Major Project -II
AN EXPERIMENTAL ANALYSIS OF A SINGLE CYLINDER DIESEL ENGINE FUELLED WITH ISO-PROPYL ALCOHOL, BIODIESEL AND DIESEL

Submitted to **Delhi Technological University** in partial fulfilment of the requirement for the award of the Degree of

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 **"AN EXPERIMENTAL ANALYSIS OF A SINGLE CYLINDER DIESEL ENGINE FUELLED WITH ISO-PROPYL ALCOHOL, BIODIESEL AND DIESEL"** in partial fulfilment 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 **“AN EXPERIMENTAL ANALYSIS OF A SINGLE CYLINDER DIESEL ENGINE FUELLED WITH ISO-PROPYL ALCOHOL, BIODIESEL AND DIESEL”** by **ASHISH KUMAR SINGH, (**Roll No.-**2K11/THE/04)** in partial fulfilment of requirements for the award of **Degree of Master of Technology in Thermal Engineering**, is an authentic record of student’s own work carried by him under my supervision.

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

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ABSTRACT

The global thirst for energy is steeply increasing in the last couple of decades due to the densely populated emerging economies across Asia and Africa. Major chunk of this energy is confined to exhaustible fossil fuels like coal and petroleum. Mineral diesel comprises a larger pie in the energy consumption diasporas, mostly used for automotive, agricultural and small industrial power generation purpose worldwide. Energy crisis, global warming and climate change concepts of the last decade has intensified this exploration in recent years. According to IEA, the amount of carbon dioxide being added to the atmosphere is doubling every 30-35 years. In this regard exhaustive research has been carried on alcoholic fuels like methanol and ethanol but little work has been done on exploring the potential of higher alcohols for automotive application. Alcohols can be blended with both the petroleum based and bio-origin based fuels such as vegetable oil and biodiesel. Addition of alcohols reduces dependence of diesel fuel with attractive emission levels. Biodiesel have always been considered as a good alternative to diesel for last many years. However, their density and viscosity is higher as compared to the diesel fuel. The addition of alcohol in the blends of diesel and biodiesel lowers the density as well as viscosity, thus promotes better atomization of the fuel.

In the present investigation, five blends of cottonseed biodiesel, diesel fuel and iso-propyl alcohol were prepared i.e. B20, B20IPA5, B20IPA10, B20IPA15 and B20IPA20. All the blends were found to be homogenous and stable. It was observed that the density and viscosity of the B20 blend was highest and it decreased with the addition of iso-propyl alcohol. The calorific value of all the blends was found to be lesser as compared to neat diesel fuel. The B20IPA20 blend was found to be having minimum calorific value. The maximum brake thermal efficiency was obtained with B20 blend. The brake thermal efficiency of B20IPA5 and B20IPA10 blend was higher in comparison to neat diesel fuel but lower than B20 blend. The brake thermal efficiency of B20IPA15 and B20IPA20 was found to be lower than neat diesel. The minimum brake specific energy consumption was obtained for B20 blend. The brake specific energy consumption of B20IPA5 and B20IPA10 blend was higher in comparison to B20 blend but lower than diesel fuel. The brake specific energy consumption of B20IPA15 and B20IPA20 was found to be higher than neat diesel. The minimum CO and HC emissions were observed with the B20 blend. However, on blending the B20 blend with iso-propyl alcohol the CO and HC emissions were found to increase. The smoke opacity of all the blends was found lower as compared to neat diesel fuel. The maximum NO_X emissions were observed with the B20 blend. However, on blending the B20 blend with iso-propyl alcohol; the NO_X emission decreased.

The peak in-cylinder pressure for the B20 blend occurs before the diesel baseline in terms of the crank angle. However, with increase in volume fraction of the alcohol, the crank angle corresponding to the peak in-cylinder pressure moves towards the diesel baseline. The peak cylinder pressure of B20IPA5, B20IPA10, B20IPA15 and B20IPA20 was lower than B20 blend. Due to lower calorific value of the fuel, iso-propyl alcohol blended fuels showed lower maximum heat release per crank angle than B20 blend and diesel baseline. However, higher heat release rate in the premixed phase of combustion was observed for iso-propyl alcohol blends. The crank angle corresponding to maximum heat release rate shifted rightwards for the isopropyl alcohol blends as compared to baseline data.

From an overall analysis, it can be concluded that blending diesel with cottonseed biodiesel and iso-propyl alcohol provides significant reduction in emissions with marginal drop in the performance.

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NOMENCLATURE

@	At the rate
A/F	Air to Fuel
AC	Alternate Current
AN	Acid Number
ASTM	American Society for Testing and Materials
ATDC	After Top Dead Center
AVL-437	AVL-437 Smoke Meter
B20	20% cottonseed biodiesel + 80% diesel (v/v)
B20IPA5	20% cottonseed biodiesel +5% Iso-propyl Alcohol + 75% diesel (v/v)
B20IPA10	20% cottonseed biodiesel +10% Iso-propyl Alcohol + 70% diesel (v/v)
B20IPA15	20% cottonseed biodiesel +15% Iso-propyl Alcohol + 65% diesel (v/v)
B20IPA20	20% cottonseed biodiesel +20% Iso-propyl Alcohol + 60% diesel (v/v)
BIS	Bureau of Indian Standard
BMEP	Break Mean Effective Pressure
BSEC	Brake Specific Energy Consumption
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
BTDC	Before Top Dead Center
^{o}C	Degree Celsius
CA	Crank Angle
CAGR	Compound Annual Growth Rate
cc	Cubic centimeter
CI	Compression Ignition
cm^{-1}	Per Centimeter

CN	Cetane Number
CO	Carbon Monoxide
CO_2	Carbon Dioxide
cSt	Centi Stoke
Cu	Copper
CV	Calorific Value
D100	Neat Diesel
DI	Direct Injection
DF	Diesel fuel
$dQ/d\Theta$	Apparent Net Heat transfer Rate
$dQ_{ch}/d\Theta$	Gross Heat Release Rate
$dQ_{ht}/d\Theta$	Heat Transfer across the cylinder walls, J/°CA
EOI	End of Injection
EV	Electric Vehicle
°F	Degree Fahrenheit
F/A	Fuel to Air
FFA	Free Fatty Acid
FIT	Fuel Inlet temperature
FIP	Fuel Injection Pump
FT	Fourier Transform
FTIR	Fourier Transform Infra red
g	Gram
$GtCO_2$	Gigatons CO_2
g/cc	Gram per cubic centimeter
HC	Hydrocarbon
H_2O	Water

HP	Horse Power
Hz	Hertz
IC	Internal Combustion
IDI	Indirect Injection
IR	Infra Red
IS	Indian standard
JO	Jatropha oil (Unheated)
Kgoe	Kilogram of oil equivaleant
KOH	Potassium Hydroxide
KVA	Kilo Volt Ampere
kW	Kilo Watt
kW-h	Kilo Watt Hour
LSD	Low Sulphur Diesel
LPM	Liter per Minute
1M	1 Mole
Min.	Minute
ml	Milliliter
mm	Millimeter
Mt	Million Tonnes
Mtoe	Million Tonne of Oil Equivalent
NO	Nitric Oxide
Nos.	Numbers
NO_2	Nitrogen Di-oxide
NO_x	Oxides of Nitrogen
O_2	Oxygen
p.a.	per annum

PM	Particulate Matter
ppm	Parts per million
rpm	Revolutions Per Minute
SAE	Society of Automobile Engineering
sfc	Specific Fuel Consumption
TDC	Top Dead Center
THC	Total Hydrocarbon
ULSD	Ultra Low Sulphur Diesel
UBHC	Unburnt Hydrocarbon
Vs	Versus
v/v	Volume/ Volume
WEO	World Economic Outlook
ρ	Density
%	Percent

CHAPTER 1

INTRODUCTION

1.0 ENERGY CRISIS

Energy is the prime mover of economic growth and is vital to the sustenance of a modern economy. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible and environmentally friendly. In the past few decades there has been a serious focus on the strategies to reduce air pollution and its hazardous effects like global warming and ozone layer depletion.

In the case of the developing countries, the energy sector assumes a critical importance in view of the ever-increasing energy needs requiring huge investments to meet them.

The Internal combustion engines have revolutionized the world in last hundred years but also contributed significantly towards environmental degradation. Post Kyoto Protocol; there have been considerable efforts to reduce GHG emissions and more emphasis is now given on using clean source of energy.

Diesel Engines due to its higher efficiency and ruggedness play a very significant role in Indian economy as these are used in agriculture, transport and industrial sectors. However, diesel engines also emit harmful emissions and pollute environment. Hence, from the point of view of protecting the global environment and the concern for long-term supplies of conventional diesel fuel, it becomes necessary to develop alternative fuels that give engine performance at par with diesel.

In this scenario, non-edible oils and its derivative – biodiesel provides a sustainable solution to the problem. By replacing a substantial amount of diesel fuel with an oxygenated alternative fuel, a significant reduction in emissions of the internal combustion engine could be achieved.

1.1 ENERGY SCENARIO

Secure, reliable and affordable energy supplies are fundamental to global economic stabilty and growth. There has been an enormous increase in the global demand for energy in recent years as a result of industrial development and population growth. Many countries spent billions of rupees to meet their current energy demand. The largest reserve of fossil fuels that is available in india is that of coal. India ranks fifth in terms of reserves of global coal reserves and shares 7 % of the global coal reserve and this reserve is used to fed the thermal power plants throughout the country.

India is among the fastest growing economy of world and use energy extensively to sustain its growth. Together, coal and oil represent about two-thirds of total energy use. Natural gas accounts for a seven percent share, which is expected to grow with the discovery of new gas deposits. Combustible renewables and waste constitute about one forth of Indian energy use. This share includes traditional biomass sources such as firewood and cow dung, which are used by more than 800 million Indian households for cooking[1].

Table 1.1: The primary energy requirements of different countries (in million tonnes of oil equivalent)[2]:-

Country	Oil	Natural Gas	Coal	Nuclear Energy	Hydro electric	Renewable	Total
USA	833.6	26	509.1	188.2	74.3	45.3	2269.3
CANADA	103.1	4.3	21.8	21.4	85.2	4.4	330.3
FRANCE	82.9	6.3	9.0	100.0	10.3	4.3	242.9
RUSSIAN FEDERATION	136.0	82.1	90.9	39.2	37.3	0.1	685.6
UNITED KINGDOM	71.6	2.2	30.8	15.6	1.3	6.6	198.2
CHINA	461.8	17.6	1839.4	19.5	157	17.7	2613.2
INDIA	162.3	5.0	295.6	7.3	29.8	9.2	559.1
JAPAN	201.4	5.0	117.7	36.9	19.2	7.4	477.6
WORLD	4059.1	905.6	3724.3	599.3	791.5	194.8	12274.6

From the table 1.1 it is clear that India accounts for 4.55% of world’s primary energy consumption in 2011. The per capita electricity consumption is lower than many developing countries. The per capita energy consumption in 2009 was 585 kgoe and that of the world was 1802.5 kgoe. [2]

Currently, India is one of the world’s fastest-growing economies. During the period between 2006 and 2010, the country’s gross domestic product (GDP) increased at a CAGR of 8.2%, while global GDP increased at a CAGR of 4.5%.[3]The rapid increase in economic activity has been accompanied by rising energy consumption. During the period between 2006 and 2010, India’s primary energy consumption increased at a CAGR of 8.3%, from 381.4 million tons of oil equivalent (mtoe) to 524.2 mtoe. Coal, oil and natural gas are the major sources of primary energy in India, accounting for 52.9%, 29.6% and 10.6%, respectively, of the primary energy consumption. Although the country has the world’s fourth-largest coal reserves, the demand-supply gap of coal has been consistently increasing, with domestic production unable to keep pace with the demand. The deficit, in case of oil and gas, is even more. India holds just 0.7% of the world’s proven oil reserves while accounting for 3.9% of the global oil consumption, thus importing 73% of its oil consumed. The country has 0.8% of the world’s proven natural gas reserves accounting for 1.9% of the worldwide gas consumption, which results in importing nearly 20% of its natural gas consumed through LNG [2].

India does not have huge reserves of crude petroleum and it is heavily dependent upon imports to meet its requirement for automobiles and other sectors.

In the fiscal year 2010-11, indigenous crude petroleum production in India stood at 37.71 million tonnes, where as consumption was nearly 201.3 million tonnes resulting in a humongous forex outflow of $82.9 billion for crude oil import. A major culprit in the arena of trade deficit witnessed by an emerging economy like India is its excessive dependence on overseas crude oil for domestic requirements.

To improve the present energy crisis, future energy conversion in India should be sustainable which include increase share of renewable fuel, increase efficiency of fuel conversion, reduce environmental impacts, and increase knowledge. In this context, efforts must be put to develop and promote the use of renewable sources of energy to meet the ever increasing energy requirement.

Oil constitutes over 35% of the primary energy consumption in India. It is expected that this would rise both in terms of absolute amount and proportion. The demand projections placed over 250 million metric tons by 2024-25 [4]

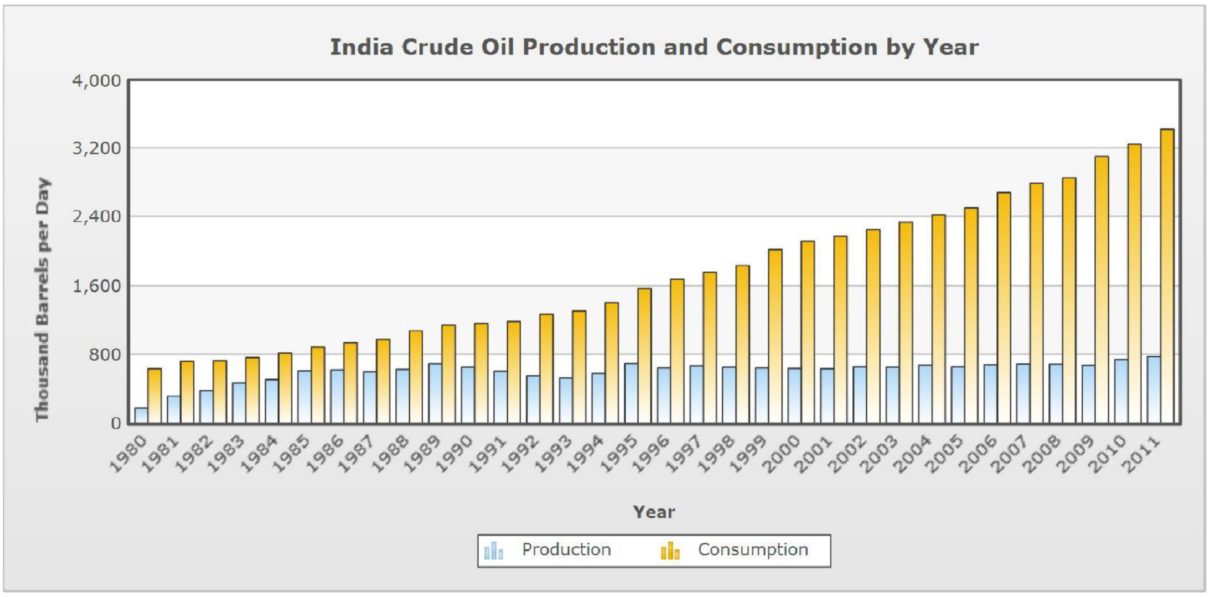


Fig. 1.1:India crude oil production and consumption by year

Table.1.2: yearwise crude oil production and consumption in India [5]

year	Production	Consumption
2000	646.34	2,127.44
2001	642.40	2,183.73
2002	664.75	2,263.44
2003	660.03	2,346.33
2004	683.11	2,429.62
2005	664.66	2,512.43

2006	688.61	2,690.90
2007	697.53	2,800.75
2008	693.71	2,864.00
2009	680.43	3,112.74
2010	751.30	3,255.39
2011	782.34	3,426.00

The fig.1.1 and table 1.2 shows the production and consumption of crude oil over the past three decades. It can be seen from figure 1.1 that production of crude oil as compared to the consumption of crude oil is much lesser. Hence India has to heavily depend on imports to meet its crude oil requirement.

The country imported 163.59 million tonnes of crude oil in 2010-2011 to meet its oil requirement thereby spent nearly 4.559 trillion INR.

The world’s oil consumption pattern is shown in fig1.2[2].

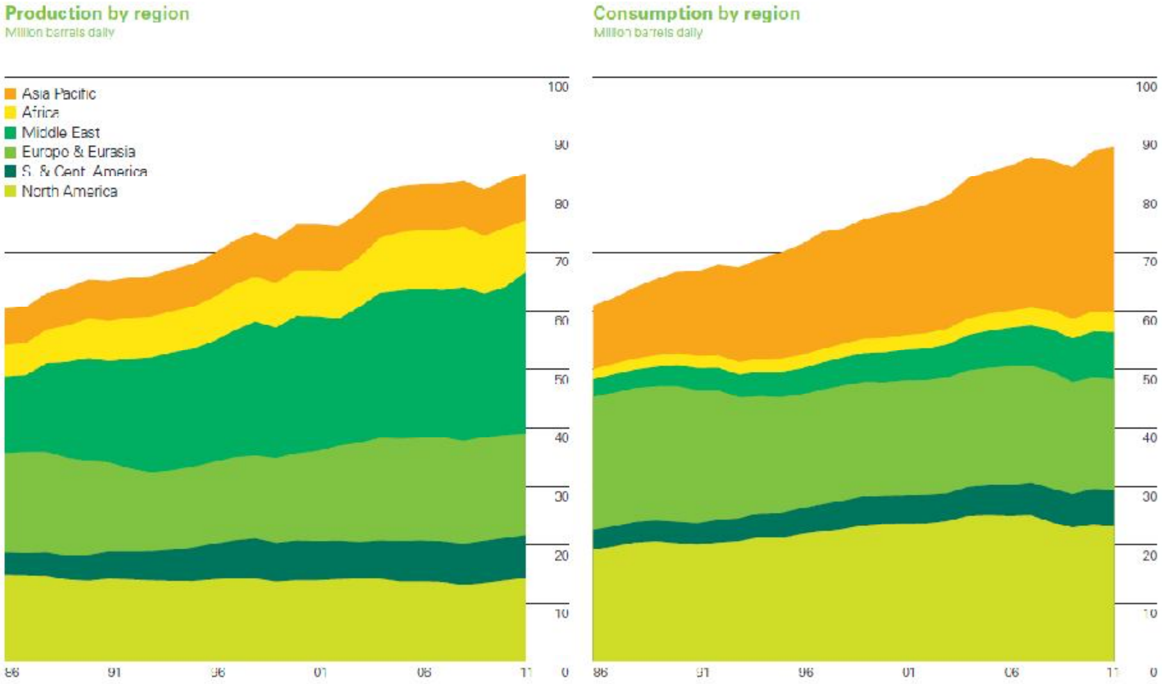


Fig. 1.2: Production and consumption of crude oil by region

From the fig. 1.2 it can be seen that the production of oil in asia pacific regions is much lower as compared to the consumption of oil products in the asia pacific region. Hence, it triggers the need for the partial or complete replacement of crude oil products with the alternate fuels.

