Major Project

Dissertation on

UTILISATION OF BLENDS OF JATROPHA METHYL ESTER & N-BUTANOL IN A NATURALLY ASPIRATED COMPRESSION IGNITION ENGINE

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

Master of Technology
In
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SIDHARTH

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UNDER THE SUPERVISION OF

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CERTIFICATE

It is to certify that the dissertation entitled "**UTILISATION OF BLENDS OF JATROPHA METHYL ESTER & N-BUTANOL IN A NATURALLY ASPIRATED COMPRESSION IGNITION ENGINE**" submitted by SIDHARTH, 12/THR/2010 in partial fulfillment for the award of the Degree of Master of Technology in Thermal Engineering, is an authentic record of student's own work carried out by him under my guidance and supervision.

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

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ABSTRACT

Depleting oil researves, stringnent environmetal policies and consistent increase in fossil fuel prices has mandated the researchers to search for alternative fuels which are of renewable nature and cleaner than fossil fuels. In that context, bio-origin fuels are very promising and could help in solving issues related to depletion and enviornmental degradation. Bio-origin fuels are essentially non-petroleum and results in energy security and environmental benefits.

The present study was carried on an unmodified diesel engine. The main objective of the present investigation was to evaluate suitability of n-butanol as a blending stock in jatropha biodiesel for use in a C.I. engine and to evaluate the performance and emission characteristics of the engine.

Blends formed were observed for homogeneity and they remained homogenous even after three months and no significant change was observed. The calorific value, kinematic viscosity and density of blends decrease by increasing the blending percentage. The thermal efficiency of the engine was higher with blends. BTE increases by increasing the percentage of n-butanol mixture in the blend and the brake specific energy consumption of the engine were lower and continued to decrease by increasing the percentage of n-butanol in the blends. Carbon monoxide (CO), the oxides of nitrogen (NO_X) and smoke opacity of blends were found lower than jatropha biodiesel during the whole experimental range. However, Unburnt Hydrocarbon (HC) emission was found to have slightly increased.

The experimental results show that the engine performance has improved with blends of n-butanol and biodiesel in comparison to biodiesel and could be concluded that n-butanol is a potential alternative fuel to be blended with jatropha biodiesel for diesel engine application.

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NOMENCLATURE

CI	Compression Ignition
GDP	Gross Domestic Product
MNES	Ministry Of Non-Conventional Energy Sources
MNRE	Ministry Of New And Renewable Energy
KW	Kilowatt
MW	Megawatt
GW	Gigawatt
OECD	Organization For Economic Co-Operation And Development
O_3	Ozone
NO	Nitric Oxide
NO_2	Nitrous Oxide
OH	Hydroxyl
Cl	Chlorine
Br	Bromine
NASA	National Aeronautics And Space Administration
FAO	Food And Agriculture Organization
UN	United Nation
CO_2	Carbon Dioxide
NO_X	Nitrogen Oxide
^{O}C	Degree Celsius
ppm	Parts Per Million

I.C.	Internal Combustion
i.e.	that is
%	Percent
e.g.	Example
kWh	Kilowatt Hour
rpm	Revolutions Per Minute
GHG	Green House Gas
CDM	Clean Development Mechanism
m	Meters
cm	Centimeter
g	Gram
PTSA	P-Toluenesuphonic Acid
H2SO4	Sulphuric Acid
FFA	Free Fatty Acid
NAOH	Sodium Hydroxide
KOH	Potassium Hydroxide
ABE	Acetone-Butanol-Ethanol
CA	Clostridium Acetobutylicum
CB	Clostridium Biejerinckii
CN	Cetane Number
ASTM	American Society For Testing And Materials
mm	Millimeter

s	Seconds
min	Minimum
max	Maximum
wt	Weight
BIS	Bureau of Indian Standards
n-butanol	Normal Butanol
~	Nearly
BSEC	Brake Specific Energy Consumption
BTE	Brake Thermal Efficiency
BSFC	Brake Specific Fuel Consumption
CO	Carbon Monoxide
HC	Hydrocarbon
UBHC	Un-Burnt Hydrocarbons
SFC	Specific Fuel Consumption
HP	Horse Power
MJ/kg	Mega Joule Per Kg
cal/gm	Calorie Per Gram
JB100	100% jatropha biodiesel
95JB 5B	95% jatropha biodiesel + 5% n-butanol
90JB 10B	90% jatropha biodiesel + 10% n-butanol
80JB 20B	80% jatropha biodiesel + 20% n-butanol

CHAPTER 1

INTRODUCTION

1.0 ENERGY CRISES

Over the past few decades there has been a considerable effort to reduce the problems associated with air pollution, as it is causing serious environmental degradation and also resulting in global warming. The ever increasing prices of petroleum derived products due to depleting oil reserves has also put up a heavy task in front of researchers to look for alternative fuels that are much cleaner and economical than the present day petroleum derived fuels such as diesel and gasoline.

Diesel engines are the backbone of Indian economy due to their notable usages in agriculture, industrial and transportation sectors. Despite usage of diesel as one of the widely used fuels in India and many other countries worldwide, it is still one of the major producers of environmental pollution.

Therefore, search for sustainable alternative fuel for diesel engines has become very important now a days. Vegetable oil and its derivative – biodiesel- provide an opportunity to replace a substantial portion of petroleum diesel usage in compression ignition (CI) engines in order to achieve significant emission reduction [1].

1.1 ENERGY SCENARIO

Energy is one of the most important factors concerned with the development of any country's economy and well being of people living there. Many developing countries are not able to fulfill their energy demands from the resources available in their own country and have to depend upon other countries for meeting it. Though, India is rich in coal reserves and most of electricity generation in thermal power plants is derived from coal. However, India imports huge quantity of coal from abroad to run these thermal power plants. Further, India is endowed with large potential of solar, hydro, wind and bio-origin based energy sources, however, their exploitation is very much limited.

Despite the sustained efforts of Government of India, crude oil production during the year 2010-11 is 37.71 million metric tonnes which is 11.91 % higher than during the year 2009-10. The consumption of crude oil during 2010-11 was 206.15 million metric tonnes [2]

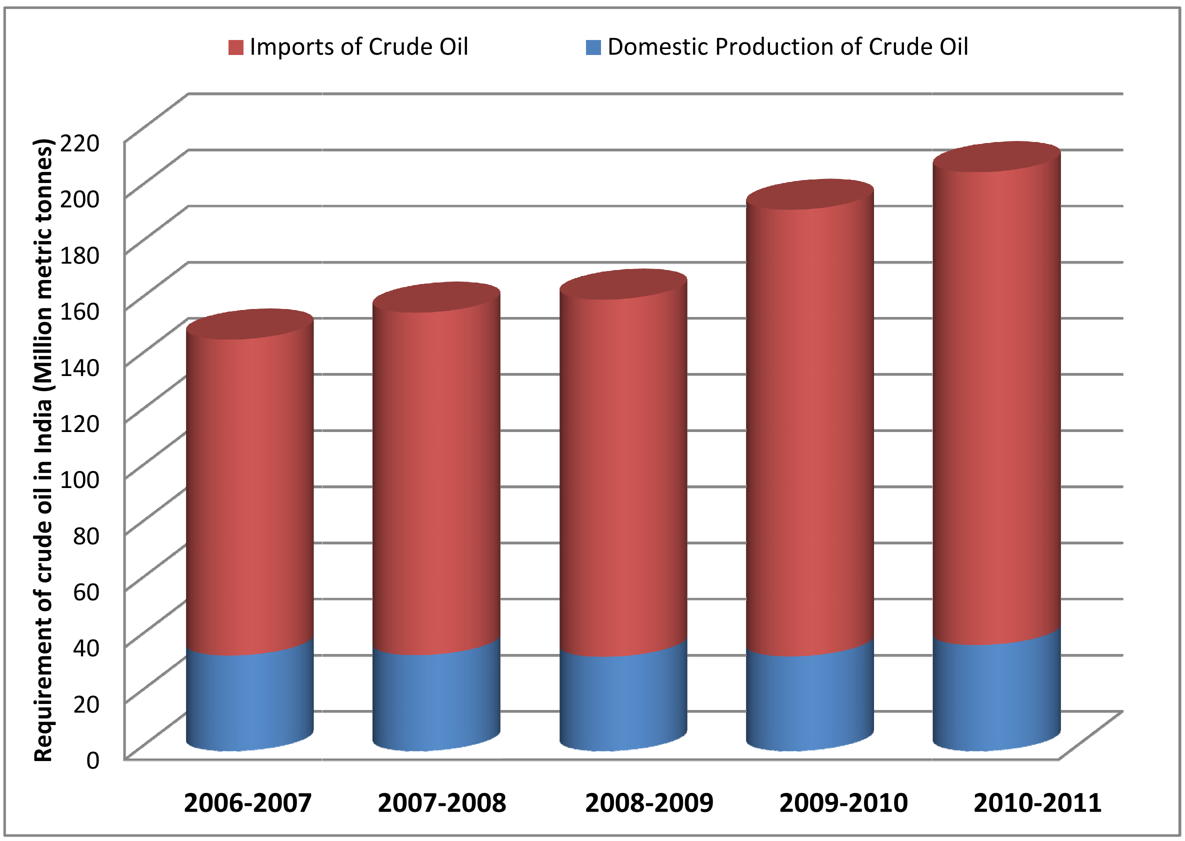


Fig. 1.1 Annual Requirement of Crude Oil in India for past few years [2]

It is clearly seen from Fig 1.1 that India is importing aroung 80% of its crude requirements. Dependence on import of crude petroleum in hige quantities is seriously affecting India's economy and has been the main cause of diversion of foreign exchange. Fig 1.2 shows that the the expenditure for importing oil is rising considerably each year and the country spent Rs. 4559.09 billion to purchase crude oil during 2010-11 [2].

