseed oil has been considered as a sustainable substitute to diesel fuel. Linseed is found in many parts of Madhya Pradesh, Uttar Pradesh, Maharashtra, Punjab & Gujarat. Since it is not used as edible oil in many part of country, so it can be used to drive diesel engine without any problem of wastage of food resource. Similarly ethanol is a

high oxygen content (35%) renewable bio fuel which can be used for CI engine as a blend with biodiesel.

Very less research is done on the Ethanol-Biodiesel blend as a fuel for C I engine. The problems associated with linseed oils are the high viscosity & low volatility. The issue of high viscosity needs to be resolved for its long term utilization in diesel engine. Due to high viscosity, there are two strategies for using linseed oil as fuel for use in diesel engine. The first one is to modify the engine to adapt to the fuel and the second one is to process the fuel to adapt to the engine or blending. Production of biodiesel from linseed oil and then blending of ethanol in this biodiesel is a better option due to reduced viscosity and enhanced volatility of blend.

India is fourth in the production of linseed oil in the world and largest producer of sugarcane in the world. These two points pushed me to work on the linseed biodiesel and ethanol blends. It was found that blends have better BTE than diesel, lower emissions such as  $\text{NO}_x$ , unburned HC and PM. All such characteristics attribute to use low ethanol blend with biodiesel.

The present work aims at performance & emission evaluation of blends of Ethanol-Linseed Biodiesel in a diesel engine. The performance & emission characteristics of exhaust gases from the engine are analyzed and compared with diesel. The experimental result shows that fuel consumption & power output are comparable to diesel fuel. Emissions of nitrogen oxides ( $\text{NO}_x$ ), HC & PM are lower than diesel fuel.

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## NOMENCLATURE

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GDP	Gross Domestic Product
KGOE	Kilogram of Oil Equivalent
Btoe	Billion tonnes of oil equivalent
CO <sub>2</sub>	Carbon Dioxide
ppm	Parts per million
NOAA	National Oceanic and Atmospheric Administration
p.a.	per annum
UNFCCC	United Nations Framework Convention on Climate Change
GHGs	Greenhouse gases
N <sub>2</sub> O	Nitrous Oxide
O <sub>3</sub>	Ozone
CFCs	Chlorofluorocarbons
IC	Internal Combustion
CO	Carbon monoxide
NO <sub>x</sub>	Nitrogen oxides
PM	Particulate matter
UBHC	Un-burnt hydrocarbon
SCR	Selective catalytic reduction
CI	Compression Ignition
DI	Direct Injection
g	Gram
kwh	Kilowatt hour
° K	Degree Kelvin

atm	Atmospheric
psi	Pounds per square inch
° C	Degree Celsius
TDC	Top dead centre
rpm	Revolutions per minute
SVO	Straight vegetable oil
WVO	Waste vegetable oil
TDI	Turbocharged Direct Injection
DME	Dimethyl Ether
DEE	Diethyl Ether
ETBE	Ethyl Tertbutyl Ether
BHT	Butylatedhydroxytoluene
° F	Degree Fahrenheit
THC	Total hydrocarbon
EGR	Exhaust gas recirculation
DPF	Diesel particulate filter
DGM	Diethylene glycol dimethyl ether
DMM	Dimethoxy methane
MTBE	Methyl tertiary butyl ether
DBE	Di butyl ether
DMC	Di methyl carbonate
m/s	Meters per second
Btu/lb	British thermal unit/ pound
Gal	Gallon
SCF	Standard cubic foot

NREL	National Renewable Energy Laboratory
~	Nearly
LPG	Liquefied petroleum gas
HCCI	Homogeneous Charged Compression Ignition
F-T	Fischer-Tropsch
v/v	volume/volume ratio
CDM	Clean development mechanism
ASTM	American Society of Testing and Materials
KJ	Kilojoules
mm	Millimeters
bhp	Brake horsepower
KVA	Kilovolt ampere
AC	Alternating current
Min	Minutes
nm	Nanometer
D100	Neat diesel
L100	Linseed Biodiesel / Linseed Oil Methyl Ester (LOME)
E5 L95	5% Ethanol + 95% Linseed Biodiesel (v/v)
E10 L90	10% Ethanol + 90% Linseed Biodiesel (v/v)
E15 L85	15% Ethanol + 85% Linseed Biodiesel (v/v)
E20 L80	20% Ethanol + 80% Linseed Biodiesel (v/v)
Cst	Centistokes
BTE	Brake thermal efficiency
BSFC	Brake Specific Fuel Consumption

## 1.0 INTRODUCTION

Inventions are for the betterment of mankind and changed the way we look at the world. Many inventions have taken several centuries to develop into their modern forms. Each invention may be just one small step on the road to ultimate goal. Many people today take for granted the very means of travel available to them. From the wheel to the supersonic jet, humanity has made leaps and bounds in safer & faster transportation.

The wheel is probably the most important mechanical invention of all time. Nearly every machine built since the beginning of the Industrial Revolution involves a single, basic principle embodied in one of mankind's truly significant inventions. It's hard to imagine any mechanized system that would be possible without the wheel. Archaeologists believe that the very first step toward man-made transportation began in either Mesopotamia or Asia, sometime around 4000-3500 BC, with the invention of the wheel. The invention of the wheel would eventually make man's ability to transport his crops from one place to another less awkward, and birth the idea of trade and exchange. The invention of the wheel would lead to the development of mass transportation, as man put his new invention to practical uses.

The next logical evolutionary step from the wheel was the invention of the cart and chariot. The two-wheel chariot found its birthplace in Sumeria and is believed to be the world's first form of wheeled transportation. Built around 3500 BC, this chariot increased the speed of travel over land, and eventually led to the four-wheeled cart, which took the burden of carrying supplies and equipment off of the shoulders of the common man. Mass transit improved travel by land with the invention of Watt steam engine. In 1804, locomotives, which used steam to power a series of pistons, came into use. These locomotives were enough powerful. Over the next one hundred years, various improvements would be made to the locomotive, speeding up transit and attempting to make train travel safer. Then, during World War II, the diesel engine came into widespread use, and steam engine was almost completely forgotten. This is often considered as one of the most important milestones in development of the modern world. Subsequently, by the inputs and efforts of many engineers and scientists such as Carnot, Otto, Benz etc. more and more designs sprung up.



In the wake of current energy scenario, major research is focused on sustainable energy solution with major emphasis on energy efficiency and use of renewable energy sources. Diesel engines have proven their utility in the transportation and power sectors due to their higher efficiency and ruggedness. They are also potential sources of decentralized energy generation for small electrification plant. However, concerns about long-term availability of petroleum diesel and the stringent environmental norms have mandated the search for a renewable alternative to diesel fuel to address these problems. Liquid bio-origin fuels are renewable fuels coming from biological sources and have proved to be a good substitute for petroleum derived oil in transportation and small energy needs. These fuels are gaining worldwide acceptance as a solution for problem of environmental degradation, energy security, restricting import, rural employment and agricultural economy. A large variety of alternative fuels are considered potential substitute to petroleum based diesel, however, modification, handling and transportation, ease of production, and investment cost are some of the important parameters that should be considered before using an alternative fuel in an existing diesel engine. The modification required in the engine design need to be made in such a way so as to minimize the investment cost in the engine modification [1].

## **1.1 ENERGY CRISIS**

Energy plays an important role in development of any country. It is considered as an indicator of economic growth and social development. Per capita energy consumption is considered as a measure of prosperity of a country besides GDP and per capita income. The world has witnessed industrial revolution in the past century, but it has also faced serious problems of indiscriminate utilization of the energy resources. The general ideology has always been that high energy consumption is a must for fast pace industrial development and it never took into account the better and efficient use of energy. The US oil embargo and subsequent Gulf war were very crucial for both developed and developing countries. It was for the first time that petroleum importing nations faced the heat as the oil exporting countries pressed for higher prices. This energy crisis forced the world to look for alternative sources of energy. This also resulted in a change in the attitude towards efficient utilization of energy. The focus of country planners changed to 'More efficiency, more productivity and reduced production cost'. This resulted in immediate, long term and multi-faceted solutions to the problems emerging from increased energy demands against short supplies. Energy conservation and management has since

become the buzz word in industrial circles and 'energy' is considered as a major component in the production cost.

Above positive mind-set has changed the energy use pattern all over the world. Developed countries have increased their productivity while maintaining the same energy consumption levels. The world is moving towards a sustainable energy era with major emphasis on energy efficiency and use of renewable energy sources. The renewable sources of energy are very important and relevant to today's world. They cause lesser emissions and are available locally. Their use can, to a large extent, reduce chemical, radioactive, and thermal pollution. They stand out as a viable source of clean and limitless energy.

## **1.2 ENERGY SCENARIO IN INDIA**

Although India is rich in coal and abundantly endowed with renewable energy in the form of solar, wind, hydro and bio-energy, its oil reserve is 0.8 billion tonnes which is really very small (0.3 per cent of world's reserve). India primary energy consumption is 563.5 mtoe. India accounted for 11.29 % of total primary energy consumption in Asia-Pacific region and 4.5 % of world primary consumption in 2012 [2]. Per capita energy consumption remains low as 565.64 KGOE (Kilogram of oil equivalent) compared with a world average of 1,851 KGOE in 2010 [3].

India extensively uses its energy resources to sustain the high rate of growth and achieve the targets it has set. Since India does not have huge reserves of petroleum products, it is heavily dependent upon the import of petroleum products to cater to its need for automobiles and other applications despite larger initiatives by government and exploration of new sources. Escalating prices, insufficient supply and limited reserves of petroleum have imposed an enormous burden on country's foreign exchange. In year 2011-12, the indigenous production of crude oil was 38.09 million metric tonnes (MMT) whereas consumption was 211.42 million tonnes forcing to import 172.11 MMT. India spented Rs. Billion 6690.68 worth valuable foreign exchange towards import of crude petroleum which could otherwise be utilized for various other development works, that might ultimately prove to be more beneficial to India [4]. To improve the present energy scenario, future energy conversion in India should be sustainable which includes increased share of renewable fuels, increased efficiency of fuel conversion and reduced environmental impact. In this regard, the subsidy on traditional fossil fuels must be reduced in a phased

manner and efforts must be put to develop and promote the use of renewable sources of energy to meet the energy requirements.

### 1.3 RENEWABLE ENERGY SOURCES

India has high potential for generation of renewable energy from various sources- wind, solar, biomass, small hydro and cogeneration bagasse. The total potential for renewable power generation is estimated at 89774 MW. This includes wind power potential of 49130 MW (54.73%), small hydro power potential of 15399 MW (17.15%), biomass power potential of 17538 MW (19.54%) and 5000 MW (5.57%) from bagasse-based cogeneration in sugar mills [6].

**Table 1.1 Renewable Energy in India as on 31.12.2012 [5]**

<b>S. No.</b>	<b>Sources</b>	<b>Installable Potential</b>	<b>Installed Capacity</b>
1	Wind Power	49130 MW	18550 MW
2	Biomass	17000 MW	-
3	Small Hydro	19749 MW	3496 MW
4	Solar PV	-	130 MW
5	Aero-generators & wind-solar hybrid system	-	2091 kW

India's renewable energy installed capacity has grown from 3.9 GW in 2002-03 to about 27.3 GW in January 2013. Wind energy has been the predominant contributor to this growth. It also accounts for 68% of the installed capacity, followed by small hydro power (3.55 GW), biomass power (3.56 GW) and solar power (1.4 GW).

### 1.4 THE FUTURE OUTLOOK

The global primary energy demand is projected to increase by 1.6% per year between 2010 and 2030, reaching 17.1 billion tonnes of oil equivalent (Btoe) as shown in Table 1.2.

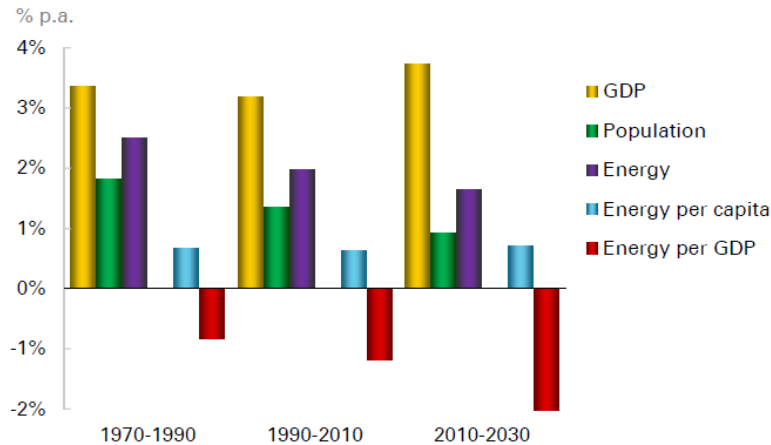
Fossil fuels are projected to remain the dominant sources of primary energy globally. They will account for close to 83% of the overall increase in energy demand between 2010 and 2030. Oil will remain the single largest fuel in the primary fuel mix in

2030, though its share will drop, from 35% now to 33%. The renewable energy technologies, including bio-fuels, wind, solar, geothermal, wave and tidal energy, will see the fastest increase in demand, but their share of total energy use will still reach only 18% in 2035- up from 13% in 2010 [8].

**Table 1.2 World Primary Energy Demand (Btoe) [7]**

<b>Year</b>	<b>1980</b>	<b>2010</b>	<b>2015</b>	<b>2030</b>	<b>2010-2030</b>
<b>Coal</b>	1785	3354	3666	4441	1.8%
<b>Oil</b>	3107	4366	4750	5575	1.3%
<b>Gas</b>	1237	2686	3017	3869	2.0%
<b>Nuclear</b>	186	775	810	861	0.7%
<b>Hydro</b>	148	280	317	408	2.0%
<b>Biomass &amp; waste</b>	765	1283	1375	1645	1.3%
<b>Other Renewable</b>	33	99	136	296	6.6%
<b>Total</b>	<b>7261</b>	<b>12842</b>	<b>14071</b>	<b>17095</b>	<b>1.6%</b>

Primary energy consumption growth to 2030 decelerates to 1.6% p.a. (compared to 2.0% p.a. the last 20 years); energy consumption per capita grows at 0.7% p.a., about the same rate as it since 1970 [7].



**Fig. 1.1 Global Growth Rate [7]**

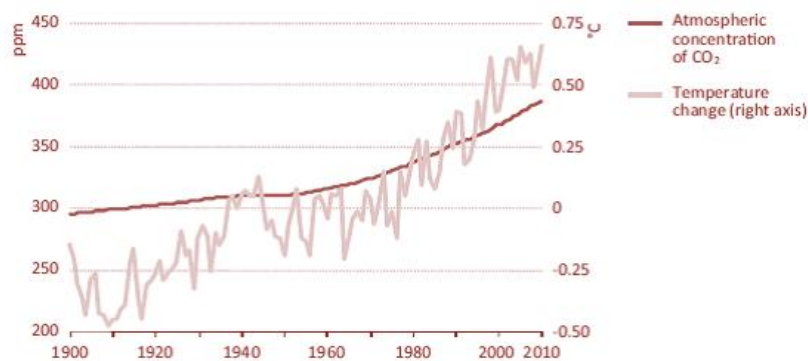
## 1.5 GLOBAL ENVIRONMENTAL DEGRADATION

The indiscriminate and inefficient energy utilization has also resulted in environmental degradation which needs to be adequately studied. The process of energy generation, transport and utilization leads to air pollutants. In-efficient use of energy has

stretched the global environment to its limits as can be seen from the unprecedented and unpleasant responses of the nature in the past few years. Green house effect, global warming, acid rain, smog, deforestation, shift in climatic conditions etc. are some of the indications. Increase in the CO<sub>2</sub> concentration is shown in Fig.1.2 which clearly represents that most of the CO<sub>2</sub> rise has taken place in post industrial revolution era. The curve of CO<sub>2</sub> concentration has been climbing exponentially (except in the mid 1990s when the economy of Eastern Europe and the Soviet Union collapsed).

Scientists at the Mauna Loa observatory in Hawaii say that CO<sub>2</sub> levels in the atmosphere now stand at 400 parts per million (ppm), up almost 41% since the industrial revolution and the highest for at least the last 650,000 years [8]. The figures, published by the US National Oceanic and Atmospheric Administration (NOAA) also confirm that carbon dioxide, the chief greenhouse gas, is accumulating in the atmosphere faster than expected. The annual mean growth rate for 2007 was 2.14ppm – the fourth year in the past six to see an annual rise greater than 2ppm. From 1970 to 2000, the concentration rose by about 1.5ppm each year, but since 2000 the annual rise has leapt to an average 2.1ppm. [1].

The growth of global CO<sub>2</sub> emissions from energy averages 1.2% p.a. for the period 2010-2030 as compared to 1.9% p.a. from 1990-2010 leaving emissions in 2030 higher by 27% than today [5].

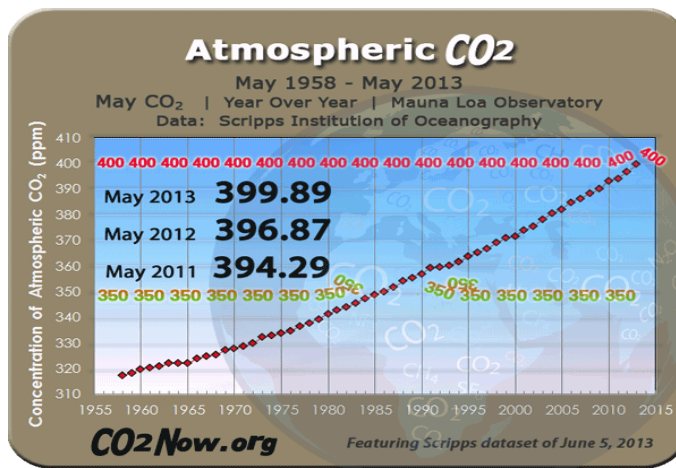


**Fig. 1.2 World atmospheric concentration of CO<sub>2</sub> & Average global temperature change [11]**

Global greenhouse-gas emissions continue to increase at a rapid pace. The 450 ppm threshold is drawing ever closer (Fig 1.3). CO<sub>2</sub> level in the atmosphere reached 400 ppm in May 2013, having jumped by 2.7 ppm in 2012- the second-highest rise. Average global temperatures have already increased by around 0.8 °C, compared with pre-industrial level.

## 1.6 CO<sub>2</sub> EMISSION OUTLOOK

Global energy-related carbon-dioxide (CO<sub>2</sub>) emissions are expected to increase by 1.2 % per year over 2010-2030 [5]. It shall reach 40.4 billion tonnes in 2030, an increase of 14.3 billion tonnes, over the 2010 level as shown in Table 1.2. In 2010, emissions were 48% higher than in 1990. However, the aggregate increase is much smaller for Annex I countries with commitments to limit emissions under the Kyoto Protocol. Power generation is projected to contribute a little less than half the increase in global emissions from 2010 to 2030.



**Fig. 1.3 Atmospheric CO<sub>2</sub> Concentration [12]**

Transport contributes one-fifth, with other uses accounting for the rest. Transport remains the second-largest sector for emissions worldwide, with its share of total emissions stable at around 20% throughout the projection period.