1.2 RENEWABLE ENERGY RESOURCES

The potential of renewable energy sources is enormous as they can meet the world’s energy demand. Renewable energy sources such as biomass, wind, solar, hydropower, and geothermal can provide sustainable energy services, based on the use of routinely available, indigenous resources. A transition to renewables-based energy systems is looking increasingly likely as their costs decline while the price of oil and gas continue to fluctuate. In the past 30 years solar and wind power systems have experienced rapid sales growth, declining capital costs and costs of electricity generated, and have continued to improve their performance characteristics. In fact, fossil fuel and renewable energy prices, and social and environmental costs are heading in opposite directions and the economic and policy mechanisms needed to support the widespread dissemination and sustainable markets for renewable energy systems are rapidly evolving. It is becoming clear that future growth in the energy sector will be primarily in the new regime of renewable energy, and to some extent natural gas-based systems, not in conventional oil and coal sources. Because of these developments market opportunity now exists to both innovate and to take advantage of emerging markets to promote renewable energy technologies, with the additional assistance of governmental and popular sentiment. The development and use of renewable energy sources can enhance diversity in energy supply markets, contribute to securing long term sustainable energy supplies, help reduce local and global atmospheric emissions, and provide commercially attractive options to meet specific energy service needs, particularly in developing countries and rural areas helping to create new employment opportunities there[6].

Fig.1.3. shows the share of various sources in power generation.

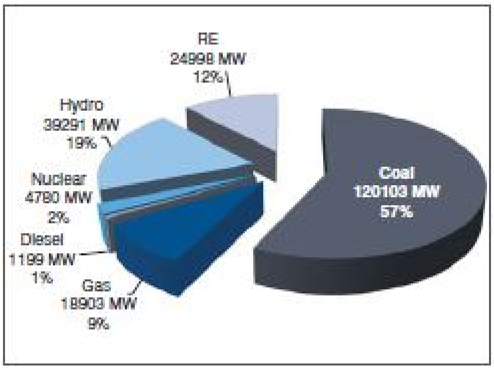


Fig.1.3: Share of various sources in power generation

India, which has to build up its energy infrastructure to keep pace with the economic and social changes, faces a formidable challenge. Energy and electricity requirements have risen sharply in recent years, and this trend is likely to continue in the foreseeable future. As on October 2012, India has a total installed capacity of 209.28 GW, with coal being the principal source of electricity, followed by large-scale hydroelectric power. Renewable energy takes third place at 12%, having jumped nearly four times in the last decade [7].

1.3 FUTURE OUTLOOK

World primary energy consumption is projected to grow by 1.6% p.a. over the period 2010 to 2030, adding 39% to global consumption by 2030. The growth rate declines, from 2.5% p.a. over the past decade, to 2.0% p.a. over the next decade, and 1.3% p.a. from 2020 to 2030 Almost all (96%) of the growth is in non-OECD countries. By 2030 non-OECD energy consumption is 69% above the 2010 level, with growth averaging 2.7% p.a. (or 1.6% p.a. per capita), and it accounts for 65% of world consumption (compared to 54% in 2010). OECD energy consumption in 2030 is just 4% higher than in 2010, with growth averaging 0.2% p.a. to 2030. OECD energy consumption per capita is on a declining trend (-0.2% p.a. 2010-30).

The renewable energy technologies, including biofuels, wind, solar, geothermal, wave and tidal energy, see the fastest increase in demand, but their share of total energy use still reaches only 5.2% in 2030 up from 1.3 percent in 2010[8].

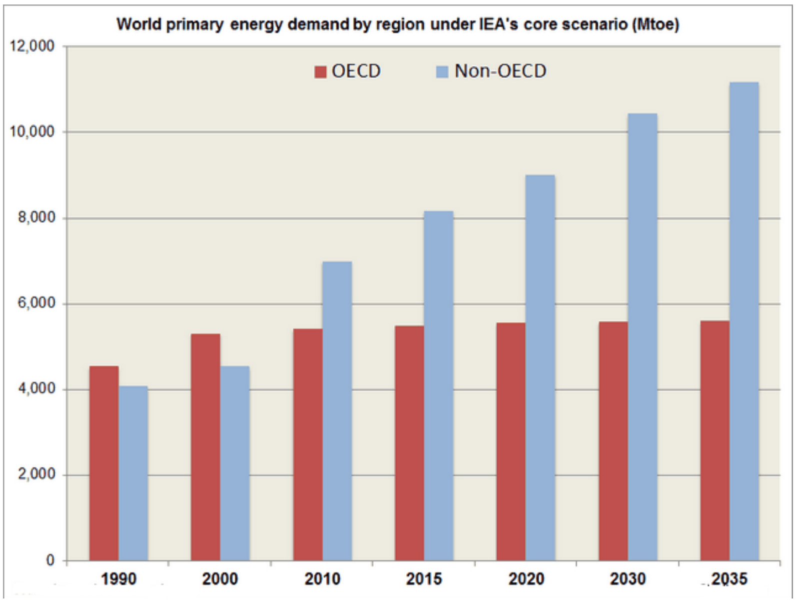


Fig.1.4 : World primary energy demand by region under IEA's core scenario.

From the figure 1.4, it can be concluded that the primary energy demand of the Non-OCED countries will be twice the primary energy demand for the OCED countries in 2035. And the demand for the primary energy for the Non-OECD countries also doubles in the next two decades.

1.4 ENVIRONMENT DEGRADATION AND ITS EFFECT GLOBALLY

The indiscriminate use of fossil fuels has increased the air pollution comprising of the emissions of unburnt Hydrocarbons, NO_X emissions, CO emissions and CO_2 emissions. All these emissions tend to degrade the environment and cause Global Warming and ozone layer depletion.

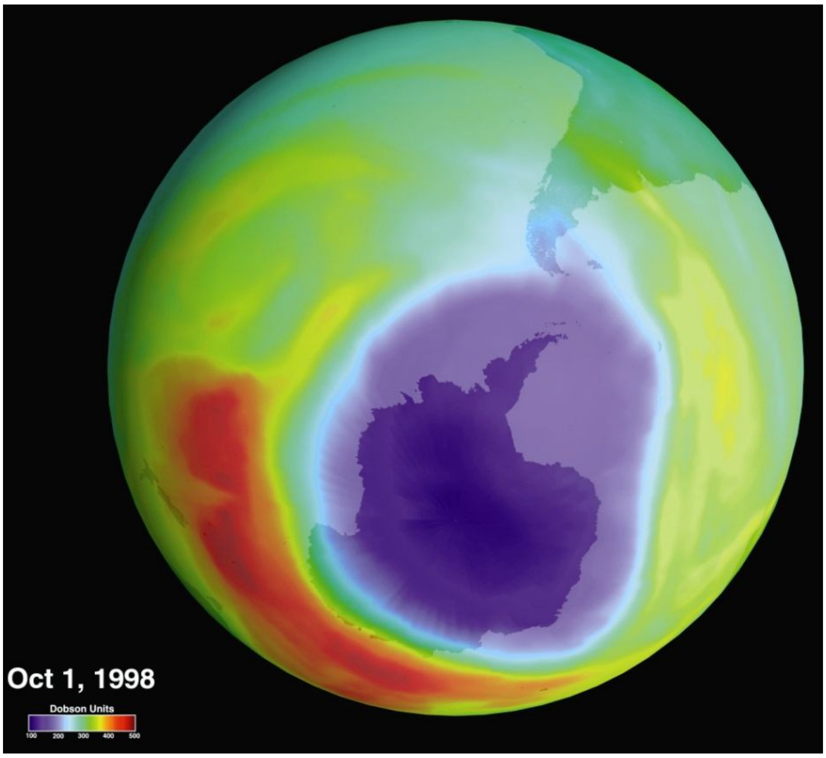


Fig.1.5 Hole in the Ozone Layer Over Antarctica

The ozone layer is a layer in Earth's atmosphere which absorbs most of the Sun's UV radiation. It contains relatively high concentrations of ozone (O_3), although it is still very small with regard to ordinary oxygen, and is less than ten parts per million, the average ozone concentration in Earth's atmosphere being only about 0.6 parts per million. The ozone layer is mainly found in the lower portion of the stratosphere from approximately 20 to 30 kilometres (12 to 19 mi) above Earth, though the thickness varies seasonally and geographically. The ozone layer absorbs 97–99% of the Sun's medium-frequency ultraviolet light (from about 200 nm to 315 nm wavelength), which potentially damages exposed life forms on Earth. The ozone layer can be depleted by free radical catalysts, including nitric oxide (NO), nitrous oxide (N_2O), hydroxyl (OH), atomic chlorine (Cl), and atomic bromine (Br). Hence the emissions from the internal combustion engines tends to increase the NO_X emission thereby indirectly contributing to ozone layer depletion.[9].

1.5 GLOBAL WARMING

Global warming is the rise in the average temperature of Earth's atmosphere and oceans since the late 19th century and its projected continuation. It is one of the major threats in the present scenario. One of the prominent reason that contribute towards global warming is the increase in CO_2 concentration in the atmosphere. The other factors which tend to increase Global warming are nitrous oxide emissions and methane.

The increase in global CO_2 concentation in the atmosphere is shown in fig.1.6

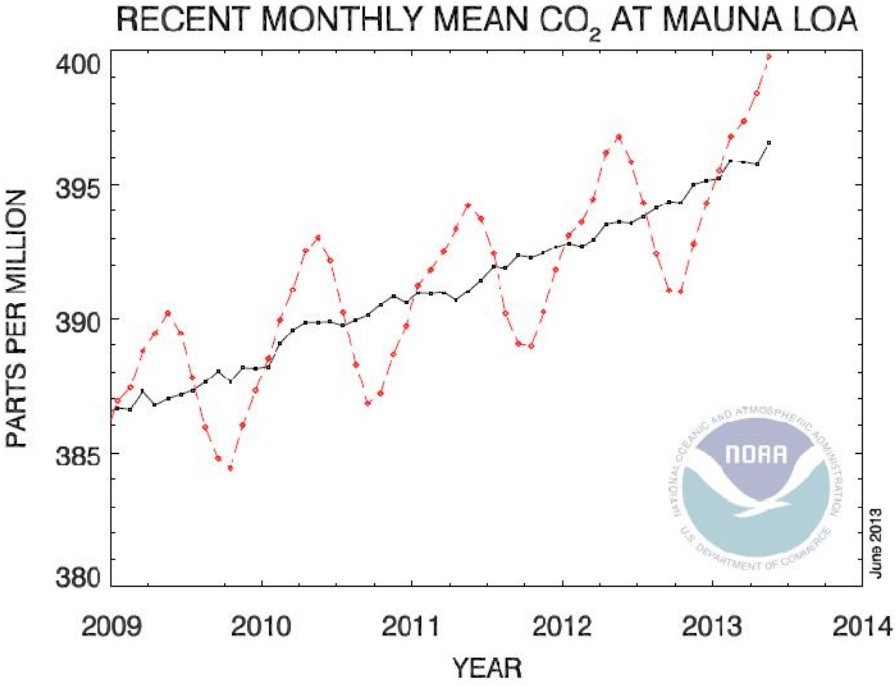


Fig. 1.6: Global CO2 concentration recorded at Mauna Loa Observatory

The last four complete years of the Mauna Loa CO_2 record plus the current year are shown. Data are reported as a dry air mole fraction defined as the number of molecules of carbon dioxide divided by the number of all molecules in air, including CO_2 itself, after water vapor has been removed.

In the figure 1.6, the dashed red line with diamond symbols represents the monthly mean values, centered on the middle of each month. The black line with the square symbols represents the same, after correction for the average seasonal cycle. It can be concluded that the global CO_2 emissions are increasing yearly. In April 2012, the CO_2 emissions level at Mauno Lao observatory was estimated at as 396.18 ppm.

Scientists have high confidence that global temperatures will continue to rise for decades to come, largely due to greenhouse gasses produced by human activities. The Intergovernmental Panel on Climate Change (IPCC), which includes more than 1,300 scientists from the United States and other countries, forecasts a temperature rise of 2.5 to 10 degrees Fahrenheit over the next century.

According to the IPCC, the extent of climate change effects on individual regions will vary over time and with the ability of different societal and environmental systems to mitigate or adapt to change.

The IPCC predicts that increases in global mean temperature of less than 1.8 to 5.4 degrees Fahrenheit (1 to 3 degrees Celsius) above 1990 levels will produce beneficial impacts in some regions and harmful ones in others. Net annual costs will increase over time as global temperatures increase.

"Taken as a whole," the IPCC states, "the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time."[10]

Since the beginning of the heavily researched period of global warming, more certainties have been known, and some new connections have been made that are likely. Scientists in the mid and late 1980's, understood a good deal about greenhouse gases, but could not make an appropriate connection with the increase of the global mean temperature. Today, scientists have discovered that greenhouse gases trap heat in the Earth's atmosphere and tend to warm the planet.

By increasing the levels of greenhouse gases in the atmosphere, human activities are strengthening Earth's natural greenhouse effect. The key greenhouse gases emitted by human activities remain in the atmosphere for periods ranging from decades to centuries.

The effects of the warming are in some cases as broad as some of the hypothesis of the cause of the warming. Rising global temperatures are expected to raise sea level, and change precipitation and other local climate conditions. Changing regional climate could alter forests, crop yields, and water supplies. It could also affect human health, animals, and many types of ecosystems. Deserts may expand into existing rangelands, and features of some of our National Parks may be permanently altered. Most of the United States is expected to warm, although sulphates may limit warming in some areas. Scientists have made a connection between greenhouse gases and the increase in global mean temperature. Some greenhouse gases occur naturally in the atmosphere, while others result from human activities. Once, all climate changes occurred naturally. However, during the Industrial Revolution, we began altering our climate and environment through changing agricultural and industrial practices. Before the Industrial Revolution, human activity released very few gases into the atmosphere, but now through population growth, fossil fuel burning, and deforestation, we are affecting the mixture of gases in the atmosphere [11].

1.6 CO_2 EMISSIONS OUTLOOK

Since the beginning of the Industrial Revolution, the burning of fossil fuels has contributed to a 40% increase in the concentration of carbon dioxide in the atmosphere from 280 ppm to 400 ppm. Global CO2 emissions rose by 4.6% in 2010, after having declined in 2009 due to the impact of the financial crisis, in particular on Western economies. In absolute terms, global CO2 emissions increased by 1.3 GtCO2 between 2009 and 2010. In 2010, 43% of CO2 emissions from fuel combustion were produced from coal, 36% from oil and 20% from gas. Between 2009 and 2010, CO2 emissions from the combustion of coal increased by 4.9% and represented 13.1 GtCO2. Currently, coal fills much of the growing energy demand of those developing countries (such as China and India) where energy-intensive industrial production is growing rapidly and large coal reserves exist with limited reserves of other energy sources.

Without additional abatement measures, the WEO 2012 projects that emissions from coal will grow to 15.3 GtCO2 in 2035. However, adopting a pathway towards limiting the long-term temperature increase to 2°C as in the WEO 2012 450 Scenario – through use of more efficient plants and end-use technologies as well as increased use of renewables, nuclear and carbon capture and storage (CCS) technologies – could see coal consumption drop and CO2 emissions from coal reduced to 5.6 Gt by 2035. Energy Technology

Perspectives 2012 (ETP 2012) also shows that intensified use of coal would substantially increase CO2 emissions unless there was a very widespread deployment of CCS.

Traditionally, industrialised countries have emitted the large majority of anthropogenic greenhouse gases (GHGs). More recently, however, shares of developing country emissions have been rising very rapidly and are projected to continue to do so.

The Kyoto Protocol commits industrialised countries (as a group) to curb domestic emissions by about 5% relative to 1990 by the 2008-12 first commitment period. Alongside the agreement to negotiate a new climate agreement by 2015, certain countries have agreed to take commitments under a second commitment period of the Kyoto Protocol to begin in 2013. The Kyoto Protocol also creates “flexible mechanisms” by which industrialised countries can transfer emission allowances among themselves and earn emission credits from emissions reduction projects in participating developing countries and economies in transition (EITs). Despite its extensive coverage (192 countries), the Protocol is limited in its potential to address global emissions since not all major emitters are included in reduction commitments. The United States remains outside of the Protocol’s jurisdiction and though most developing countries have signed, they do not face emissions target.[12]

The CO_2 emissions of different countries in million tonnes and per capita emissions of CO_2 are shown in figure 1.7[13].

Country	Emissions 2011	Per capita emissions			
		1990	2000	2010	2011
United States	5420	19.7	20.8	17.8	17.3
EU27	3790	9.2	8.4	7.8	7.5
Germany	810	12.9	10.5	10.2	9.9
United Kingdom	470	10.3	9.3	8.1	7.5
Italy	410	7.5	8.1	6.9	6.7
France	360	6.9	6.9	6.1	5.7
Poland	350	8.2	7.5	8.8	9.1
Spain	300	5.9	7.6	6.3	6.4
Netherlands	160	10.8	10.9	10.5	9.8
Russian Federation	1830	16.5	11.3	12.4	12.8
Japan	1240	9.5	10.1	10	9.8
Canada	560	16.2	17.9	16	16.2
Australia	430	16.0	18.6	17.9	19.0
Ukraine	320	14.9	7.2	6.7	7.1
China	9700	2.2	2.8	6.6	7.2
India	1970	0.8	1.0	1.5	1.6
South Korea	610	5.9	9.7	12.2	12.4
Indonesia	490	0.9	1.4	2	2.0
Saudi Arabia	460	10.2	13.0	15.8	16.5
Brazil	450	1.5	2.0	2.2	2.3
Mexico	450	3.7	3.8	3.9	3.9
Iran	410	3.7	5.2	5.4	5.5
South Africa	360	7.3	6.9	7.1	7.2
Taiwan	270	6.2	10.5	11.7	11.8
Thailand	230	1.6	2.7	3.3	3.3

Fig. 1.7: The CO_2 emissions of different countries in million tonnes and per capita emissions of CO_2

It can concluded from the figure 1.7 that maximum CO_2 emissions were from china followed by united states. The CO_2 emissions in india have doubled in the past two decades[13].

1.7 DIESEL ENGINE AND INDIAN ECONOMY

Diesel engines are the backbone of Indian economy. In India, the consumption of diesel fuel is nearly five times higher as consumption of gasoline. Diesel Engines due to its higher efficiency and ruggedness play a very significant role in Indian economy as these are used in agriculture, transport and industrial sectors. However, diesel engines also emit harmful emissions and pollute environment [14]. In the financial year 2011-12 the consumption of diesel in India was 64.74 million tones and the consumption of petroleum in India was 13.77 million tones [15].