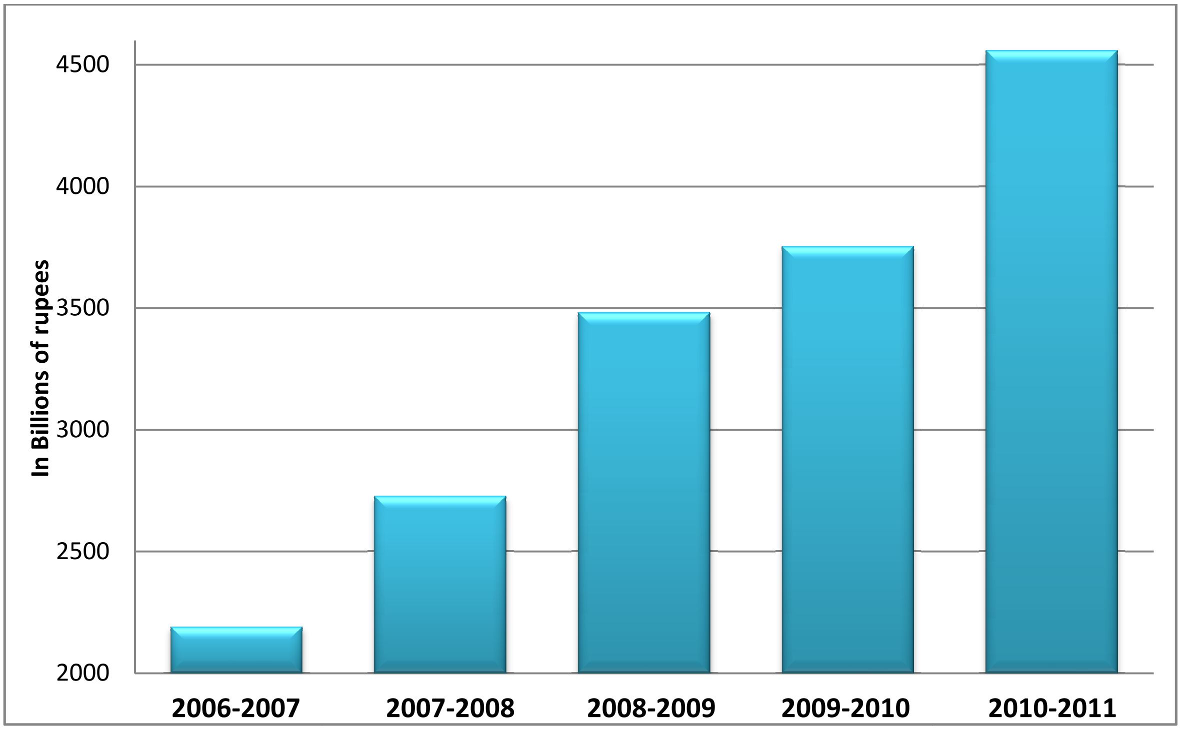


Fig. 1.2 Expenditure incured in importing Crude oil (in Billion Rupees) [2]

Table 1.1 depicts the consumption pattern of primary energy for the last few years. Global primary energy consumption has increased from 10,827.3 mtoe in year 2006 to 11,843.8 mtoe in 2010 showing an annual increase of nearly 2.5% [2].

Table 1.1: World's primary energy consumption in mtoe [2-3]

ENERGY TYPE	2006	2007	2008	2009	2010
Oil	3911	39.9	3960	3908.7	4028.1
Natural Gas	2558	2652	2717	2661.4	2858.1
Coal	3039.1	3184	3286	3305.6	3555.8
Hydro Electricity	684.3	696	731	736.3	775.6
Nuclear Energy	634.9	622	620	614	626.2
Total	**10827.3**	**11094.2**	**11315.2**	**11226**	**11843.8**

It is also evident from above statistics that Global energy requirement is mainly derived from fossil fuels comprising of oil, natural gas and coal which constitute nearly 90% of total primary energy requirements.

Oil is known as black gold as its contribution in country's economy is significant and its being responsible for large chunk of GDP. A trend observed from Fig. 1.3 shows that the world's demand for oil products is increasing day by day which in turn promotes formation of air pollutents entering the environment.

The variation of consumption of different oil products for last three decades is represented in Fig 1.3 which suggests that consumption of middle distillates which also includes diesel has been the highest amongst different product mix.

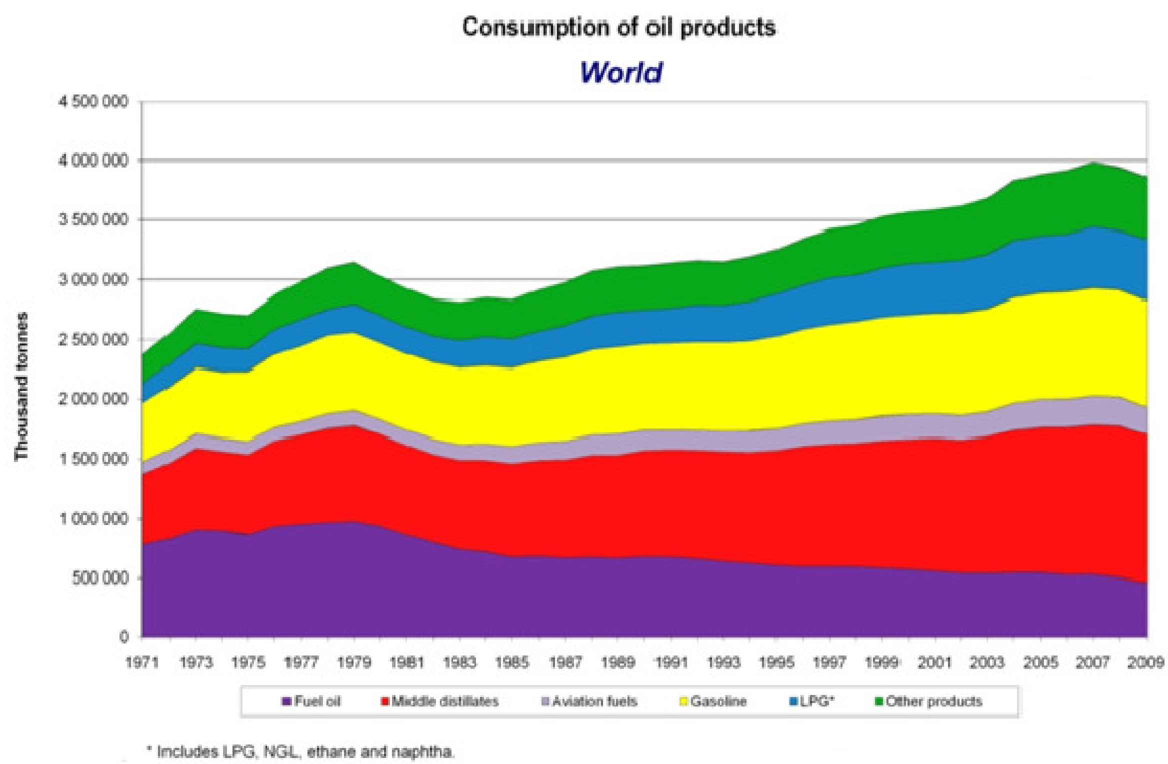


Fig. 1.3 World's consumption of Oil products from 1971 to 2009 in Thousand Tonnes [4]

Table 1.2 summarizes the primary energy requirmeent of India in 2009 and 2010 and as already elaborated, India being a developing country, fulfills most of its primary energy demand from fossil fuels including crude oil. The oil consumption level has consistently increased despite a volatility is witnessed in the prices on crude petroleum.

Table 1.2 India Primary Energy Consumption For Years 2009-10 (In mtoe) [3]

ENERGY TYPE	2009	2010
OIL	151	155.5
NATURAL GAS	45.9	55.7
COAL	250.6	277.6
NUCLEAR ENERGY	3.8	5.2
HYDRO ELECTRICITY	24	25.2
RENEWABLE ENERGY	4.6	5
TOTAL	**480**	**524.2**

India's primary energy consumption has increased from 480 mtoe to 524.2 mtoe between year 2009-10 showing an increase of 9.2 % . It is relevant to mention that world's primary energy consumption in 2009 is 11,363.2 mtoe which has increased by 5.6 % to 12,002.4 mtoe [3].