**Table 1.3 increase in CO<sub>2</sub> concentration due to different sources [5]**

	1990	2010	2015	2030	2010-2030
<b>Power Generation</b>	6 955	12 818	14 209	17 680	2.0%
<b>Industry</b>	4 474	5 679	6 213	7 255	1.6%
<b>Transport</b>	3 885	5 900	6 543	8 246	1.7%
<b>Residential and services</b>	3 353	3 573	3 815	4 298	1.0%
<b>Other</b>	1 796	2 396	2 552	2 942	1.2%
<b>Total</b>	<b>20 463</b>	<b>30 367</b>	<b>33 333</b>	<b>40 420</b>	<b>1.7%</b>

## **1.7 CLIMATE CHANGE**

Climate is referred to as the prevalent long-term weather conditions in a particular area. Climatic elements include precipitation, temperature, humidity, sunshine and wind velocity phenomena such as fog, frost, and hail storms. Thus, climate change can be defined as any change in climate over time, whether due to natural variability or human activity. The Reports by the United Nations Framework Convention on Climate Change (UNFCCC) define it as “a change of climate as attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods”. Climate change is caused by increases in the atmospheric concentration of so-called greenhouse gases (GHGs). The build-up of GHGs is rapidly changing how the atmosphere absorbs and retains energy. These GHGs include: carbon dioxide (CO<sub>2</sub>) (from burning fossil fuels), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O) (created by agriculture, land use and changes in land use where these gases are emitted), ozone (O<sub>3</sub>) (generated mostly by fumes from car exhausts) and chlorofluorocarbons (CFCs). The increase of these GHGs in the atmosphere further prevents infrared radiation escaping from the earth’s atmosphere into space, causing what is called ‘global warming’. This acceleration of global warming by humans is referred to as the enhanced greenhouse effect or anthropogenic climate change [9]. Mitigation and adaptation to climate change are the two main pillars of climate change policy. Both pose significant analytical and policy challenges, and thus their respective discussions have evolved at different paces. On the one hand, mitigation of climate change refers to: “The stabilization of greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system which would enhance global warming. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, so as to ensure that food production is not threatened whilst at the same time enabling economic development to proceed in a sustainable manner”.

## **1.8 EFFECT OF GLOBAL WARMING**

It is generally difficult to attribute specific natural phenomena to long-term causes, but some effects of recent climate change may already be occurring. 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.

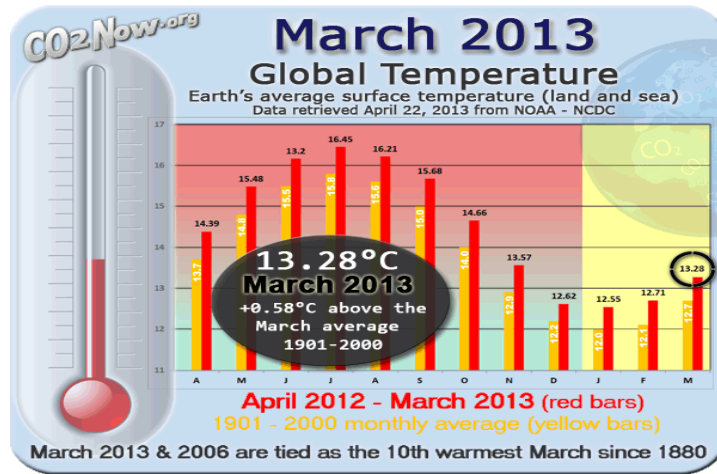


Fig. 1.4 Global Temperature variation [12]

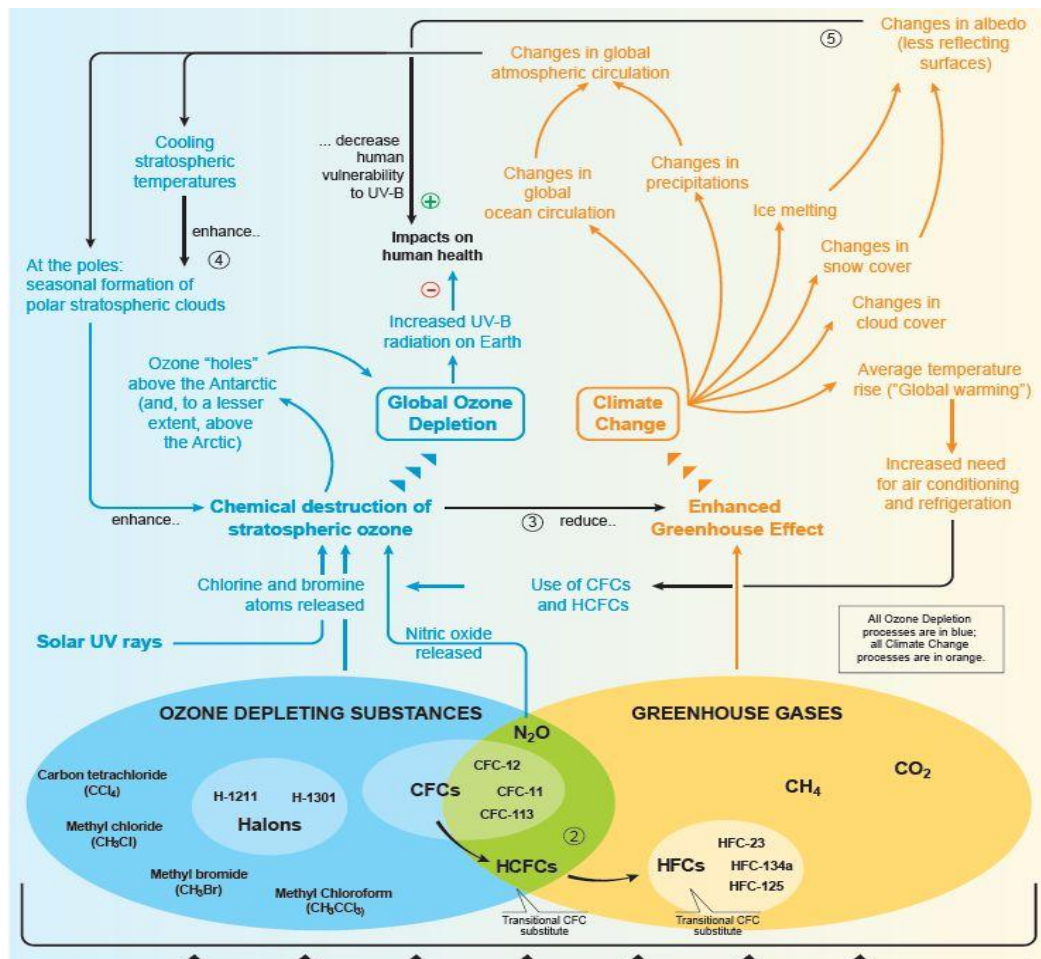


Fig. 1.5 Effects of Greenhouse Gases



## **1.9 GREEN HOUSE GAS EMISSION AROUND THE WORLD**

Globally, 2.57% increase in carbon dioxide emissions was experienced during the period 2004-2010. China was the major contributor to the increase in CO<sub>2</sub> emissions. As of 2009, China's CO<sub>2</sub> emissions were estimated to be about 5.7% higher than those from the USA. With this, China tops emissions globally whereas CO<sub>2</sub> emissions per person (in metric tonnes) are as follows: USA (16.9), Russia (10.8), UK (7.5), China (5.13) and India (1.37). In USA, CO<sub>2</sub> emissions increased by 1.8% in 2007, as compared to 2006. The list of CO<sub>2</sub> emitting countries, having about a quarter shares in global CO<sub>2</sub> emissions (24%), includes the USA (21%), the EU-15 (12%), India (8%) and the Russian Federation (6%). Together, they comprise 71% of the total global CO<sub>2</sub> emission [10].

## **1.10 KYOTO PROTOCOL**

The Kyoto Protocol was a response to a worldwide acknowledgment of greenhouse gas emissions and their effects on global warming. The protocol is a well-known international accord that sets limits on the amount of greenhouse gases that industrialized countries produce. Hence the name, the Kyoto protocol was adopted in Kyoto, Japan, in December 1997. It also supplements the United Nations framework Convention on Climate Change that was adopted in 1992.

India is a signatory to Kyoto Protocol and committed to adopt recommendation of this protocol. Government of India is looking for renewable, bio-origin fuel produced from locally available resources since these fuels can reduce the atmospheric CO<sub>2</sub> which shall ultimately help to clean the environment.

## **1.11 MONTREAL PROTOCOL**

The Montreal Protocol was adopted in Montreal, Quebec, Canada. Signed by 150-plus countries, this international agreement was created to limit the output of substances such as chlorofluorocarbons and others that damage the stratospheric ozone layer.

## **1.12 EMISSIONS OF COMBUSTION**

The operation of IC engines results in the emission of hydrocarbons (UBHC), carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), and particulate matter (PM). The actual concentration of these pollutants varies from engine to engine, mode of operation, and is strongly related to the type of fuel used. Various emission control technologies exist for IC

engines which can afford substantial reductions in all four criteria pollutants listed above. However, depending on whether the engine is being run rich, lean, or stoichiometrically and the emission control technology used, the targeted emissions vary as do the levels of control. For example, an oxidation catalyst can be used to control UBHC, CO, and PM emissions from diesel engines which inherently operate in a lean environment, whereas selective catalytic reduction (SCR) could be used to additionally control NO<sub>x</sub> emissions. More recently, lean-NO<sub>x</sub> catalysts have been demonstrated to provide greater than an 80 percent reduction in NO<sub>x</sub> emissions from a stationary diesel engine, while providing significant CO, UBHC, and PM control as well. PM emissions from stationary diesel engines are more of a concern than those engines using other fuels. Several emission control technologies exist for diesel engine PM control. Oxidation or lean-NO<sub>x</sub> catalyst can be used not only to reduce the gaseous emissions associated with the use of diesel engines but further provide significant PM control. Likewise, diesel particulate filter systems can be used to achieve up to and greater than 90 percent PM control while in some instances, also providing reductions in the gaseous emissions.

### 1.12.1 Oxides of Nitrogen (NO<sub>x</sub>)

NO<sub>x</sub> refers to NO and NO<sub>2</sub>. They are produced during combustion, especially at high temperature. NO<sub>x</sub> is generally formed when the flame temperature is greater than 1500 K and oxygen is also available in the combustion zone.



NO formed in the flame zone can be rapidly converted to NO<sub>2</sub> via reactions such as,



Subsequently NO<sub>2</sub> is converted to NO



### **1.12.2 Carbon Monoxide (CO)**

CO, also called carbonic oxide, is a colourless, odourless and tasteless gas which is lighter than air. It is highly toxic to humans and animals in higher quantities. It is a product of incomplete combustion generally formed due to deficiency of oxygen in the intake mixture. CO oxidises and converts to CO<sub>2</sub>.

### **1.12.3 Hydrocarbon (HC)**

Hydrocarbon emission is due to unburned or partially burned fuel and is a major contributor to urban smog, as well as being toxic. Following are the reasons for HC emissions in CI engine:

- The heterogeneous mixture is too rich to ignite or sustain the flame.
- The heterogeneous mixture is too lean to ignite or sustain combustion.

### **1.12.4 Particulate Matter (PM)**

Diesel particulates consist principally of combustion generated carbonaceous material (soot) on which some organic compounds has become absorbed. Most PM results from incomplete combustion of fuel and some are contributed by lubricating oil.

### **1.12.5 Soot**

The formation of soot particles is primarily due to the carbon in the diesel fuel. The formation process starts with a fuel molecule containing 12 to 22 carbon atoms and an H/C ratio of about 2, and ends up with particles typically a few hundred nanometers in diameter composed of spherules 20 to 30 nm in diameter each containing some 10<sup>5</sup> carbon atoms. It is most prominent at combustion chamber temperatures between 1000 and 2800 K, at pressures of 50 to 100 atm. It is characterised by conditions of insufficient air available for the fuel to burn completely.

## **1.13 ROLE OF DIESEL ENGINE IN INDIAN ECONOMY**

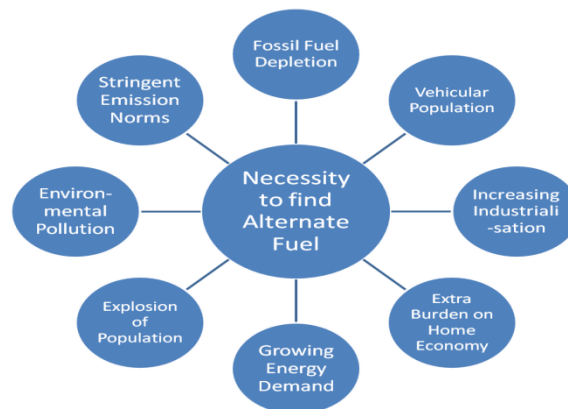
Diesel Engine plays a very important role in Indian economy and also contributes to pollution significantly. These engines is used in heavy trucks, city transport buses, locomotives, electric generators, farm equipment, underground mine equipment etc [11, 12]. The dual problem of fast depletion of petroleum based fuels and air pollution can be handled by switching from fossil fuel based economy to renewable source of energy. Our country is

an 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 sources which are used in agriculture sector. Because of mechanized farming the amount of energy consumed has increased multi times since independence in terms of oil and electricity.

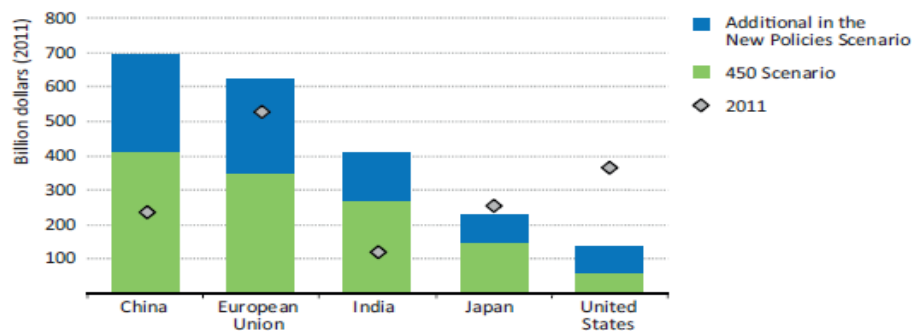
### 1.14 NECESSITY OF ALTERNATIVE FUEL

It is clear from the above discussions that India is facing the twin problems of fast depletion of fossil fuels and environmental degradation. There is an urgent need to reduce dependence on petroleum derived fuels for better economy and environment.



**Fig. 1.6 Necessity for Alternate Fuel**

Adaptation of bio-origin alternative fuels can address both these issues. These fuels are essentially non-petroleum and result in energy security and environmental benefits. These fuels are available either in one form or other for more than one hundred years. Before the introduction of gasoline as a motor fuel in the late 1800s, vehicles were often powered by what are now considered alternative fuels. The first internal combustion engine designed, built, and demonstrated by Rudolf Diesel at the 1900 Paris World's Fair ran on peanut oil. This was the product of his dream-an efficient internal combustion engine, powered by crude oil or even vegetable oil.



**Fig. 1.7 Fossil fuel import bill by 2035 [11]**

In 2035, the five-largest fossil-fuel importers spend \$850 billion less in the 450 Scenario than in the New Policies Scenario. In 2035, China oil imports are 3.6 million barrels per day (mb/d) lower while imports into the India are 1 mb/d lower [11].

Identification of alternative fuels for use in I.C. Engines has been subjected to studies throughout the globe. Performance tests have shown suitability of variety of alternative fuels such as hydrogen, alcohols, biogas, producer gas and various types of edible and non edible oils. However, in Indian context, the bio-origin fuels like alcohols, vegetable oils, and biogas can contribute significantly towards the problems related to fuel crises.

### 1.15 BIO-FUELS

Bio-fuels are renewable liquid fuels coming from biological raw material and have been proved to be good substitutes for oil in the transportation and agriculture sector. Bio-fuels are gaining worldwide acceptance as a solution for problems of environmental degradation, energy security, restricting imports, rural employment and agricultural economy. The most promising bio-fuel, and closest to being competitive in current markets without subsidy, are ethanol, methanol, vegetable oils and biodiesel. India has 294 thousand tonnes oil equivalent of biofuels production which is 0.5% share of world biofuels production [2].

Ethanol is used as fuel or as oxygenate to gasoline. Raw material used for producing ethanol varies from sugar in Brazil, cereals in USA, sugar beet in Europe to molasses in India. Use of 5% ethanol-gasoline blend is already approved by BIS and is dispensed in some Indian states.

Methanol could conceivably be made from grain, but its most common source is natural gas.

Biodiesel is derivative of vegetable oils. Biodiesel is made from virgin or used vegetable oils (both edible & non-edible) and animal fats through a chemical process named transesterification. Biodiesel can be blended in any ratio with petroleum diesel fuel. Its higher Cetane number improves the combustion even when blended in the petroleum diesel. It can also be used as an additive to achieve the following objectives:

1. To reduce the overall sulfur content of blend,
2. To compensate for lubricity loss due to sulfur removal from diesel fuel,
3. To enhance the Cetane number of diesel fuel.

Emissions of CO<sub>2</sub>, which translate into a greenhouse effect, are a feature of most fuels. If biomass energy is used instead of fossil fuels, however, there is normally a net reduction in CO<sub>2</sub> emissions. SO<sub>2</sub> emissions from using biomass energy tend to be considerably lower because relevant plants and trees contain only trace quantities of sulphur compared to much higher emissions from coal, gasoline, and even some natural gas.

#### **1.15.1 IMPORTANCE OF BIO FUEL:**

Bio-fuel is the most valuable form of renewable energy that can be used directly in any existing, unmodified diesel engine.

**I. Energy Independence:** Considering that oil priced at \$ 107 per barrel has had a disproportionate impact on the poorest countries; the question of trying to achieve greater energy independence one day through the development of bio-fuels has become one of 'when' rather than 'if,' and, now on a near daily basis, a bio-fuels program is being launched somewhere in the developing world [13].

**II. Smaller Trade Deficit:** Own living resources could be used to power our development and enhance our economies rather than importing other countries ancient natural resources. The world could look to the tropics for bio-fuels instead of looking to the Middle-east for oil. producing more bio-fuels will save foreign exchange and reduce energy expenditures and allow developing countries to put more of their resources into health, education and other services for their neediest citizens.

**III. Economic Growth:** Bio-fuels create new markets for agricultural products and stimulate rural development because bio-fuels are generated from crops; they hold enormous potential for farmers. Bio-fuels have enormous potential to improve former's situation for the better.

At the community level, farmers that produce dedicated energy crops can grow their incomes and grow their own supply of affordable and reliable energy. At the national level, producing more bio-fuels will generate new industries, new technologies, new jobs and new markets.

**IV. Cleaner Air:** Bio-fuels burn more cleanly than gasoline and diesel. Using biofuels means producing fewer emissions of carbon monoxide, particulates, and toxic chemicals that cause smog, aggravate respiratory and heart disease, and contribute to thousands of premature deaths each year.

**V. Less Global Warming:** Bio-fuels contain carbon that was taken out of the atmosphere by plants and trees as they grew. The Fossil fuels are adding huge amounts of stored carbon dioxide (CO<sub>2</sub>) to the atmosphere, where it traps the Earth's heat like a heavy blanket and causes the world to warm. Studies show that bio-diesel reduces CO<sub>2</sub> emissions to a considerable extent and in some cases all most nearly to zero.

### **1.15.2 BIOFUEL POLICY**

The national biofuel policy, aimed at facilitating development of indigenous biomass feedstock for production of biofuels, has been cleared by the Cabinet. The draft of the policy was prepared by the ministry of new and renewable energy (MNRE), the coordinating ministry for biofuel development. Setting up of a National Biofuel Coordination Committee to provide policy guidance has also been approved. It is to be headed by the prime minister. A Bio-fuel Steering Committee chaired by the cabinet secretary will also be set up to oversee the implementation of the policy.

Promotion of bio-fuels could meet India's energy needs in an environmentally-sustainable manner, while reducing its import dependence on fossil fuels. The policy has proposed an indicative target of 20 per cent blending of bio-fuels both biodiesel and bio-ethanol by 2017. The government had already made 10 per cent ethanol blending with petrol. The bio-fuel policy has also proposed financial incentives including subsidies and grants for second generation bio-fuels like cellulosic ethanol and algal biodiesel. The policy also mentions that a minimum support price (MSP) for non-edible oilseeds would be announced with periodic revision to provide fair price to the growers. A minimum purchase price (MPP) for purchase of bio-ethanol and biodiesel would also be announced with periodic revision.