Diesel (HSD), largely a transport fuel, forms the biggest chunk (35 per cent) of total petroleum product consumption in India. Diesel is mainly used in the road transport, rail transport, and agriculture and power generation sectors. Road transport and agriculture account for 73-75 percent of total diesel consumption. The balance is accounted for by the railways 4-5 per cent, the manufacturing industry (captive power generation) and power utilities 13-14 per cent and other end-users. The transport fuel demand was met with by considerable imports in past six years.[16] From the point of view of protecting the global environment and the concern for long-term supplies of conventional diesel fuel, it becomes necessary to develop alternative fuels that give engine performance at par with diesel.[17]

1.8 NEED FOR ALTERNATE FUELS

The world is facing crisis due to the dwindling sources of fossil fuels. Rapid depletion of conventional energy is a matter of serious concern for the mankind. It is clear from the above data that the large portion of the primary energy requirement is derived from oil (a fossil fuel) and country spent trillions of rupees to meet the oil energy requirement. Hence all this mandate the need to look for options such as substitute fuels, fuel conversion technologies, renewable energy and efficient energy systems etc. There is a necessity to find alternate fuels for different industrial needs.

Alternate fuels can be suitably used in automobiles and aircrafts. Different researchers have conducted experiments on vegetables oils and alcohols as alternative fuels for I.C engines.

The selection of alternate fuels should be done so as to ensure:-

- No or minimum modification in the design of engine
- Use of same storage and transportation infrastructure
- No toxicity and bio degradability providing safe transportation and handling
- Capability of being produced locally and low investment cost.

These fuels are essentially non-petroleum and result in energy security and environmental benefits. The alternate fuels tend to solve the problem of depleting fossil fuels and environmental degradation too.

According to the IEA, improvements in Internal Combustion Engine Technology and uptake of next generation vehicles as well as alternatives will lead to a 56% reduction in new car emission intensity by 2030.

1.9 POTENTIAL FUELS AVAILABLE

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. The economics of the fuels like vegetable oils, ethanol, and methanol etc. compared to the traditional petroleum resources are marginal.

The fuels available as alternate fuels are:-

1.9.1 ALGAE BASED FUELS

Algae based biofuels have been hyped in the media as a potential panacea to our Crude Oil based Transportation problems. Algae could yield more than 2000 gallons of fuel per acre per year of production. Algae based fuels that were successfully tested by the U.S. Navy Algae based plastics show potential to reduce waste and the cost per pound of algae plastic is expected to be cheaper than traditional plastic prices.

1.9.2 BIODIESEL

Biodiesel is made from animal fats or vegetable oils, renewable resources that come from plants such as, soybean, sunflowers, corn, olive, peanut, palm, coconut, safflower, canola, sesame, cottonseed, etc. Once these fats or oils are filtered from their hydrocarbons and then combined with alcohol like methanol, biodiesel is brought to life from this chemical reaction. These raw materials can either be mixed with pure diesel to make various proportions, or used alone. Despite one’s mixture preference, biodiesel will release a smaller number of its pollutants (carbon monoxide particulates and hydrocarbons) than conventional diesel, because biodiesel burns both cleaner and more efficiently. Even with regular diesel’s reduced quantity of sulfur from the ULSD (ultra-low sulfur diesel) invention, biodiesel exceeds those levels because it is sulfur-free.

1.9.3 Alcohol fuels

Methanol and Ethanol fuel are primary sources of energy; they are convenient fuels for storing and transporting energy. These alcohols can be used in "internal combustion engines as alternative fuels", with butanol and iso propyl alcohol also having known advantages, such as being the only alcohol-based motor fuel that can be transported readily by existing petroleum-product pipeline networks, instead of only by tanker trucks and railroad cars.

1.9.4 Hydrogen

Hydrogen is an emissionless fuel. The by product of hydrogen burning is water, although some mono-nitrogen oxides NOx are produced when hydrogen is burned with air[18].

1.10 ALCOHOL BLENDED FUEL

In context to Compression ignition engines, some difficulties were faced by the researchers with the use of alcohols in compression ignition (CI) engines owing to mainly their low cetane number, high latent heat of vaporization and long ignition delay. However the use of alcohols in diesel engines provides significant improvement in exhaust emissions [19].

Methyl alcohol has the lowest combustion energy of all the fuels listed. However, it also has the lowest stoichiometric or chemically correct air-fuel ratio. Therefore, an engine burning methyl alcohol would produce the most power. It also is possible to take advantage of the higher octane ratings of methyl (and ethyl) alcohol and increase the engine compression ratio. This would increase the efficiency of converting the potential combustion energy to power. Finally, alcohols burn more completely, thus increasing combustion efficiency.

Alcohol also has been used in diesel engines. In this case, the alcohol may be blended with diesel fuel to produce diesohol, or the alcohol may be added to the air intake of the engine. A system for adding a mixture of ethanol and water to the air intake of a turbocharged diesel engine is commercially available. The primary function of the system is to cool the turbocharged air (using the latent heat), and thereby to increase the volumetric efficiency of the engine and produce more output power. A similar result can be obtained using an intercooler. Control of the quantity of alcohol added to the air intake may be difficult and could cause erratic engine operation and/or failure if a large quantity of alcohol was added to the air intake.

With use of ethanol in the diesel engine the primary effect of the ethanol was to lean the air-fuel mixture and produce more efficient combustion.

Methyl alcohol, because of its highly polar nature, does not mix with diesel fuel. Ethanol can be mixed with diesel fuel provided there is little water in the ethanol. A diesel engine normally will not operate on ethanol nor will ethanol provide lubrication for the fuel injection system. Another problem with adding ethanol to diesel fuel is that the cetane number (ignition characteristic) may decrease below the level recommended by the engine manufacturer.

Butyl alcohol can be mixed with diesel fuel in virtually any concentration. It does not separate as water is added or as the temperature is decreased. Further, butyl alcohol does not significantly change the cetane number of diesel fuel. In blends with diesel fuel, butyl alcohol tends to reduce the solidification temperature of the fuel at low temperatures[20].

Iso propyl alcohol has its properties similar to butyl alcohol.

1.11 ALTERNATIVE FUEL IMPUTES

There are some very important parameters which should be considered before adaptation of an alternative fuel in an existing engine. These includes: no or minimum modification required in design of engine, use of same storage and transportation infrastructure, biodegradable and non-toxic assuring safe handling and transportation, capability of being produced locally and low investment cost [21,22].

Public policies need to be revised to encourage the development of these resources. Land for production need to be explored, an extraction and transesterification plant would be required, distribution and storage facilities constructed and monitoring of major users for detection of problems in large scale use are all needed before the technology can be recommended for general use. The magnitude of our energy needs provides an inexhaustible market of our total agriculture production capacity at the highest possible level.

1.12 RATIONALE OF ALCOHOL BLENDED FUELS IN INDIA

The rationale of taking up a major Programme for the production of alcohol fuels for utilization in I.C. Engines in our country lies in the context of :-

- Ethanol and biodiesel being superior fuels from the environmental point of view,
- Use of alcohol blended fuel becomes imperative in view of the stringent emission norms and court interventions,
- Need to provide energy security, specially for the rural areas.
- Need to create employment, specially for the rural poor living in areas having a high incidence of land degradation,
- Providing nutrients to soil, checking soil erosion and thus preventing land degradation, addressing global concern relating to containing Carbon emissions,
- Reducing dependence on oil imports,
- Usability of alcohol blended fuel in the present engines without any major modification,
- Use of alcohol blended fuel not requiring major or time consuming studies or research.

1.13 PRESENT WORK

In context to present work, a more elaborate discussion on adaptation of blends of cottonseed bio-diesel, iso-propyl alcohol and diesel is made. The use of vegetable oils in the diesel engines was known since 1920s. Biodiesel is an alternative fuel that can be made from SVO in a chemical process called transesterification or sometimes two step transesterification process depending on the amount of free fatty acid content of the fuel. Biodiesel has substantially different properties than SVO and results in better engine performance. In particular, biodiesel has a lower boiling point and viscosity than SVO. Because of its improved qualities, vehicle and engine manufacturers generally approve the use of biodiesel blends in their products, though not all approve blend levels as high as 20%[23]. The biodiesel can be made from different edible and non-edible oils. In united states soybean oil is of prime interest because of its easy availability. Similarly in European countries more focus is given producing bio-diesel from rapeseed oil. Countries with tropical climate prefer to utilize coconut oil or palm oil. Other vegetable oils, including sunflower, safflower, etc., have also been investigated. Furthermore, other sources of biodiesel studied include animal fats and used or waste cooking oils[24]. In India, a variety of non-edible oils are used to produce bio-diesel. The price of these non-edible oil is higher as compared to petroleum products. But the motivation should be given and sincere efforts are to be made to increase the yield and oil extraction from the oil seeds to meet the current energy demand of crude oil.

Alcohol is one of the biofuel which gained the importance as a fuel for internal combustion engines since their invention.. Historically, the level of interest in using alcohol as a motor fuel has followed cycles of fuel shortages and/or low feed-grain prices. The properties of methyl, ethyl, propyl and butyl alcohol are compared with octane (high quality gasoline) and hexadecane (high quality diesel fuel) and it was found these alcohols can be used for blending in fuel in internal combustion engine showing promising results. Octane and hexadecane (petroleum fuels) have higher boiling points, lower latent heats and are insoluble in water. The alcohols become more like petroleum fuels as their chemical weights increase[25].

At present many researchers have done experiments on methyl and ethyl alcohol and found that on blending diesel with alcohol the emission from the diesel engine decreases significantly. And the efficiency also increases due to better combustion inside the engine cylinder. Methanol and ethanol are corrosive in nature hence they tends to cause in diesel engine. Corrosion inhibitors are used when diesel blended with methanol and ethanol is used. However the corrosive effect of iso propyl alcohol and iso butanol is less as compared to methanol and ethanol.

2.1 INTRODUCTION

As elaborated in the previous section, rising crude oil prices and rapid decrease in fossil fuel reserves have driven the focus of the researchers to look for the sustainable alternative fuels for crude oil that may give the performance at par with the mineral diesel. Today there are many gasoline and diesel fuel additives available in the market to increase horsepower and improve engine operation, engine life, and fuel economy. They were also claimed to reduce emissions. There additives are the by-product of the refining process and the businessmen make it more profitable.

Biodiesel, as an alternative fuel of diesel, is described as fatty acid methyl or ethyl esters from vegetable oils or animal fats. It is renewable, biodegradable and oxygenated. Many researches pointed out that it might help to reduce green house gas emissions, promote sustainable rural development, and improve income distribution. The biodiesel can be made from edible as well as non-edible oils, but because of the food security, in general it is made from non-edible oils. In the present scenario many researchers made sincere efforts on the use of biodiesel in diesel engines.

In addition to biodiesel, an increased interest of the researchers has emerged for the use of alcohols, and particularly lower alcohols with different amounts and different techniques in diesel engines during recent years. Earlier alcohol was known to be used in gasoline engines due to their renewable nature and lower emission. The potential of alcohol in diesel engines is still under observation. Sincere efforts are being made by many researchers to promote the use of alcohols by directly blending with diesel fuel or by using alcohols with biodiesel.

The potential of alcohols needs to be explored to meet the current energy crisis and to reduce the dependence on fossil fuels and simultaneously achieving the reduction in emission levels.

2.2 BIODIESEL AS A POTENTIAL C. I. ENGINE FUEL

A large number of alternate fuels are available for the replacing the mineral diesel partially or completely. Among those different alternate fuels the most popular ones are the biodiesel, vegetable oils, alcohols, dimethyl ethers and other related fuels. Biodiesel is produced from vegetable oils by transesterification of large, branched triglycerides in to smaller, straight chain molecules of methyl esters, using an alkali or acid or enzyme as catalyst.

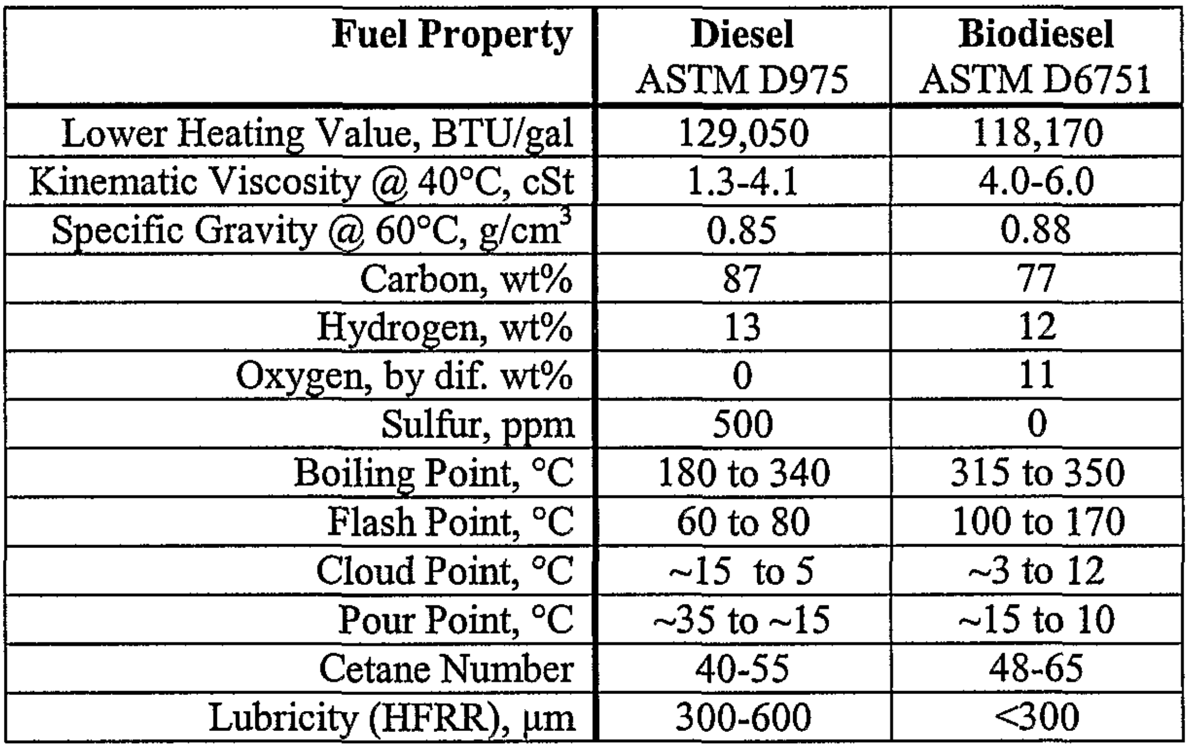
The properties of transesterified vegetable oil is much better as compared to straight vegetable oil. After the esterification of straight vegtable oils, the kinematic viscosity, and specific gravity is reduced, the viscosity of straight vegetable oil is 3-4 times more than transesterified oils. The properties of esterified oils are comparable with that of diesel[26].

Since the properties of transesterified vegetable oil is closer to diesel fuel, hence it is possible to replace the mineral diesel partially or completely with the biodiesel fuel. 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[27]. The conversion of triglycerides in the straight vegetable oil through transestification process reduces the molecular weight to one-third that of triglycerides, the viscosity by a factor of eight and reduces the volatility marginally. The biodiesel contains 15-20% oxygen which may enhance the combustion process inside the cylinder than the hydrocarbon fuel.

The cetane number of biodiesel is close to 50. Biodiesel has lower volumetric heating values (about 10%) than mineral diesel but has a high cetane number and flash point. The esters have cloud point and pour points that are 15–25 C higher than those of mineral diesel.[28]

The American Society for Testing and Materials (ASTM) standards for commercial diesel (ASTM D975) and biodiesel (ASTM D6751) can be found in Table 2.1[29]

Table 2.1: ASTM Standards for Various properties of diesel and biodiesel



Fuel Property	Diesel ASTM D975	Biodiesel ASTM D6751
Lower Heating Value, BTU/gal	129,050	118,170
Kinematic Viscosity @ 40°C, cSt	1.3-4.1	4.0-6.0
Specific Gravity @ 60°C, g/cm^3	0.85	0.88
Carbon, wt%	87	77
Hydrogen, wt%	13	12
Oxygen, by dif. wt%	0	11
Sulfur, ppm	500	0
Boiling Point, °C	180 to 340	315 to 350
Flash Point, °C	60 to 80	100 to 170
Cloud Point, °C	~15 to 5	~3 to 12
Pour Point, °C	~35 to ~15	~15 to 10
Cetane Number	40-55	48-65
Lubricity (HFRR), μm	300-600	<300

Advantages of the biodiesel 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.

It is clear that the use of biodiesel as fuels for diesel engines depends on their physical and chemical properties, and on their combustion characteristics as well as the type of engine use and the conditions of operation. They also have a lower Kinematic viscosity and density and higher cetane number, stoichiometric mixture ratio, and specific enthalpy of combustion than the diesel fuel. Though the properties vary from one type of oil to another, this general comparison with the diesel fuel is valid for all.[30]

The chemical structure of fatty acid content of biodiesel is shown in table 2.2[31]:

Table 2.2 : Chemical structure of some common fatty acids present in biodiesel.

Fatty Acids			
Acid Name	**Structure**	Melting Point	Graphic
SATURATED			
Lauric	$CH_3(CH_2)_{10}COOH$	+44	Graphic
Palmitic	$CH_3(CH_2)_{14}COOH$	+63	
Stearic	$CH_3(CH_2)_{16}COOH$	+70	Graphic
UNSATURATED			
Oleic	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$	+16	Graphic
Linoleic	$CH_3(CH_2)_4(CH{=}CHCH_2)_2(CH_2)_6COOH$	-5	Graphic
Linolenic	$CH_3CH_2(CH{=}CHCH_2)_3(CH_2)_6COOH$	-11	
Arachidonic	$CH_3(CH_2)_4(CH{=}CHCH_2)_4(CH_2)_2COOH$	50	Graphic

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 [32].

Problems faced on using the neat vegetable oil

a) The increased viscosity of the neat vegetable oils leads to poor atomization and incomplete combustion with an unmodified fuel injection system.

b) The clogging of the fuel system.

c) Polymerization during storage.

d) Blow-by causing polymerization of the lubricating oil [33].

e) Thickening and Gelling of the lubricating oil as a result of contamination by the vegetable oil.

f) Oil ring sticking.

g) Carbon deposits around the nozzle orifice, the upper piston ring grooves and on the piston rings [34].