1.2 RENEWABLE ENERGY RESOURCES

Depleting oil researves, stringnent environmetal policies and consistent increase in fossil fuel prices has mandated the researchers to find a appropriate form of renewable energy which is cleaner and economical than fossil fuels based energy system.

India's framework of policies started on time but due to unstable economic and political conditions, its implementation has been quite late. It has gained importance since formation of Ministry of Non-conventional Energy Sources (MNES) which was later renamed to Ministry of New And Renewable Energy (MNRE) in the year 2006.

Various MNRE plans later worked fine to increase the total installed capacity of renewable energy power generation to 24,503.45 MW as on May 2012 [5].

In India power generation by renewable energy sources was only 3,475 MW in 2002 which was 2% of the total installed capacity in the country [6]. However, as on 10.05.2012, it has reached to 24.5 GW [5] , which consitutes to about 12% of the total installed capacity of 199.63 GW in India [5].

1.3 FUTURE OUTLOOK

The global energy consumption is projected to increase from 12,002.2 mtoe in the year 2010 to 16,631.6 mtoe in 2030 showing an increase of 1.92 % per year [7].

The bar graph in Fig. 1.4 shows the dependence on different fuels for Organization for Economic Co-operation and Development (OECD) and non-OECD countries. The graph predicts that the total consumption of three main fossil fuels i.e. oil, gas and coal for OECD will remain almost same between 2006 and 2030 but the consumption for non-OECD nations will becomes twice from 2006 to 2030.

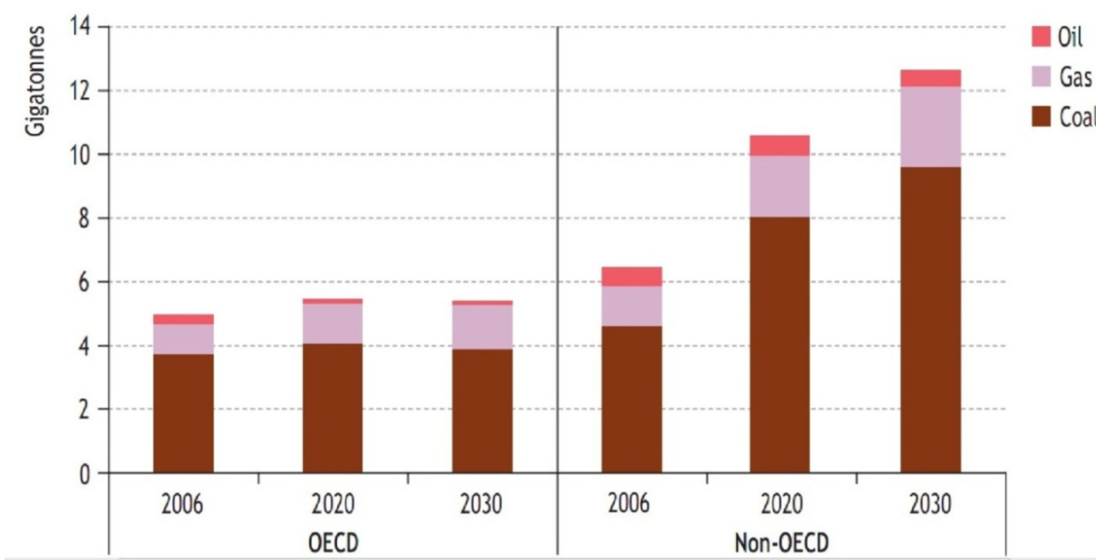


Fig 1.4 Dependence on different fuels for OECD and non-OECD countries [8]

Fossil fuels are projected to remain the dominant sources of primary energy globally. They account for nearly 81% of the overall increase in energy demand between 2010 and 2030.

The renewable energy technologies, including biofuel, 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% in 2010 [7].

1.4 ENVIRONMENTAL DEGRADATION AND ITS EFFECTS GLOBALLY

Indiscriminate usage of fossil fuels and deforestation have resulted in serious ozone layer depletion and elevated the quantity of harmful emissions products to global environment. Due to the consumption of various forms of energy for power generation, transportation and other sectors, there is also an increase in air pollution. Green house effect, global warming, acid rain, smog, deforestation, shift in climatic conditions etc. are some of the indications of over usage of fossil fuels which seriously affect nature.

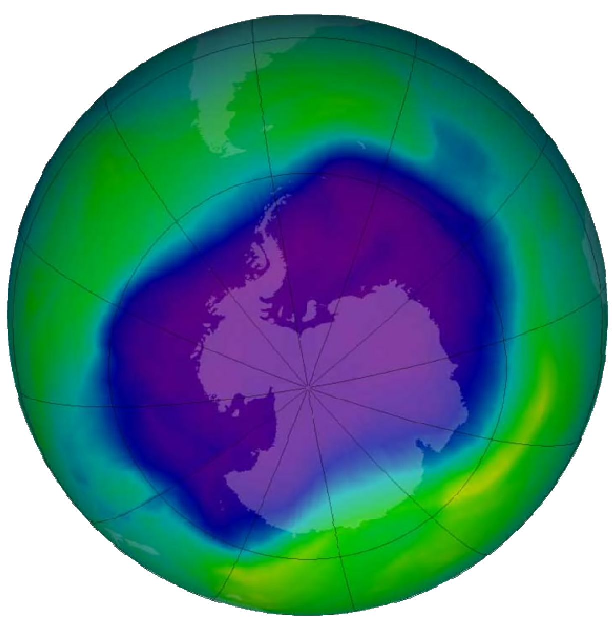


Fig. 1.5 Ozone layer depletions over Antarctica in 2012, Source NASA [10]

The ozone layer is a layer in Earth's atmosphere which contains relatively high concentrations of ozone (O_3). This layer absorbs 97–99% of the Sun's high frequency ultraviolet light, which potentially damages the life forms on Earth. It is mainly located in the lower portion of the stratosphere from approximately 20 to 30 kilometers above Earth, though the thickness varies seasonally and geographically. 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) [9].

Usage to renewable fuels and strict government regulations and global policies has certainly reduced the depletion of ozone layer. A study has revealed that Antarctica ozone levels have already recovered by an amount of 15% since the late 1990s [11].

1.5 GLOBAL WARMING

Apart from ozone layer depletion, Global warming is also one of the problems that is to be dealt by humans living on Earth. Global warming occurs due to increase in CO_2 and other harmful emissions liberated in atmosphere.

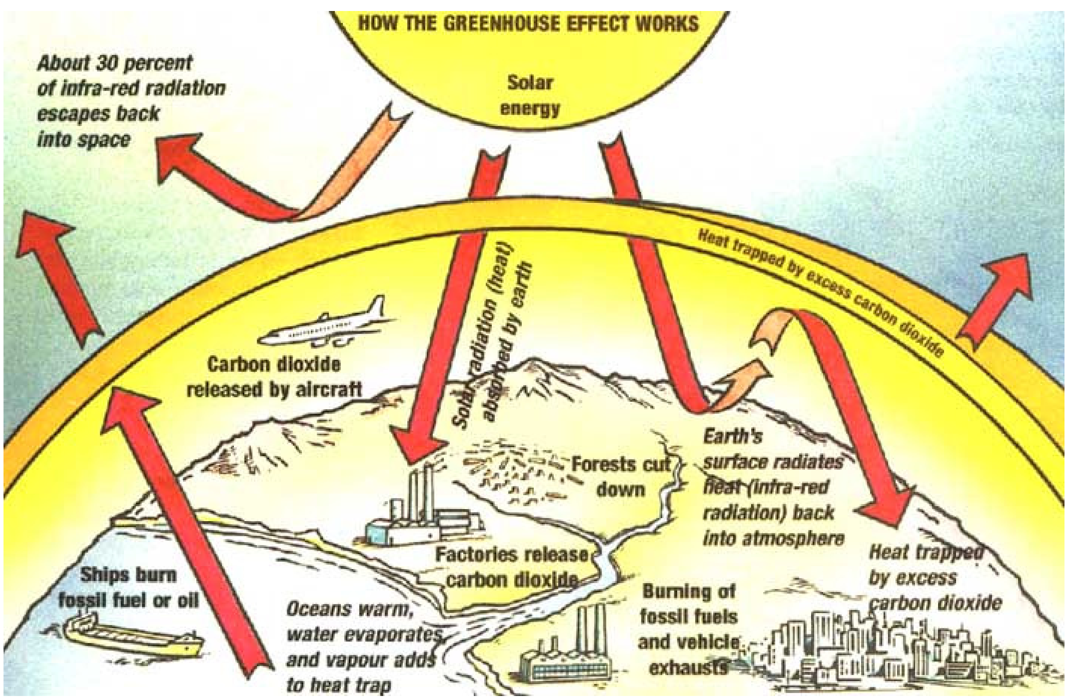


Fig. 1.6 Green House Effects, **Source FAO of UN [12]**

Fig. 1.5 shows the few common process by which green house effect takes place. For last few decades, it effect has increased mainly due to industrialization and modernization. Of the three main green house gases liberated i.e. CO_2, NO_X and methane; CO_2 is produced in abundance and it plays a major role in causing global warming.