The greatest barrier to large-scale commercialization of bio-fuels is their relatively high cost of production. Because they are used primarily to replace gasoline or diesel, world petroleum product prices drive commercial viability of bio-fuels to a large extent. Bio-fuels are derived from renewable bio-mass resources and help promote sustainable development. Besides supplementing conventional energy sources in meeting the rapidly increasing requirements for transportation fuels associated with high economic growth, as well as in meeting the energy needs of India's vast rural population.

### **1.16 VEGETABLE OIL & BIODIESEL**

Diesel engines are the most efficient prime movers and 70% of I C engine used diesel in India [13]. So it becomes necessary to develop alternative fuels with properties comparable to petroleum based fuels. Now bio-fuels are getting a renewed attention because of global stress on reduction of green house gases and clean development mechanism. Alternative fuels should be easily available at low cost, locally (maximum crude oil imported), be environment friendly and fulfill energy needs without sacrificing engine's performance. For the developing countries, bio-origin fuels provide a feasible solution to the twin crises of fossil fuel depletion and environmental degradation. For diesel engines, a significant research effort has been directed towards using vegetable oils. Vegetable oils have comparable calorific value, kinetic viscosity, density, Cetane number, flash point, and heat of vaporization with mineral diesel. In addition, they are biodegradable, non-toxic, and have a potential to significantly reduce pollution. Vegetable oils and their derivatives in diesel engines lead to substantial reductions in emissions of sulfur oxides, carbon monoxide (CO), poly-aromatic hydrocarbons (PAH), smoke, particulate matter (PM) and noise. Furthermore, contribution of bio-fuels to greenhouse effect is insignificant, since carbon dioxide (CO<sub>2</sub>) emitted during combustion is recycled in the photosynthesis process in the plants so bio-fuel is a renewable source of energy [16].

Vegetable oil comes in very many shapes and sizes, with varying properties. The most important consideration is melting point. The actual vegetable oil molecule is composed of three long carbon chains on a glycerol 'backbone' and its properties are determined by the individual 'fatty acid' chains. Rapeseed oil, for example, may be composed of different combinations of about 6 different fatty acids and each one of these creates a unique molecule, with unique properties. Some waste oil contains 'free fatty acid', which is a result of water in fried food reacting with the triglyceride to split it up into its four components. Waste oil also



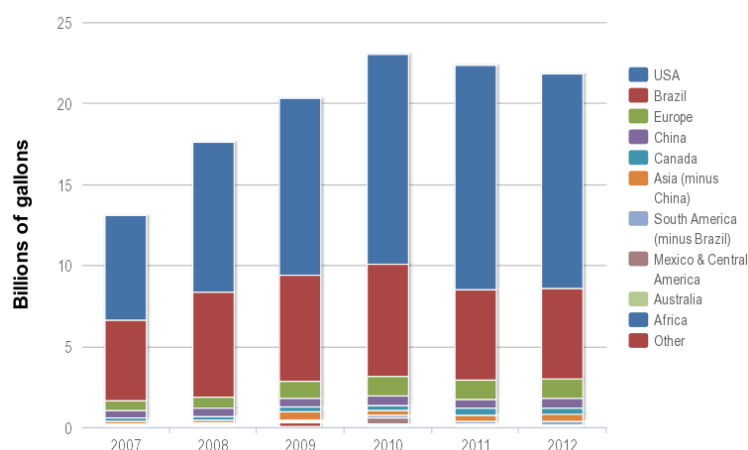
contains varying amounts of animal and fish oils which may be solid at room temperature in their natural state.

The problem of substituting vegetable oil for diesel engine as a fuel is mostly associated with high viscosity, low volatility and polyunsaturated characters. These can be changed at least four different ways: Pyrolysis, Microemulsion, Dilution and Transesterification. Biodiesel can be prepared by transesterification. The purpose of transesterification process is to reduce the viscosity of oil.

### 1.17 ALCOHOLS

Alcohol is an organic compound in which the hydroxyl functional group (-OH) is bound to a carbon atom. In particular, this carbon center should be saturated, having single bonds to three other atoms. Alcohols can be classified into Simple/Lower Alcohols & Higher Alcohols. Lower alcohols are short chain alcohols having alkyl chains of 1-3 carbons e.g. methyl alcohol, ethyl alcohol etc. Higher alcohols are those containing 4-10 carbon atoms. They are viscous or oily and have heavier fruity odours e.g. butanol.

Ethanol is a renewable fuel made from various plant materials collectively known as biomass. Ethanol ( $\text{CH}_3\text{-CH}_2\text{-OH}$ ) also known as ethyl alcohol is a clear, colorless liquid. Ethanol is produced from starch and sugar based feedstocks, such as corn grain, sugar cane, or from cellulosic feed stocks. The  $\text{CO}_2$  released when ethanol is burned is balanced by the  $\text{CO}_2$  captured when the crops are grown to make ethanol.



**Fig. 1.8 Global Ethanol Production**

The current fuel quality standard for gasoline allows blending up to 5% ethanol by volume. Higher blends of ethanol are applied in Brazil (20-30% ethanol). E85, a blend of

85% ethanol by volume in gasoline, is rather successful in Scandinavia. Due to relative shortage of fossil diesel and relative surplus of gasoline on the European market, the option to apply ethanol on the Diesel market is gaining growing interest [15].

### **1.18 CURRENT SITUATION DUE TO PETROL PRICE HIKE**

Due to petrol price hike environmentalists continue to be a worried bunch and their fears are not unfounded, for petrol getting out of reach for many people means there will be more diesel vehicles on the road in the years to come. This will have an adverse impact on the environment as diesel engine emissions are over three times more toxic than petrol. This has been collated by Centre for Science and Environment's analysis of the 2011-12 car sales data, which revealed that the demand for diesel run SUVs has gone up. Also, 85% of petrol cars sold during the period had engine sizes smaller than 1200 cc.[16]. WHO and many other public health organizations have already informed that diesel emissions are carcinogenic. There is a really high public health risk. People are buying big diesel cars, of engine size above 1500cc because diesel is cheap. The subsidy on diesel is absolutely unacceptable. As of now 13 cities in the country comply with Bharat stage IV norms and the rest follow Bharat stage III norms.

The pollutants that are of major concern are particulate matter and nitrous oxide (NO<sub>2</sub>). Diesel cars are legally allowed to emit these pollutants more than petrol. In fact the legal limit NO<sub>2</sub> for diesel cars is three times higher than for petrol cars. But the fact that diesel is more fuel efficient and gives better mileage masks the down side of increase in diesel cars. Diesel contains more energy than petrol and the vehicle's engine combustion process is more efficient, adding up to higher fuel efficiency and lower CO<sub>2</sub> emissions when using diesel. But the pollutants emitted from diesel and petrol is characteristically different. While petrol emits more carbon monoxide (CO) and hydrocarbons (HC), diesel emits more smoke and particulate matter that have worse health impacts [14].

### **1.19 PRESENT WORK**

In context to present work, an experimental analysis on the performance and emission characteristics of the unmodified single cylinder diesel engine was made by fuelling blends of Ethanol and Linseed-Biodiesel in varying proportions, and comparing the same with baseline diesel data. Oil seed crops can provide a fuel grade product using relatively simple extraction

and processing technology which could be performed on individual farms. Vegetable oils are promising fuels, particularly for diesel engines.

Due to high viscosity of Linseed oil it can be transesterified. Biofuels such as ethanol and biodiesel, have been explored to reduce fuel consumption and engine emissions. Blending ethanol into biodiesel appears as an alternative that present a number of potential advantages such as the substitution of imported oil by domestic and renewable resources.

**2.0 INTRODUCTION**

As per previous chapter, rapidly increasing prices, uncertainties of petroleum availability and concern about environment has forced technologists and scientists to work for alternative fuel sources. Biodiesel is a promising alternative because it has several advantages. It is renewable, environmental-friendly, biodegradable and produced easily in rural areas. There are more than 450 species of vegetable oil which can be used for biodiesel production. Among them the use of non-edible vegetable oils compared to edible oils is more significant because of the issue of food security. The idea of using vegetable oils as fuel for diesel engines is not radically new. Rudolph diesel used peanut oil to fuel one of his engines at the Paris Exposition in 1900. In recent years systematic efforts have been made by several researchers to use biodiesel as fuel in diesel engines. Due to increase in number of vehicle on the road, the shortage of oil in near future will drastically become bigger and increase the main source of emissions that are responsible to urban air pollution. Harmful emissions like nitrogen oxide and particulate matters from the diesel engines are detrimental to the environment as well as to the human being.

Alternative fuels like biodiesel, ethanol etc. are getting importance due to their renewable nature and performance and emission characteristics. Biofuels being renewable, can supplement fossil fuels.

To meet the environmental regulation norms for exhaust gas emissions from diesel engine, exhaust gas after-treatment has become a necessity in most industrialised countries. Major challenge for diesel engine is to reduce  $\text{NO}_x$  and smoke emissions, since HC and CO emissions in the exhaust gas from diesel engine are relatively less than petrol engine. There exist many techniques that are capable of improving the combustion processes of diesel engines, such as fuel injection retarding, exhaust gas recirculation (EGR), high pressure injection and supercharging. However, due to trade-off between the  $\text{NO}_x$  and PM emissions, it is very difficult to have simultaneous reductions of both.

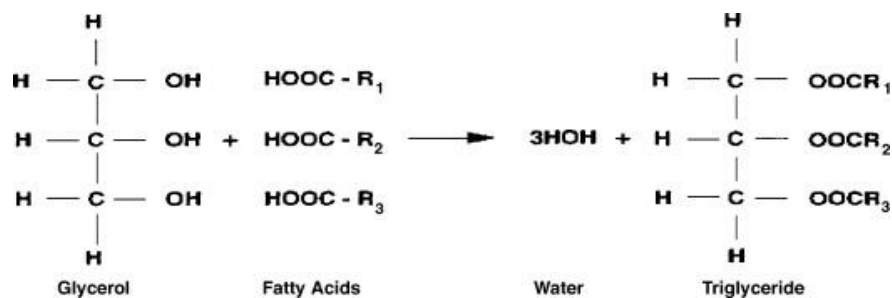
Diesel vehicles employ two types of technical strategies to meet Euro IV (Bharat Stage IV) emission standards:

- (i) Reduce NO<sub>x</sub> by EGR and PM by diesel particulate filter (DPF)
- (ii) Control PM by high pressure injection and reduce NO<sub>x</sub> by selective catalytic reduction (SCR)

## 2.1 BIODIESEL AS A POTENTIAL C. I. ENGINE FUEL

Biodiesels are methyl and ethyl esters of vegetable oils. The characteristics of biodiesel fall within a fairly a narrow band and are closer to those of Diesel Oil. The Kinematic viscosity of vegetable oils varies in the range of 30-40 cst at 38°C. High viscosity of these oils is due to larger molecular mass and chemical structure. Vegetable oils have high molecular weights in the range of 600-900, which are three or more times higher than diesel fuel. The flash point of vegetable oils are very high (above 200° C). The heating value of these oils are of the range of 39-40 MJ/Kg which are low compared to diesel fuels (about 45 MJ/Kg). The presence of chemically bond oxygen in vegetable oils lower the heating value by about 10%. The Cetane number is in the range of 45 to 55. The iodine value ranges from 0 to 200 depending upon un- saturation. The cloud and pour point of vegetable oils are higher than diesel fuel [61].

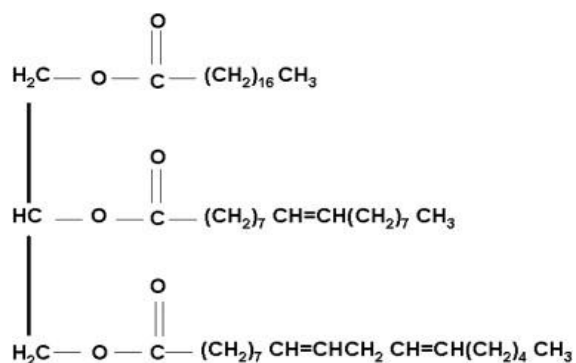
Petroleum based diesel fuels have different chemical structure than vegetable oil. The former contain only carbon and hydrogen atoms which are arranged in normal (straight chain) or branched chain structures as well as aromatic configurations. The normal structure is preferred for better ignition quality. Diesel fuel can contain both saturated and straight or unbranched chain unsaturated hydrocarbons, but the later are not present in large amounts to make oxidation a problem [60]. Vegetable oils consist of triglycerides to about 97%, the other 3% distribute among di and mono glycerides and further more 3 fatty acids and the fat accompanying which are mostly removed with refining. Structurally, a triglyceride is a reaction product of one molecule of glycerol with three fatty acid molecules to yield three molecules of water and one molecule of triglyceride [36].



**Fig.2.1 Chemical Structure of Vegetable Oils**

Where R<sub>1</sub>, R<sub>2</sub> and R<sub>3</sub> are the alkyl groups of different carbon chain lengths (varying between 12-18), and -COO- is an carboxyl group [61].

The large size of the vegetable oil molecules and the presence of oxygen in the molecules suggest that some fuel properties of the vegetable oils would differ markedly from those of hydrocarbon fuels [60].



**Fig. 2.2 Structure of a Typical Triglyceride Molecule**

Oil can be extracted from a variety of plants and oilseeds. Under Indian condition only such plant sources can be considered which is essentially non edible oil and available in appreciable quantity and can also be grown on large-scale on wastelands. Moreover, some plants and seeds in India have tremendous medicinal value, considering these plants for biodiesel production may not be a viable and wise option. Considering all the above options, probable biodiesel yielding trees or crops in India are:

- *Linum Usitatissimum* or Linseed
- *Jatropha curcas* or Ratanjot
- *Pongamia pinnata* or Karanj
- *Calophyllum inophyllum* or Nagchampa
- *Hevea brasiliensis* or Rubber seeds
- *Calotropis gigantia* or Ark
- *Euphorbia tirucalli* or Sher
- *Boswellia ovalifololata*

Advantages of the vegetable oils as engine fuels lie in their renewable nature and wide availability from the variety of sources. This is particularly attractive to countries lacking sources of liquid fossil fuels. They can also be produced on small scale, for on-farm operation to run tractors, pumps and small engines for power generation. There is a potential for a lower contribution, on combustion, to the atmospheric concentration of “Green house gas”

carbon dioxide, than from the fixed carbon in fossil fuels.

Some of the properties of diesel and test methods required by ASTM are summarized in table 2.1.

**Table 2.1: Tests and Limits for Fuel Properties [60]**

Test	ASTM Test	ASTM limits
Kinematic Viscosity, mm <sup>2</sup> /s	D445	1.9-4.1
Distillation Temperature, °C	D86	282-338 @ 90% pt.
Cloud Point, °C	D2500	
Pour Point, °C	D97	4.4-5.5 °C
Flash Point, °C	D93	52 °C min
Water & Sediment, Vol %	D1796	0.05% max
Carbon Residue @ 10% residue	D524	0.35% max
Ash by Weight, %	D482	0.01% max
Sulphur by Weight, %	D129	0.5% max
Copper Strip Corrosion	D130	3 max
Cetane No.	D613	40 min

Cloud Point is not specified by ASTM. Satisfactory operation should be achieved in most cases if the cloud point is 6 °C above the tenth percentile minimum temperature for the area where the fuel will be used.

There are several problems associated with the use of vegetable oil. They can be categorized as operational and durability problems. The former included the ignition quality characteristics, e.g. poor cold engine start-up, misfire, and ignition delay, and the latter include characteristics demonstrating incomplete combustion, e.g. nozzle coking, deposit formation, carbonization of injector tips, ring sticking and lubricating oil dilution and degradation [62].

The various vegetable oils are distinguished by their fatty acid compositions. Triglyceride molecules have molecular weights between 800 and 900 and are thus nearly four times larger than typical diesel fuel molecules [25]. Chemical structure of common fatty acids is given in table 2.2.

**Table 2.2: Chemical Structure of Common Fatty Acids [61]**

Fatty acid	Systematic name	Structure	Formula
Lauric	Dodecanoic	12:0	C <sub>12</sub> H <sub>24</sub> O <sub>2</sub>
Myristic	Tetradecanoic	14:0	C <sub>14</sub> H <sub>28</sub> O <sub>2</sub>
Palmitic	Hexadecanoic	16:0	C <sub>16</sub> H <sub>32</sub> O <sub>2</sub>
Stearic	Octadecanoic	18:0	C <sub>18</sub> H <sub>36</sub> O <sub>2</sub>
Arachidic	Eicosanoic	20:0	C <sub>20</sub> H <sub>40</sub> O <sub>2</sub>
Behenic	Docosanoic	22:0	C <sub>22</sub> H <sub>44</sub> O <sub>2</sub>
Lignoceric	Tetracosanoic	24:0	C <sub>24</sub> H <sub>48</sub> O <sub>2</sub>
Oleic	Cis-9-Octadecenoic	18:1	C <sub>18</sub> H <sub>34</sub> O <sub>2</sub>
Linoleic	Cis-9,cis-12-Octadecenoic	18:2	C <sub>18</sub> H <sub>32</sub> O <sub>2</sub>
Linolenic	Cis-9,cis-12,cis-15-Octadecatrienoic	18:3	C <sub>18</sub> H <sub>30</sub> O <sub>2</sub>
Erucic	Cis-13-Docosenoic	22:1	C <sub>22</sub> H <sub>42</sub> O <sub>2</sub>

Problems faced on using the neat vegetable oil:

- The increased viscosity of the neat vegetable oils leads to poor atomization and incomplete combustion with an unmodified fuel injection system.
- The clogging of the fuel system.
- Polymerization during storage.
- Blow-by causing polymerization of the lubricating oil [65].
- Thickening and Gelling of the lubricating oil as a result of contamination by the vegetable oil.
- Oil ring sticking.
- Carbon deposits around the nozzle orifice, the upper piston ring grooves and on the piston rings [32].

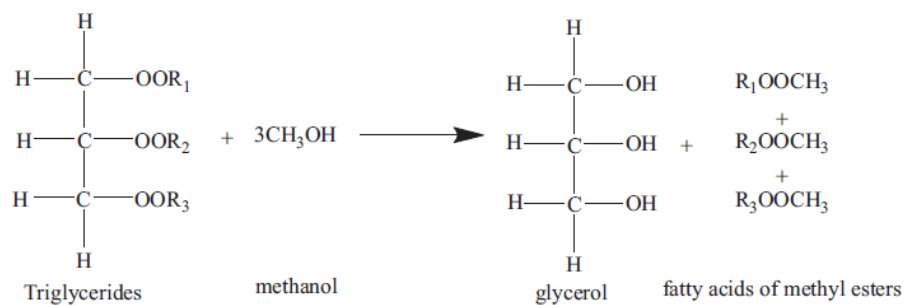
Because of the above stated problems, straight vegetable oil is not suitable as fuel for diesel engines; they have to be modified to bring their combustion related properties closer to diesel. This fuel modification is mainly aimed at reducing the viscosity to eliminate flow/atomization related problems. Four techniques can be used to reduce the viscosity of vegetable oils:



- 1) Heating/Pyrolysis,
- 2) Dilution/blending,
- 3) Micro-emulsion, and
- 4) Transesterification.