Because of the above mentioned problems the use of straight vegetable oil in the diesel engines is avoided. Hence the properties of vegetable oil have to be modified to make them suitable for diesel engines. The major problem that is associated with vegetable oils is their higher viscosities which cause poor atomization. Four techniques can be used to lower the viscosity of straight vegetable oil:

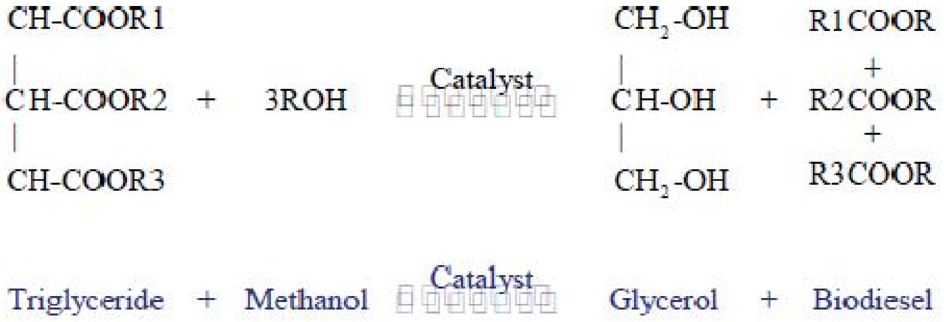
1) Heating/Pyrolysis,

2) Dilution/blending,

3) Micro-emulsion, and

4) Transesterification

The conversion of vegetable oil into biodiesel through transesterification process is commonly known without significant operational and durability issues. However, this adds extra cost of processing because of the transesterification reaction involving chemical and process heat inputs. Transesterification is an equilibrium reaction in which excess alcohol is required to drive the reaction of straight vegetable oil very close to completion. The vegetable oil is chemically reacted with an alcohol in presence of a catalyst to produce methyl esters. Glycerol is produced as a by-product of transesterification reaction.



$$\begin{array}{l} \text{CH-COOR1} \\ | \\ \text{CH-COOR2} \\ | \\ \text{CH-COOR3} \end{array} + 3\text{ROH} \xrightarrow{\text{Catalyst}} \begin{array}{l} \text{CH}_2\text{-OH} \\ | \\ \text{CH-OH} \\ | \\ \text{CH}_2\text{-OH} \end{array} + \begin{array}{c} \text{R1COOR} \\ + \\ \text{R2COOR} \\ + \\ \text{R3COOR} \end{array}$$

$$\text{Triglyceride} + \text{Methanol} \xrightarrow{\text{Catalyst}} \text{Glycerol} + \text{Biodiesel}$$

Where R1, R2, & R3 are long chain hydrocarbons and –COO- is the carboxyl group.

The mixture is stirred continuously and then allowed to settle under gravity in a separating funnel. Two distinct layers form after gravity settling for 24 h. The upper layer is of ester and lower layer was of glycerol. The lower layer is separated out. The separated ester is mixed with some warm water (around 10 % volume of ester) to remove the catalyst present in ester and is allowed to settle under gravity for another 24 h. The catalyst gets dissolved in water, which is separated and the moisture is removed by heating[35].

2.3 ALCOHOL AS C.I. ENGINE FUEL

Biodiesel has lower viscosity and volatility as compared to vegetable oil. However, it still has higher viscosity as compared to mineral diesel. Nowadays, researchers have started blending biodiesel with oxygenated fuel such as alcohols to lower their viscosity and increase their volatility forming biodiesel alcohol blends.

Among the various alcohols methanol, ethanol and iso-propyl alcohol are an edge over others. Since in India there is tremendous potential for the production of large quantities of alcohol from various agricultural feed stocks. Among alcohols, ethanol in the form of azeotropic product of distillation containing 4 to 5 % water or more, is being given the utmost importance from its production point of view. The use of stabilized emulsions of alcohol in diesel fuel offers the advantage that no retrofit is required for the diesel engines. Alcohols have very low cetane numbers so their self-ignition temperatures are very high. So it requires a compression ratio of 25 to 30 to produce the required order of temperature for the ignition of alcohols. The lower viscosity of alcohol effects the delivery characteristics of the pumping, limiting the output of the pump. So it requires considerable modifications for the conventional diesel engines. Among the alcohols iso-propyl has always an edge over the other C.I. engine fuels due to its higher cetane numbers.

Ethanol is one of the possible alternative fuels for partial replacement of mineral diesel in CI engines. The application of ethanol as a supplementary fuel may reduce environmental pollution, strengthen agricultural economy, create job opportunities, reduce diesel requirements, and thus contribute in conserving a major commercial energy source[28].

The alcohols received importance as they can be used as either blends with the conventional fuels in the existing engines or as an additive in biodiesel production. [36]. Due to their higher octane number and high oxygen content, use of alcohol in gasoline engine shows promising results as compared to gasoline[37].

In context to Compression ignition engines, some difficulties were reported with the use of alcohols in compression ignition (CI) engines owing to mainly their low cetane number, high latent heat of vaporization and long ignition delay. However, the use of alcohols in diesel engines provides significant improvement in exhaust emissions [19].

As already mentioned the isopropyl alcohol has higher cetane number, higher net heating value and higher miscibility with diesel fuel, so its potential in diesel engines is still needed to be discovered. The properties of iso-propyl alcohol is shown in Table 2.3

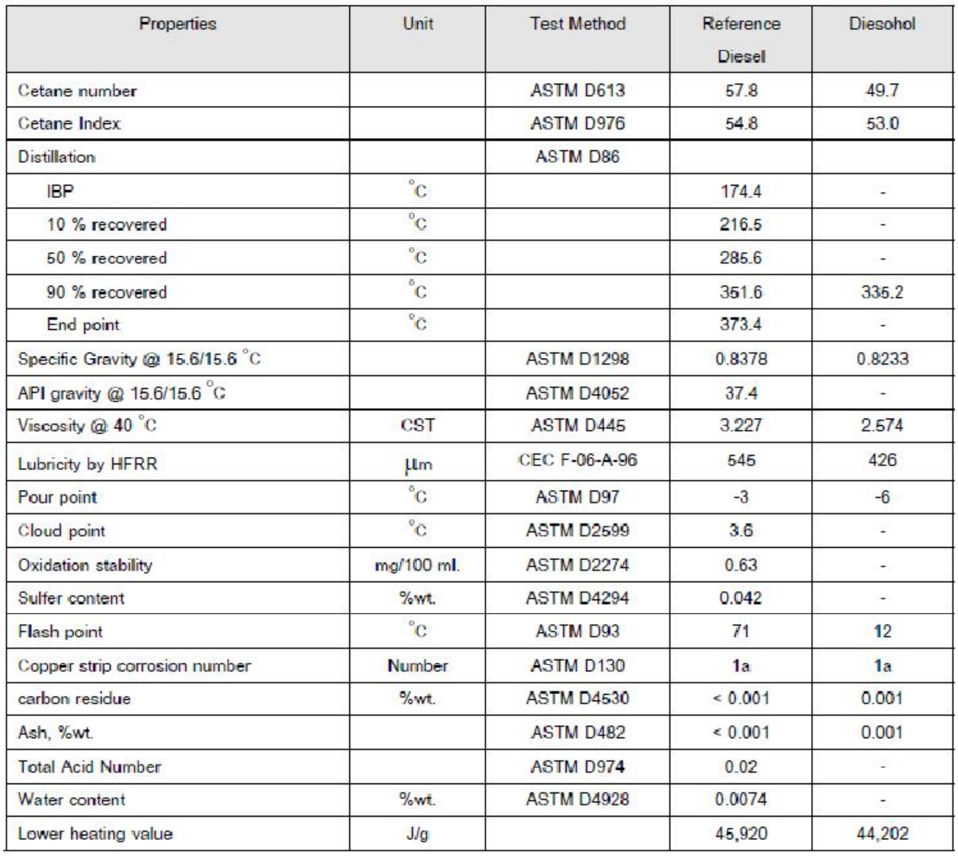
Table 2.3: Properties of iso-propyl alcohol [38]

PROPERTIES	**DESCRIPTION**
Odour	Pleasant. Odour resembling that of a mixture of ethanol and

	acetone.
Taste	Bitter. (Slight.)
Molecular Weight	60.1 g/mole
Colour	Colourless.
Boiling Point (°C/°F)	82.5/180.5
Melting Point (°C/°F)	-88.5/127.3
Critical Temperature (°C/°F)	235/455
Vapor Pressure kPa (@ 20°C)	4.4
Vapor Density (Air = 1)	2.07
Auto-Ignition Temperature (°C/°F)	399/750.2
Cetane Number	13
Flash Points (°C/°F)	11.667/53 - 12.778/55
Viscosity (cSt)	2.92 cSt at 15 °C 2.04 cSt at 25 °C 1.84 cSt at 30 °C
Calorific Value (MJ/Kg)	32.04

Various properties of iso-propyl alcohol are summarized in table 2.3. The chemical composition of iso-propyl alcohol is ($CH_3(CHOH)CH_3$) and the mass fraction oxygen present in iso-propyl alcohol is 26.67%. The low heating value of iso-propyl alcohol is higher compared to ethanol and methanol. The volatility and auto-ignition temperature of alcohols decreases with increase in number of carbon atoms. This indicates that iso-propyl alcohol will have fewer tendencies to result in cavitation phenomenon and it will not encounter any ignition problem when working at lower loads. The iso-propyl alcohol readily mixes with diesel fuel and it has better solubility in diesel as compared to methanol and ethanol. All these properties indicate that iso-propyl alcohol has potential to overcome the drawbacks of methanol and ethanol.

Table 2.4:- ASTM TEST AND LIMITS FOR FUEL PROPERTIES



Properties	Unit	Test Method	Reference Diesel	Diesohol
Cetane number		ASTM D613	57.8	49.7
Cetane Index		ASTM D976	54.8	53.0
Distillation		ASTM D86		
IBP	°C		174.4	-
10 % recovered	°C		216.5	-
50 % recovered	°C		285.6	-
90 % recovered	°C		351.6	335.2
End point	°C		373.4	-
Specific Gravity @ 15.6/15.6 °C		ASTM D1298	0.8378	0.8233
API gravity @ 15.6/15.6 °C		ASTM D4052	37.4	-
Viscosity @ 40 °C	CST	ASTM D445	3.227	2.574
Lubricity by HFRR	μm	CEC F-06-A-96	545	426
Pour point	°C	ASTM D97	-3	-6
Cloud point	°C	ASTM D2599	3.6	-
Oxidation stability	mg/100 ml.	ASTM D2274	0.63	-
Sulfer content	%wt.	ASTM D4294	0.042	-
Flash point	°C	ASTM D93	71	12
Copper strip corrosion number	Number	ASTM D130	1a	1a
carbon residue	%wt.	ASTM D4530	< 0.001	0.001
Ash, %wt.		ASTM D482	< 0.001	0.001
Total Acid Number		ASTM D974	0.02	-
Water content	%wt.	ASTM D4928	0.0074	-
Lower heating value	J/g		45,920	44,202

Table 2.4 shows the ASTM test and limits for mineral diesel and diesohol(blend of diesel and alcohol).

2.4 LITERATURE REVIEW

A pool of good quality recent research works on the potential of alcohols and biodiesel for internal combustion engines applications have been thoroughly reviewed. Some of these works have been described below:-

- Karabektas et. al conducted experiment on a single cylinder, direct injection (DI) diesel engine and tested blends of iso-butanol in diesel fuel. They replaced upto 20% (v/v) of diesel fuel with isobutanol and found 10% isobutanol blend to be an optimum blend in terms of performance and exhaust emissions. It was also concluded that isobutanol can be used as blend with diesel fuel in CI engine without any modification and found 10% isobutanol blend to be an optimum blend in terms of performance and exhaust emissions [19].

- Krishanan et. al conducted tests on ASTM-CFR engine, in duel fuel injection by carburetion method to determine optimum proportions between ethanol and diesel fuels for the higher output and higher efficiency and used some additives to increase the ignition quality. [39].
- Fernández et. al investigated the utilization of ethanol butanol and pentanol diesel blends in three-cylinder, four-stroke, water-cooled, 18.5:1 compression ratio, direct injection diesel engine. They found that 30% Butanol/diesel fuel blend and 25% pentanol/diesel fuel blend could be replaced the use of 100% diesel fuel on unmodified diesel engines without much compromise with the performance [40].
- Sathiyagnanam et. al evaluated the performance and emission characteristics of hexenol, ethanol blends with neat diesel on DI kirloskar TV1 diesel engine. It was found that hexanol can be used to increase the stability of ethanol in diesel fuel. The brake thermal efficiency of 20% blend of ethanol with neat diesel was reported to exceed by 1.89 % at full load than the other blends and mineral diesel fuel. [41].
- Jilin Lei et. al investigated the performance and emission characteristics of 3.298 L, direct injection, turbocharged diesel engine using diesel ethanol blends and varying the pressure. It was found that HC and CO emission increase with decrease in speed and load while NOX and smoke opacity decreased at 81 kpa pressure. Increase in pressure had insignificant effect on engine performance. [42]
- Karthikeyan et al studied performance characteristics of a glowplug assisted low heat rejection diesel engine using ethanol. The experiments were conducted on normal and LHR engine to study the characteristics of glowplug assisted ceramic coated engine and used glowplug for ignition assistance in the engine. It was reported that ethanol with glowplug

assistance in LHR mode has better performance characteristics as NOX and HC emissions were decreased and volumetric efficiency increased. [43].

- Dattatray et. al. studied the feasibility of using higher percentage of ethanol in ethanol-diesel blends with biodiesel as co solvent on multicylinder direct injection diesel engine using diesel–ethanol–biodiesel blends of high ethanol content. It was found that brake specific fuel consumption increased considerably as thermal efficiency improved slightly. The remarkable reduction in smoke opacity was found at higher loads. NOX variation depends on operating conditions while CO emissions drastically increased at low loads. Blend which replaced 50% diesel gave satisfactory performance. [44]
- The methanol diesel fuel blends are unstable and phase separation takes place immediately when mixed. **Liu et al** prepared emulsion of methanol and diesel using a rotating packed bed. The method was suitable to overcome the homogeneity concerns while making diesel methanol blend. The viscosity of the emulsified fuel appeared similar to Newton fluids. A reduction in surface tension was noticed with increase in surfactant concentration in the emulsion where as the stability of the fuel was found to be high with higher rate of agitation, additive amount and higher liquid flow rate. [45].
- The ethanol biodiesel blend can reduce the particulate matter by 30 % with slight increase in NO_X emissions [46].
- The fuel composition and the air/fuel equivalence ratio also has an significant impact on the exhaust emissions of organic acids from the spark ignition engine. Exhaust formic acid is slightly enhanced from aromatics and oxygenated compounds; acetic acid is slightly enhanced from the oxygenated fuel components; propionic acid comes from fuel aromatic compounds. Air/fuel equivalence ratio increases the exhaust concentration of formic, acetic acid (for the fuels without oxygenated compounds), and acrylic acid and decreases the concentration of isovaleric acid. The emissions of all HC generally decrease with the addition of oxygenated compounds, except sometimes in the case of methane, ethane and cyclohexane. Under rich conditions, the relative increase of exhaust methane and benzene is

more important than the other saturated HC. Some HC are correlated with the physical properties of the fuel and other exhaust pollutants [47,48,49,50]

- Labeckas et. al [51] studied an four cylinder, four stroke, direct injection, unmodified naturally aspirated diesel engine operating on neat Rapeseed Methyl Ester and its 5%, 10%, 20% and 35% blends with Diesel fuel. In their investigation it was found that the brake specific fuel consumption at maximum torque and rated power for RME is higher by 18.7% and 23.2% relative to Diesel fuel. The maximum brake thermal efficiency varies from 0.356 to 0.398 for RME and from 0.373 to 0.383 for Diesel fuel. The carbon monoxide, CO, emissions and visible smoke emerging from the biodiesel over all load and speed ranges are lower by up to 51.6% and 13.5% to 60.3%, respectively. The carbon dioxide, CO2, emissions along with the fuel consumption and gas temperature, are slightly higher for the B20 and B35 blends and neat RME. The emissions of unburned hydrocarbons, HC, for all biofuels are low, ranging at 5–21 ppm levels.

- Sureshkumar et. al [52] evaluated the behaviour of PPME and diesel in varying proportions for use in internal combustion engines. The results reveal that blends of PPME with diesel up to 40% by volume (B40) provide better engine performance (BSFC and BSEC) and improved emission characteristics.

- Ramesh et. al [53] investigated the performance and emission characteristics of Diesel engine with jatropha bio-diesel and its blends. It was observed that in the case of jatropha biodiesel alone, the fuel consumption in the diesel engine was about 14 per cent higher than that of diesel. The percent increase in specific fuel consumption ranged from 3 to 14 for B20 to B100 fuels. The brake thermal efficiency for biodiesel and its blends was found to be slightly higher than that of diesel fuel at tested load conditions and there was no difference between the biodiesel and its blended fuels efficiencies. For jatropha biodiesel and its blended fuels, the exhaust gas temperature increased with increase in load and amount of biodiesel.

- Puhan et. al [54] studied the effect of biodiesel fatty acid composition specifically unsaturation for the engine combustion by comparing five Biodiesel produced from different vegetable oils those were tested on a diesel engine. Biodiesel (93% unsaturated fatty acid ester composition) with 55% linolenic ester emitted more oxides of nitrogen of 16.83 g/kWh and exhibited higher thermal efficiency of 29.76% compared to diesel of 12.83 g/kWh and 28.41% respectively. No significant differences in unburnt hydrocarbon (UBHC), carbon monoxide (CO) and smoke emissions among the biodiesel fuels were noticed except linseed oil methyl ester.

- Aydin et. al[58] performed investigation on performance and emission characteristics of a single cylinder, four strokes, air cooled diesel engine fuelled with the blends of cottonseed methyl ester. For the study, cottonseed oil methyl ester (CSOME) was added to diesel fuel, numbered D2, by volume of 5%(B5), 20%(B20), 50%(B50) and 75%(B75) as well as pure CSOME (B100). The experimental results showed that the use of the lower blends (B5) slightly increases the engine torque at medium and higher speeds in compression ignition engines. However, there were no significant differences in performance values of B5, B20 and diesel fuel. Also with the increase of the biodiesel in blends, the exhaust emissions were reduced. They concluded that the lower contents of CSOME in the blends can partially be substituted for the diesel fuel without any modifications in diesel engines.

- Nabi et. al[59] produced biodiesel from cottonseed oil and studied its effect on engine performance and exhaust emissions. The engine experimental results showed that exhaust emissions including carbon monoxide (CO) particulate matter (PM) and smoke emissions were reduced for all biodiesel mixtures. However, a slight increase in oxides of nitrogen (NOx) emission was experienced for biodiesel mixtures.

- Karabektas et. al[60] studied the effects of preheated cottonseed oil methyl ester on the performance and exhaust emissions of a single cylinder, four stroke, naturally aspirated diesel engine. In their investigation, before supplying to the engine, COME was preheated to four different temperatures, namely 30, 60, 90 and 120^0 C. The test data were used for evaluating the brake power and brake thermal efficiency (BTE) together with CO and NOx emissions. The results revealed that preheating COME up to 90^0 C leads to favourable effects on the BTE and CO emissions but causes higher NOx emissions. Moreover, the brake power increases slightly with the preheating temperature up to 90^0 C. When the COME is preheated to 120^0 C, a considerable decrease in the brake power was observed due to the excessive fuel leakage caused by decreased fuel viscosity. The results suggest that COME preheated up to 90^0 C can be used as a substitute for diesel fuel without any significant modification in expense of increased NOx emissions.