CO_2 being a greenhouse gas has adverse effects on environment which are the possible consequences of global warming. The greenhouse effect refers to the interaction between the Earth's atmosphere and surface to absorb, transfer, and emit energy as heat, cycling it through the atmosphere and back to the surface. The natural greenhouse effect is necessary for life as it exists on Earth today [13].

Sun's radiation heats land, oceans and atmosphere, making life on earth possible. The radiation coming from sun can easily penetrate through the atmosphere in order to reach the Earth, some of it was absorbed on earth by different sources and the remaining was radiated back to space.

The amount of radiation which escapes the earth's atmosphere depends upon the concentration of greenhouse gases (including carbon dioxide, methane etc) present. However, greenhouse effect is very much necessary as without it, the temperature of the surface of the Earth would be well below freezing point of water.

By the increase in carbon emissions, the amount of radiation that escapes from earth decreases. This means that the surface temperature of the Earth increases 0.6°C ± 0.2°C over the last century. It may not sound like a larger value, but this much warming will increase with time, and could have serious consequences. These might include:

- Rise in Sea level – The densely settled coastal plains could become uninhabitable with just a small rise in sea level, which could be a result of melting of ice from the ice caps
- Reduction of ozone layer - Warming would result in increase in high cloud cover during winter, giving chemical reactions a platform in the atmosphere, which could result in depletion of the ozone layer
- Increased extreme weather - A warmer climate could change the weather systems of the earth, meaning there would be more droughts and floods, and more frequent and stronger storms
- Impacts on agriculture - Global warming could have major effects on agricultural productivity
- Spread of diseases - Diseases would be able to spread to areas which were previously too cold for them to survive in
- Ecosystem change - As with the diseases, the range of plants and animals would change, with the net effect of most organisms moving towards the North and South Poles

The effects of carbon dioxide emissions could be extremely far reaching and cause major problems. Even a small reduction in harmful emissions could help to solve the problem of global warming that future generations are likely to face [14].

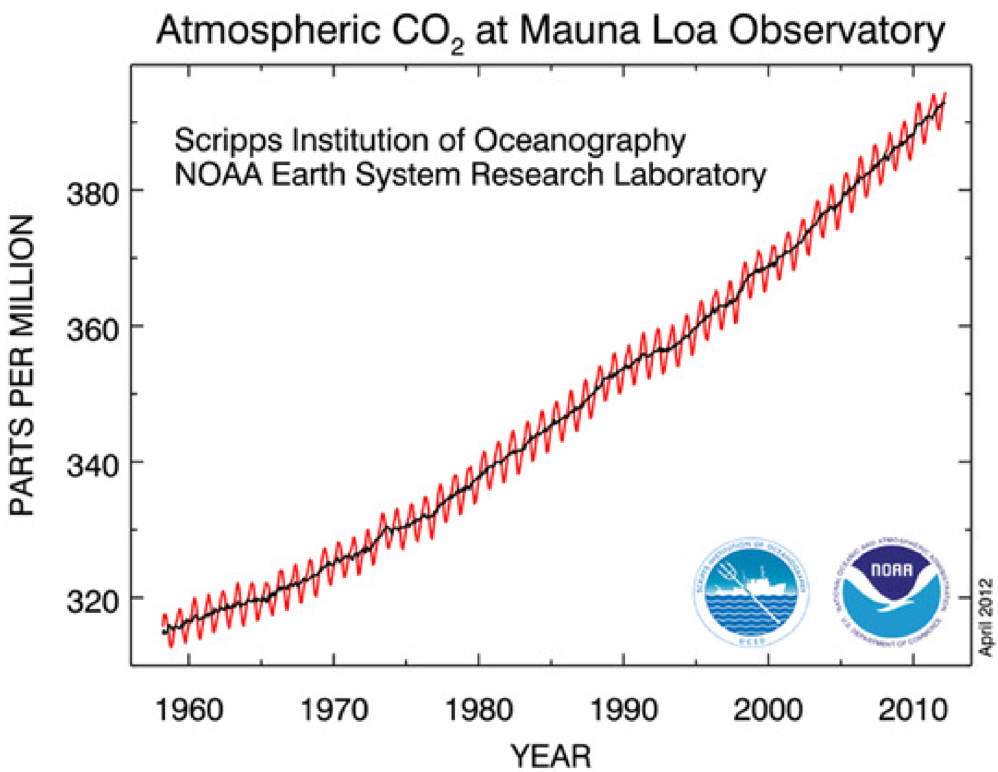


Fig 1.7 Atmospheric CO_2 at Mauna Lao observatory for last five decades [15]

Fig. 1.7 shows that the concentration of CO_2 in atmosphere has constantly increased which needs to be prevented for decreasing the effects of global warming. In April 2012, CO_2 level is estimated at Mauna Lao observatory as 396.18 ppm [16].

1.6 CO_2 EMISSION OUTLOOK

IEA predicted the amount of CO_2 emissions for few major countrires. In India the amount of CO_2 emssions has already increased by nearly four times between the years 1980-2006 with a further increase of 1.6 times from 2006 to 2010 as compared to World's increase of nearly 50% during 2006 to 2010 [8] . So it is a matter of concern for india to inhibit the quantity of CO_2 emissions to atmosphere.

Table 1.3 CO_2 Emissions Based On Region (Gigatonnes) [8]

Region	1980	1990	2000	2006	2020	2030
United States	4.66	4.85	5.66	5.67	5.77	5.8
Europe	4.12	3.89	3.9	4.06	4.16	3.99
Japan	0.88	1.07	1.19	1.21	1.15	1.06
Russia	n.a.	2.18	1.5	1.57	1.92	2
Asia	2.14	3.52	5.2	8.36	14.17	17.3
China	1.42	2.24	3.08	5.65	10	11.71
India	**0.29**	**0.59**	**0.98**	**1.25**	**2.19**	**3.29**
Middle East	0.34	0.59	0.97	1.29	2.09	2.61
Africa	0.41	0.55	0.69	0.85	1.08	1.17
World	**18.05**	**20.95**	**23.41**	**27.89**	**36.4**	**40.55**

1.7 DIESEL ENGINE AND INDIAN ECONOMY

Diesel engines are the workhorse of Indian economy but they are also major producers of air pollution. Diesel fuel consumption in India is nearly 4-5 times that of gasoline. In the year 2010-11, gasoline consumption was only 14.192 million tonnes as compared to 59.990 million tonnes of diesel [2]. These figures clearly indicates that India is very much dependent on diesel fuel.

Diesel engines are used mainly in heavy trucks, city transport buses, locomotives, electric generators, farm equipment, underground mine equipments [17]. The dual problem of fast depletion of petroleum based fuels and air pollution can be handled by switching from fossil fuels to renewable source of energy. Our country is an agriculture based economy and agriculture is an energy transformation process as energy is produced and consumed in it. Agriculture in India is heavily based upon petroleum and its derived products such as fertilizers and pesticides. Energy sources used in agriculture are oil and electricity whereas indirect energy sources are chemical fertilizers and pesticides.

Diesel fuel and electricity are the two major energy types used heavily in agriculture sectors. Since independence the consumption of diesel and electricity has increased multifold due to modernisation and mechanisation of farming equipments.

1.8 NEED OF ALTERNATIVE FUELS

It is clearly elaborated from the above discussions that India is facing the twin problems of environmental degradation and fast depletion of fossil fuels. For the sake of Indian economy and to reduce environmental pollution, dependance on petroleum derived fuels needs to be reduced.

Due to volatility of fossil fuel prices globally, a much cleaner and economical fuel than present day fossil fuels needs to be explored.

Adaptation of bio-origin based fuels can help in solving both these issues. Bio-origin fuels are essentially non-petroleum and results in energy security and environmental benefits.

To decrease the dependance on fossil fuels is by searching alternative fuels.Performance tests have shown suitability of variety of alternative fuels such as hydrogen, alcohols, biogas, producer gas and various types of edible and non edible oils. However, in Indian context, the bio-origin fuels like alcohols, vegetable oils, biodeisel and biogas can contribute significantly towards the problems related to fuel crises.

1.9 RATIONALE OF BIOFUELS IN INDIA

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

- Alcohols and biodiesel being superior fuels from the environmental point of view,

- Use of biofuels becomes important in view of the stringent emission norms and court interventions,
- Need to provide much focussed energy security, specially for the rural areas,
- Need to create employment, specially for rural poor people living in areas having a high incidence of land degradation,
- Providing essential nutrients to soil, checking soil erosion and thus preventing land degradation, addressing global concern relating to Carbon emissions,
- Reducing country's dependence on crude oil imports,
- Usability of biofuels in the present engines without any major modification,
- Use of biofuels not requiring major or time consuming studies or research.

1.10 ATTRIBUTES FOR ALTERNATIVE FUELS

For attaining the maximum benefit by the use of alternative fuels in our engine certain important considerations has to be should be taken into account.

These includes: no or minimum modifications in design of engine, use of same storage and transportation infrastructure, biodegradable and non-toxic fuel type assuring safe handling and transportation, capability of being produced locally and have low investment cost [18-19].

Apart from these, public policies need to be revised for encouraging the development of new resources. Land requirement 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.