### 2.1.1 TRANSESTERIFICATION

The purpose of transesterification process is to lower the viscosity of the oil. The viscosity and flash point values of linseed oil methyl and ethyl esters highly decrease after transesterification process. Transesterification can be catalyzed by acids, bases or enzymes. It is most common and popular method of bio-diesel production from vegetable oil. It refers to acid catalyst or base catalyst chemical reaction involving oil (triglyceride) and an alcohol (methyl/ethanol) to yield mono-alkyl esters of long chain fatty acid (bio-diesel) and glycerol. The main factors affecting transesterification are the amount of alcohol, free fatty acid content, presence of water, and catalyst reaction, temperature, pressure and time. Vegetable oil consists of three carbon backbones with long chain fatty acids and bio-diesel composed of fatty acid chains that are chemically bonded to one methanol molecule.



**Fig.2.3 Transesterification of Vegetable Oil**

Following are the methods of transesterification:

1. Base/ Alkali catalyzed transesterification
2. Acid catalyzed transesterification
3. Enzymatic transesterification
4. Supercritical and subcritical alcohol transesterification

Base catalysis method is the most popular way and most often used commercially for biodiesel production. It is using for low fatty acid feed oil. In this method, a triglyceride reacts with an alcohol in the presence of a catalyst such as strong base (KOH/NaOH), producing a mixture of fatty alkyl esters (known as bio-diesel) and glycerol.

Transesterification of triglycerides by an alkaline catalyst also called alcoholysis [17]. Mixing can be via mechanical stirring, Ultrasonic cavitation or hydrodynamic cavitation.

## 2.2 LITERATURE REVIEW

There are limited literatures focused on the application of ethanol-biodiesel blends to diesel engine. Few attempts have been made for producing biodiesel from linseed oil. So this work is very young from the literature point of view.

**Dixit et al. [17]** reviewed the linseed oil as a potential source for biodiesel. They found that linseed oil is non-edible oil in India. Under optimum conditions the oil content of linseed seeds varies from 33 to 47%. Linseed plant is traditionally cultivated for the production of textile fiber. It is also a high source of oil which can be converted into biodiesel and provide a major source of renewable energy both locally and inter-nationally. The fuel properties of linseed bio-diesel are comparable to those of fossil diesel. Linseed oil has lower oxidative stability and linseed oil esters have better stability compared to the linseed oil.

**Guzatto et al. [19]** used Transesterification Double Step Process (TDSP) for the production of biodiesel from vegetable oil. TDSP was modified to yield a shorter reaction time and products with improved quality. It consists in a two step transesterification procedure which starts with a basic catalysis, followed by an acidic catalysis. The process modifications included a reduction in the concentration of catalysts, a reduction in the reaction time of the first step and the direct mixing of methanol/acid solution, without cooling the system between the first and second step. They compared between washed and unwashed biodiesel and found that the final washing and drying procedure is necessary for satisfactory results. They analyzed the products by H-NMR. The modified procedure resulted in a high conversion index (97% for waste cooking oil and soybean oil and 98% for linseed oil) and high yield ( $87\pm 5\%$  for waste cooking oil,  $92\pm 3\%$  for soybean and  $93\pm 3\%$  for linseed oil). The biodiesel produced by the modified TDSP met ASTM, EN ISO and ABNT standards.

**Jain et al. [20]** revealed that biodiesel is more prone to oxidation when exposed to higher temperature due to the formation of oxidation products like aldehydes, alcohols, shorter chain carboxylic acids, insolubles, gum and sediment in the biodiesel, which may often be responsible for fuel filter plugging, injector fouling, deposits formation in engine combustion chamber and various components of the fuel system. Most commonly used

methods to investigate the thermal stability are Rancimat test, ASTM D 6408-08, D 5304-06 and thermo gravimetric analysis (TGA)/ differential temperature analysis (DTA). Rancimat test has been suggested as an important method to measure the thermal stability of oils, fats and biodiesel fuels. Further the KF Coulometer has also been suggested as suitable method to measure the thermal as well as oxidation stability of vegetable oils. Further, TGA/DTA has been found as an effective method to check the deterioration of oil with respect to temperature using activation energy and order of reaction as the parameter to monitor the deterioration of oil.

**Zhu et al. [18]** experimentally analysed the combustion, performance and emission characteristics of a DI diesel engine. They used blends of ethanol & biodiesel of waste cooking oil as fuel and compared the results with biodiesel & Euro V diesel. Compared with Euro V diesel fuel, for biodiesel, the maximum pressure is higher at high engine loads; the maximum heat release rate of premixed combustion phase is lower in all test modes, and occurs earlier; combustion starts earlier and the combustion duration is shorter. Compared with biodiesel, the maximum pressure and the heat release rate of the BE blends increase with the increase of ethanol fraction in the blended fuel and occurs further away from the TDC; the start of combustion is retarded and the combustion duration is shortened. The brake thermal efficiency increases slightly with BE5, while there is no significant difference with BE10 and BE15. Biodiesel produces lower CO, HC and PM emissions, while higher NO<sub>x</sub> and NO<sub>2</sub> emissions, in comparison with Euro V diesel fuel. Compared with biodiesel, BE5 gives slightly lower CO and HC emissions in all test modes while BE10 and BE15 have higher CO and HC emissions at light and medium engine loads but similar level of emissions at medium and high engine loads. In generally, the BE blends have lower NO<sub>x</sub> and higher NO<sub>2</sub> emissions, compared with biodiesel. With the increase of ethanol in the blended fuel, the NO<sub>x</sub> emissions decrease and the NO<sub>2</sub> emissions increase at low engine loads, while there is no significant difference among the BE blends at medium and high engine loads. The BSPM emissions of the BE blends decrease obviously, compared with Euro V diesel fuel and biodiesel. Compared with the diesel fuel, biodiesel gives lower particulate emission but higher NO<sub>x</sub> emissions. However, the BE blends gives lower particulate emission as well as lower NO<sub>x</sub> emission.

**Sukumar et al. [44]** were determined effect of injection pressure on performance, emission and combustion characteristics of high linolenic linseed oil methyl ester in a diesel engine. In the experiment they selected a constant speed DI diesel engine and varied fuel

injection pressures (200, 220 & 240 bar). The test results show that the optimum fuel injection pressure is 240 bar. At this optimised pressure the thermal efficiency is similar to diesel and reduction in CO, unburned HC and smoke emissions with an increase in NO<sub>x</sub>.

**Agarwal et al. [43]** evaluated the performance of non-edible vegetable oil fuelled CI engine. These oils were blended with diesel in different proportions. They found that straight vegetable oil poses operational & durability problems when subjected to long-term uses in CI engine. These problems are attributed to high viscosity, low volatility and polyunsaturated character of vegetable oils. They suggested transesterification process as an effective method of reducing vegetable oil viscosity and eliminating operational and durability problems.

**Humke et al. [36]** during engine tests with degummed crude soybean oil and crude soybean oil found that nozzle deposit formation after 10 hours caused engine performance to decrease and emissions to increase [30].

**Popa et al. [21]** were analyzed the fatty acids composition of linseed oil with GC-MS method. Linseed oil was found to contain high levels of linolenic (53.21%) followed by oleic (18.51%) and linoleic (17.25%) while the dominant saturated acids were palmitic (6.58 %) and stearic (4.43%). In fatty acid composition, the saturates composed an average of 11.01 % of the total fatty acids and of 88.97% unsaturated acid. The major saturated fatty acid was palmitic (16:0) and stearic acid (C18:1). The major unsaturated fatty acid in the oils samples was linolenic (18:3), followed by oleic (18:1) and linoleic (18:2).

**Hebbal et al. [28]** selected deccan hemp oil, a non-edible vegetable oil for the test on a diesel engine and its suitability as an alternate fuel is examined. The viscosity of deccan hemp oil is reduced first by blending with diesel in 25/75%, 50/50%, 75/25%, 100/0% on volume basis, then analyzed and compared with diesel. Further blends are heated and effect of viscosity on temperature was studied. The performance and emission characteristics of blends are evaluated at variable loads of 0.37, 0.92, 1.48, 2.03, 2.58, 3.13 and 3.68 kW at a constant rated speed of 1500 rpm and results are compared with diesel. The thermal efficiency, brake specific fuel consumption (BSFC), and brake specific energy consumption (BSEC) are well comparable with diesel, and emissions are a little higher for 25% and 50% blends. At rated load, smoke, carbon monoxide (CO), and unburnt hydrocarbon (HC) emissions of 50% blend are higher compared with diesel by 51.74%, 71.42% and 33.3%, respectively. For ascertaining the validity of results obtained, pure deccan hemp oil results are compared with results of jatropha and pongamia oil for similar works available in the



**Jutia et al. [31]** elucidates the chemical mechanisms which trigger both phenomena. Low-temperature oxidation of linseed oil and its active components, linoleic, linolenic and oleic acids in equi-molar O<sub>2</sub>/N<sub>2</sub> mixture has been investigated in a plug flow reactor housed inside an oven at an initial temperature between 60 and 100 °C, with the liquids impregnated onto the glass wool support. They have studied the effect of transition metal salts on the oxidation of linseed oil and identified the gaseous species produced in the oxidation by means of Fourier transform infrared (FTIR) spectroscopy and gas chromatography-mass spectrometry (GC-MS), and quantified them by micro gas chromatography (GC). FTIR spectroscopy indicated the presence of aldehydes and carboxylic acids, with identification of these species confirmed by GC-MS. In the presence of a metal catalyst, the oxidation process involves the formation of metal-dioxygen (superoxide) adducts. The catalytic effect of a metal cation depends on its ability to form superoxide. Cobalt is the most effective catalyst among other transition metal salts, followed by manganese and iron. In the absence of a catalyst, we found the oil samples to undergo a slower auto-oxidation process, probably associated with cross-linking or polymerization together with partial fragmentation to form the observed low molecular weight products.

**Rakopoulos et al. [37]** conducted to evaluate and compare the use of a variety of vegetable oils of various origins as supplements to conventional Diesel fuel at blend ratios of 10/90 and 20/80 in a direct injection (DI) Diesel engine. They found that NO<sub>x</sub> were reduced with use of vegetable oil in the diesel engine.

**Xue et al. [58]**, after analysing literatures concluded that the blends of biodiesel with small content by volume could replace diesel in order to help in controlling air pollution and easing the pressure on scarce resources to a great extent without significantly sacrificing engine power and economy. Loss in engine power mainly due to the reduction in heating value of biodiesel compared to diesel, but there exists power recovery for biodiesel engine as the result of an increase in biodiesel fuel consumption. Increased biodiesel consumption is due to low heating value and high density and viscosity of biodiesel. Biodiesel favors to reduce carbon deposit and wear of the key engine parts, compared with diesel. It is attributed to the lower soot formation, which is consistent to the reduced PM emissions and the inherent lubricity. The higher oxygen content and lower aromatic compounds has been regarded as the main reasons. NO<sub>x</sub> emissions will increase due to higher oxygen content for biodiesel.

Cetane number and different injection characteristics also have an impact on NO<sub>x</sub> emissions for biodiesel. CO emissions reduce when using biodiesel due to the higher oxygen content and the lower carbon to hydrogen ratio in biodiesel compared to diesel. HC emissions reduce when biodiesel is fueled instead of diesel. This reduction is mainly contributed to the higher oxygen content of biodiesel, but the advance in injection and combustion of biodiesel also favor the lower THC emissions.

**Schlick et al. [39]** conducted experiments on a direct injection diesel engine operating on mechanically expelled unrefined soybean oil and sunflower oil blended with diesel fuel on a 25:75 v/v basis. They evaluated that the power remained constant throughout 200 hrs of operation.

**Hemmerlein et al. [40]** conducted experiments on naturally aspirated exhaust gas turbocharged air cooled and water cooled engines using rapeseed oil. Experiments were conducted using filtered rapeseed oil. It has been reported that the brake power and torque using rapeseed oil as fuel are 2% lower than that of diesel. The heat release rate is very similar for both fuels. With all the engines tested, maximum brake power was obtained with rapeseed oil. Also, lower mechanical stresses and lower combustion noise were observed. The emission of CO and HC are higher, whereas NO<sub>x</sub> and particulate emission were lower in comparison with diesel fuel.

**Rakopoulos [41]** reported use of olive fuel as a fuel supplement in DI and IDI Diesel Engines. He conducted an experimental study to evaluate 25/75 % and 50/50% blends of olive and commercial diesel fuel in four strokes DI and IDI Diesel Engines with swirl combustion chambers. The influence of the blends, for a large of loads, was examined on fuel consumption, maximum pressure, exhaust smoke, and exhaust gas emissions. A small penalty in sfc, and essentially unaltered maximum pressures and moderate increases in exhaust smoke were reported. There were moderate decreases in emitted NO<sub>x</sub> and increases in HC as well as negligible increases in CO.

**Ziejewski et al. [42]** tested blends of 25% high oleic sunflower oil/75% diesel fuel and 25% high oleic safflower oil/75% diesel fuel and they evaluated that results from both the fuels were comparable with standard diesel fuel. The fuels were compared on the performance and emission results including , power output, fuel consumption, CO, CO<sub>2</sub> , NO<sub>x</sub> and HC and the carbon and lacquer residue formation on the internal part of the engine.

The results indicated no significant change in engine performance for the tested fuel, throughout the duration of the investigation. The carbon and lacquer deposits were within a normal range for both fuels in comparison to the results from the results of standard diesel fuel.

**Karaosmanoglu et al. [45]** tested sunflower oil as a fuel in a single cylinder, direct injection air cooled diesel engine and concluded that no significant drop or increase in power and fuel consumption was observed. The engine didn't display any fluctuations due to the change in the balancing force and the lubricating oil characteristics exhibited no remarkable change [39].

**Machacon et al. [57]** revealed the effects of pure coconut oil and coconut oil diesel fuel blends on the performance and emissions of a direct injection diesel engine. Operation of the test engine with pure coconut oil and coconut oil {diesel fuel blends} for a wide range of engine load conditions. The blends tested were 20{80}, 40{60}, 60{40} and 80{20} coconut oil {diesel fuel} (by volume ratios). The trial was shown to be successful even without engine modifications. They found that by increasing the amount of coconut oil in the coconut oil {diesel fuel blend} resulted in lower smoke and NO<sub>x</sub> emissions. However, this resulted in an increase in the BSFC. This was attributed to the lower heating value of neat coconut oil fuel compared to diesel fuel.

**Masjuki et al. [47]** to evaluated the performance, emission and wear characteristics of an indirect diesel engine fueled by blends of coconut oil and diesel fuel. The performance and emission characteristics results showed that 10–30% coconut oil blends produced a slightly higher performance in terms of brake power than that of diesel. All the coconut oil blends produced lower exhaust emissions including polycyclic aromatic hydrocarbons and particulate matter. The wear and lubricating oil characteristics results showed that coconut oil blends up to 30% produced similar results to that of diesel.

**Silvico et al. [48]** used heated palm oil as the fuel in a diesel generator. Studies revealed that exhaust gas temperature and specific fuel consumption were increased with an increase in charge percentage. The carbon monoxide emission was increased with the increase of load. Unburned HC emissions were lower at higher loads, but tended to increase at higher loads. This was due to a lack of oxygen resulting from the operation at higher equivalence ratios. Palm oil NO<sub>x</sub> emissions were lower as compared to the diesel fuel. They



also reported that a diesel generator can be adapted to run with heated palm oil and would give better performance.

**Qudais et al. [49]** used shale oil in a single cylinder , direct injection diesel engine. They compared shale oil based fuels with petroleum based diesel oil in terms of performance, exhaust gaseous emission and particulate emission. They found that shale oil burned more efficiently than the baseline diesel fuel and therefore, resulted in higher thermal efficiency. The shale oil resulted in lower un-burnt hydrocarbon (HC) and less Carbon Monoxide (CO) than the diesel fuel. However the shale oil produced higher oxides of nitrogen ( $\text{NO}_x$ ) at lower load as compared to diesel fuel.

**Bari et al. [50]** performed short term performance tests using crude palm oil as a fuel for diesel engine and found crude palm oil to be a suitable substitute, with a peak pressure about 5% higher and ignition delay about 3° shorter compared with diesel. Emissions of NO and CO were about 29 and 9% higher respectively for crude palm oil, However prolonged use of Crude palm oil as fuel caused the engine performance to deteriorate. After 5—hours cumulative running with CPO, the maximum power was reduced by about 20% and the minimum bsfc was increased by about 26%.

**Yu et al. [51]** conducted a study on waste cooking oil collected from the noodle industry. The oil was used as fuel in the engine without any further treatment. The performance and emission characteristics have also been compared with diesel fuel. The experimental results indicated that combustion characteristics were generally similar to that of diesel. The energy released at the late combustion phase was higher, which was due to heavier molecular weight materials present in the waste cooking oil. The engine performance was similar to that of diesel fuel. The emissions of CO,  $\text{NO}_x$  and  $\text{SO}_x$  were higher for waste cooking oil compared to that of diesel. At high temperatures, tar like substances were found to be depositing in the combustion chamber.

**Pramanik [52]** analyzed performance of the engine using blends of diesel and jatropha oil in a single cylinder C.I. engine and compared with diesel. Significant improvement in engine performance was observed compared to vegetable oil alone. The specific fuel consumption and the exhaust gas temperature were reduced due to decrease in viscosity of the vegetable oil. Acceptable thermal efficiencies of the engine were obtained with blends containing up to 50% volume of jatropha oil. From the properties and engine test

results it has been established that 40–50% of jatropha oil can be substituted for diesel without any engine modification.

**Ramdhas et al. [53]** used rubber seed oil in a compression ignition engine and have reported that rubber seed oil blend fueled engine has higher carbon deposits inside combustion chamber than diesel-fueled engine. Utilization of blends required frequent cleaning of fuel filter, pump and the combustion chamber.

**Reddy et al. [54]** investigated the use of neat Jatropha oil on a single cylinder, constant speed, direct injection diesel engine. They changed injection timing, injector opening pressure, injection rate and air swirl level to study their influence on performance, emissions and combustion and compared results with neat diesel operation. Advancing the injection timing from the base diesel value and increasing the injector opening pressure increase the brake thermal efficiency and reduce hydro carbon (HC) and smoke emissions significantly. When the injection timing is retarded with enhanced injection rate, a significant improvement in performance and emissions was noticed. In this case emissions with Jatropha oil are even lower than diesel. Enhancing the swirl has only a small effect on emissions. The ignition delay with Jatropha oil is always higher than that of diesel under similar conditions. Improved premixed heat release rates were observed with Jatropha oil when the injector opening pressure is enhanced.

**Yilmaz [55]** Biodiesel (45%)-methanol (10%)-biodiesel (45%), biodiesel (40%)-methanol (20%)-biodiesel (40%), biodiesel (45%)-ethanol (10%)-biodiesel (45%) and biodiesel (40%)-ethanol (20%) biodiesel (40%) blends were run in a diesel engine under the same operating conditions and compared to a baseline diesel fuel. Overall, brake specific fuel consumption of alcohol blends is higher than for diesel, while ethanol-blended fuels show lower BSFC than methanol-blended fuels. There is no significant different in exhaust gas temperature. Increasing alcohol concentration reduces NO emissions, while increasing CO and HC emissions. Biodiesel-ethanol-diesel blends, as compared to standard diesel, increase CO and HC emissions while reducing NO emissions. Interestingly, biodiesel-methanol-diesel blends have opposite effects on the emissions. Methanol blends would be the choice if CO and HC emissions are the aim. Ethanol blends would be the right choice for reducing NO emissions for the concentrations investigated in this work. Overall, emissions strongly depend on engine operating conditions and alcohol blend ratios, which could have positive and negative effects overall, due to oxygen content and cooling effects.