- An experimental investigation was conducted by Qi et. al [62] to evaluate the effects of using methanol as additive to biodiesel–diesel blends on the engine performance, emissions and combustion characteristics of a direct injection diesel engine under variable operating conditions. BD50 (50% biodiesel and 50% diesel in vol.) was prepared as the baseline fuel. Methanol was added to BD50 as an additive by volume percent of 5% and 10% (denoted as BDM5 and BDM10). The results indicated that the combustion started later for BDM5 and BDM10 than for BD50 at low engine load, but was almost identical at high engine load. At low engine load of 1500 r/min, BDM5 and BDM10 showed the similar peak cylinder pressure and peak of pressure rise rate to BD50, and higher peak of heat release rate than that of BD50. At low engine load of 1800 r/min, the peak cylinder pressure and the peak of pressure rise rate of BDM5 and BDM10 were lower than those of BD50, and the peak of heat release rate was similar to that of BD50. The crank angles at which the peak values occurred were later for BDM5 and BDM10 than for BD50. At high engine load, the peak cylinder pressure, the peak of pressure rise rate and peak of heat release rate of BDM5 and BDM10 were higher than those of BD50, and the crank angle of peak values for all tested fuels were almost same. The power and torque outputs of BDM5 and BDM10 were slightly lower than those of BD50. BDM5 and BDM10 showed dramatic reduction of smoke emissions. CO emissions were slightly lower, and NOx and HC emissions were almost similar to those of BD50 at speed characteristic of full engine load.

- The performance, emission and combustion characteristics of a single cylinder four stroke variable compression ratio multi fuel engine when fueled with waste cooking oil methyl ester and its 20%, 40%, 60% and 80% blends with diesel (on a volume basis) were investigated by Muralidharan et. al [63] and compared with standard diesel. The results indicated longer ignition delay, maximum rate of pressure rise, lower heat release rate and higher mass fraction burnt at higher compression ratio for waste cooking oil methyl ester when compared to that of diesel. The blend B40 was found to give maximum thermal efficiency. The blends when used as fuel resulted in reduction of carbon monoxide, hydrocarbon and increased nitrogen oxides emissions.

- Agarwal et. al evaluated the performance, emission and combustion characteristics of Karanja oil and mineral diesel blends in a four stroke, single cylinder compression ignition engine. They carried out the engine tests at constant fuel injection pressure (200 bar) for diesel, as well as Karanja oil blends (10%, 20%, 50%, 100% v/v) i.e. K10, K20, K50, K100 respectively. Detailed combustion analysis revealed that the combustion duration increased significantly even with smaller concentration of Karanja oil in the fuel blend. HC, CO and Smoke emissions were found to decrease for 20-50% (v/v) Karanja oil content in the fuel blends.
- Sahoo et. al[65] investigated the combustion characteristics of Jatropha, Karanja and Polanga based biodiesel in a diesel engine. The investigations on the combustion characteristics were conducted on a small size 6 kW air-cooled single cylinder four-stroke diesel engine (Kirloskar Oil Engines Ltd., India) fueled with the different biodiesel fuel blends. They conclude that that biodiesel from unrefined Jatropha, Karanja and Polanga seed oil was quite suitable as an alternative to diesel. They also concluded that neat Polanga biodiesel (PB100) which resulted in maximum peak cylinder pressure (6.61 bars higher than that of diesel) was the optimum fuel blend as far as the peak cylinder pressure is concerned. The ignition delays were consistently shorter for JB100, varying between 5.9^0 and 4.2^0 crank angle lower than diesel with the difference increasing with the load. Similarly, ignition delays were shorter for KB100 (varying between 6.3^0 and 4.5^0 crank angle) and PB100 (varying between 5.7^0 and 4.2^0 crank angle) lower than diesel.

- Gogoi et. al [66] analyzed the performance and combustion characteristics of 10%, 20%, 30% and 40% blending of Koroch Seed Oil Methyl Ester (KSOME) and Jatropha Methyl Ester (JME) with diesel as fuels in a diesel engine. They found that the brake specific fuel consumption (BSFC) was more for the methyl ester blends and particularly for the JME blends. The brake thermal efficiency (BTE) was slightly lower for the biodiesel blends and for the JME blends it was less compared to that of the KSOME blends. The indicated power was more in case of the blends; however it reduced significantly for the 40% blend of KSOME. Both the KSOME and JME blends exhibited similar combustion trend with that of diesel, however, the blends showed an earlier start of combustion with shorter ignition delay. The ignition delay was less and the combustion duration was more for the JME blends as compared to the KSOME blends. They observed that the KSOME blending up to 30% showed an acceptable performance and combustion trend whereas the JME blends showed favorable combustion trend but due its comparatively higher fuel consumption characteristics and the engine BTE was less with the JME fuel blends.

The above all literature survey showed that larger amount of investigation had been done on blends of alcohol and biodiesel but the comprehensive investigation had not been carried out on the potential use of blends of iso propyl alcohol, cottonseed oil biodiesel and diesel fuel for use in direct injection diesel engine.

2.5 STATEMENT OF THE PROBLEM

It is clear from the above literature that alcohol is gaining importance as an alternate fuel in diesel engine. However corrosiveness limits the use of alcohol in diesel engines. With the use of higher alcohols, corrosive effect of alcohol can be minimised. Alcohols can be used directly or indirectly with the diesel fuel. The use of alcohol with biodiesel is an emerging trend nowadays. The biodiesel is blended with alcohol to reduce its viscosity and increase its volatility. A good quality of research has been done on blends of biodiesel and methyl or ethyl alcohol. But the potential of iso-propyl alcohol with biodiesel still needs to be explored.

Therefore, the following objectives were envisaged for the present research work:-

- Comprehensive literature survey
- Identification of suitable alcohol for blending with diesel and biodiesel blend
- Preparation of stable and homogenous blends of diesel, biodiesel and alcohol
- Determination of physico-chemical properties of the various blends formed
- Performance and emissions analysis
- Result discussion and analysis

Chapter 3

SYSTEM DEVELOPMENT AND EXPERIMENTAL PROCEDURE

3.0 INTRODUCTION

Diesel engines are amongst the most efficient prime mover amongst all the power producing machines. Also keeping the fact of depletion of petroleum based fuels and environmental degradation into consideration it becomes necessary to develop a environment friendly fuel having properties similar to the diesel which should meet the future energy demand.

In this context bio-origin fuels are getting attention due to its renewable property and comparable properties. These fuels also have less tendency to pollute the environment. The bio-origin fuels may be alcohol, vegetable oil, animal fats and biogas.

The diesel engine finds its application in the heavy-duty field, for example, industrial power plants, marine propulsion, railroad locomotives, trucks, tractors, buses and farm equipments. Due to high thermal efficiency leading to low fuel consumption and industrial growth, the use of diesel engine has increased exponentially in the last decade. The oil crisis and the emphasis to conserve petroleum- based fuels have provided the motivation for several studies on the developments and testing of alternate fuels. Among these substitute fuels, the emulsions of diesel fuel with alcohols have been found to yield some beneficial effects. To explore some of the beneficial effects of the emulsions of diesel fuel with alcohols, several experiments are conducted with different proportions of various alcohols in diesel. Now-a-days, a thorough research work is being done on using alcohols as a fuel in I.C. Engines in many other countries including India. In a country like ours in which the production of alcohol is vast and alcohol, being an eco-friendly fuel, will definitely find its way into using it as a future fuel for I.C. Engines. Alcohols are bio-degradable and oxygenated, hence they tend to reduce emission and control pollution. Also the biodiesel possess similar tendency to reduce emission as they are oxygenated fuels. Their cetane rating and net heating value are higher and comparable to diesel fuel. 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. Cotton seed oil is one of promising fuel that can be converted to biodiesel in India.

3.1 COTTON PLANT DESCRIPTION

The cotton plant belongs to the genus Gossypium of the family Malvaceae (mallow family); the same family as hollyhock, okra and hibiscus. It is generally a shrubby plant having broad three-lobed leaves and seeds in capsules, or bolls; each seed is surrounded with downy fiber, white or creamy in color and easily spun. The fibers flatten and twist naturally as they dry. There are different species of Cotton - Gossypium hirsutum, Gossypium barbadense, Gossypium herbaceum and Gossypium arboreum, the first two species being the most commonly cultivated.

One or two Weeks after sowing of seeds shoots appear and 50 to 80 days later flowering begins. First buds are formed. After three weeks blossoms appear after blossoming the petals fall of and the offspring or the boll developes. The boll is divided by partision in to 3-5 sections containg seeds. Fibre grows on the seeds. The plant has certainly been grown and used in India for at least 5000 years and probably for much longer. Cotton was used also by the ancient chinese, Egyptians, and North and South Americans.

Successful cultivation of cotton requires a long growing season, plenty of sunshine and water during the period of growth, and dry weather for harvest. It is cultivated in countries with hot climate as India, China ,Egypt, USA, Afganistan, Pakistan, Uzbekistan etc.

Cotton producing areas in India are spread throughout the country. Punjab, Haryana, Rajasthan, Maharashtra, Gujarat, Madhya Pradesh, Andhra Pradesh, Tamil Nadu and

Karnataka are the major cotton producing states. Cotton is sown around May & June and harvested around september to December in different parts of the country.

Cotton seed:-

Once a waste-disposal problem for gins, cottonseed is now a valuable by-product . The seed goes to oil mills, where it is delinted of its linters in an operation similar to ginning. The bare seed is then cracked and the kernel removed. The meal that remains after the oil has been extracted is high in protein. Linters are used for padding in furniture and automobiles, for absorbent cotton swabs, and for manufacture of many cellulose products such as rayon, plastics, lacquers, and smokeless powder for munitions. The hulls, or husks, are used as feed for cattle. Kernels, or meats, provide cottonseed oil. The cake and meal are used for feed and flour. Foots, the sediment left by cottonseed oil refining, provides fatty acids for industrial products. Also in india cotton seed is directly expelled and cotton seed cake containing oil upto 6% is directly used as a cattle feed.

The disadvantage of using cottonseed oil as a fuel in diesel engine is that its viscosity is much higher as compared to diesel fuel owing to large molecular weight and chemical structure of cotton seed oil. Studies have shown that high viscosity causes problems in pumping, combustion and atomization in injector system of diesel engines [59].

3.2 CONVERSION OF COTTONSEED OIL INTO COTTONSEED METHYL ESTER

In the literature review the problems associated with the use of straight vegetable oils have already been discussed. Hence straight vegetable oil needs to be transesterified before using in diesel engines in order to improve its properties. Biodiesel can be produce using a single step or two step conversion process. Karmakar.et.al [55] gave the flow chart for a two step transesterification process shown in fig.3.1. Normally the free fatty acid content of cottonseed oil biodiesel is less than 1%. Hence, it can be directly tranesterified in a single step to make biodiesel.

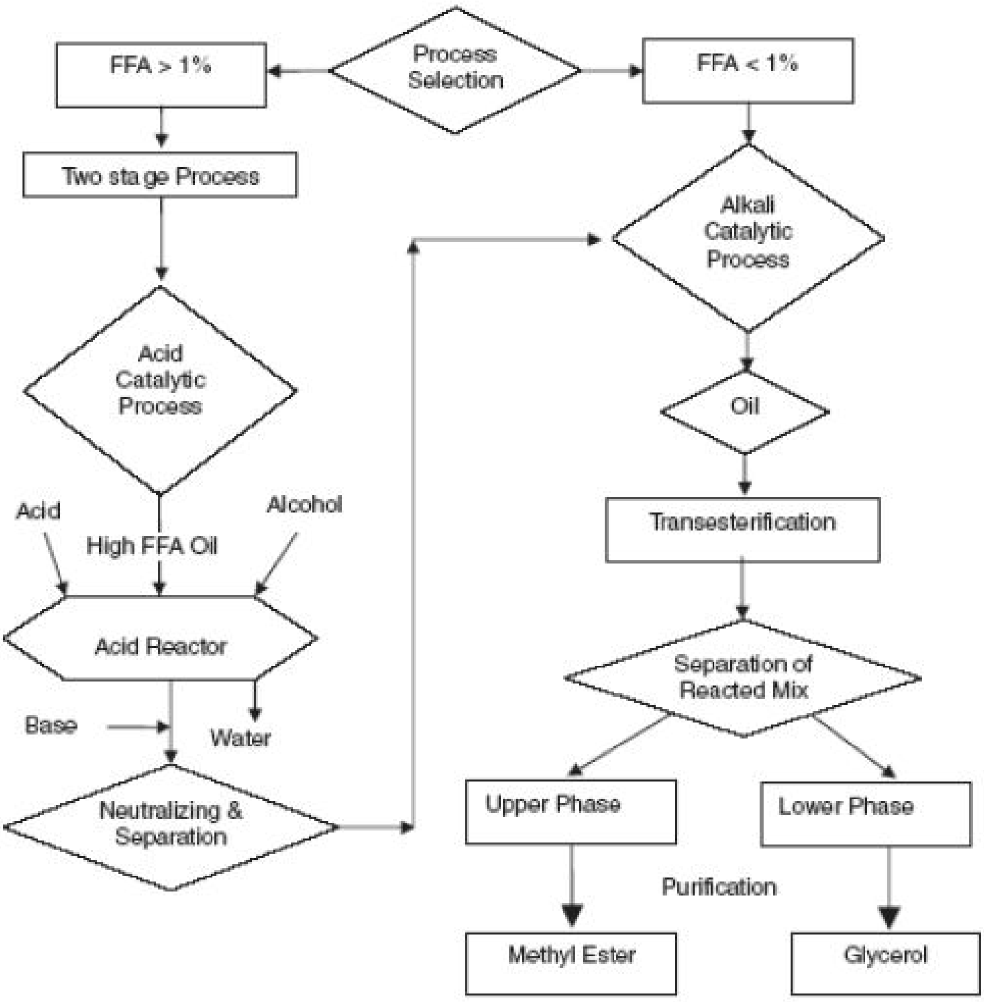


Fig. 3.1: Two step transesterification flow chart

The cottonseed oil was treated with methanol and KOH for the transesterification process. Then the sample was water washed to remove the unreacted catalyst and methanol. Finally the sample was heated to remove the moisture from the sample.

3.3 PRODUCTION OF ISO-PROPYL ALCOHOL

Isopropyl alcohol is a common name for a chemical compound with the molecular formula C_3H_8O or C_3H_7OH. It is a colorless, flammable chemical compound with a strong odor. It is the simplest example of a *secondary alcohol*, where the alcohol carbon is attached to two other carbons sometimes shown as $(CH_3)_2CHOH$. It is a structural isomer of propanol.

It can be produced by three methods[56]:-

1. indirect hydration of propylene
2. direct hydration of propylene
3. catalytic hydrogenation of acetone

3.3.1 Indirect hydration of propylene

The indirect process reacts propene with sulfuric acid to form a mixture of sulfate esters. Subsequent hydrolysis of these esters by steam produces isopropyl alcohol, which is distilled. Di-isopropyl ether is a significant by-product of this process; it is recycled back to the process and hydrolyzed to give the desired product.

3.3.2 Direct hydration of propylene

Direct hydration reacts propene and water, either in gas or liquid phases, at high pressures in the presence of solid or supported acidic catalysts. Higher purity propylene (> 90%) tends to be required for this type of process.

3.3.3 Catalytic Hydrogenation of Acetone

Crude acetone is hydrogenated in the liquid phase over Raney nickel or a mixture of copper and chromium oxide to give isopropyl alcohol. This process is useful when coupled with excess acetone production, such as the cumene process.

Both direct and indirect hydration processes require that the isopropyl alcohol be separated from water and other by-products by distillation. Isopropyl alcohol and water form an azeotrope and simple distillation gives a material which is 87.9% by weight isopropyl alcohol and 12.1% by weight water [57].

3.4 DIESEL , COTTONSEED BIODIESEL AND ISOPROPYL ALCOHOL BLEND FORMATION

The process of making blends of diesel, cottonseed biodiesel and isopropyl alcohol is not very complex process. All the fuels have tendency to readily mix into each other. The composition of various blends formed is shown in the table 3.1:-

Table 3.1 Nomenclature of the various blends formed:-

S.No.	NOMENCLATURE	% OF	% OF	% OF ISO-

		MINERAL DIESEL	COTTONSEED BIODIESEL	PROPYL ALCOHOL
1	**D100**	**100**	**0**	**0**
2	**B20**	**80**	**20**	**0**
3	**B20IPA5**	**75**	**20**	**5**
4	**B20IPA10**	**70**	**20**	**10**
5	**B20IPA15**	**65**	**20**	**15**
6	**B20IPA20**	**60**	**20**	**20**

D100 refers to neat diesel fuel. B20 refers to blend of diesel and cottonseed oil biodiesel formed by mixing 20% by volume of cottonseed oil biodiesel with 80% by volume of diesel. B20IPA5 refers to the blend formed by mixing 20% by volume of cottonseed oil biodiesel, 5% by volume of iso-propyl alcohol and 75% volume of diesel fuel. Similarly for B20IPA10, B20IPA15 and B20IPA20 blends are formed by mixing 20% by volume of cottonseed oil biodiesel, 10%, 15% and 20% by volume of iso-propyl alcohol and 70%, 65% and 60% volume of diesel fuel respectively. The different blends formed are shown in Plate 3.1.

Plate 3.1: Different test fuels formed during the investigation

3.5 HOMOGENEITY TEST

All the blends were kept undisturbed for over three months in closed bottles and were regularly checked for phase separation and homogeneity.

3.6 PHYSICO-CHEMICAL PROPERTIES

The properties that were investigated under present work and the instrument use to measure them are summarized below.

3.6.1 DENSITY AND SPECIFIC GRAVITY

Many instruments are available in the market for the determination of density and specific gravity. The instrument used in this investigation to determine the density and specific gravity is DMA 4500 anton paar density meter. The DMA 4500 ME density measuring module determines a liquid’s density or concentration. The measurement is based on the proven oscillating U-tube principle ensuring highly accurate density values. DMA 4500 ME can be combined with master instruments of the Alcolyzer M series. The determination of density is carried out at 15^0 C. The figure of density meter is shown in plate 3.2

Plate 3.2: Anton Paar Densitymeter

3.6.2 KINEMATIC VISCOSITY

Viscosity is an important property of fuel and it can be defined as measure of the resistance of a fluid which is being deformed by either shear stress or tensile stress. Viscosity describes a fluid's internal resistance to flow and may be thought of as a measure of fluid friction. In general too viscous fuel tends to form scum and deposits on cylinder walls, piston head etc and cause atomisation problems. So it is desirable that viscosity of fuel should be low. The different blend samples are prepared are investigated for viscosity at 40^0 C using a kinematic viscometer as per the specification given in ASTM D445. It consists of a capillary tube in which sample to be test is filled. The capillary tube has two marks engraved on it. The time for flow of fuel sample from upper mark to lower mark is measured and kinematic viscosity is calculated using time taken by each sample. The figure of the kinematic viscometer apparatus is shown in plate 3.3.

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

$V = k \times t$

Where, v= kinematic viscosity of sample

k = constant for viscometer

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

Plate 3.3: Kinematic Viscometer

3.6.3 CALORIFIC VALUE

Calorific value of a fuel refers to the amount of heat released on complete combustion of unit mass of the fuel. To measure the calorific value of the various samples, numerous calorimeters are available in the market. In general higher is the calorific value of fuel; better is the performance of fuel sample in internal combustion engine. The calorific value of various fuel samples in this investigation is calculated using Parr 6100 Bomb Calorimeter.