1.11 PRESENT WORKS

In context to present work, a more elaborate discussion on adaptation of blends of biodiesel derived from Jatropha curcas and butanol is made. Biodiesel despite being a biofuel is also having an added advantage over that of its oil in terms of viscosity, volatility and emission levels.

A two step transesterification process is used to convert vegetable oil to its corresponding biodiesel which is having quite similar properties in comparison to diesel. This biodiesel can be prepared from both edible and non-edible vegetable oils depending upon the availability and abundance of oil in a country. In United States, soybean oil is of prime importance while many European countries are concerned with rapeseed oil, and countries with tropical climate prefer to utilize coconut oil or palm oil. Other vegetable oils, including sunflower, safflower, etc., have also been investigated. In India, variety of non-edible oil has been used to produce biodiesel which can be utilized to fuel the engines. The current prices of biodiesel derived from non-edible vegetable oils in India are comparable with petroleum derived fuels. Constant motivations and efforts for the production and usage of these fuels need to be undertaken by the government to overcome the problems associated with petroleum based fuels.

Alcohols are also considered one of the primarily important fuels due to their economical and cleaner nature. Alcohols can be blended both with petroleum baaed and bio-origin based fuels such as vegetable oil and biodiesel, Addition of alcohols gives an advantage of reduction in dependence of diesel engine fuel with attractive emission levels.

The production of alcohols was one of the first large-scale industrial fermentation processes developed. With the recent developments in biotechnology sector, global increase in the crude oil prices and the strong interest of the governments on the use of various renewable raw materials for the production of fuels have resulted in a increased interests in the fermentation process of production of alcohols including ethanol and butanol [20].

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

As already elaborated in previous chapter, perturbation in petroleum prices and uncertainties regarding the availability of petroleum products has mandated the researchers to search for sustainable alternative fuels for diesel engine that are superior to conventional fossil derived diesel fuel in terms of both performance and emission characteristics.

Biodiesel due to its advantage of renewable and attractive emission levels is getting limelight for quite some time. Both edible and non-edible vegetable oils obtained from rural areas can be utilized to produce biodiesel. Even animal fats can be used to produce biodiesel, but due to issues concerned with food security the use of non-edible oils compared to edible oils is more significant. In recent years systematic efforts have been made by several researchers to use biodiesel as fuel in diesel engines.

Apart from biodiesel, usage of alcohols is also considered as an emerging technology by researchers. For the last 3-4 decades, alcohols are preferred in gasoline engine due to their renewable nature and low emissions. Their usage in diesel engine is still under observation. Researchers are seeking suitable methods to use alcohol as a fuel directly or as a blend with diesel and other diesel engine fuels such as vegetable oil and biodiesel.

The potential of alcohols needs to be explored to achieve the benefit of decreasing the usage of conventional diesel fuel with reduction in harmful emission levels.

2.1 BIODIESEL AS POTENTIAL C.I. ENGINE FUEL

Many alternative fuels had already being proposed to be used in a diesel engine. Popular ones are biodiesel, vegetable oils, di-methyl ether and other related fuels. Biodiesel is a derivative of vegetable oils and can be made from virgin or used vegetable oils (both edible & non-edible) and animal fats through a chemical process named transesterification.

Biodiesel produced by means of the transesterification method exhibits improved fuel properties as compared to its corresponding oil. Biodiesel shows improved volatility approaching those of petroleum diesel fuel [21]. Improved volatility and fuel properties lead to an improved cetane number (CN) [22].

The characteristics of biodiesel are close to mineral diesel, and, therefore, biodiesel becomes a strong candidate to replace the mineral diesel if the need arises. The conversion of triglycerides into methyl or ethyl esters through the transesterification process reduces the molecular weight to one-thirds that of the triglycerides, the viscosity by a factor of about eight and increases the volatility marginally. These vegetable oil esters contain -10–11% oxygen by weight, which may encourage combustion than hydrocarbon-based diesel in an engine.

The cetane number of biodiesel is around 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^{o}C higher than those of mineral diesel [23].

Some of the properties of Diesel and biodiesel and test methods required by ASTM to determine these properties are mentioned in Table 2.1

Table 2.1- Tests and limits for fuel properties [24]

Property	ASTM Test	Diesel	Biodiesel
Flash point	D 93	52 ^{0}C min	130 ^{0}C
Water and sediment	D 2709	0.05 max %vol.	0.05 max %vol.
Kinematic viscosity (at 40^{O}C)	D 445	1.3–4.1 mm^2/s	1.9–6.0 mm^2/s
Sulfated ash	D 874	–	0.02 max %wt.
Ash	D 482	0.01 max %wt.	–
Sulfur	D 5453	.05 max %wt.	–
Sulfur	D 2622/129	–	0.05 max %wt.
Copper strip corrosion	D 130	3 max	3 max
Cetane number	D 613	40 min	47 min
Carbon residue	D 4530	–	0.05 max %mass
Carbon residue	D 524	0.35 max %mass	–

Advantages of the biodiesel as engine fuel lies in their renewable nature and ease of production from the variety of oils. This is particularly attractive in 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 the 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 than the diesel fuel [23]. Though the properties vary from one type of fuel to another this general comparison with the diesel fuel is valid for all.

Vegetable oils due to their very high viscosity and low calorific value are avoided to be directly used in a diesel engine.

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 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 [25].

The problems faced on using the neat vegetable oil include:

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 [26].

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 [27].

So to overcome problems associated with vegetable oil, certain methods can be used to improve their properties. These methods are transesterification, pyrolysis and catalytic cracking, microemulsions and dilution with diesel fuel [23-24,28-29]. Among all these methods, transesterification is a method commonly used to lower the viscosity of vegetable oils [30-32,28].

Transesterification is the reaction of a fat or oil with an alcohol to form esters and glycerol. Alcohol combines with the triglycerides to form glycerol and esters. A catalyst is usually used to improve the reaction rate and yield. Since the reaction is reversible, excess alcohol is required to shift the equilibrium to the product side.

Among the alcohols that can be used in the transesterification process are methanol, ethanol, propanol, butanol and amyl alcohol [23]. Alkali-catalyzed transesterification is much faster than acid-catalyzed transesterification and is most often used commercially [31–32,23].

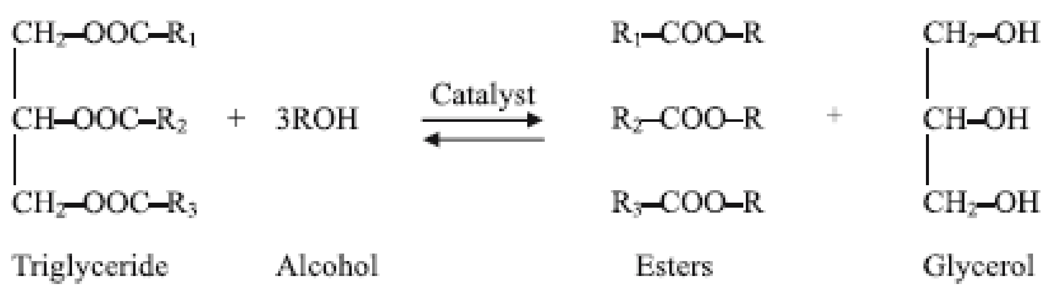


Fig. 2.1 Chemical structure of biodiesel

Here, R1, R2, R3 and R represent various alkyl groups of different carbon chain lengths and –COO- is a carboxyl group [24].

2.2 BUTANOL AS C.I ENGINE. FUEL

Biodiesel is having very low viscosity and higher volatility in comparison to vegetable oils but when compared to diesel, it is still having the problem of relatively higher viscosity (nearly two times of diesel) and lower volatility. To overcome these problems, a new technique is emerging now a day towards reduction of viscosity and to increase its volatility, is by the introduction of some oxygenated compounds like alcohols in biodiesel fuel forming biodiesel-alcohol blends.

Ethanol is suitably used in gasoline engines for many decades. Raw material used for producing ethanol varies from sugar in Brazil, cereals in USA, sugar beet in Europe to molasses in India. Brazil uses ethanol as 100 % fuel in about 20% of vehicles and 25% blend with gasoline in the rest of the vehicles. USA uses 10% ethanol-gasoline blends whereas a 5% blend is used in Sweden. Australia uses 10% ethanol-gasoline blend. Use of 5% ethanol-gasoline blend is already approved by BIS and is dispensed in some Indian states.

But ethanol is not considered as a suitable fuel for diesel engine due to its lower cetane number and calorific value than diesel and also it is not miscible with diesel.

So, the next strong competitor that is emerging now a days to be used as a fuel directly in diesel engines is n-butanol, which, has been hardly evaluated as a diesel engine fuel. Butanol is of particular interest as a renewable biofuel as it has low solubility in water and it possesses higher heating value, higher cetane number, lower vapor pressure, and higher miscibility than ethanol, making butanol one of the promising biofuel for blending with conventional diesel fuel and other fuels such as biodiesel and vegetable oil in compression ignition engine.

Therefore, the problems associated with ethanol as a diesel fuel, i.e. low calorific value, low cetane number and low miscibility with diesel, vegetable oil and biodiesel are solved to a considerable extent by using n-butanol, which has properties much closer to neat diesel fuel [32-34, 20].