**Lapureta et al. [56]** studied effects of biodiesel fuels on diesel engine emission. At partial load operation, no differences in power output should be expected, since an increase in fuel consumption in the case of biodiesel would compensate its reduced heating value. At full-load conditions, a certain decrease in power has been found with biodiesel, but such a decrease is lower than that corresponding to the decrease in heating value. An increase in bsfc has been found when using biodiesel in most of the reviewed studies. Such an increase is generally in proportion to the reduction in heating value (9% in volume basis, 14% in mass basis). Consequently, the thermal efficiency of diesel engines is not appreciably affected when substituting diesel by biodiesel fuel either pure or blended. report slight increases in NO<sub>x</sub> emissions when using biodiesel fuels. The reason most frequently pointed out is that the injection process is slightly advanced with biodiesel. The physical properties of biodiesel or the response of the electronic unit could cause such an advance. sharp reductions in particulate emissions with biodiesel as compared to diesel fuel. This reduction is mainly caused by reduced soot formation and enhanced soot oxidation. The oxygen content and the absence of aromatic content in biodiesel have been pointed out as the main reasons. emissions such as those of THCs and CO are usually found to significantly decrease with biodiesel. A more complete combustion caused by the increased oxygen content in the flame coming from the biodiesel molecules has been pointed out as the main reason. emission of aromatic and polyaromatic compounds, as well as their toxic and mutagenic effect, has been generally considered to be reduced with biodiesel.

As per **Liu et al. [59]** when ethanol is used in the diesel engine, a cetane number (CN) improver, such as isoamyl nitrite, is generally added in diesel/ethanol blends to compensate for the decrease of CN because of ethanol addition. They validated mechanism for the auto-ignition of *n*-heptane/ ethanol/ isoamyl nitrite mixtures with the shock-tube data and homogeneous charge compression ignition (HCCI) engine combustion experiment. They studied the effects of ethanol and isoamyl nitrite addition on the ignition delay of diesel where *n*-heptane was used to simulate diesel. With the numerical analyses they showed that the addition of ethanol decreases the amount of OH radicals and consequently, retarded the ignition. The reactive *i*-C<sub>5</sub>H<sub>11</sub>O and NO radicals generated in the isoamyl nitrite thermal decomposition process accelerated the low-temperature reactions and shortened the ignition delay.

### **2.3 STATEMENT OF THE PROBLEM**

After literature review it can be concluded that biodiesel is an attractive replacement of diesel fuel. Blends of ethanol with diesel are referred as E-Diesel or eDiesel. eDiesel has been used by many researchers as a diesel engine fuel. But there are very few work on the ethanol-biodiesel blends. Ethanol can reduce the viscosity of biodiesel in blends. Ethanol can be blended with biodiesel without phase separation.

Following objectives were envisaged for the present research work.

1. Comprehensive literature survey.
2. Determination of important Physico-chemical properties of ethanol-biodiesel blends.
3. Development of dual fuel mode experimental diesel engine test rig.
4. To conduct exhaustive experiments on the test rig to evaluate performance and emission characteristics of biodiesel & blends and compare with base line data of diesel.
5. Analysis of Results.

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**SYSTEM DEVELOPMENT AND EXPERIMENTAL PROCEDURE****3.0 INTRODUCTION**

Diesel engines are amongst the most efficient prime movers and with the view of protecting global environment and concerns for long-term energy security, it has become necessary to develop alternative fuels with properties comparable to petroleum based diesel fuels. For the developing countries, fuels of bio-origin provide a feasible solution to the above twin crisis. Bio-fuels are getting a renewed attention because of global stress on reduction of green house gases (GHGs) and clean development mechanism. The fuels of bio-origin may be alcohol, vegetable oils, biomass, and biogas. Biodiesel from vegetable oils have comparable Physico-chemical properties with mineral diesel and they are biodegradable, non-toxic, and have a potential to significantly reduce pollution.

Each country can proceed in the production of particular oil, 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 seeds of Linseed & Jatropha has been found very suitable as a substitute to diesel fuel.

**3.1 LINSEED PLANT DISCRPTION**

Linseed oil, its scientific name is *Linum Usitatissimum*, belongs to the family *Linaceae* and the genus *Linum* which has 100 species. It originated from Mediterranean coastal countries and is cultivated in Canada, Argentina, India and USA. It is growing to a height of 0.3-1 m, which is cultivated for the production of textile fiber, seed and linseed oil. Linseed is cultivated in Araucaria region for oil extraction. Studies have shown that crop yield is higher in this region, because of its soil and climate characteristics. Linseed is best suited for fertile, fine textured and loamy soils: an important factor is the amount of rain fall during the growing period. Adequate moisture and relatively cool temperatures, particularly during the period from flowering to maturity, seem to favor both oil content and oil quality. The seed is located in the extremities of the branches in round capsules, each of which contains from one to ten seeds. In India, it is grown mainly for seeds, used for extracting oil.

Under optimum conditions the oil content of linseed seeds varies from 33 to 47%. In India various states have sufficient forest area for the plantation of linseed. Madhya Pradesh leads in yield and acreage, followed by Uttar Pradesh and Maharashtra, Bihar, Rajasthan, Karnataka and West Bengal also grow linseed in large areas. Madhya Pradesh and Uttar Pradesh together contribute to the national linseed production to the extent of about 70%. India accounts for about 1.9 million hectares, with a seed production of 4.98 lakhs of tones. The crop in northern India generally gives higher yield than in central and peninsular India. The irrigated crop may yield 1200 to 1500 kg per ha. and occupies the third rank among the linseed-producing countries Australia and Canada [17]. Linseed oil is the most commonly used carrier in oil paint. It is available in Asian countries. It is an important oil seed in the world. Linseeds are a source of high quality proteins, soluble fiber and a high content of polyunsaturated fatty acids. They present values of 30-40% lipids, 20-25% proteins, 4-8% moisture, 3-4% ash and 20-25% dietary fiber. Common names of linseed are flax, alsii, tisi, kshuma, lin, llion, liner, linum, line, linen, lein.

### 3.1.1 CULTIVATION OF LINSEED CROP

Flax is a broadleaf with small, narrow leaves that are less than an inch long. Stems are slender, flexible, branched, near base of plant, with height 30-36 inches, dividing at their tips into inflorescences bearing attractive blue flowers. Flowers are mostly self-pollinated, with some cross pollination by insects. New flowers will emerge for a few weeks, each developing into a round seed capsule or boll about one-third inch in diameter. Each capsule contains 4 - 10 seeds, Glossy in appearance, traditionally brown colour. However, a new variety of flax, Omega, is golden-coloured to make it more acceptable in the food market. If exposed to water, flax seeds will become sticky due to mucilage in the seed coat [35].



(a) Flower



(b) Capsules



(c) Seeds

**Fig. 3.1 Linseed Crop**

## Climate

Crop, grown for seed, performs well in moderately cold climate, but the crops for fibre purpose, requires cool and moist climate. Linseed requires moderate or cool temperature during vegetative stage and dry weather during the maturity of the crop. It requires temperature of 25-30 °C during germination, 15-20 °C during seed formation. It requires high humidity. Temperature above 32 °C along with the drought during flowering reduces yield, oil content and oil quality of linseed. Plants are susceptible to frost and cause injury to blossom. It is resistant to drought and grows well in areas receiving an annual rainfall of 450-750 mm [35].

## Soils

Crops grow on well drained, moderately deep silt loam, clay loam & silty clays. Light silts area not suitable especially in low rainfall areas. Crop can tolerate soil acidity but ideal pH is 6.0 [35].

**Table 3.1 Varieties of Linseed Crop [35]**

State	Utera	Rainfed	Irrigated
Himachal Pradesh	Surabhi, Jannki, Himalini	Surabhi, Janki	Janki, Himalini, Nagarkol
Maharastra	R-552	Kiran, Sheetal	Jawahar-23
Madhya Pradesh	R-552	Kiran, Sheetal	Jawahar-23
Punjab		LC-54, Himalini	LC-54, Himalini
Uttar Pradesh		Swetha, Shubra	Garima, Shubra, Neelam

### 3.1.2 USES OF LINSEED PLANT

Flax is roughly 40% oil by weight, about 55% of which is alpha linolenic acid (also called omega-3 fatty acid). On a small scale seed is directly used for edible purpose and 80% of oil goes to industries. Oil is rich in Linolenic acid (66% and above) and is a perfect drying oil and used in paint and varnishes. Its use is limited to animal feed because of undesirable compounds like phytic acid, cyanogenic glucoside and goitrogen. It is used in the manufacture of lithographic inks and soaps. Oil cake is good feed for milch cattle and also as a manure having microbial activity. Linseed stem yields fibre of good quality having strength

and durability. The fibres are lustrous and blend with the wool and silk. The fibre is used in gloves, foot wear, netting sports, paper and textile industry, cigarette wrapping paper, strong canvas, suitings and shirtings. Woody matter and short fibres used as raw pulp in paper industries. One hundred kg retted flax yields the following co-product.

**Table 3.2 Uses of Linseed Plant**

S. No.	Products	Quantity (Kg)	Utility
1	Sketched flax	16	Spinning
2	Tow broken fibre	8	High grade paper
3	Woody parts	54	Chip board panels
4	Seed	10	Oil and Meal
5	Straw	7	For fodder
6	Dust	5	Compost

### **Cake/meal utilization**

After extraction of the linseed oil a large quantity of cake remains. The linseed cake is mainly used as a cattle feed. It is a very good manure and animal feed. Linseed cake/meal is used as an additive in baking products. Linseed meal is used normally for ground un-extracted seed (35%), ground linseed cake (10% oil) and linseed meal (3%) from a solvent plant. Rich oil content can affect texture and flavor of meat and butter obtained.

### **Protein, gluten and carbohydrates**

Amino acids are the building blocks of protein (20-25%). Pattern of linseed protein is similar to that of soybean protein. Linseed is gluten-free and it is low in carbohydrates.

### **Fibers**

Linseed straw produces fiber of good quality and fiber accounts for about 28% of the weight of linseeds fat. It was most popular plant used to produce fibers for linen in Egypt. There are two main varieties of linseed, one gives a high yield of seed and other fiber. Fiber occurs as structural material in the cell walls of plants and has important health benefits for humans and it is also used in paper making.

### **Phenolics, phenolic acid, flavonoids and lignans**

Phenolics are plant compounds that have many different functions, including adding color to the plant and attracting bees and other insects for pollination. Linseed contains at





### **3.1.4 EXTRACTION OF CRUDE LINSEED OIL**

Linseed oil is obtained from linseed. It is obtained by various methods including pre-exPELLing, and hexane extraction of the press cake. The yellowish drying oil is derived from dried ripe seeds of linseed plant through pressing and extraction. It is available in varieties such as cold pressed, alkali refined, sun bleached, sun thickened and polymerized (stand oil) marketed as linseed oil. The seeds are pre-pressed and solvent extracted to obtain oil. As the seed itself is very hard, it must be crushed or softened by boiling before being fed. Both gums and waxes occur in the crude oil, settling in tanks for up to three weeks allows 1% of the oil to separate. Subsequently if the decanted oil is warmed rapidly to 110 °C a further deposit of 0.5% takes place. Such treatment is longest abolished and described as a break of the oil. Further degumming, neutralisation and washing may be based on the refining of oil where the difficulties are comparable. Supercritical carbon dioxide (SC-CO<sub>2</sub>) and organic solvent extraction were used to extract linseed oil. Extraction yields using organic solvent extraction (OS) are higher than those obtained with the supercritical CO<sub>2</sub> extraction (SC-CO<sub>2</sub>) technique.

### **3.2 BIODIESEL PRODUCTION FROM LINSEED OIL**

Under optimum conditions linseed seeds can yield up from 33-47% oil content. Climatic and soil condition of our country is convenient for the production of linseed (*Linum usitatissimum*) crop. Major problems encountered with linseed oil as biodiesel used in CI engine are its low volatility and high viscosity due to long chain structure. Methyl ester of linseed oil produced from transesterification process by using methanol and potassium hydroxide (KOH) as an alkali-catalyst. The viscosity of linseed oil biodiesel highly decreases after transesterification process. Properties of linseed biodiesel produces by transesterification are comparable with conventional diesel fuels. Higher yield 88% biodiesel was found at 20% methanol, 0.5% NaOH and 55 °C reaction temperature. The maximum biodiesel production measured after 15 h reaction time [64]. Enzymatic synthesis of linseed oil methyl ester from linseed oil supercritical alcohol and supercritical carbon dioxide and it is a most promising method to replace the catalyst transesterification process. High yield was obtained at a short time at supercritical conditions and the conversion increases with molar ratio of alcohol to oil up to 40:1. The transesterification of linseed oil in supercritical fluids such as methanol and ethanol has proved to be the most promising process. Methyl ester produced from linseed oil by using transesterification double step process (TDSP) eliminates soap or emulsion

formation problems. TDSP involves two step transesterification process with a basic catalyst included a reduction in the catalysts concentration and reaction time of the first step and modified to bio-diesel yield 98% for linseed oil [17].

### 3.2.1 FUEL PROPERTIES OF LINSEED BIODIESEL

**Table 3.4 Fatty acid compositions (wt%) of linseed biodiesel [17]**

<b>Fatty Acid</b>	<b>Linseed methyl ester</b>	<b>Linseed ethyl ester</b>
Palmitic (16:0)	5.2	5.1
Stearic (18:0)	3.2	3.1
Oleic (18:1)	14.5	13.7
Linoleic (18:2)	15.3	15.2
linolenic (18:3)	61.9	62.9

**Table 3.5 Fuel Properties of linseed oil alkyl esters [17]**

<b>Properties</b>	<b>Linseed methyl ester</b>	<b>Linseed ethyl ester</b>
Density at 25 °C (g/ml)	0.887	0.884
Dynamic viscosity at 400 °C (10 <sup>-4</sup> Pa s)	3.32	3.64
Acid value (mg KOH/g)	0.335	0.324
Cloud point (°C)	0	-2
Pour point (°C)	-9	-6
Gross heat of combustion Hg (MJ/kg)	40	39.65
Volatilization (°C)	176.1	178.4
Higher heating value (MJ/kg)	40	39.65
Distillation temperature (°C)	188.8	191.9

### 3.2.2 BIODIESEL PREPARATION BY BIODIESEL REACTOR

Biodiesel (linseed oil methyl ester) was prepared by using 10 litre biodiesel reactor. Reactor was used for controlled temperature and stirring. Reactor is also helpful in recovering methanol by cooling methanol vapour in condenser.



**Plate 3.1 Biodiesel Reactor-10 liter**



(a)KOH pellets    (b)Water Washing    (c)Heating

**Plate. 3.2 Steps in biodiesel preparation**

Reactor was cleaned by methanol. Water flow in the condenser was started by running the water pump. Linseed oil (5 kg) was heated in reactor. Then 50 gram of KOH pellets was mixed in 1000 ml of methanol by stirring. This solution was mixed with linseed oil in reactor at equal rate and interval. Reactor temperature was maintained at approx 60 °C. Biodiesel (linseed oil methyl ester) was produced after 5 hours of operation. Approx. 1 liter of glycerin was produced as a byproduct.

### 3.3 BLEND PREPARATION

The blends (ethanol in biodiesel vol./vol.) were made of different compositions by mixing the constituents. The blends (100 ml) were designated as follows:

E5 L95	-	Ethanol 5 ml + Linseed oil methyl ester 95 ml
E10 L90	-	Ethanol 10 ml + Linseed oil methyl ester 90 ml
E15 L85	-	Ethanol 15 ml + Linseed oil methyl ester 85 ml
E20 L80	-	Ethanol 20 ml + Linseed oil methyl ester 80 ml
L100	-	Linseed oil methyl ester 100 ml
D100	-	Diesel 100 ml

### 3.4 PHYSICO-CHEMICAL PROPERTIES

#### 3.4.1 DENSITY

Density is the mass per unit volume. The measurement was made at room temperature. The density was measured with the help of a U-Tube Oscillating True Density meter. The density of Linseed oil and blends with diesel were measured and then compared with that of diesel fuel. The equipment used for density determination is shown in plate 3.3.



**Plate 3.3: U-Tube Oscillating True Density Meter**

#### 3.4.2 VISCOSITY

When a fluid is subjected to external forces, it resists flow due to internal friction. Viscosity is a measure of internal friction. The viscosity of the fuel affects atomization and fuel delivery rates. It is an important property because if it is too low and too high then atomization and mixing of air and fuel in combustion chamber gets affected. Kinematic viscosity of liquid fuel samples were measured using Kinematic viscometer shown in plate 3.4 at 40 °C as per the specification given in ASTM D446. A suitable capillary tube was selected, and then a measured quantity of sample was allowed to flow through the capillary

viscometer. Efflux time was measured by stop watch for calculating Kinematic viscosity using the formula given below:

$$v = k \times t$$

Where,  $v$  = Kinematic viscosity, cSt or  $\text{mm}^2/\text{sec}$

$k=0.009427$ ( constant);  $\text{mm}^2/\text{sec}^2$

$t$  = time,( second)



**Plate 3.4 Kinematic Viscometer**

### **3.4.3 CALORIFIC VALUE**

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  $\text{kJ per kg or m}^3$ . 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 its 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. The water equivalent of bomb calorimeter was determined by burning a known quantity of benzoic acid and heat liberated is absorbed by a known mass of water. Then the

fuel samples were burnt in bomb calorimeter and the calorific value of all samples were calculated. The Bomb Calorimeter used for determination of calorific value.



**Plate 3.5 Bomb calorimeter**

The heat of combustion of the fuel samples was calculated with the help of equation given below:

$$H_c = \Delta W_c T / M_s$$

Where,  $H_c$  = Heat of combustion of the fuel sample, kJ/kg

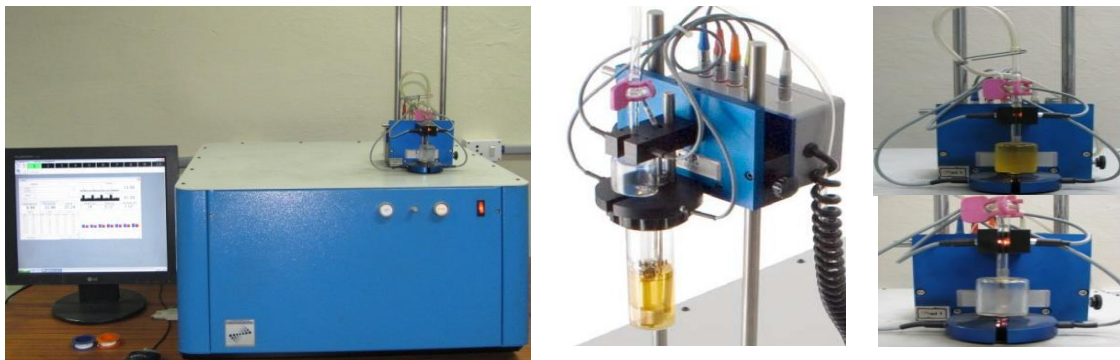
$W_c$  = Water equivalent of the calorimeter, kJ/°C

$T$  = Rise in temperature, °C

$M_s$  = Mass of sample burnt, kg

### 3.4.4 COLD FILTER PLUGGING POINT

Cold Filter Plugging Point (CFPP) is defined as the minimum temperature at 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 vegetable oils reflects its cold weather performance.