It is an oxygen bomb calorimeter used to measure the higher calorific value of the fuel as per the specification given in ASTM D240. In the oxygen bomb calorimeter the fuel sample is burned electrically by the use of electrodes fitted in the bomb. The schematic view of Bomb calorimeter is shown in plate 3.4.

Plate 3.4: Parr 6100 Bomb Calorimeter

3.6.4 COLD FILTER PLUGGING POINT (CFPP)

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. It defines the fuels limit of filterability. The apparatus for CFPP measurement is shown in plate 3.5

Plate 3.5: Cold Filter Plugging Point Apparatus

3.6.5 GAS CHROMATOGRAPH

A gas chromatograph is a chemical analysis instrument for separating chemicals in a complex sample. A gas chromatograph uses a flow-through narrow tube known as the column, through which different chemical constituents of a sample pass in a gas stream (carrier gas, mobile phase) at different rates depending on their various chemical and physical properties and their interaction with a specific column filling, called the stationary phase. As the chemicals exit the end of the column, they are detected and identified electronically. The function of the stationary phase in the column is to separate different components, causing each one to exit the column at a different time (retention time). Other parameters that can be used to alter the order or time of retention are the carrier gas flow rate, column length and the temperature.

In a GC analysis, a known volume of gaseous or liquid analyte is injected into the "entrance" (head) of the column, using a micro syringe (or, solid phase micro extraction fibers, or a gas source switching system). As the carrier gas sweeps the analyte molecules through the column, this motion is inhibited by the adsorption of the analyte molecules either onto the column walls or onto packing materials in the column. The rate at which the molecules progress along the column depends on the strength of adsorption, which in turn depends on the type of molecule and on the stationary phase materials. Since each type of molecule has a different rate of progression, the various components of the analyte mixture are separated as they progress along the column and reach the end of the column at different times (retention time). A detector is used to monitor the outlet stream from the column; thus, the time at which each component reaches the outlet and the amount of that component can be determined. Generally, substances are identified (qualitatively) by the order in which they emerge (elute) from the column and by the retention time of the analyte in the column.

The instrument present here is equipped with a FID (flame ionization detector), enabling us to quantify the quantities of various organic compounds present in the sample being tested.

Hence, we can find out precisely the percentage of different fatty acid present in the biodiesel.

Plate 3.6: Gas Chromatograph Apparatus

3.7 SELECTION OF THE DIESEL ENGINE

Diesel engines are robust and due to their higher efficiency, they play a very significant role in Indian economy as these are used in agriculture, transport and industrial sectors. However, they emit harmful emission that cause the air pollution. Hence it is necessary to change the trend of increasing emissions by changing the fuel in the diesel engine which can bring the considerable change in the environment. 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.

3.8 EXPERIMENTAL TEST RIG:-

The setup consists of single cylinder, four stroke, VCR (Variable Compression Ratio) Diesel engine connected to eddy current type dynamometer for loading. The test rig is shown in plate 3.7 The compression ratio can be changed without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. Setup is provided with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The set up has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement. The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance. Labview based Engine Performance Analysis software package "Enginesoft is provided for on line performance evaluation.

The technical specifications of the engine is summarized in table 3.2

Table 3.2 Technical Specifications of the VCR engine

Make	**Kirloskar**
Model	**VCR TEST SETUP 234**
Rated Brake Power (kW)	**3.5**
Rated Speed (rpm)	**1500**
Number of Cylinder	**One**
Bore X Stroke (mm)	**87.5 x 110**
Compression Ratio	**17.5:1**
Variable compression ratio	**12 to 18**
Cooling System	**Water Cooled**

Dynamometer	**Eddy current**
Piezo sensor	**Range 5000 PSI, with low noise cable**
Crank angle sensor	**Resolution 1 Deg, Speed 5500 RPM with TDC pulse**
Load sensor	**type strain gauge, range 0-50 Kg**
Cubic Capacity	**661cc**
Air flow transmitter	**Pressure transmitter, Range (-) 250 mm WC**
Inlet Valve Open (Degree)	**4.5 BTDC**
Inlet Valve Closed (Degree)	**35.5 ABDC**
Exhaust Valve Open (Degree)	**35.5 BBDC**
Exhaust Valve Closed (Degree)	**4.5 ATDC**
Fuel Injection Timing (Degree)	**26 BTDC**

Plate 3.7 Test engine

The schematic diagram of experimental test rig is shown in figure 3.2:-

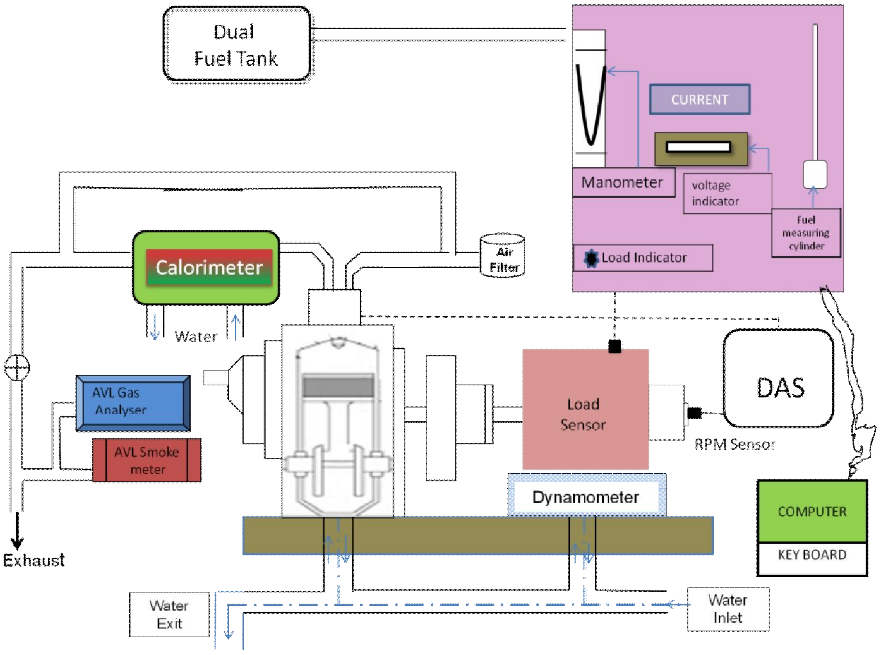


Fig. 3.2: Schematic Diagram of Experimental Test Rig

A voltmeter, ammeter and wattmeter were connected between alternator and load bank. A nut was welded on the flywheel and the photo reflective sensor was mounted on a bracket attached to engine body. 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 iso-propyl alcohol, cottonseed biodiesel and diesel fuel blends 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. Being an air cooled engine it was suitable for hot climate. Absence of radiator, water body and pump made the system more suitable for the tests.

3.9 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. Speed of the engine

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

1. Voltage generated by the alternator

2. Current generated by the alternator

3. RPM of the engine

4. Exhaust gas temperature at inlet and outlet of heat exchanger

5. Blended fuel inlet and outlet temperature across heat exchanger

6. Fuel consumption rate

7. AVL 437 smoke meter

8. 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.

3.10 EXHAUST EMISSION ANALYSIS

The major pollutants appearing in the exhaust of a diesel engine are the oxides of nitrogen. Exhaust gas analysis was done for exhaust smoke opacity, UBHC, CO, CO_2 and NOx using the AVL Di-Gas analyzer (AVL-4000 Light Model). For measuring the smoke opacity, AVL 437 smoke analyzer was utilized. This instrument gave reading in terms of percentage opacity. Of the light beam projected across a flowing stream of exhaust gases, a certain portion of light is absorbed or scattered by the suspended soot particles in the exhaust. The remaining portion of the light falls on a photocell, generating a photoelectric current, which is a measure of smoke density.

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.

The instruments that were used for the analysis of emissions are shown in plate 3.8 and plate 3.9

Plate 3.8 AVL Di-Gas 4000 Light

Plate 3.9 AVL 437 Smokemeter

The technical specification of smokemeter and AVL Di-gas 4000 light are summarized in table 3.3

Table 3.3: Specifications of AVL Di-gas 4000 light and AVL Smokemeter

Emission sensor	Measurement range	Resolution
CO	0-10% Vol.	.01 % Vol.
CO_2	0-20%Vol.	.1 % Vol.
NO_X	0-5.000 ppm Vol.	1 ppm
HC	0-20.000 ppm Vol.	1 ppm
AVL Smoke meter	0-100%	± 1%

3.11 EXPERIMENTAL PROCEDURE

The engine was started at no load by pressing the exhaust valve with decompression lever and it was released suddenly when the engine was hand cranked at sufficient speed. After feed control was adjusted so that engine attains rated speed and was allowed to run (about 30 minutes) till the steady state condition was reached. With the fuel measuring unit and stop watch, the time elapsed for the consumption of 10, 20 and 30cc of fuel was measured and average of them was taken. Fuel Consumption, RPM, exhaust temperature, smoke density, CO, NO_x, HC , CO_2 and power output were also measured. Fuel leakages from the injector were measured with small measuring cylinder. The engine was loaded gradually keeping the speed with in 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 B20 blend was used to evaluate its suitability as a fuel. The performance and emission characteristics of neat B20 were evaluated and compared with diesel fuel. Then subsequently B20IPA5, B20IPA10, B20IPA15 and B20IPA20 blends were used in the engine and their performance and their performance and emission characteristics were evaluated. These data were than compared with bo the diesel fuel. The engine was always started with diesel as a fuel and after it was run for 20-25 minutes, then it was switched over to different blends. Before turning the engine off, each blend was replaced with diesel oil and it was run on diesel oil till all the blend in fuel filter and pipe line is consumed.

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 blends of diesel, cottonseed biodiesel and iso-propyl alcohol and performance and emission studies of the diesel engine when run on various blends and compares the results with baseline data.

4.1 COMPARISON OF PHYSICO-CHEMICAL PROPERTIES BETWEEN DIESEL AND VARIOUS BLENDS

The Diesel fuel and various blends formed were analyzed for several physical, chemical and thermal properties. Density and viscosity of the various blends formed was found higher than diesel. Presence of oxygen in the blended fuel improves combustion properties and emissions but reduces the calorific value of the fuel. All the blends have approximately 85-90% calorific value compared to diesel. Nitrogen content of the fuel also affects the NO_x emissions (by formation of fuel NO_x).

The various Physico-chemical Properties are shown in table 4.1

Table 4.1 : Physico-chemical Properties Comparision of various blends

S.No.	BLEND	DENSITY (Kg/m^3)	VISCOSITY (mm^2/sec)	CALORIFIC VALUE(MJ/Kg)	CFPP RESULT(^0C)
1	D100	824.2	3.123	45.49	-5
2	B20	838.46	3.535	43.93	-4
3	B20IPA5	835.83	3.468	43.12	-14
4	B20IPA10	833.89	3.398	41.29	-15
5	B20IPA15	832	3.351	40.04	-16
6	B20IPA20	830.69	3.271	39.74	-17

The cold flow properties of the blends containing iso-propyl alcohol shows much improved cold flow properties and it improves with the increasing percentage of iso-propyl alcohol.

4.2 PHASE SEPARATION AND HOMOGENEITY

No phase separation was observed in the blends even after three months. Visual inspection and Centrifuge test were used to determine the stability of the blends.

4.3 GAS CHROMATOGRAPHY

The gas chromatography of cottonseed methyl ester was done and fatty acid profile of cottonseed methyl ester was obtained. The gas chromatography was conducted by injection of 20mg of the cottonseed methyl ester into the gas chromatographic equipped with a split/split-less injection port using flame ionization detector and N_2 as the carrier gas flowing at a rate of 8ml/min. The split ratio was 50:1 while the injection temperature was kept at 350^oC and sample elusion time of 45 mins. The percentage composition by mass of the individual acids was computed. Fatty acid profile of cottonseed methyl ester in summarized in table 4.2 The fatty acid profile graph is shown in fig 4.2

Table 4.2 Fatty Acid Profile of Cotton Seed Oil Biodiesel

Fatty Acid	**Chemical Structure**	**Systematic Name**	**Molecular Formula**	**Mol. weight**	**Percentage comp. (% wt)**
Caprylic acid	C8:0	Caprylic acid	$C_8H_{14}O_2$	144.22	0.83
Mysteric acid	C14:0	Tetradecanoic	$C_{14}H_{28}O_2$	228.38	23.39
Oleic acid	C18:1	*cis-9-*octadecanoic	$C_{18}H_{34}O_2$	282.47	22.64
Linoleic acid	C18:2	*cis-9,12-*octadedienoic	$C_{18}H_{32}O_2$	280.5	51.87
Linolenic acid	C18:3	*cis-9,12,15-*octadecatrienoic	$C_{18}H_{30}O_2$	278.4	0.51
Arachidic acid	C20:0	Eicosanoic	$C_{20}H_{40}O_2$	304.47	0.43
Erucic acid	C22:1		$C_{22}H_{44}O_2$	338.6	0.12
Saturated					**24.65**
Unsaturated					**75.14**
Total					**99.79**

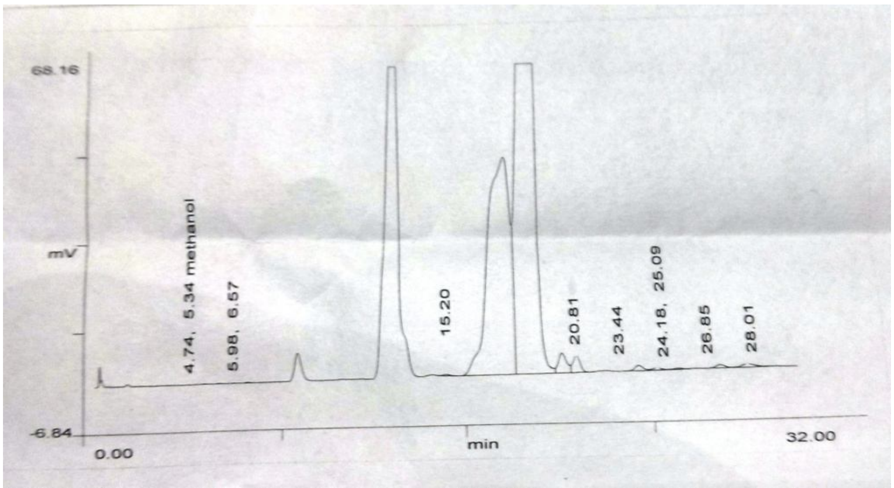


Fig. 4.1 fatty acid profile of cottonseed methyl ester

4.4 PERFORMANCE CHARACTERISTICS

Various performance characteristics were analyzed and they are summarized in this section. The performance characteristics of different blends were compared with baseline data obtained from diesel fuel.

4.4.1 BRAKE THERMAL EFFICIENCY

The variation of brake thermal efficiency with respect to percentage load is shown in figure 4.2. It can be observed that brake thermal efficiency increases on replacing the 20%(v/v) of diesel fuel with cottonseed methyl ester (B20 blend) . The break thermal efficiency of B20IPA5 and B20IPA10 is slightly higher than diesel fuel but lower than B20 blend. Subsequently, the BTE of B20IPA15 and B20IPA20 decreases as compared to diesel fuel and the BTE decreases with increase in the blending percentage of iso-propyl alcohol. The maximum brake thermal efficiency for B20, B20IPA5, B20IPA10, B20IPA15 and B20IPA20 are 28.33%,27.64%,27.85%, 27.39%and 27.15% respectively where for neat diesel the maximum brake thermal efficiency was 27.66%. The increase in brake thermal efficiency for the B20 blend corresponds to promoted the combustion inside the engine cylinder due to more availability of the oxygen content in the fuel. However, for the blends containing iso-propyl alcohol brake thermal efficiency reduces due to lower cetane number and lower net heating value of the iso-propyl alcohol. The results are in close confirmation with the investigations made by Karebetkas et. al[19], Karthikeyan et. al[43], Aydin et. al[58], Nabi et. al [59].

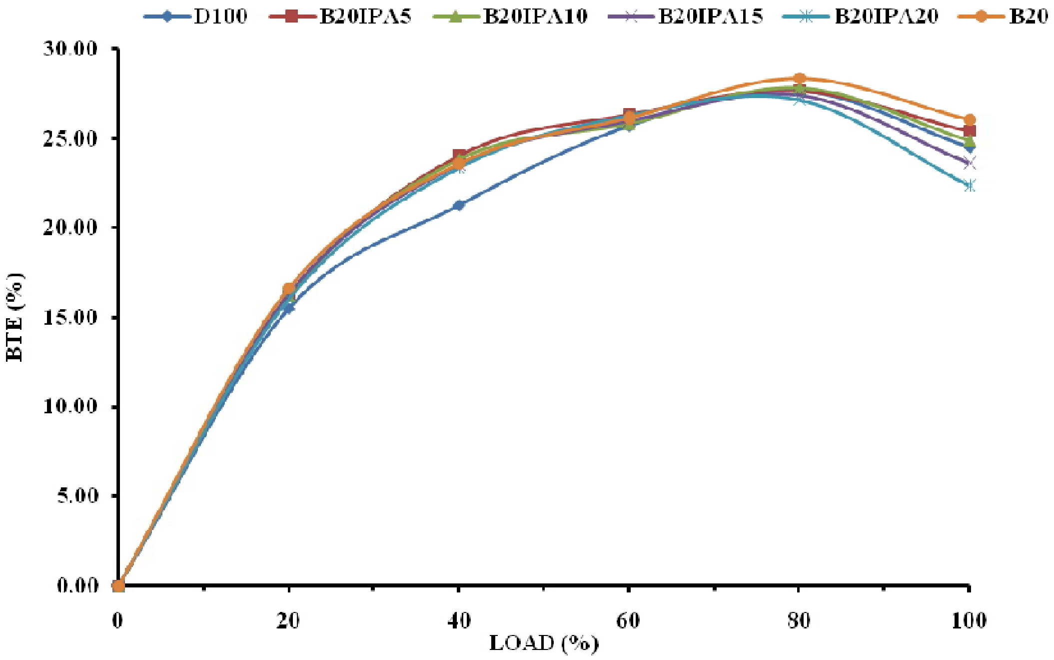


Figure 4.2: Variation of brake thermal efficiency for various blends with respect to the percentage load.

4.3.2 BRAKE SPECIFIC ENERGY CONSUMPTION

Brake specific fuel consumption is not the reliable parameter to be considered for comparing the performance of the blends of diesel, cottonseed biodiesel and iso-propyl alcohol. As the calorific value and density of iso-propyl alcohol and cottonseed biodiesel are significantly different. In this regard brake specific energy consumption plays an important role in determining the energy requirement for various blends to produce the unit power. The variation in brake specific energy consumption for various blends with respect to percentage load is shown in fig 4.3 In can be seen that the brake specific energy consumption reduces for the B20 blend as compared to neat diesel. This can be attributed to better combustion due to more oxygen content in the fuel. However, the BSEC for B20IPA5 and B20IPA10 is lower as compared to neat diesel but higher than B20 blend. The BSEC for B20IPA15 and B20IPA20 blends is higher as compared to diesel fuel. The increase in BSEC for blends containing iso-propyl alcohol as compared to B20 blend can be attributed to lower net heating value of iso-propyl alcohol. Hence for generating the same amount of power, more fuel is consumed in case of blends containing iso-propyl alcohol. The results are in consistence with the investigations made by Karebetkas et. al[19], Karthikeyan et. al[43], Aydin et. al[58], Nabi et. al [59].