Table 2.2: Properties of diesel and n-butanol [35-37]

Properties	Diesel Fuel	N-butanol
Chemical Formula	$C_{12}H_{23}$	C_4H_9OH
Density(kg/cm^3)	0.83	0.81
Boiling Point (^{o}C)	180-230	117.7
Lower Heating Value (MJ/kg)	42-45	32-35
Cetane Number	40-50	<17
Stochiometric air/ fuel ratio	14.3	11.2
Auto-ignition temperature (^{O}C)	200-220	385
Molecular Weight	190-220	74.1
% of Carbon (wt.)	~86	64.8
% of Hydrogen (wt.)	~14	13.6
% of oxygen (wt.)	0	21.6

Various properties of diesel and n-butanol is summarized in Table 2.2. The chemical composition of n-butanol is $CH_3(CH_2)_3OH$, and the mass fraction oxygen present in n-butanol is 21.6%. Typically the low heating value (LHV) of alcohol rises with an increase in carbon atoms. It is seen that n-butanol has quite high LHV in comparison to other lower carbon alcohols. Also the volatility and auto-ignition temperature of alcohols decreases with an increase in carbon atoms. This means that n-butanol will have fewer tendencies to result in cavitation phenomenon, and it will not encounter any ignition problem when working at low load conditions. Alcohol molecules consists of alkyl and hydroxyl, the more amount of carbon in alcohols molecules, the easier that alcohols can be blended with diesel fuel. In fact, n-butanol has a very good intersolubility with diesel without any requirement of cosolvents. These properties indicate that n-butanol has the potential to overcome the drawbacks brought by low-carbon alcohols such as methanol and ethanol. All of these properties make n-butanol as an appropriate oxygenated additive to diesel engine fuel [37].

2.3 LITERATURE REVIEWS

Srivastava et.al. studied the triglycerides (vegetable oils/animal fats) as an alternative fuel for diesel engine. To improve the fuel properties of triglycerides; catalytic transesterification of triglycerides with alcohols is carried out to form mono-alkyl esters of long chain fatty acids, known as biodiesel which is quite similar in properties of hydrocarbon based diesel fuel. Similar characteristics and engine performance with attractive emission levels are observed for biodiesel fuel [38].

Lu et.al. described two step process consisting of pre-esterification and transesterification to produce biodiesel from crude Jatropha curcas oil. Temperature is found to influence the reaction rate. Higher yield was obtained at a higher temperature between 35^{o}C and 65^{o}C. Conversion yield increases with an increase in reaction time. The first 15 minutes is the fastest period of the reaction, in which a conversion of 90% is possible [39].

Puhan et.al. transesterified mahua oil using methanol. Sodium hydroxide is used as a catalyst to obtain mahua oil methyl ester. 6:1 molar ratio of methanol to oil is used to obtain methyl ester having low viscosity of 5.2 cSt. Cetane number is found to be slightly higher by an amount of 10% which is favorable for combustion. Flash and fire points are quite higher than diesel, which can create problems in low temperature regions. The specific fuel consumption is higher (20%) than that of diesel and thermal efficiency is lower (13%) than that of diesel. Carbon monoxide, hydrocarbon, smoke number, oxides of nitrogen were reduced by 30%, 35%, 11% and 4% respectively, as compared to diesel [40].

Sangha et.al. had studied about the properties of four plant oil esters, viz., linseed, jatropha, sunflower and rice bran. It was observed that methyl esters exhibited lower values of viscosity, flash point and density as compared to their un-etherified plant oils in all cases. However, no significant variation was noticed in the gross heat values of these oils [41].

Altun et.al. conducted experimental work to evaluate the effects of using normal butanol, fossil derived diesel fuel and biodiesel blends to have a comparative analysis of engine's performance and exhaust emissions of a single cylinder direct injection diesel engine. The experiments were conducted on a constant speed engine and at three different engine loads. First a blend of cottonseed biodiesel and diesel fuel was prepared named as B20 (containing 20% cottonseed biodiesel and 80% diesel by volume). Then n-butanol was added to this formed sample B20 by volume percent of 10% and 20%.

The results show that the brake specific fuel consumption of B20 was higher as compared to that of conventional diesel fuel. On the other hand, the addition of n-butanol to B20 fuel blend caused a slight increase in the brake specific fuel consumption and brake thermal efficiency in comparison to the B20 fuel blend. More the amount of butanol in B20, more is the increase in BSFC and BTE.

Exhaust emissions, carbon monoxide (CO) and hydrocarbon (HC) was reduced by addition of biodiesel to diesel and the emissions further decreased by increasing the percentage of n-butanol in B20 mixture. NO_X emission remained almost unchanged for all the blends at low engine loads but it is observed that NO_X was reduced at high engine loads. All the fuel blends showed a sharp reduction in smoke opacity for whole range of engine tests and the maximum reduction is for B20 blend with 20% n-butanol.

It is finally concluded that the addition of n-butanol in B20 fuel blends showed satisfactory results in terms of performance and exhaust emissions than that of biodiesel diesel blends. Taking these facts into account, biodiesel, fossil fuels derived diesel and n-butanol mixtures can be considered as a very promising alternative fuel for our present day diesel engines [42].

Laza et.al. had studied the role of various alcohols including 1-propanol, 2-propanol, isobutanol, 1-butanol and 2-butanol in a diesel engine when blended with vegetable oil. It was concluded from the study that these alcohols can be blended with rapeseed oil (vegetable oil) and can be used in a diesel engine upto 20%. The results indicated that the viscosity, cold filter plugging point, density, cetane number and heating value of the blends decrease with an increase in concentration of alcohols in the blends. Further it was observed that the viscosities of rapeseed oil blends were temperature dependent and approaches that of diesel fuel at higher temperatures. These blends were having higher flash points than those of conventional diesel fuel, making them much safer than normal diesel fuel in terms of safety for storage and transportation [36].

Lujaji et.al. conducted experiments on a four cylinder turbocharged direct injection diesel engine using a blend of vegetable oil, alcohol and mineral diesel. It was observed that the fuel property of croton oil had improved by blending croton oil, butanol, and diesel fuel. Butanol addition in these blends resulted in an increase in BSEC at higher engine loads as compared to diesel. Addition of butanol in the blends decreased the BTE. Croton oil-butanol-diesel blends helps in achieving high cylinder pressure and improved heat release rate as compared to that of diesel fuel. Blends results in reduction of CO, CO_2 and smoke levels at high engine loads. NO_X emission levels of the blends were similar to those of the diesel [1].

Dogan had studied the performance and exhaust emissions of a single cylinder diesel engine. Under his investigation, the engine was made to run at constant engine speed of 2600 rpm and four different engine loads. Fuel used for experiments was n-butanol blended with diesel. The following conclusions were drawn from his study. When n-butanol was blended with diesel upto 20 % n-butanol on volume basis no phase separation was observed. The BSFC and the BTE were higher by a small amount on increasing n-butanol content in fuel blends with respect to those of the diesel fuel. Exhaust emissions i.e. NO_X, CO, smoke content and exhaust gas temperature was reduced by the use of these blends [43].

Rakopoulos et.al. had undergone the experimental investigation to evaluate the effects of using blends of n-butanol and diesel, blended in 8%, 16% and 24% (by volume of n-butanol), on the performance and exhaust emissions of a standard, fully instrumented, four-stroke, high-speed, direct injection (DI), Ricardo/Cussons 'Hydra' diesel engine.

The experimental result showed that the smoke density, NO_X and CO emissions were significantly reduced by the use of the butanol–diesel fuel blends over those of the neat diesel fuel. More the amount of n-butanol in the blend greater was the reduction in these emissions.

But the formation of unburned hydrocarbons HC or UBHC emissions increased with the use of blends in diesel engine. Blends showed greater SFC and BTE and slightly lower exhaust gas temperatures as compared to baseline diesel fuel. They also concluded that n-butanol, can be used safely and it is advantageous to blend butanol in higher ratios in diesel fuel, taking into consideration of better thermal efficiency and less exhaust emissions, having high solubility in the diesel fuel requiring no solubiliser which happens normally with the corresponding ethanol–diesel fuel blends requiring a solubiliser [44].

Karabektas et.al. performed a study to investigate the suitability of isobutanol–diesel fuel blends for diesel engine by determining experimentally the effects of fuel blends on engine performance and exhaust emissions. For this purpose, four different isobutanol–diesel fuel blends containing 5%, 10%, 15% and 20% isobutanol by volume were prepared and then tested in a naturally aspirated four stroke direct injection diesel engine at full load conditions and running at different speeds between 1200 and 2800 rpm with a step intervals of 200 rpm.

The test result indicated that the break power decreased with the increase in the isobutanol content in the blends. There was some increase in BSFC with the addition of isobutanol content in the blends as compared to diesel. The results also reveals that, compared to diesel fuel, CO and NO_X emissions reduced with the use of the isobutanol-diesel blends, while HC emission had increased considerably [45].