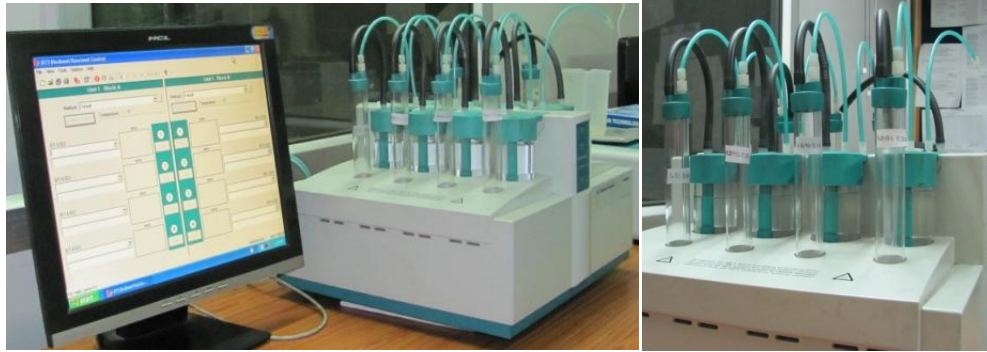
**Plate 3.6 CFPP Apparatus**



It defines the fuels limit of filterability. The apparatus for CFPP measurement is shown in plate 3.6.

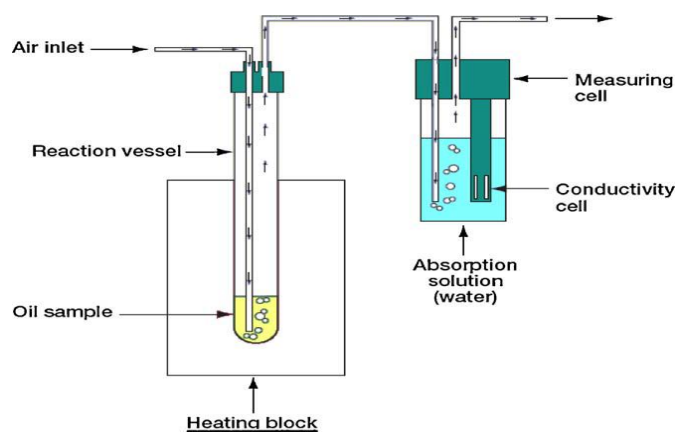
### 3.4.5 THERMAL/ OXYGEN STABILITY TEST

The length of time before the rapid acceleration of oxidation is the measure of the resistance to oxidation and is commonly referred to as the induction period, or Oxidative Stability Index (OSI).



**Plate 3.7 Biodiesel Rancimat Apparatus**

The 873 Biodiesel Rancimat is a modern, PC-controlled instrument for the convenient determination of the oxidation stability of biodiesel and biodiesel blends (mixtures of biodiesel and conventional diesel fuel) as per EN14112 and EN 15751. The OSI test is the commonly used test in Europe where biodiesel fuels should meet the specification of an induction period (IP) of at least 6 h when tested at 110 °C.



**Fig. 3.3 Schematic of Rancimat test**

The Metrohm Rancimat apparatus is frequently used to measure OSI and the term ‘Rancimat’ and ‘OSI’ are often used interchangeably while referring to the test method. OSI,



commonly used in experiments, requires passing air through a heated sample of the fatty oil or ester. The air coming out of the sample is finally passed through water contained in a tube fitted with a conductivity meter. A sharp rise in conductivity is interpreted as indicative of the formation of short chain, water soluble carboxylic acids, i.e. secondary oxidation products.

### **3.4.6 FLASH AND FIRE POINT**

Flash point is the minimum temperature at which the oil vapour, which when mixed with air forms an ignitable mixture and gives a momentary flash on application of a small pilot flame. The flash and fire point of the test fuels were measured as per the standard of ASTM D 93. The sample was heated in a test cup at a slow and constant rate of stirring for proper and uniform heating. A small pilot flame was directed into the cup through the opening provided at the top cover at the regular intervals. The temperature at which these vapour catches flash is observed and called as the flash point of that liquid. Fire point is an extension of flash point in a way that it reflects the condition at which vapour burns continuously for at least for 5 seconds. Fire point is generally higher than the flash point by 5-8° C.



**Plate 3.8 Pensky Marten Flash Point Apparatus**

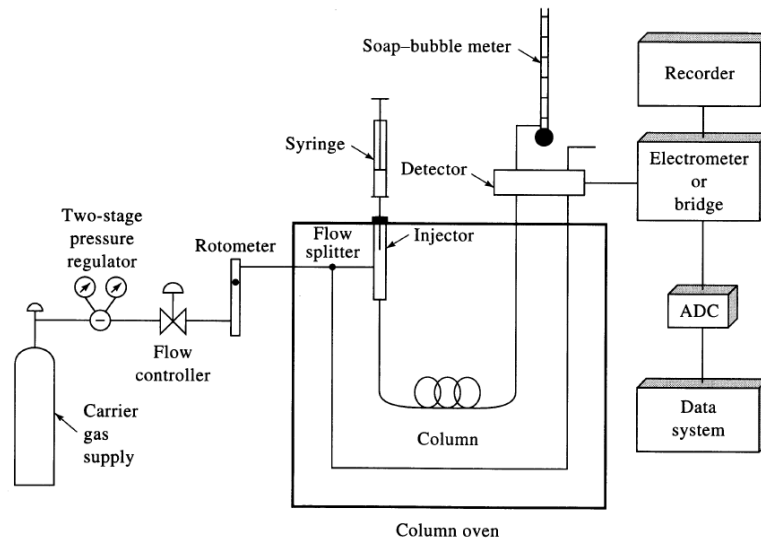
### **3.4.7 GAS CHROMATOGRAPH**

Gas Chromatograph is used to detect the components based on the selective affinity of components towards the adsorbent materials. The sample is introduced in the liquid/gas form with the help of GC syringe into the injection port, it gets vaporized at injection port then

passes through column with the help of continuously flowing carrier stream, mainly H<sub>2</sub> and gets separated/detected at the detection port with suitable temperature programming. We visualize this on computer in the form of peaks.



**Plate 3.9 Gas Chromatograph**



**Fig 3.4 Schematic diagram of Gas Chromatograph**

### 3.5 ENGINE SELECTION

There is no difference of opinion that India is going to face a severe fuel crisis in future because fuel consumption has increased in all the vital sectors specially transportation and agricultural sector. As diesel engines plays an indispensable role in transportation and agriculture sector and as such diesel consumption will increase multi-fold in time to come. The diesel engine continues to dominate the agriculture sector in our country in comparison to spark ignition engine and have always been preferred widely because of power developed, specific fuel consumption and durability.

Fuel is burnt in diesel engine by self-ignition at higher temperature and pressure conditions of the order of 600°C and 40 bar, respectively. Diesel as a fuel is injected into the combustion chamber at the end of compression stroke and after certain ignition delay; it burns to give the motive power. In India, almost all irrigation pump sets, tractors, mechanized farm machinery and heavy transportation vehicle are powered by direct injection diesel engines. Keeping the specific features of diesel engine in mind, a typical engine system, which is actually used widely in the Indian agricultural sector, has been selected for the present experimental investigations.

### **3.6 DEVELOPMENT OF AN EXPERIMENTAL TEST RIG**

A Kirloskar make, single cylinder, water cooled, direct injection, modified VCR 4-stroke diesel engine was selected for the present research work, which is primarily used for agricultural activities and household electricity generations as shown in Plate 3.10.



**Plate 3.10 Test Engine**

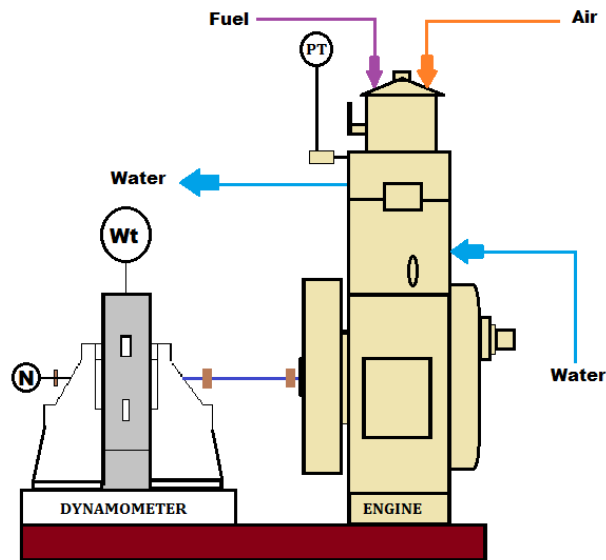
It is a single cylinder, naturally aspirated, four stroke, vertical, water-cooled VCR (Variable Compression Ratio) engine. It is connected to eddy current type dynamometer for loading through flexible coupling. The compression ratio can be changed without stopping the engine and without altering the combustion chamber geometry by tilting cylinder block arrangement. The engine can be hand started using decompression lever and is provided with

centrifugal speed governor. The cylinder is made of cast iron and fitted with a hardened high-phosphorus cast iron liner. The lubrication system used in this engine is of wet sump type, and oil is 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 are operated by an overhead camshaft driven from the crankshaft through two pairs of bevel gears. The fuel pump is driven from the end of camshaft. The detailed technical specifications of the engine are given in Table 3.1.

**Table 3.1 Specifications of Diesel Engine**

Model	TV1
Make	Kirloskar Oil Engines Ltd., Pune
Engine No.	181191/0700015
Type	4 Stroke, Water cooled
Number of cylinders	One
Bore x Stroke	87.5 mm x 110 mm
Cubic Capacity	661 c.c. (0.661 litre)
Compression Ratio	17.5:1 to 12:1
Rated Output as per BS5514/ ISO 3046/ ISO 10001	5.2 kW (7.0 hp) at 1500 rpm
Starting	Hand start with cranking handle
SFC at rated hp/1500rpm	251 g/kWh (185 g/ bhp-hr)
Fuel oil	H. S. Diesel
Lubricating Oil	SAE 30 / SAE 40
Lubrication Oil Consumption	1.5% normally exceed of fuel
Lubrication Oil Sump Capacity	2.7 liter
Fuel Tank Capacity	15 liter
Engine Weight	160 kg
Rotation while looking at flywheel	Clockwise
Peak pressure	77.5 kg/cm <sup>2</sup>
Governing class	B1
Connecting rod length	234 mm
Overall dimensions of the standard Engine	617 mm x 504 mm x 877 mm (length x width x height)

It is essential to get the various instruments mounted at the appropriate location on the experimental setup for conducting the desired set of experiments and together required data from the engine.



**Fig.3.5 Schematic Diagram of Experimental Test Rig**

### 3.7 INSTRUMENT CONTROL PANEL

The instrument control panel is equipped with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for  $P\theta$ - $PV$  diagrams. The set up consisting of air box, two fuel tanks for dual fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements. Rotameters are for the measurement of cooling water and calorimeter water flow.

One burette with stop cocks and two way valves were also mounted on the front side of the panel for fuel flow measurements. The fuel tank was mounted on the rear side of the panel at highest position.

An eddy current dynamometer is used for loading the engine. Dynamometer load is measured from a strain gauge load cell. Speed is measured from a shaft mounted sixty tooth wheel and magnetic pulse pick up. The dynamometer unit comprises basically a rotor mounted on a shaft running in bearings. In the casing two field coils are connected in series. When these coils are supplied with a direct current (DC), a magnetic field is created in the casing across the air gap. When the rotor turns in this magnetic field, eddy currents are induced creating a breaking effect between the rotor and casing. The rotational torque

exerted on the casing is measured by a strain gauge load cell incorporated in the resisting linkage between the casing and dynamometer bed plate.



**Plate 3.11 Control Panel**

The thermocouples were mounted in the exhaust manifold to measure the exhaust temperature. The AVL 437 smoke meter and AVL Di-Gas Analyzer were also kept in proximity for the measurements of various exhaust gas parameters.

Thus such a system was chosen to examine the practical utility of Biodiesel blend in such applications. Besides being a single cylinder system it was light and easy to maintain. The engine was provided with suitable arrangement, which permitted wide variation of controlling parameters.

### **3.8 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. Engine speed (rev/min)
3. Fuel consumption
4. Temperature
5. Emissions

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

1. Dynamometer load / load cell (kg)
2. RPM of the engine
3. Fuel consumption rate
4. Temperature
5. AVL 437 smoke meter
6. AVL Di Gas analyzer

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

### **3.9 MEASUREMENT METHODS**

The performance and emission characteristics of an engine can be measured with the help of the fuel consumption-measuring unit, loading arrangement, RPM meter, and temperature indicator and emission measurement equipment.

#### **3.9.1 Brake Power**

The brake power is the most important parameter in the testing of an engine. The power developed by the engine was measured with the help of an eddy current type dynamometer. The dynamometer was coupled to the engine with the help of a flexible coupling. Measurement of BP involves determination of the torque and angular speed of the engine output shaft. The output of this dynamometer is measurement of torque, displayed on the control panel. The dynamometer used in this study was a Eddy-Current Type, 'SAJ Test Plant Pvt. Ltd.' make, 7.5 kW at 1500 RPM.

#### **3.9.2 RPM of the engine**

Speed is measured from a shaft mounted sixty tooth wheel and magnetic pulse pick up. The display unit is digital and mounted on the panel board.



### 3.9.3 Exhaust Emission Measurement

Engine exhaust emissions such as CO, CO<sub>2</sub>, HC, O<sub>2</sub>, and NO<sub>x</sub> were measured using the AVL Di-Gas analyzer (AVL-4000 Light Model). Smoke is a primary sign of incomplete combustion as it is mainly composed of small un-burnt carbon particles. Smoke opacity was measured using AVL 437 smoke analyser. The instrument gave readings 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 photo cell, generating a photoelectric current, which is a measure of smoke density. These instruments were periodically calibrated using certified standard gas mixtures. Exhaust gas sampling probe was inserted up to the centre of the exhaust flow provision for which was made on the exhaust pipe. In addition a simple surge tank was mounted at the engine exhaust to ensure consistent exhaust emissions.



Plate 3.12 AVL 437 Smokemeter

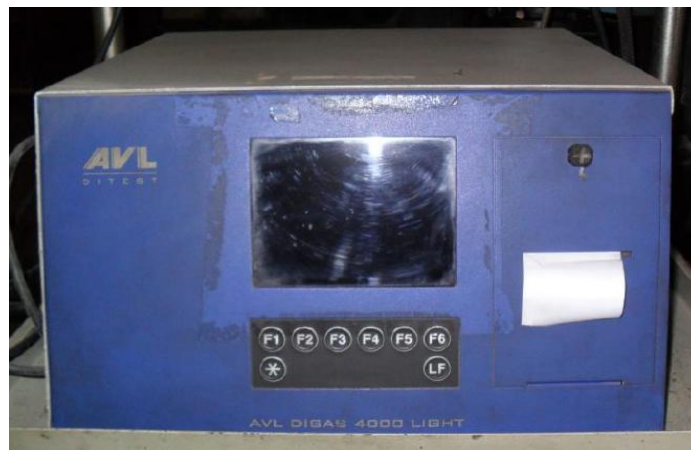


Plate 3.13 AVL Di-Gas 4000 Light



### **3.9.4 Fuel Consumption Measurements**

The fuel consumption of an engine is measured by determining the time required for the consumption of a given volume of fuel. The mass of the fuel consumed can be determined by multiplication of the volumetric fuel consumption to its density. In the present setup it is measured glass burette. The time taken by the engine to consume the fixed volume was measured by stopwatch. The volume is divided by the time to get volumetric flow rate. For this separate tank, burette and valves were provided in the panel.

### **3.9.5 Temperature 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 mill volt source up to 800°C. A K-type thermocouple was inserted into the centre of the exhaust pipe (perpendicular flow direction) 0.060 m from the engine exhaust flange.

## **3.10 EXPERIMENTAL PROCEDURE**

First of all lubricating oil in the engine and fuel in the fuel tank were checked. Air was removed from the fuel line. Dynamometer free movement was checked. Then electric supply to test rig was provided and temperature, load and speed indicator were checked for proper display. Proper water circulation was maintained through engine, calorimeter and dynamometer. Keep load regulating knob at its minimum position. The engine was started by pressing the exhaust valve with decompression lever and it was released suddenly when the engine was hand cranked at sufficient speed. Then 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. Fuel Consumption, RPM, exhaust temperature, smoke density, CO, NO<sub>x</sub>, HC, CO<sub>2</sub> and load were also measured. The engine was loaded gradually keeping the speed within the permissible range and the observations of different parameters were evaluated. Short term performance tests were carried out on the engine with diesel to generate the base line data and subsequently biodiesel & blends were used to evaluate their suitability as a fuel. The performance and emission characteristics of ethanol-biodiesel blends were evaluated and compared with diesel fuel. The ethanol-biodiesel blends were used and its performance and emission characteristics were evaluated. The data was then compared with diesel and different blend proportions.

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**RESULTS AND DISCUSSION**
**4.0 INTRODUCTION**

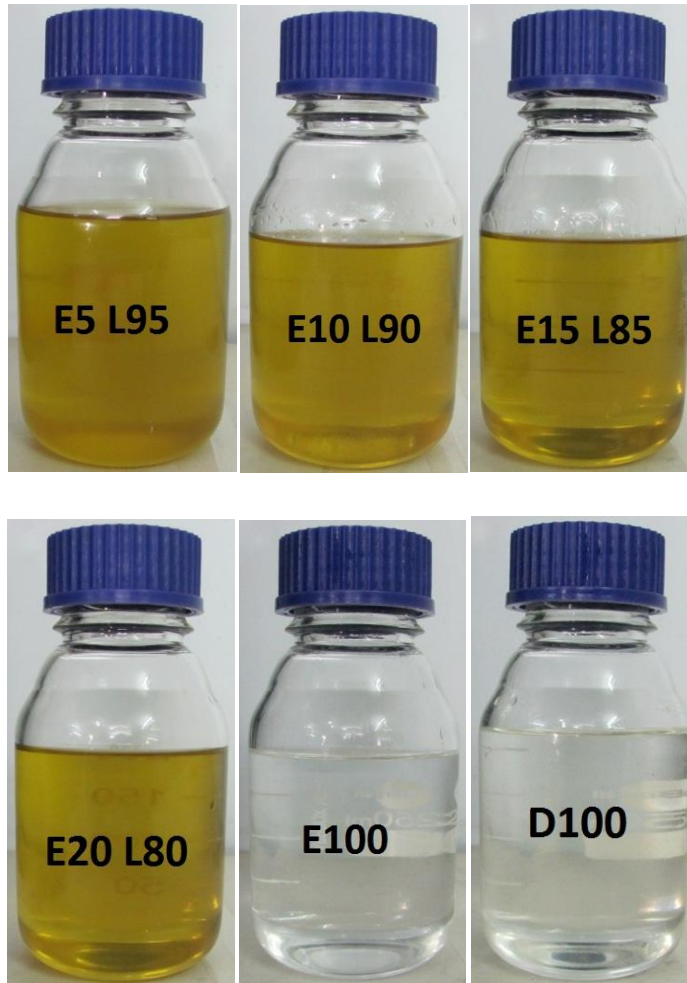
The present study was done on an unmodified diesel engine which was converted to run on a dual mode operation. The main objective of the study was to fuel the diesel engine with ethanol-biodiesel blends and performance and emission studies on blends and compare the results with baseline data.

**4.1 COMPARISON AMONG THE FUELS USED**

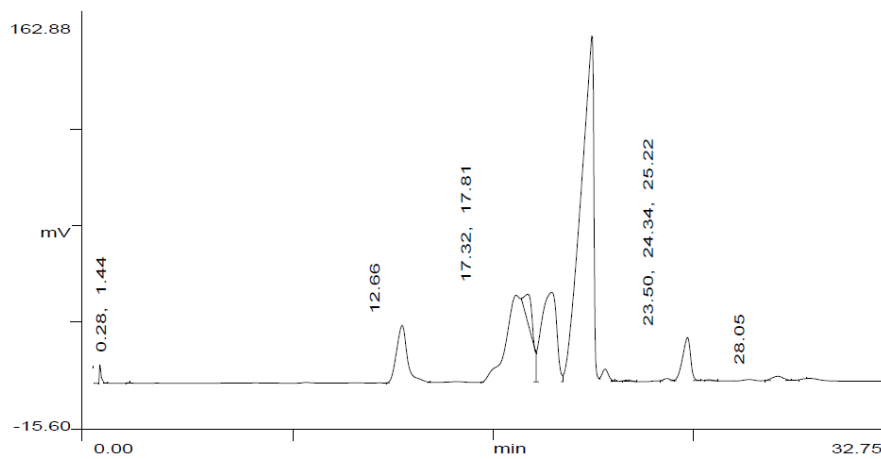
Several physical and chemical properties were analysed for D100, L100, E5 L95, E10 L90, E15 L85 and E20 L80. Biodiesel has highest density and the density goes on decreasing with increasing content of ethanol in biodiesel, diesel has lowest density.