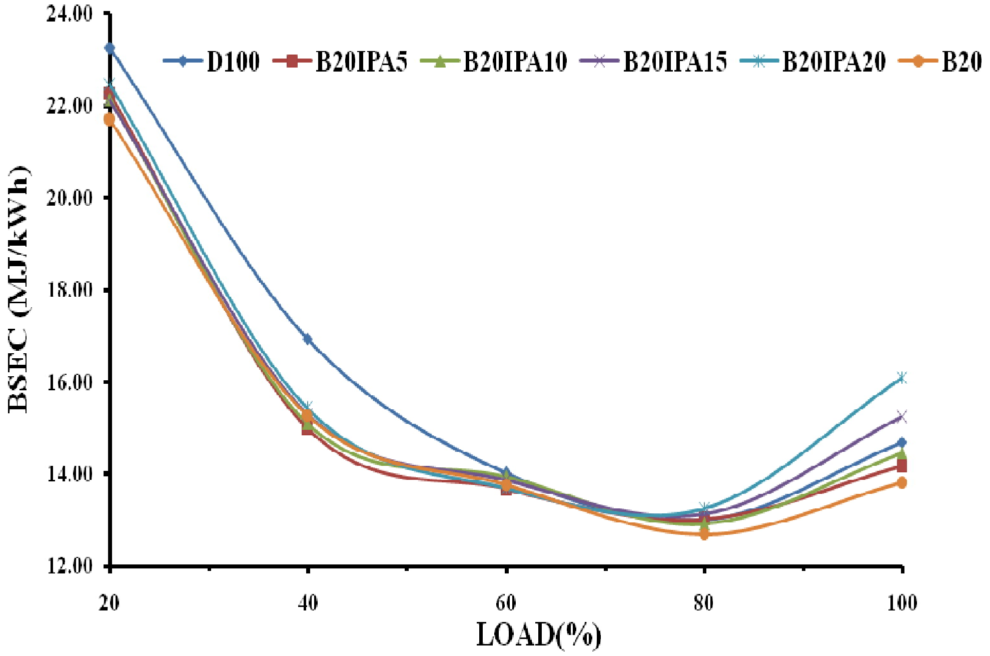


Fig.4.3:Variation of brake specific energy consumption with respect to percentage load for various blends.

4.4.3 EXHAUST TEMPERATURE

The variation in Exhaust temperature of the engine for the various blends with respect to percentage load is shown in fig 4.4. It can be observed that maximum exhaust temperature of the diesel engine was 580^{0}C which was observed for B20 blend and lowest exhaust temperature of the diesel engine was 460^{0}C and that was observed for B20IPA20 blend. The decrease in exhaust temperature of the engine for the blends containing iso-propyl alcohol may be due to quenching effect produced by the presence of iso-propyl alcohol in blends of diesel, cottonseed biodiesel and iso-propyl alcohol blends. The results are in consistence with the investigations made by Karebetkas et. al[19], Karthikeyan et. al[43], Aydin et. al[58], Nabi et. al [59].

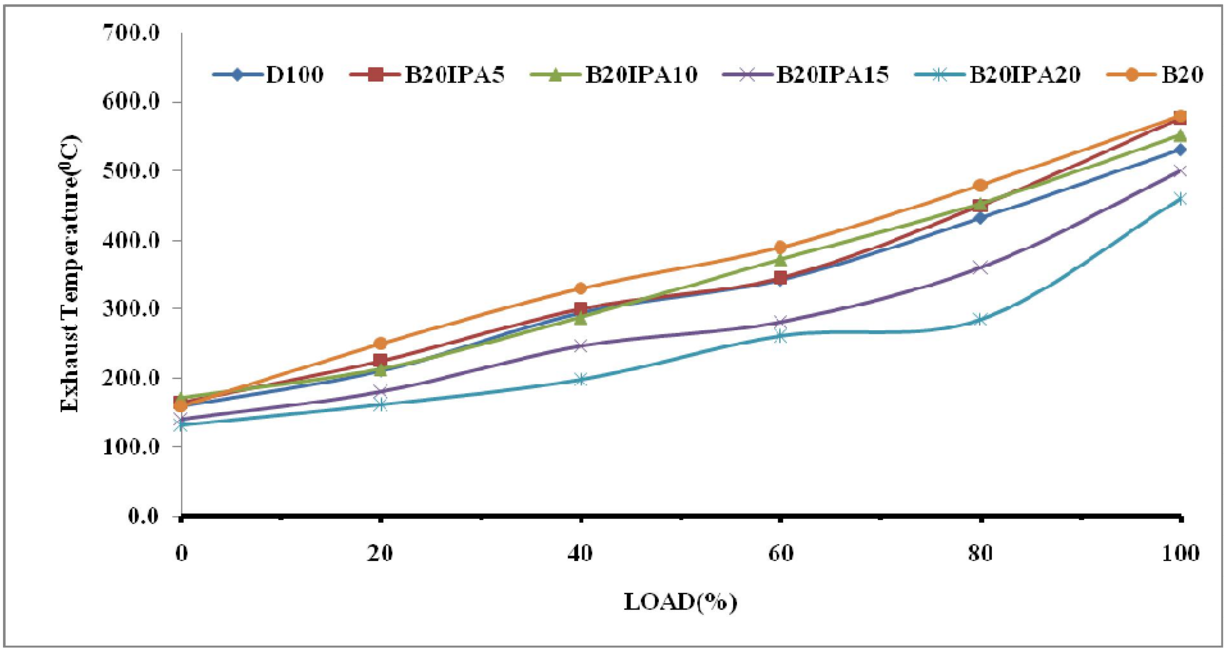


Fig. 4.4: Variation in exhaust temperature of the engine for the various blends with respect to the percentage load.

4.5 EMISSION CHARACTERISTICS

The emission characteristics of the engine for the various test fuels are summarized in this section. The main exhaust of the diesel engine include UBHC, CO, NO_X and smoke opacity.

4.5.1 CO EMISSIONS

The variation in CO emissions of the engine for the different test fuels with respect to percentage load is shown in fig 4.5. It can be concluded that the CO emissions of the engine is lower for B20 blend at all the loads. This can attributed to promoted combustion process inside the engine cylinder due to more availability of oxygen content in the fuel. At peak loads\ the CO emissions of the engine for all the blends containing iso-propyl alcohol increases due to incomplete combustion as more fuel is injected at peak load and there is lack of availability of oxygen at peak load. The results are in close confirmation with the investigation done by Karebetkas et. al[19], Karthikeyan et. al[43], Aydin et. al[58], Nabi et. al [59].

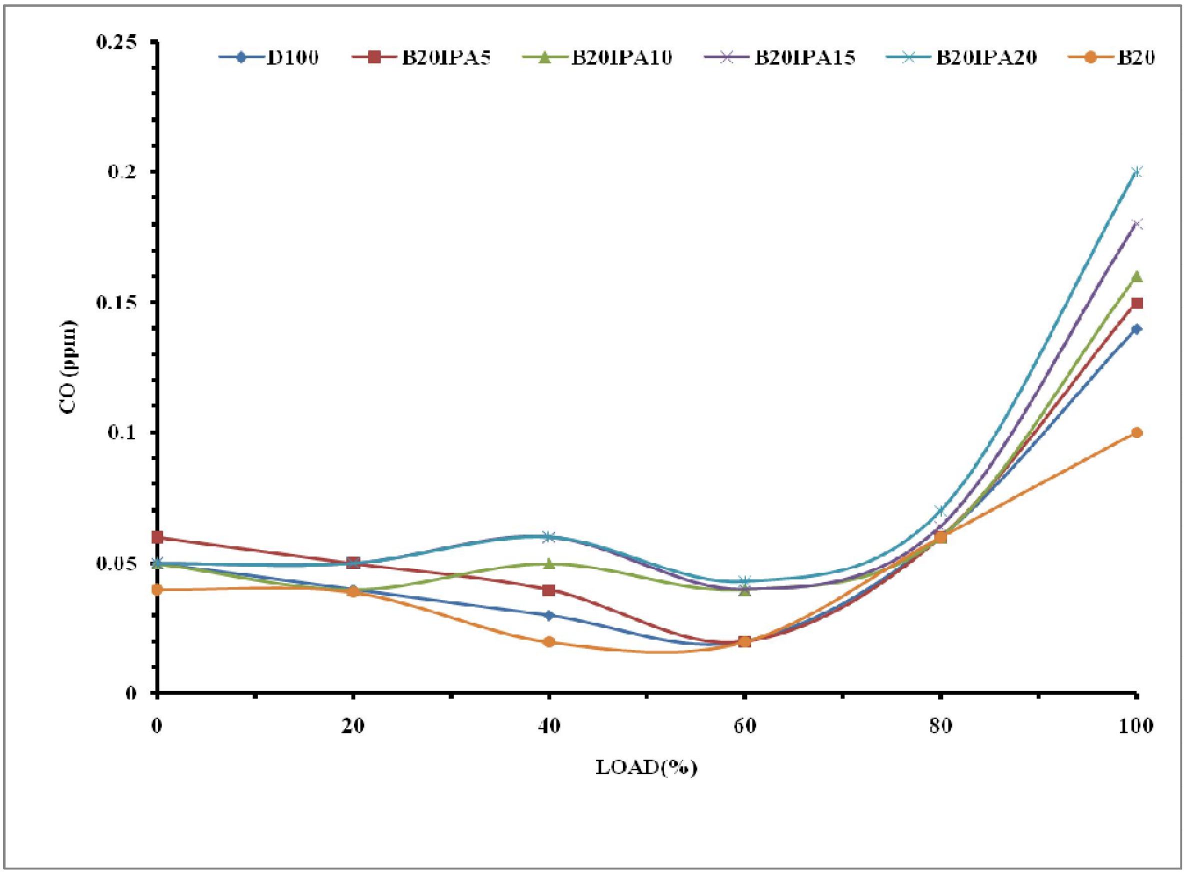


Fig.4.5: variation in CO emissions of the engine for different test fuels with respect to the percentage load.

4.5.2 UNBURNT HYDROCARBONS

The variation in unburnt hydrocarbon emissions of the engine for the various blends with respect to the percentage load is shown in fig. 4.6 It can be observed that the urburnt hydrocarbon emissions of the diesel engine decreases for the B20 blend compared to diesel fuel at all the loads. This can be attributed to promoted combustion inside the engine cylinder due to more availability of the oxygen inside the cylinder. For the blends containing iso-propyl alcohol, the unburnt hydrocarbon emission of the engine increases as compared to B20 blend. The UBHC emissions increase with increase in blending percentage of iso-propyl alcohol. UBHC emissions are formed as an outcome of incomplete combustion that may occur due to lack of sufficient availability of air, insufficient combustion duration, poor cetane rating of the fuel etc. In the present case, it seems that poor cetane rating of IPA played a detrimental role for HC emissions. The lower cetane number deteriorates self-ignition characteristics of the blends and promotes quenching effect in the leaner mixture zone of the cylinder. Insufficient combustion duration may be a plausible reason subjected to further investigation of combustion phenomena which is out of the scope of the present work. The results are in close conformation with the investigations made by Karebetkas et. al[19], Karthikeyan et. al[43], Aydin et. al[58], Nabi et. al [59].

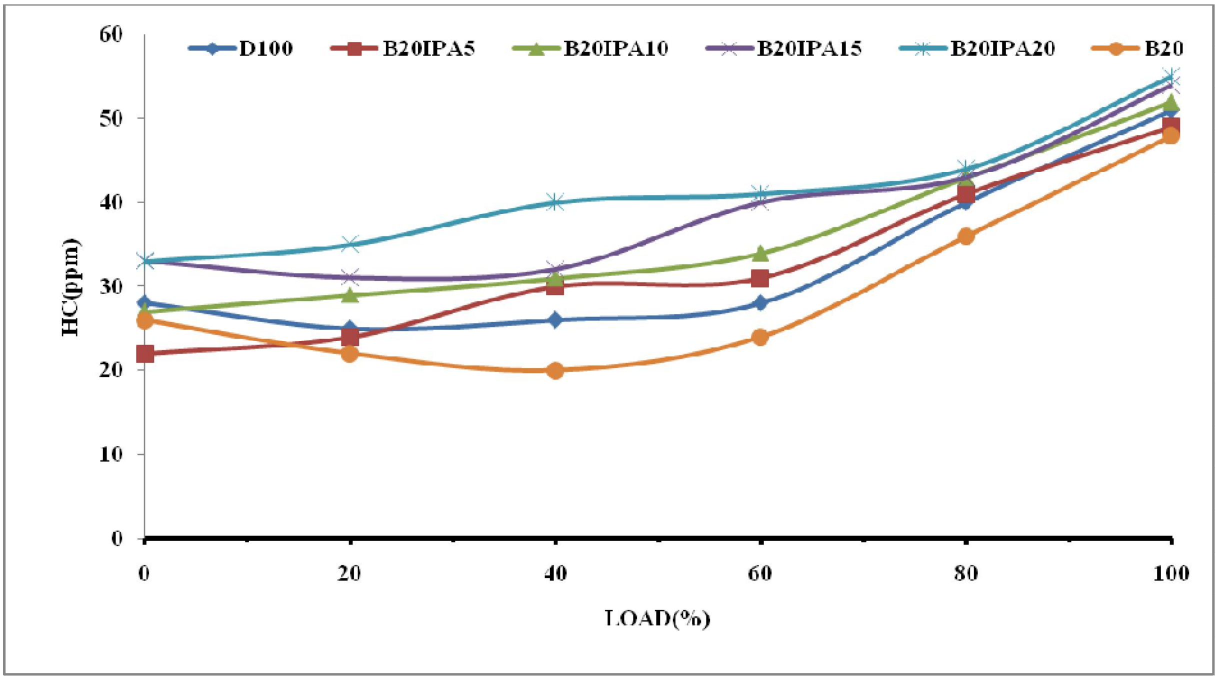


Fig.4.6: Variation in the UBHC emissions of the test engine for different test fuels with respect to the percentage load

4.5.3 NO_X EMISSIONS

The Variation in NO_X emissions of the test engine for the different test fuels with respect to the percentage load is shown in fig.4.7 It can be observed that for the B20 blend NOX emissions of the engine increases as compared to the neat diesel fuel. Combustion flame temperature, availability of oxygen and time for oxygen-nitrogen reaction are the major factor controlling NO formation in diesel engine. In the case of B20 blend, combustion flame temperature and availability of oxygen are the pre dominant factors in the formation of NOx emissions. Hence because of higher combustion flame temperature and more availability of oxygen the NOx emission increases. However, for the blends containing iso-propyl alcohol, the NOX emissions are found to decrease as compared to B20 blend with increase in percentage of iso-propyl alcohol. The lower cetane number of IPA blends deteriorates self-ignition characteristics of the blends and promotes quenching effect in the leaner mixture zone of the cylinder. In the case of blends containing iso-propyl alcohol, combustion flame temperature is the pre dominant factor in the formation of NOx emissions. Hence because of lower combustion flame temperature, the NOx emission decreases. The results are in close confirmation with the investigations made by Karebetkas et. al[19], Karthikeyan et. al[43], Aydin et. al[58], Nabi et. al [59].

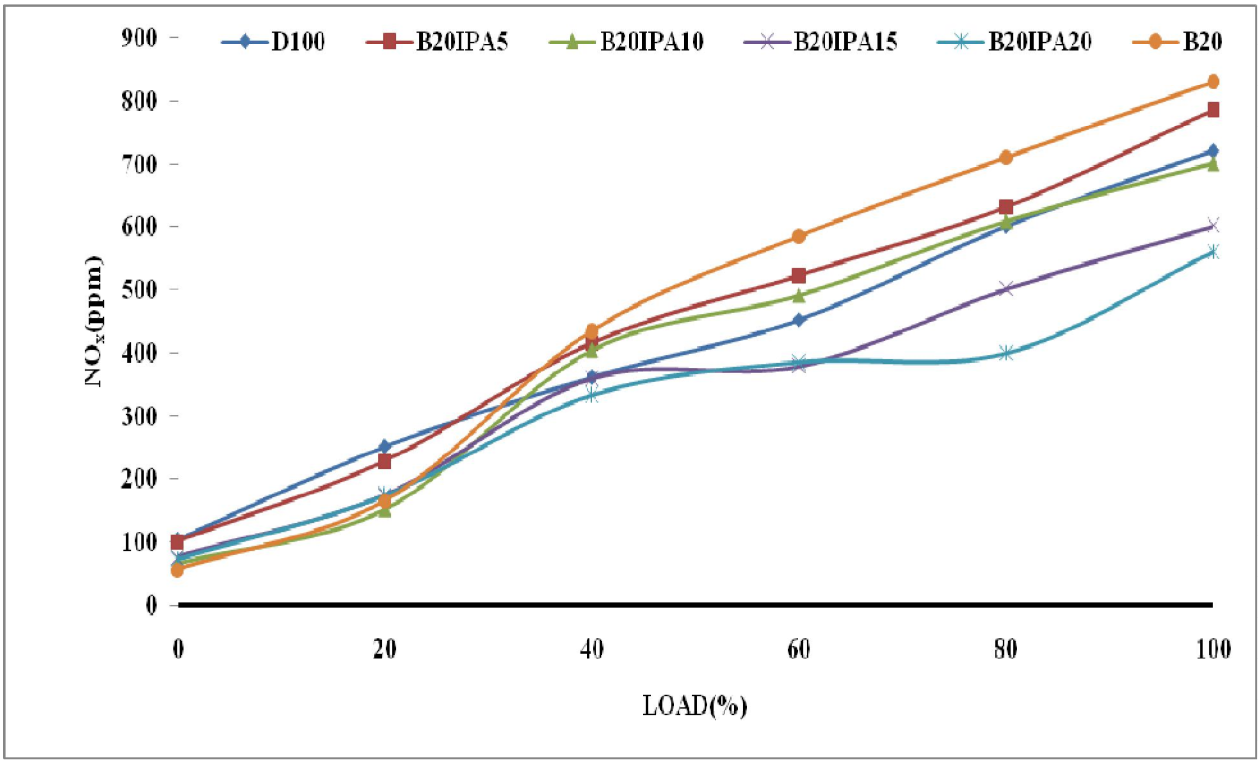


Fig. 4.7: Variation in NO_X emissions of the test engine for the different test fuels with respect to the percentage load.

4.5.4 SMOKE OPACITY

The variation in the smoke opacity of the engine for the different test fuels with respect to percentage load is shown in fig 4.8. It can be concluded that the smoke opacity reduces for all the blends with respect to neat diesel fuel. This can be attributed to complete and stable combustion of the biodiesel, diesel and iso-propyl alcohol blends, which contain more amount of oxygen. This also occurs due to longer ignition delay which accumulates the fuel inside the combustion chamber, higher temperature in the cycle and earlier termination of the combustion process. The residence time is therefore increased. All these factors have found to reduce smoke opacity in exhaust. The results are in consistence with the investigations made by Karebetkas et. al[19], Karthikeyan et. al[43], Aydin et. al[58], Nabi et. al [59].