Huang et.al. conducted an experimental study on diesel engine with the blends of ethanol and diesel. Butanol (5% by vol.) was also added in blends to increase the solubility of ethanol in diesel. It was concluded that ethanol cannot be blended with neat diesel without the assistance of some additive such as normal butanol. For experiments, four blends of 10%, 20%, 25% and 30% ethanol (by volume) with diesel were formed. It was observed that all the ethanol-diesel blends separated into two layers. Upper layer was of ethanol and lower layer is of diesel. To overcome this problem, 5% butanol was added into the blends of ethanol and diesel. The blends of ethanol, butanol and diesel lasted much longer (11-14 days) and no phase separation was observed in these mixtures.

It was also concluded from the results that fuel consumptions of engine running on these blends was more than those running on neat diesel. Greater the quantity of ethanol in blends, the higher the fuel consumptions. The maximum increase in fuel consumption was observed for 30% ethanol, 5% butanol and 65% diesel blend which shows a maximum increase in SFC by 31.5%

Also the thermal efficiency of the engine running on blends was comparable with those running on neat diesel, with some increase or decrease at different loads and speeds.

UBHC emissions for the blends were higher for the engine running at 1500 rpm, but the UBHC emissions decreases on increasing the loads. Similar results can be seen at 2000 rpm, except at the point of maximum power output there is slight decrease in HC emissions.

NO_X emissions from the diesel engine were also reduced at low speed of the engine running on blends. But at a high speed of 2000 rpm, the NO_X emissions increases or decreases to some extent, and there was no stable trend for NO_X emissions.

The smoke content of the emissions from the engine running on the blends reduced considerably than those running on neat diesel and the reduction in smoke content was from 16.7% to 87.5% [35].

Mehta et.al. had tested various fuel samples in a four-stroke, four- cylinder direct injection stationary CI engine in order to evaluate effect of these fuels on the performance and exhaust emission of engine used. Four blends of butanol, mineral diesel and biodiesel were prepared and named as B1, B2, B3 and B4. Blend B1 contains 5% butanol + 85% diesel and 10% jatropha curcas ethyl ester or jatropha biodiesel and notated B1 as 5/85/10, similarly B2 as 10/75/15 ,B3 as 20/55/25 and B4 as 25/50/25. These blends were analyzed for their fuel properties, stability and further these properties were compared with the baseline diesel. Physical properties of the blends such as density, viscosity, pour point, copper strip corrosion, and oxidation stability were similar to neat diesel and were within those stipulated by ASTM standards, except for flash points which showed slightly lower value due to presence of butanol in these blends. A marginal drop in calorific value and cetane number was also observed with these blends.

All the blends were observed to have a homogenous mixture which does not show any phase separation even at a temperature of 45 °C. Engine performance parameters, such as brake power decreases with the use of blends. B4 shows the maximum reduction in brake power by 4.38% as compared to neat diesel. Specific fuel consumption increases by an amount of 4.9% for B1 sample and 18.2% for B4 sample taking diesel as baseline working under the similar operating conditions. It was also observed that there is slight drop in exhaust gas temperature and the maximum drop is for B4 sample which was 9.4% lower than diesel exhaust gas temperature due to a quenching effect of butanol. Also, BTE of all the samples reduced by decreasing the amount of diesel in formed blends. B1 has a lowest BTE drop of 1.7%, for B2 sample BTE drops by 6.3%, B3 sample BTE drops by 7.6 % and B4 by 10% versus that of diesel.

It was also observed from the results that the exhaust gas emissions showed a significant decrease in CO (42%) at medium and higher loads, whereas NO showed an average reduction of 2.4%-11% as compared to diesel [46].

Yao et.al. performed the experimental study to investigate the influence of n-butanol and diesel blend for determining the performance and emissions properties of a turbocharged inter-cooled heavy duty direct injection diesel engine. Engine speed was kept constant, exhaust gas recirculation rates were adjusted in such a way so that NO_X emissions are having a constant value of 2.0 g/kWh. N-butanol was blended with mineral diesel in different proportions (5%, 10% and 15% by volume) of n-butanol. It was observed from the results that n-butanol addition can significantly improve soot and CO emissions without any serious impact on break specific fuel consumption and NO_X emission.

The impacts of pilot and post injection on engine characteristics by using blended fuels were similar to that found by using pure diesel. Early pilot injection reduces soot emission, but result in increase of CO. Post injection reduces soot and CO emissions effectively. Soot could be effectively reduced by applying multi-injection. Under each injection strategy, the increase of n-butanol content leads to further reduction of soot [37].

Lebedevas et.al. had performed an experimental research on a 3 cylinder 30 KW VALMET diesel engine undergoing the comparative analysis in two directions. First was the laboratory and motor tests of three-component mixtures containing fossil diesel fuel, conventional biodiesel fuel (rapeseed methyl esters), and butanol and the second was laboratory and motor tests of three component mixtures containing fossil diesel fuel, synthesized rapeseed oil butyl esters, and butanol.

Tests were performed to determine important characteristics i.e. viscosity and density tests of three-component fuel containing fossil diesel fuel, butanol, and RME or RBE, it was found that the density of fuel containing RBE instead of RME in the same proportions is slightly lower, while the viscosity of RBE was slightly higher.

It was concluded that the tri-component mixtures containing fossil diesel fuel and equal proportion of butanol and rapeseed oil butyl esters are the most promising fuels considering their practical application, better energy-fuel economy, and ecological properties compared to fuel mixtures containing only RME. For a mixture with 30% of bio-components, the overall efficiency was as good as that of fossil diesel fuel; an increase of bio-components to 50% causes an increase in efficiency by upto 4% as compared to neat diesel. Nearly four times decrease in concentrations of CO and HC in exhaust gases was also observed when the engine was running on mixture of D70/B15/RBE15. NO_X emissions were nearly the same but smoke emissions reduced by large amount for all the samples in comparison to fossil derived diesel fuel and the maximum reduction was observed for tricomponents of the mixtures [47].

2.4 PROBLEM STATEMENT

On the basis of the exhaustive literature review it can be concluded that n-butanol can be blended upto 25% with diesel without undergoing any modifications in the present diesel engines.

On the basis of literature review and some initial experimental work, it was found that n-butanol can be blended with diesel without any difficulties of phase separation. However, the use of biodiesel and n-butanol blend as a substitute of diesel fuel is one of the areas that are still needed to be explored, as hardly any research papers are available for study in this context.

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

1. Comprehensive Literature Review
2. Prepare and study the solubility and homogeneity of jatropha biodiesel and n-butanol blends.
3. Determination of important physico-chemical properties of jatropha biodiesel and n-butanol blends and compare it with properties of neat jatropha biodiesel.
4. Development of a diesel engine test rig.
5. Conduct exhaustive experiments on diesel engine test rig to evaluate the performance and emission characteristics of various blends prepared and compare them with the baseline data of jatropha biodiesel.
6. Analysis of results

CHAPTER 3

SYSTEM DEVELOPMENT & EXPERIMENTAL PROCEDURE

3.0 INTRODUCTION

Diesel Engines are one of the most useful and efficient prime movers among all the power producing machines. Due to this reason it is necessary to get such a workable fuel for the engine that can function well in the engine without deteriorating and reducing its life as well as to reduce the harmful emissions from the engine.

Biofuels are getting a renewed attention because of global stress on reduction of green house gases (GHGs) and clean development mechanism (CDM). The fuels of bio-origin may be alcohol, vegetable oils, biodiesel, biomass, and biogas. Biodiesel have comparable physico-chemical properties with mineral diesel and they are biodegradable, non-toxic, and have a potential to significantly reduce pollution.

Due to these reasons many countries including the developing one has started investing generously into the projects which will provide some useful fuel. Each country can move ahead in the production of fuel depending upon its climatic conditions as well as its economy. Various blend of biodiesel with alcohols prove to work as a promising fuel as already seen in the Literature Review in terms of reduction in harmful emissions in the environment and decreasing the dependency on fossil diesel to some extent.

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

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

3.1 JATROPHA CURCAS PLANT & ITS OIL

Jatropha oil is proven to be one of the most easily available oil extracted from inedible seeds of the jatropha curcas plant which can be grown easily on marginal land. The jatropha plant (Jatropha Curcas) or physic nut is a shrub belongs to the family of genus Euphorbiaceae. The jatropha curcas plant originated from South America and now the plant can be found anywhere in the world in arid, semi arid, tropical and sub-tropical areas.

The jatropha plant can be grown in almost all types of soils. It can even be grown in very poor soil and still produce an above average yield of seeds. However, light sandy soil is the most favorable. The jatropha curcas is a drought resistant plant that can live up to 50 years.