**Table 4.1 Properties of Linseed Biodiesel and Ethanol Blends**

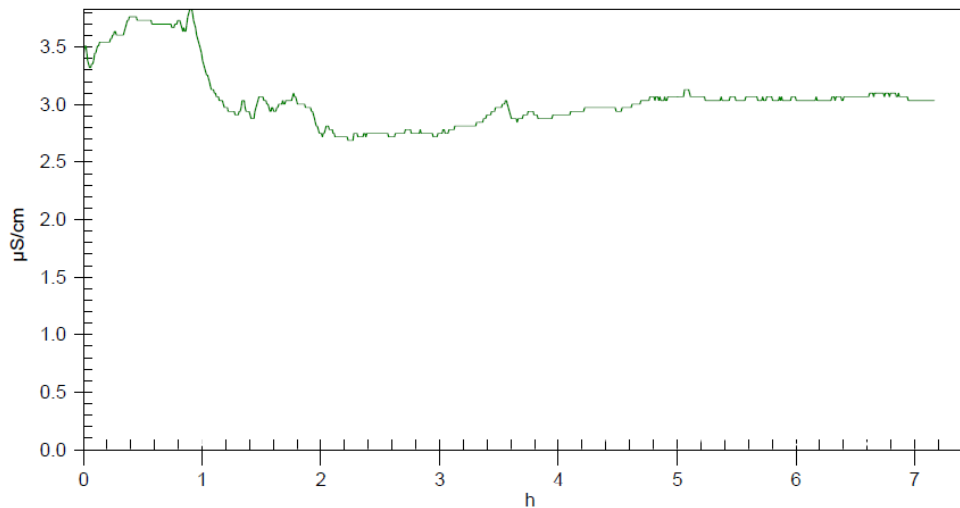
Properties Fuels	Density (kg/m <sup>3</sup> ) at 15°C	Calorific Value (MJ/kg)	Kinematic Viscosity (mm <sup>2</sup> /s) At 40°C
D100	824.2	45.49	3.1234
L100	898.35	40.95	5.100
E100	795.22	29.05	1.124
E5/L95	892.97	39.07	4.500
E10/L90	887.99	38.89	4.004
E15/L85	882.84	37.99	3.743
E20/L80	877.89	37.49	3.366



**Plate. 4.1 Blends of Ethanol and linseed biodiesel**



**Fig. 4.1 Chromatogram of Linseed biodiesel**

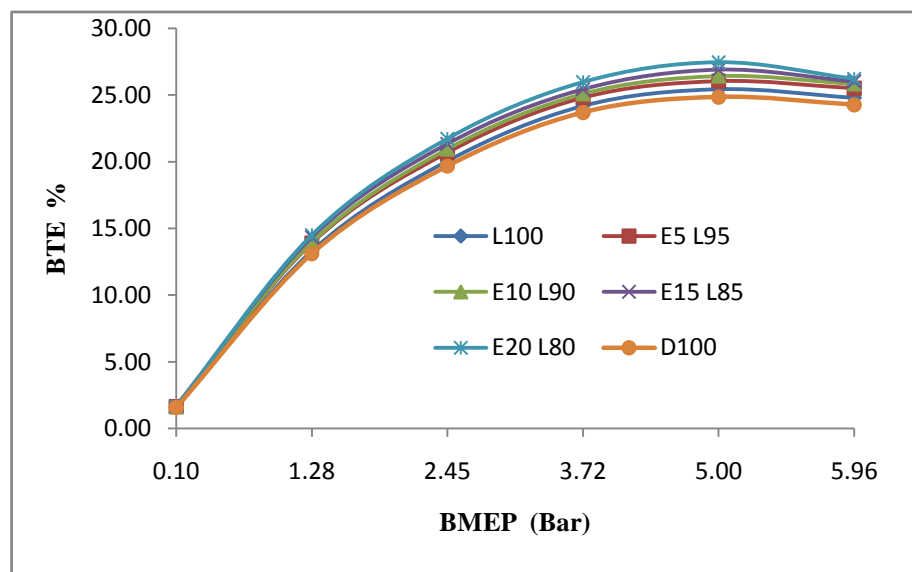


**Fig. 4.2 Oxygen Stability graph of Linseed biodiesel**

## 4.2 PERFORMANCE CHARACTERISTICS

The performance characteristics of the test engine on Ethanol-Linseed Biodiesel blends are summarized below:

### 4.2.1 BRAKE THERMAL EFFICIENCY (BTE)



**Fig 4.3 BTE Vs BMEP**

The variation of brake thermal efficiency (BTE) of the engine is shown in Fig. 4.3. From the test results it was observed that initially with increasing engine load, the brake thermal efficiencies of all the fuels were increased and then tended to decrease with further increase in engine load. The brake thermal efficiencies of biodiesel and blends were found to be higher than diesel fuel throughout the entire range. The BTE of blends were increasing with

increase in ethanol. The increase of BTE is due to the improvement of the combustion process on account of increased oxygen content in the fuels. Similar results were observed by Zhu et al. [18]. Blending of ethanol in biodiesel decreases the viscosity, due to which better atomization of blend occurs in combustion chamber.

#### 4.2.2 BRAKE SPECIFIC ENERGY CONSUMPTION (BSEC)

Since brake specific fuel consumption (BSFC) is not very reliable parameters to compare the performance of two different fuels since density and calorific value of both the fuel are significantly different. Therefore, brake specific energy was taken as a parameter to compare the energy requirement for producing unit power in case of different test fuels. The variation of BSEC with BMEP for all the test fuels is shown in Fig. 4.4. It is clear from the figure that the BSEC of biodiesel and blends are lower than diesel. It is due to higher density and higher BTE of biodiesel. BSEC for blends are slightly lower than biodiesel. E20 L80 has lowest BSEC. With increase in ethanol in blends BSEC is going to decrease. It is due to better atomization of blend in combustion chamber.

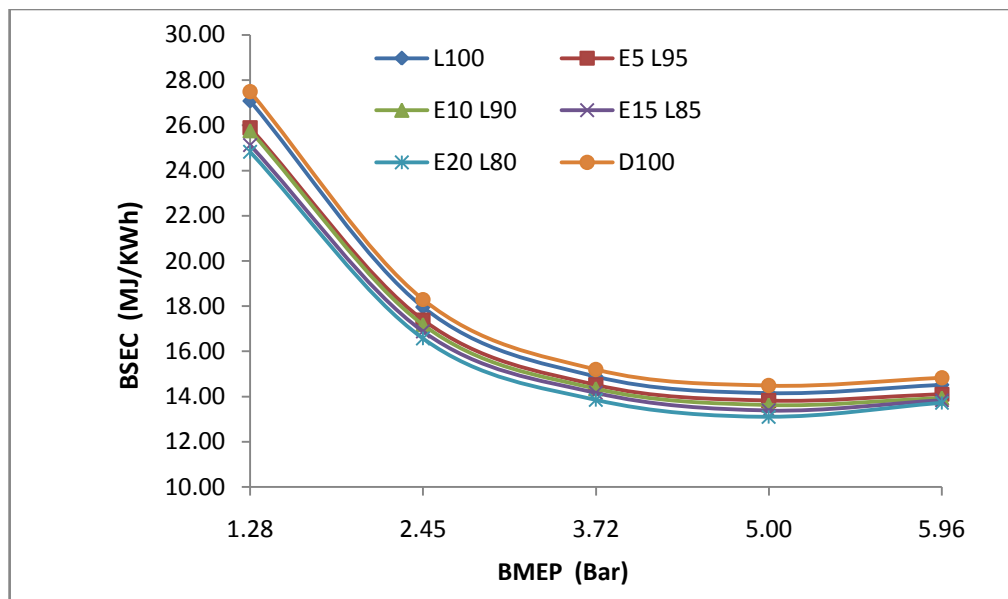
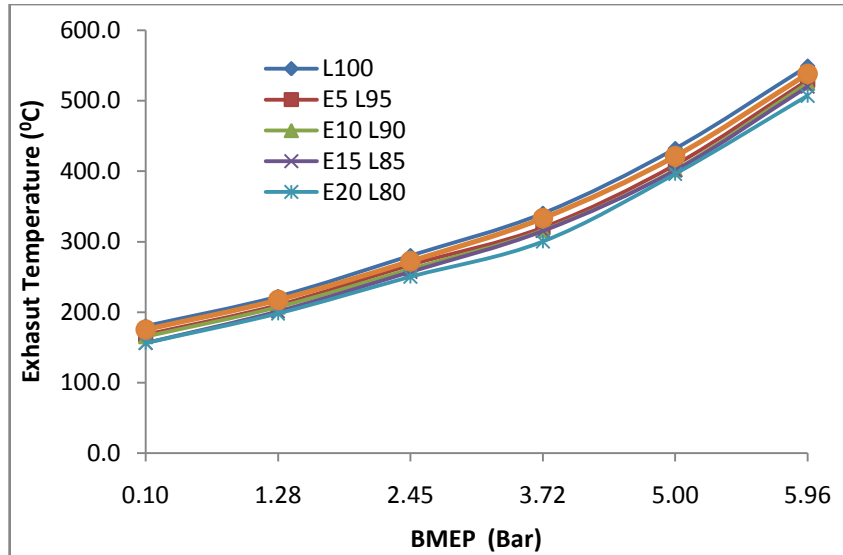


Fig 4.4 BSEC Vs BMEP

#### 4.2.3 EXHAUST TEMPERATURE

Fig. 4.5 shows the variation of exhaust gas temperature with brake mean effective pressure for diesel, biodiesel and ethanol-biodiesel blends. The results show that the exhaust gas temperatures were increasing with increase in brake power in all cases. The highest value of exhaust gas temperature of 549 °C was observed with the L100.



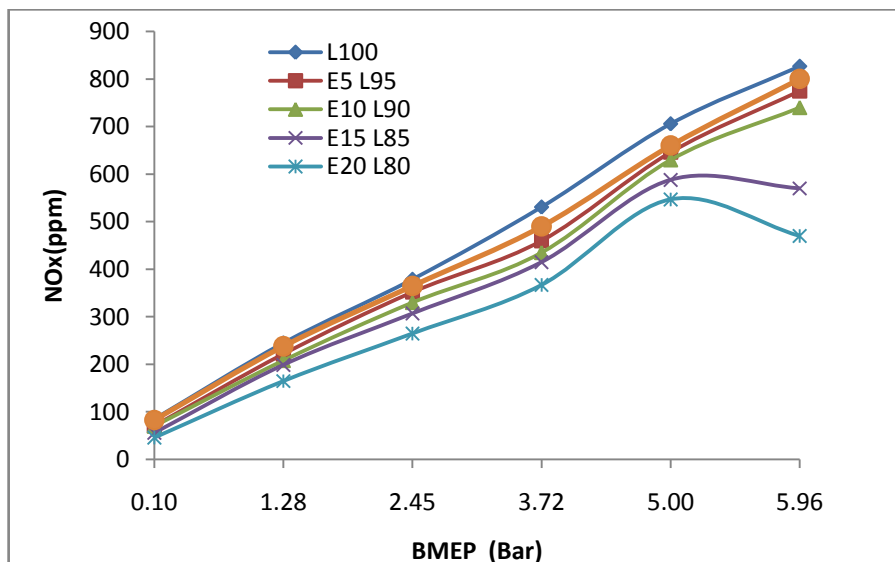
**Fig 4.5 Exhaust Temp. Vs BMEP**

### 4.3 EMISSION CHARACTERISTICS

The emission characteristics of the test engine on linseed biodiesel, ethanol blends and diesel are given below.

#### 4.3.1 NO<sub>x</sub> Emissions

The variation of NO<sub>x</sub> emissions for all the test fuels is shown in Fig.4.6. The NO<sub>x</sub> emissions increased with the increasing engine load, due to a higher combustion temperature.



**Fig 4.6 NO<sub>x</sub> Vs BMEP**

Most important factor for the emissions of  $\text{NO}_x$  is the combustion temperature in the engine cylinder and the local stoichiometry of the mixture. From Fig.4.6, it can be seen that the  $\text{NO}_x$  emissions is decreasing with increase in ethanol in the blends. Similar results were observed by Zhu et al. [18] and Yilmaz [55].

Thermal mechanism dominated the formation of  $\text{NO}_x$  in ethanol-biodiesel combustion. Thus the major factors affecting  $\text{NO}_x$  formation are combustion temperature, local oxygen concentration and residence time in the high temperature zone [18]. In biodiesel, combustion temperature as well as the oxygen content could be higher, leading to higher  $\text{NO}_x$  emission. In case of ethanol-biodiesel blends, the cooling effect of ethanol associated with its lower calorific value and higher latent heat of evaporation could reduce the combustion temperature and hence  $\text{NO}_x$  emission. The cooling effect of ethanol is dominant over reduced Cetane number and higher oxygen content.

#### 4.3.2 CO Emissions

Fig. 4.7 shows the comparison of the CO emissions for all the fuels at different engine load. Within the experimental range, the CO emission from the biodiesel and blends (E5 L95, E10 L90 and E15 L85) were lower than that from pure diesel fuel whereas CO emissions from E20 L80 were higher. Higher oxygen content of biodiesel improved the combustion, which is the reason for the reduction of CO emission. As ethanol concentration increases, the cooling effect of ethanol reduces the gas temperature and leads to higher CO emission. Results of this experiment were found to be in correlation with the result obtained by Zhu et al. [18].

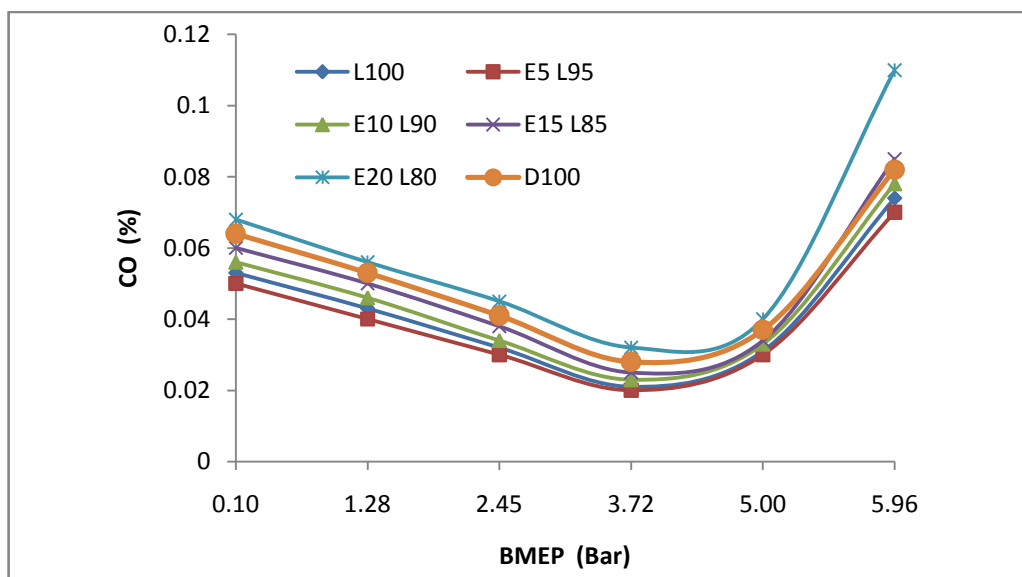


Fig 4.7 CO Vs BMEP

### 4.3.3 CO<sub>2</sub> Emissions

The variations of CO<sub>2</sub> emissions of different fuels from the engine are shown in Fig. 4.8. In the range of whole engine load, the CO<sub>2</sub> emission of ethanol-biodiesel blends were higher than diesel. This is because biodiesel is oxygenated fuel, better combustion and CO emission from biodiesel is lower. With increase in ethanol, cooling effect is increasing and due to reduction in gas temperature lower CO<sub>2</sub> emission occurs [55]. The carbon content is relatively lower in the same volume of fuel consumed at the same engine load.

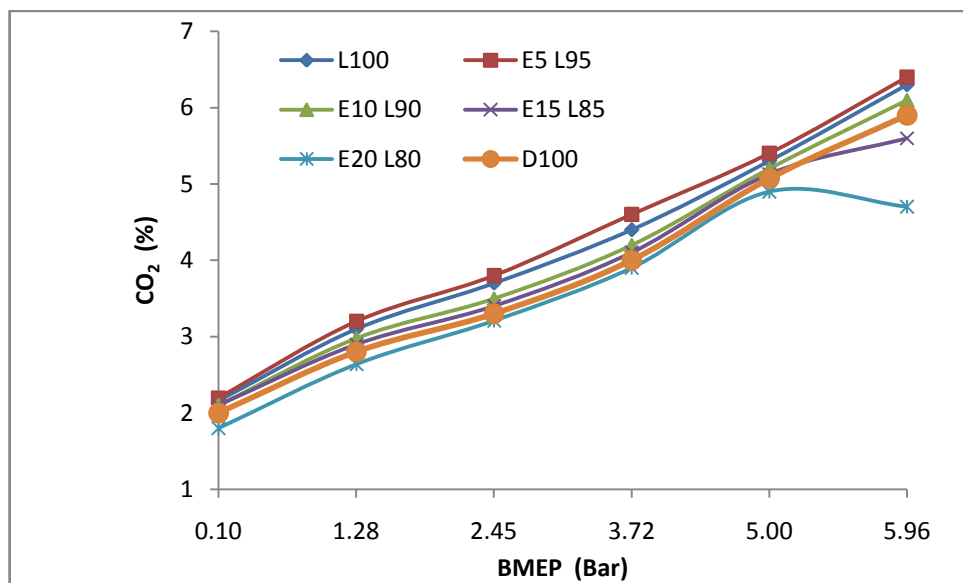


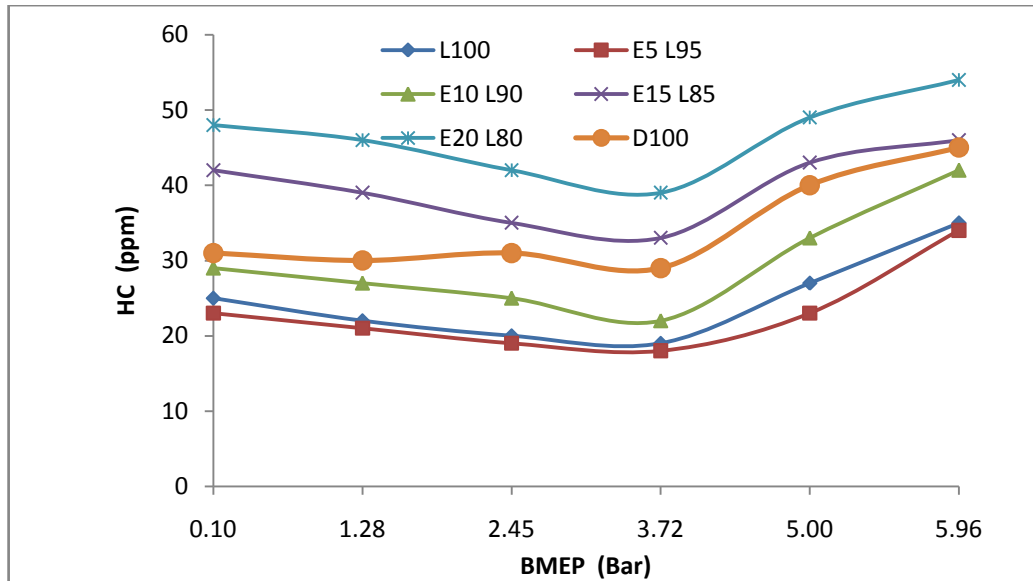
Fig 4.8 CO<sub>2</sub> Vs BMEP

### 4.3.4 Un-burnt Hydrocarbons Emissions

The variation of un-burnt hydrocarbon (HC) emissions for biodiesel and blends are shown in Fig. 4.9. The HC emissions of all the fuels were lower at partial engine load, but slightly increased at higher engine load. This is due to relatively less oxygen available for the reaction when more fuel is injected into the engine cylinder at higher engine load. Fig. 4.9 shows that the HC emission of biodiesel (L100) is lower than that of diesel fuel. As the ethanol concentration is increasing HC emission is increasing and even more than diesel fuel. The higher oxygen content of biodiesel leads to better combustion, resulting in lower HC. Small amount of ethanol in biodiesel could increase the oxygen content and reduced the viscosity and density of the blended fuel, leading to improved spray and atomization, better combustion