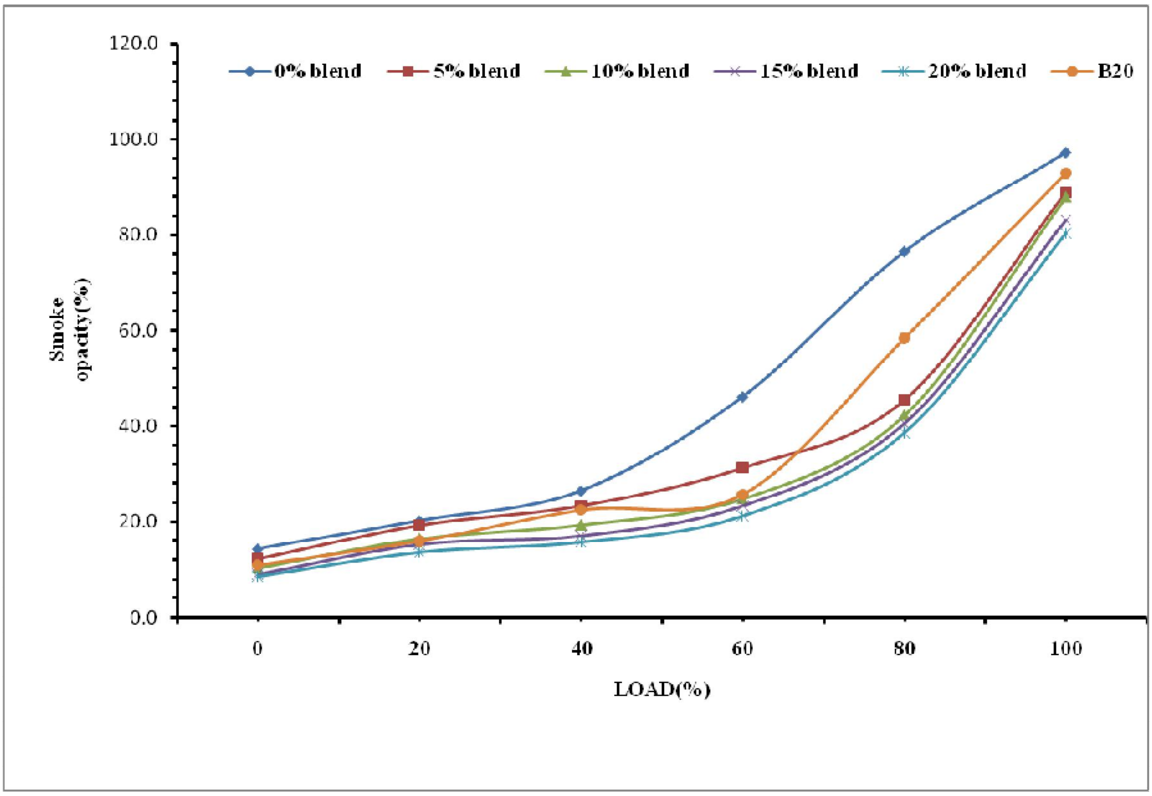


Fig.4.8 The variation in smoke opacity of the engine for the various blends with respect to percentage load.

4.5.5 HEAT RELEASE RATE AND COMBUSTION CHARACTERISTICS

Evaluation of cyclic heat release is very much significant for combustion study. Various heat release models have been developed by researchers for determining critical combustion parameters like heat release rate, pressure rise rate etc.

The heat release rate is determined by applying the first thermodynamic law using the following expression:-

$$\frac{dQc}{d\theta} - \frac{dQw}{d\theta} = \frac{d(\mathrm{mu})}{d\theta} + P\frac{dV}{d\theta} = mC_v\frac{dT}{d\theta} + P\frac{dV}{d\theta} (1)$$

Now the universal gas equation is given by

$$PV = mRT \qquad (2)$$

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

$$P\frac{dV}{d\theta} + V\frac{dP}{d\theta} = mR\frac{dT}{d\theta} \qquad (3)$$

Putting equation (3) in equation (1), the heat release rate is derived as follows.

$$\frac{dQc}{d\theta} = P\frac{Cp}{R}\frac{dV}{d\theta} + V.\frac{Cv}{R}\frac{dP}{d\theta} + mT\frac{dCv}{d\theta} + \frac{dQw}{d\theta} \qquad (4)$$

Equation (4) is further simplified for actual heat release calculation and is given below.

$$\frac{dQc}{d\theta} = \frac{1}{\gamma-1}V\frac{dP}{d\theta} + \frac{\gamma}{\gamma-1}P\frac{dV}{d\theta} + \frac{dQw}{d\theta} \qquad (5)$$

Where $\frac{dQw}{d\theta} = h.A\,(T_w - T_j)$ (6)

The heat transfer coefficient “h”was evaluated by using the correlation formula given by Woschni [61]

$$h_c = 3{:}26B^{-0.2}P^{0.8}T^{-0{:}55}W^{0.8} \qquad (7)$$

Here w is the average cylinder gas velocity.

C_p and C_V are temperature dependent parameters whose formulae are same as mentioned in reference [61]. The primary data used for heat release calculation was the pressure crank angle data obtained during experiment. Equation (5) was used for the determination of heat release rate. Pressure rise rate and cumulative heat release was calculated by standard mathematical operations in the HRR spread sheet database

The in-cylinder pressure for all the blends at full load condition is shown in fig.4.9

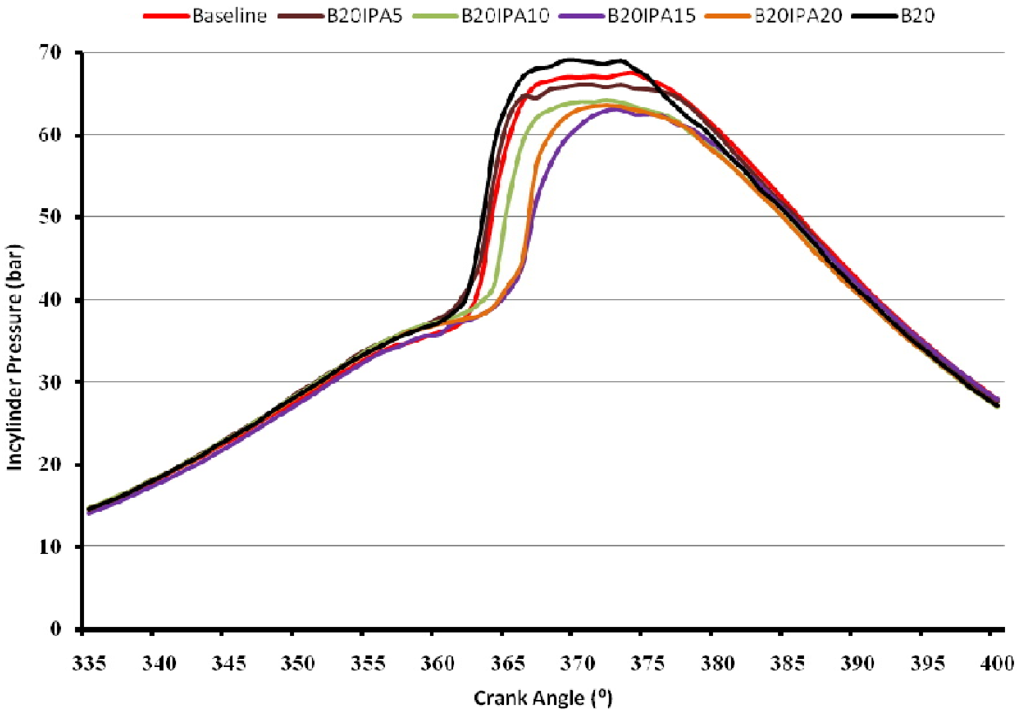


Fig. 4.9 : Incylinder pressure variation obtained for the different test fuels

The fig. 4.9 shows the in-cylinder variation obtained for the different test fuels. The peak cylinder pressure of B20IPA5, B20IPA10, B20IPA15 and B20IPA20 is evidently lower than that of B20, and the peak cylinder pressure occurs later in terms of the crank angle. The peak cylinder pressure for the neat diesel was observed to be 67.51 bar at 374^0 crank angle. While the peak cylinder pressure for B20 blend was 69.01 bar at 370^0 crank angle. The peak cylinder pressure for the B20IPA5, B20IPA10, B20IPA15 and B20IPA20 was 66.11 bar, 64.2 bar, 63.03 bar and 63.38 bar at 371^0 372^0, 373^0 and 373^0 crank angle respectively. The peak in-cylinder pressure for the B20 blend occurs before the diesel baseline in terms of the crank angle which indicates less ignition delay due to higher cetane rating of the fuel. The peak cylinder pressure of the B20 blend was observed to be higher than diesel baseline which can be attributed to higher cetane rating of the fuel and lower ignition delay. B 20 blend burns faster and leaner resulting in highest peak in-cylinder pressure. Due to this tendency, B20 emits more oxides of nitrogen as discussed earlier. However, with increase in volume fraction of the alcohol, the gain in the ignition delay due to biodiesel is reduced and the crank angle corresponding to the peak in-cylinder pressure moves to the diesel baseline. Moreover, due to lower calorific value of the iso-propyl alcohol, the peak in-cylinder pressure gets reduced. The reduced in-cylinder pressure leads to reduction in oxides of nitrogen that are evident in results section.

The heat release rate for the various blends is shown in fig.4.10. Because of the evaporation of the fuel accumulated during ignition delay period, at the beginning a negative heat release rate is observed. After combustion is initiated, this becomes positive. It can be observed that the curve of HRR shifts towards right with increase in volume fraction of iso-propyl alcohol in the test fuel which indicates ignition delay. The maximum heat release rate for the B20 blend was 72.275 J/^{0} CA at 364^0 CA. However, for the diesel fuel, the maximum heat release rate was 73.584 J/^{0} CA at 365^0 CA. Furthermore, the maximum heat release for the for the B20IPA5, B20IPA10, B20IPA15 and B20IPA20 was 65.648 J/^{0} CA at 364^0 CA, 67.53 J/^{0} CA at 366^0 CA, 66.749 J/^{0} CA at 368^0 CA and 70.776 J/^{0} CA at 368^0 CA. Ignition delay was calculated from the heat release rate curve as the difference between the crank angle corresponding to fuel injection and the crank angle at which positive heat release occurred. Due to ignition delay for the isopropyl alcohol blended fuels, more amount of fuel is accumulated inside the combustion chamber. Thus, sufficient amount of fuel was present inside the combustion chamber resulting in higher heat release rate in the premixed phase of combustion. Another notable observation showed that the crank angle corresponding to maximum heat release rate shifted rightwards for the blends containing isopropyl alcohol as compared to baseline data. Therefore, in-cylinder temperature of blended fuels was inferred to be higher than baseline data and shifted towards advanced crank angles. Total cyclic heat release was found to decrease with increase in iso-propyl alcohol volume fraction in the test fuel. It was also observed that the premixed and diffusion phases remained distinctly visible in the HRR diagram for all the test fuels. However, the percentage of heat release in premixed phase compared to the total cyclic heat release was increased with increase in iso-propyl alcohol composition. The diffusion phase duration and heat release was continuously reduced with increase in isopropyl alcohol composition. The results confirm to the investigation made by Qi et. al[62] and Muralidharan et.al [63].

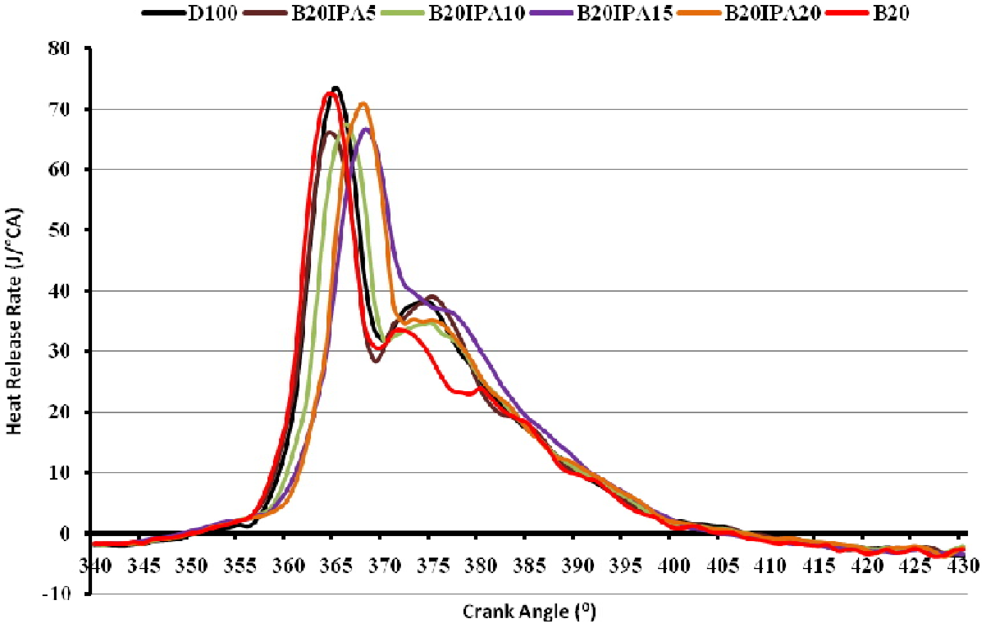


Fig.4.10 Heat release rate variation for the various test fuels.

CHAPTER 5

CONCLUSION AND SCOPE FOR FUTURE WORK

5.1 CONCLUSIONS

The present study was carried out on an unmodified single cylinder diesel engine. The main objective of the present investigation was to evaluate the suitability of iso-propyl alcohol, cottonseed biodiesel and diesel fuel blends as a fuel for use in C.I. engine and to perform combustion analysis and to evaluate the performance and emission characteristics of the engine. The experimental results show that the engine performance with blends containing iso-propyl alcohol is slightly inferior to the performance with cottonseed biodiesel and diesel fuel blends.

The density and viscosity of the B20 blend was higher as compared to mineral diesel. Subsequently on blending B20 blend with iso-propyl alcohol (up to 20%) the value of density and kinematic viscosity of the blends reduced. The calorific value of all the blends were found to be lower as compared to neat diesel.

The maximum brake thermal efficiency was obtained with B20 blend. The brake thermal efficiency of B20IPA5 and B20IPA10 blend was higher in comparison to neat diesel fuel but lower as compared to B20 blend. The break thermal efficiency of B20IPA15 and B20IPA20 was found to be lower than neat diesel. Thus it shows that the break thermal efficiency reduced on blending with iso-propyl alcohol. The minimum brake specific energy consumption was obtained with B20 blend. For the neat diesel fuel, BSEC was 14.69 MJ/kWh. For B20 blend, BSEC was 13.83MJ/kWh whereas for the B20IPA20 blend, BSEC was 16.10 MJ/kWh. The brake specific energy consumption of B20IPA5 and B20IPA10 blend was higher in comparison to B20 blend but lower as compared to diesel fuel. The brake specific energy consumption of B20IPA15 and B20IPA20 was found to be higher than neat diesel. Thus it shows that the brake specific energy consumption increased on blending with iso-propyl alcohol. The minimum CO and HC emissions were observed with the B20 blend. However, on blending the B20 blend with iso-propyl alcohol the CO and HC emissions were found to increase. At lower loads, the variation in smoke opacity for the fuel blends was insignificant. However, at higher loads the smoke opacity of all the blends was found lower as compared to neat diesel fuel. The maximum NO_X emissions were observed with the B20 blend. However, on blending the B20 blend with iso-propyl alcohol; the NO_X emission decreased. The NO_X emissions observed with B20IPA5 and B20IPA10 were higher as compared to neat diesel fuel. However, B20IPA15 and B20IPA20 exhibited lower NO_X emissions as compared to diesel fuel. 22.4% reduction in NO_X emissions was observed with B20IPA20.

The peak cylinder pressure of B20IPA5, B20IPA10, B20IPA15 and B20IPA20 is evidently lower than that of B20, and the peak cylinder pressure occurs later in terms of the crank angle. The maximum peak in-cylinder pressure was observed for the B20 blend. The peak in-cylinder pressure for the B20 blend occurs before the diesel baseline in terms of the crank angle which indicates less ignition delay. However, with increase in volume fraction of the alcohol, the peak in-cylinder pressure gets reduced. The maximum heat release rate was observed for the diesel baseline. The minimum heat release rate was observed for B20IPA5. The crank angle corresponding to maximum heat release rate shifted rightwards for the blends containing isopropyl alcohol as compared to baseline data which indicates the ignition delay. Higher heat release rate in the premixed phase of combustion was observed for B20IPA5, B20IPA10, B20IPA15 and B20IPA20 blends.

The results from the experiments suggest that blending diesel with cottonseed biodiesel and iso-propyl alcohol slightly deteriorates the performance but improves emission characteristics of the diesel engine.

5.2 SCOPE FOR FUTURE WORK

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

In the present investigation, iso-propyl alcohol concentration was limited up to 20 percent. It is suggested that higher concentration of iso-propyl alcohol may be explored in the future work.

In the present investigation, unmodified diesel engine is used. However, it is expected that certain modification in the diesel engine may be required for the better performance which includes change in injection system, injection angle variation, etc.

The long term assessment of engine durability needs to be carried out to assess the suitability of iso-propyl alcohol, cottonseed biodiesel and diesel fuel blends.

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ANNEXURE 1

Formula for calculation of Brake Thermal Efficiency and Brake Energy Fuel Consumption

Brake Thermal Efficiency (η_{th}):

$$\eta_{th} = \frac{brake\ power}{fuel\ power}$$

$$\eta_{th} = \frac{3600\ \times BP}{FC \times Q_{lcv}}$$

Where:

η_{th} = thermal efficiency;

BP = brake power [kW];

FC = fuel consumption [kg/h = (fuel consumption in L/h) x (ρ in kg/L)];

Q_{lcv} = calorific value of kilogram fuel [kJ/kg];

ρ = relative density of fuel [kg/L].

Brake Fuel Energy Consumption:

$$\text{BSEC} = \frac{m_{f} \times Q_{lcv}}{1000 \times BP} \times 3600 \text{[MJ/KWh]}$$

Where:

m_f= mass flow rate [Kg/sec];

Q_{lcv} = calorific value of kilogram fuel [kJ/kg];

BP = brake power [KW].

ANNEXURE 2

RESEARCH PAPERS PUBLISHED

PUBLICATIONS IN CONFERENCES

- **Singh A.K, Mishra C, Vibhanshu V, Kumar N.** *"Performance Evaluation and Emission Studies of a Single Cylinder diesel Engine fuelled with Isopropyl Alcohol and Diesel"*. Paper No. 13PFL-1015/2013-01-1132. . Proceedings of SAE World Congress and Exhibition, Michigan, USA, 16-18th April 2013.
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