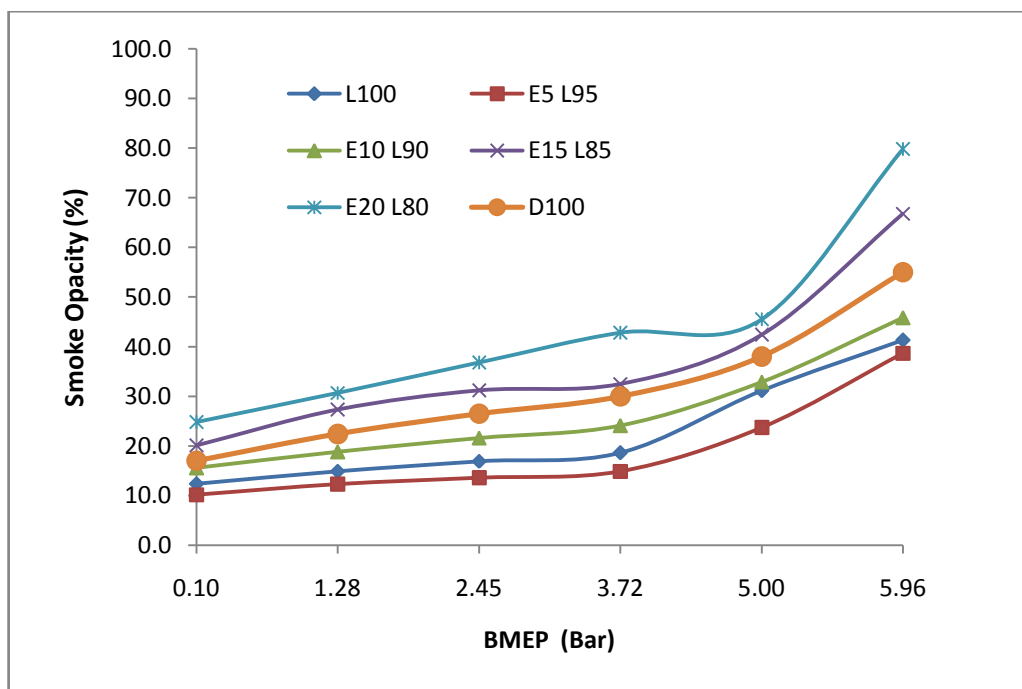
and hence lower HC emission. On the other hand more ethanol addition is expected to show a cooling effect, which causes incomplete combustion and higher HC emission [55].



**Fig 4.9 Un-burnt HC Vs BMEP**

### 4.3.5 Smoke Opacity

Fig. 4.10 shows the comparison of smoke opacity for all the test fuels at different load condition. Till 40% load smoke opacity is slowly increasing, after then increasing at slightly faster rate.



**Fig 4.10 Smoke Opacity Vs BMEP**

Biodiesel (L100) gives lower particulate matter (PM) emission in comparison to diesel fuel in all load modes. This reduction in PM emission is due to the oxygen content of biodiesel which leads to more complete oxidation. Moreover, biodiesel contains less aromatic than that of diesel fuel. The reduction of smoke may be due to the dilution of aromatics, which are soot precursors [18]. Smoke opacity was increasing with increase in ethanol concentration. Increasing ethanol produced cooling effect which resulted incomplete combustion and increased smoke opacity.

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**CONCLUSIONS AND SCOPE FOR FUTURE WORK**

The present study was carried out on a single cylinder diesel engine with objective to evaluate potential suitability, performance and emission characteristics of Linseed biodiesel-Ethanol blend as a fuel in C.I. engine. The brake thermal efficiency of the engine was higher and the brake specific energy consumption of the engine was lower when the engine was fuelled with Linseed biodiesel-ethanol blends as compared to diesel fuel. The oxides of nitrogen ( $\text{NO}_x$ ) for biodiesel fuel were higher than diesel.  $\text{NO}_x$  for ethanol-biodiesel blends during the whole range of experiment were lower than diesel fuel. The Carbon monoxide (CO) emissions for biodiesel and blends (E5 L95, E10 L90 and E15 L85) were lower in comparison to diesel during the entire engine load, whereas CO emissions from 20% ethanol blend was higher than diesel. Hydrocarbon (HC) emissions from the biodiesel and blends (E5 L95 & E10 L90) were found lower than diesel fuel during the whole experimental range, while HC emissions for blends (E15 L85 & E20 L80) were higher than diesel. Smoke opacity for ethanol-biodiesel blends (E15 L85 and E20 L80) were higher than diesel. Smoke opacity for biodiesel was lower than diesel fuel. For 5% blend smoke opacity was lowest during whole range of engine loading. The results from the experiments suggest that biodiesel from linseed oil is potentially good substitute fuel for diesel engine and performance and emissions characteristics were found to be comparable to diesel fuel. The long term assessment of engine durability needs to be examined for blends of ethanol in biodiesel.

Linseed oil is environment friendly. It is renewable, more biodegradable and less toxic. Bio-ethanol is an attractive fuel due to its renewable origin and its oxygen content, but it is unable to be used directly in diesel engines. Blending ethanol into biodiesel fuel appears as an alternative that presents a number of potential advantages such as the substitution of imported oil by a domestic and renewable resource and a significant reduction of emissions in all diesel engines.

The use of ethanol-biodiesel blends has some limitations: it has reduced Cetane number, higher volatility. The use of cetane enhancers and solvent additives can recover the potential of these blends as a promising fuel.

As economy concern, ethanol-biodiesel blends cannot economically compete with regular diesel fuel. So, sufficient back-up policy in the form of tax relaxation or mandates/obligations required.

Production of biodiesel and ethanol, being a bio-agro product can enhance employment in the rural sector of India.

## REFERENCES

1. Chauhan B.S., Kumar N., Cho H.M., 2012, "A study on the performance and emission of a diesel engine fueled with Jatropha biodiesel oil and its blends", *Energy*, 37, pp. 616-622.
2. BP Statistical Review of World Energy, June 2013
3. World Development Indicator Database 2012, [www.devdata.worldbank.org](http://www.devdata.worldbank.org)
4. Basic Statistics on Indian Petroleum & Natural Gas, Ministry of Petroleum and Natural Gas, Government of India, 2011-12.
5. Annual report 2012-13 of Ministry of New and Renewable Energy, India.
6. Energy Statistics 2013 by Central Statistics Office, Ministry of Statistics and Programme Implementation, Govt. of India.
7. BP Energy Outlook 2030, January 2012.
8. IEA World Energy Outlook 2030, January 2011.
9. <http://thinkearth.wordpress.com>
10. <http://www.iea.org/co2highlights/CO2highlights.xls>
11. World Energy Outlook Special Report-13 June 2013 by International Energy Agency, France.
12. <http://co2now.org>
13. <http://www.biodieseltechnologiesindia.com>
14. Centre for Science & Environment, [www.cseindia.org](http://www.cseindia.org)
15. BIOScopes report-Blending ethanol in diesel, May 2007.
16. The Economic Times, New Delhi, 28 may 2012.
17. Dixit S., Kanakraj S., Rehman A., 2012, "Linseed oil as a potential resource for biodiesel: A review", *Renewable and Sustainable Energy Reviews*, 16, pp. 4415-4421.
18. Zhu L., Cheung C.S., Zhang W.G., Huang Z., 2011, "Combustion, performance and emission characteristics of a DI diesel engine fueled with ethanol-biodiesel blends", *Fuel*, 90, pp. 1743-1750.
19. Guzatto R., Martini T.L., Samios D., 2011, "The use of a modified TDSP for biodiesel production from soyabean, linseed and waste cooking oil", *Fuel Processing Technology*, 92, pp. 2083-2088.
20. Jain S., Sharma M.P., 2011, "Thermal stability of biodiesel and its blends: A review", *Renewable and Sustainable Energy Reviews*, 15, pp. 438-448.
21. Popa V.M., Gruia A., Raba D.N., Dumbrava D., Moldovan C., Bordean D., Mateescu

- C., 2012, "Fatty acids composition and oil characteristics of linseed from Romania", *Agroalimentary Processes and Technologies*, 18 (2), pp. 136-140.
22. Srivastava A., Prasad R., 2000, "Triglycerides-based diesel fuels", *Renewable and Sustainable Energy Reviews*, 4, pp. 111-133.
  23. Barnwal B.K., Sharma M.P., 2005, "Prospects of biodiesel production from vegetable oils in India", *Renewable and Sustainable Energy Reviews*, 9, pp. 363-378.
  24. Bona S., Mosca G., Vamerli T., 1999, "Oil crops for biodiesel production in Italy", *Renewable Energy*, 16, pp. 1053-1056.
  25. Narayan R., 1992, "Biomass (renewable) resources for production of material", *Chemicals and Fuels*, 476, pp. 1-10.
  26. Agarwal A.K., 1998, "Vegetable oils versus diesel fuel: development and use of biodiesel in a compression ignition engine", *TERI Information Digest on Energy (TIDE)*, 8, pp. 191-203.
  27. Farsaie A., Debarhte J.V., Kenworthy W.J., 1985, "Analysis of producing the vegetable oil as an alternate fuel", *Energy in Agriculture*, 4, pp. 189-205.
  28. Hebbal O.D., Reddy K.V., Rajagopal K., 2006, "Performance characteristics of a diesel engine with deccan hemp oil", *Fuel*, 85, pp. 2187-2194.
  29. Nwafor O.M.I., 2003, "The effect of elevated fuel inlet temperature on performance of diesel engine running on neat vegetable oil at constant speed conditions", *Renewable Energy*, 28, pp. 171-181.
  30. Abraham C.J., 1996, "A solution to spontaneous combustion in linseed oil formulations", *Polymer Degradation and Stability*, 54, pp. 157-166.
  31. Jutia, Bogdan Z.D., Eric M.K., John C.M., 2011, "Oxidation reactions and spontaneous ignition of linseed oil", *Proceedings of the Combustion Institute*, 33, pp. 2625-2632.
  32. S. M. Geyer, M. J. Jacobus and S. S. Lestz; Comparison of diesel engine performance and emissions from neat and transesterified vegetable oils; *ASAE*, Vol-27, pp 375-381, 1984.
  33. Sharma V., 2008, "Spectroscopic characterization of linseed oil based polymer nanocomposites", *Polymer Testing*, 27, pp. 916-923.
  34. Massimo, 1999, "Drying and oxidative degradation of linseed oil", *Polymer Degradation and Stability*, 65, pp. 303-313.
  35. Food & Agricultural Organisation, <http://agriexchange.apeda.gov.in>

36. Humke A.L., Barsia N.J., 1981, "Performance and emission characteristics of a naturally aspirated diesel engine with vegetable oil fuels", SAE, 810955.
37. Rakopoulos C.D. , Antonopoulos K.A., Hountalas D.T., Giakoumis E.G., 2006, "Comparative performance and emissions study of a direct injection Diesel engine using blends of Diesel fuel with vegetable oils or bio-diesels of various origins", *Energy Conversion & Management*, 47, pp. 3272-3287.
38. Kumar N., Sharma P.B., 2005, "Jatropha Curcus-A Sustainable Source for Production of Biodiesel", Special Issue of *Journal of Scientific and Industrial Research (JSIR)*, 64, pp. 883-889.
39. Schlick M.L., Hanna M.A., Schinstock J.L., 1988, "Soybean and sunflower oil performance in a diesel engine", *Transactions of the ASAE*, 31(5), pp. 1345-1349.
40. Hemmerlein N., Korte V., Richter H., 1991, "Performance, exhaust emissions and durability of modern diesel engines running on rape seed oil", SAE No. 910848, pp. 400-415.
41. Rakopoulos C.D., 1992, "Olive oil as a fuel supplement in DI and IDI diesel engines", *Energy*, 17, pp. 787-790.
42. Ziejewski M., Goettler H.J., Hainees H., Huan C., 1997, "EMA durability tests on high oleic sun flower and safflower oils in diesel engines", *Transactions of the SAE No. 961856*, pp. 1963-1909.
43. Agarwal D., Agarwal A.K., 2007, "Performance and emissions characteristics of Jatropha oil (Preheated and blends) in a direct injection compression ignition engine", *Applied Thermal Engineering*, 27, pp. 2314-2323.
44. Sukumar P., Jegan K.B., Nagarajan G., 2009, "Effect of injection pressure on performance, emission and combustion characteristics of high linolenic linseed oil methyl ester in a DI diesel engine", *Renewable Energy*, 34, pp. 1227-1.
45. Karosmanoglu F., Kurt G., Ozaktas T., 2000, "Long term CI engine test on sunflower oil", *Renewable Energy*, 19, pp. 219-221.
46. Herchel T., Machacon C., Shiga S., Karasawa T., Nakamura H., 2001, "Performance and emission characteristics of a diesel engine fueled with coconut oil diesel fuel blend", *Biomass and Bioenergy*, 20(1), pp. 63-69.
47. Masjuki H.H., Kalam M.A., Maleque M.A., Kubo A., Nonak T., 2001, "Performance, emissions and wear characteristics of an indirect diesel engine using coconut oil blended fuel", *Proc. Inst. of Mech. Engr.*, 215(D), pp. 393-404.

48. Silvio C.A., Almeida, 2002, "Performance of a diesel generator fuelled with palm oil", *Fuel*, 81, pp. 2097-2102.
49. Qudais M.A., Al-Widyan M.I., 2002, "Performance and emissions characteristics of a diesel engine operating on shale oil", *Energy Conversion and Management*, 43, pp. 673-682.
50. Bari S., Yu C.W., Lim T.H., 2002, "Performance deterioration and durability issues while running a diesel engine with crude palm oil", *Proceedings of Inst. of Mech. Engineers*, 215(D), pp. 785-792.
51. Yu C.W., Bari S., Amen A., 2002, "A comparison of combustion characteristics of waste cooking oil with diesel as fuel in a direct injection diesel engine", *Proceedings of IME*, 215(D), pp. 237-242.
52. Pramanik K., 2003, "Properties and use of Jatropha Curcas oil and diesel fuel blends in C.I Engines", *Renewable Energy*, 28, pp. 239-248.
53. Ramadhas A.S., Jayaraj S., Muraleedharan C., 2005, "Characterization and effect of using rubber seed oil as fuel in the compression ignition engines", *Renewable Energy*, 30, pp. 795-803.
54. Reddy J.N., A. Ramesh, 2006, "Parametric studies for improving the performance of a Jatropha oil-fuelled CI engine", *Renewable Energy*, 31, pp. 1994-2016.
55. Yilmaz Nadir, 2012, "Comparative analysis of biodiesel-ethanol-diesel and biodiesel-methanol-diesel blends in a diesel engine", *Energy*, 40, pp. 210-213.
56. Lapuerta M., Armas O., Fernandez J.R., 2008, "Effect of biodiesel fuels on diesel emissions", *Progress in Energy and Combustion Science*, 34, pp. 198-223.
57. Machacon H.T.C., Shiga S., Karasawa T., Nakamura H., 2001, "Performance and emission characteristics of a diesel engine fueled with coconut oil diesel fuel blend", *Biomass and Bioenergy*, 20(1), pp. 63-69.
58. Xue J., Grift T.E., Hansen A.C., 2011, "Effect of biodiesel on engine performances and emissions", *Renewable and Sustainable Energy Reviews*, 15, pp. 1098-1116.
59. Liu J., Li G., Liu S., 2011, "Influence of ethanol and cetane number (CN) improver on the ignition delay of a direct-injection diesel engine", *Energy Fuels*, 25 (1), pp. 103-107.
60. Goering C.E., Schwab A.W., Pryde E.H., Gaugherty M.J., Heakin A.J., 1982, "Fuel properties of eleven vegetable oils", *ASAE*, 25, pp. 1472-1477.
61. Subramanian K.A., Singhal S.K., Saxena M., Singhal S., 2005, "Utilization of liquid



biofuels in automotive diesel engine: An Indian perspective”, Biomass and Bioenergy, 29, pp. 65-72.

62. W Thomas Ryan and O. Maurin Bagby; Identification of chemical change occurring during the transient injection of selected vegetable oils; SAE-paper No. 930933, pp 201-210, 1993.
63. Sciencelab.com, Inc., Houston, Texas
64. Nabi N., Najmul, Hoque S.M., 2008, “Bio-diesel production from linseed oil and performance study of a diesel engine with diesel bio-diesel fuels”, Journal of Mechanical Engineering, 39 (1).
65. [www.chemicalbook.com](http://www.chemicalbook.com)

### Technical Specifications of AVL Di-Gas 4000 Light

Measurement principle:	CO, HC, CO <sub>2</sub>	Infrared Measurement
	O <sub>2</sub>	Electromechanical
	NO	Chemiluminiscence
Operating Temperature	5 - 45°C	
Operating voltage	230 V AC ± 10% / 110 V AC ± 10%	
Power Consumption	90 VA	
Dimensions (W x H x D)	355 x 216 x 370 mm	

### Measurement Ranges of AVL Di Gas 4000 Light

	Measurement Range	Resolution
CO	0 – 10 % Vol.	0.01 % Vol.
CO <sub>2</sub>	0 – 20 % Vol.	0.1 % vol.
HC	0 – 20.000 ppm Vol.	1 ppm
NO <sub>x</sub>	0 – 5.000 ppm Vol.	1 ppm
O <sub>2</sub>	0 – 25 % Vol.	0.01 % Vol.
λ- Calculation	0 – 9.999	0.001
Engine Speed	250 – 9990 rpm/min	10 rpm/min
Oil Temperature	0 - 150 °C	1 °C
Ignition Angle TDC Sensor	- 60 – 100 °c.a.	0.1 °c.a.
Ignition Angle Stroboscope	0 – 60 °c.a.	0.1 °c.a.

### Technical Specifications of AVL 437 Smoke Meter Specifications

Accuracy and Reproducibility	$\pm 1\%$ full scale reading
Measuring Range	0 - 100% capacity in % 0 - $\infty$ absorption m-1
Measurement Chamber	Effective length 0.430 m $\pm$ 0.005
Heating Time	220V in approx 20 min
Light Source	Halogen bulb 12V/5W
Color Temperature	3000 K $\pm$ 150K
Detector	Selenium photocell diameter 45mm Max Sensitivity in light, in frequency range 550 to 570 nm. Below 430 nm to 680 nm sensitivity is less than 4% related to the maximum sensitivity.
Maximum smoke temperature: at entrance	250 °C