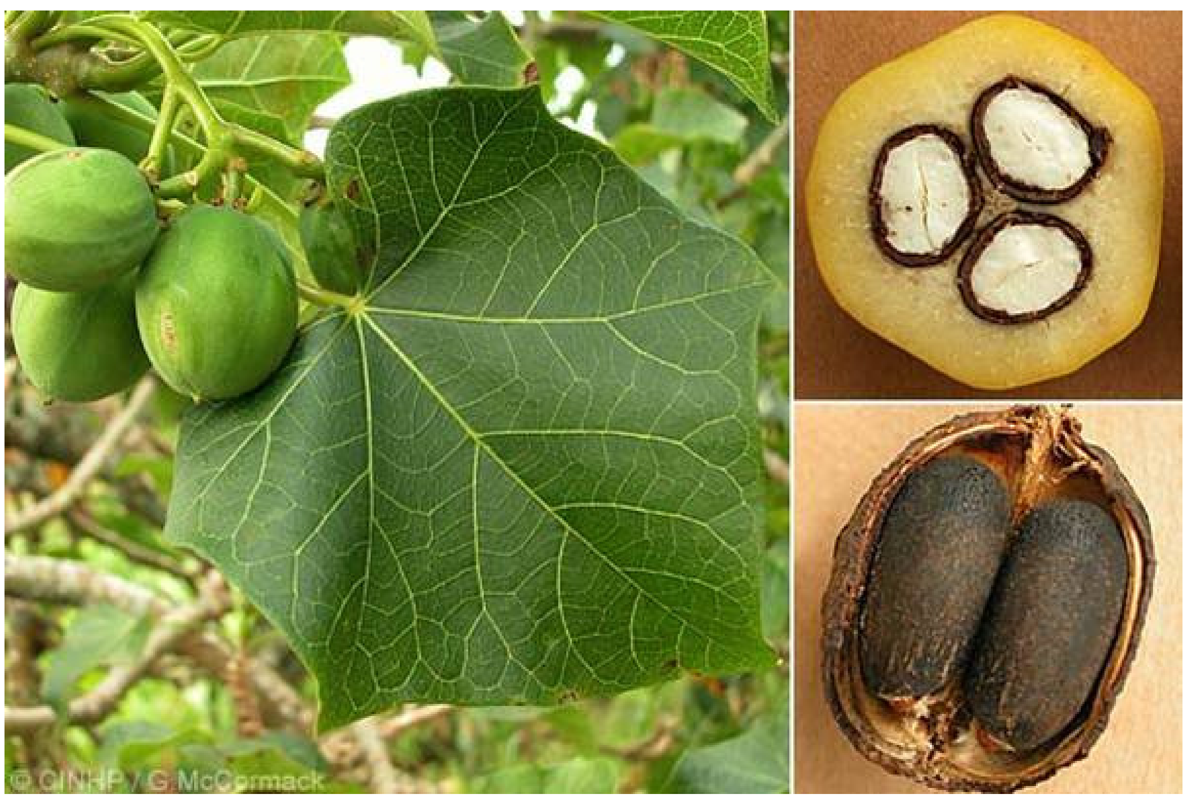


Plate 3.1 Jatropha Curcas Plant and Its Seeds

Jatropha curcas can grow even with a minimum annual rainfall of 250 mm and it can withstand a maximum annual rainfall of 3000 mm. The minimum rainwater requirement depends upon the humidity, i.e. higher the humidity, less the minimum rainfall jatropha plant can tolerate. Jatropha curcas plants can be found at varying altitudes i.e. from sea level to 1800 m altitudes. The tree grows to a maximum height of nearly 5 m. Jatropha oil is a very promising fuel for using in a diesel engine due to several advantages: Jatropha oil is a renewable fuel that could last for many years without much problems. Jatropha oil is environmentally friendly fuel and can be easily produced in rural areas.

The plant starts producing yield after 4 – 5 months of plantation. Jatropha tree produces a round fruit which has a soft brownish skin, have 1.5 – 3 cm in diameter and weigh 1.5 – 3 g. The seeds contain approximately 30-35% oil. The oil is pale yellow to brown in colour. The oil contains a toxic compound known as curcas which have a strong purging effect.

The major disadvantage of jatropha oil as a fuel in a diesel engine is the high viscosity of jatropha oil that is due to the large molecular mass and chemical structure of jatropha oil. Previous studies show that the high viscosity causes problems in pumping, combustion and atomization in injector systems of diesel engines [48-50].

3.2 CONVERSION OF JATROPHA CURCAS OIL TO JATROPHA METHYL ESTER

As already seen in literatures, the viscosity, volatility and exhaust emissions of vegetable oils deviate far away from properties of diesel. To make use of vegetable oils in a effective way it should be converted into biodiesel using a single or a two step conversion process. Normally the free fatty acid (FFA) of jatropha oil is quite high i.e. over 5 %. So we need to undergo esterification process with the help of alcohols like methanol, ethanol etc. and acid catalyst like PTSA or H2SO4 etc. which reduces the amount of FFA in oil. This esterified oil of nearly 1% FFA is now transesterified with the help of alcohols and base catalyst like NaOH and KOH to get biodiesel.

A two step transesterification process is discussed by Karmakar et. al. [51]. A flow chart is shown in Fig. 3.1 to make biodiesel from raw oil.

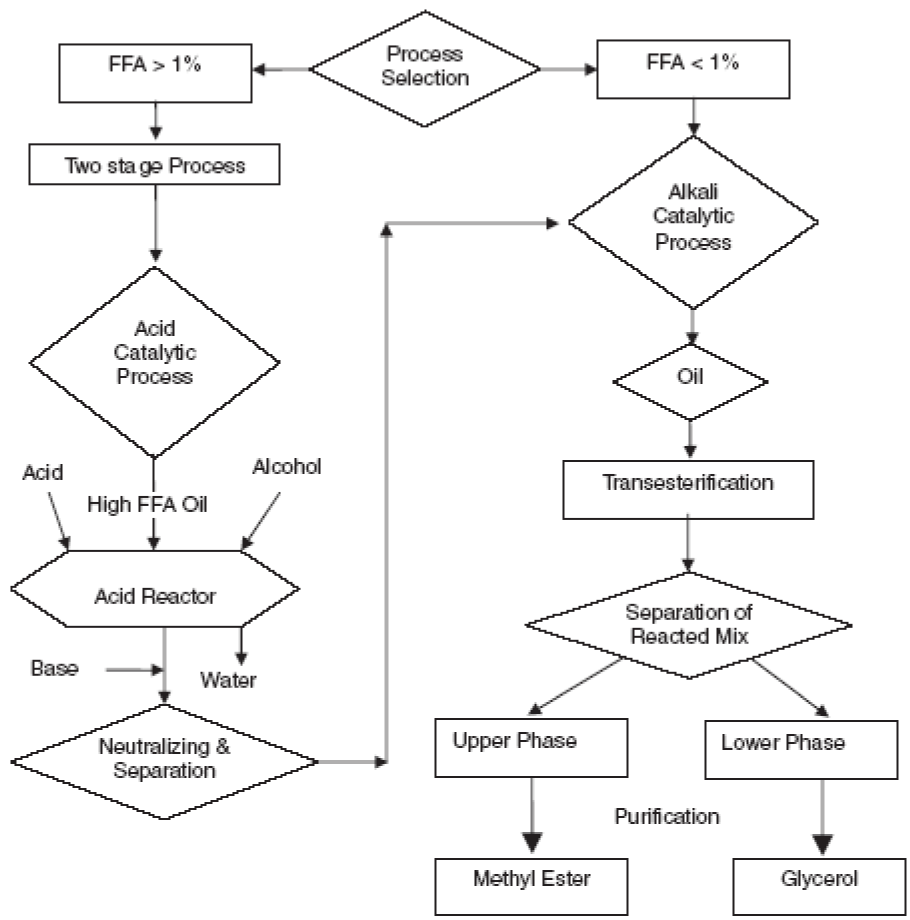
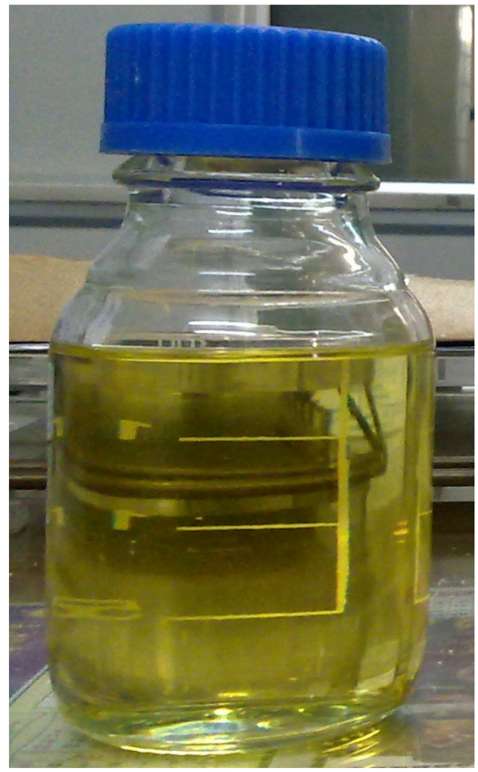


Fig. 3.1 Two step transesterification process [51]

Similar procedure is used to make biodiesel for the project work from jatropha oil using methanol and PTSA for esterification and methanol and KOH for transesterification to obtain jatropha methyl ester. This transesterified oil is then water washed to remove un-reacted catalyst and methanol and then finally heated at remove moisture from biodiesel.

Plate 3.2 below shows the changes in appearance of jatropha oil and jatropha biodiesel (obtained after transesterification) which is shiny and yellowish in colour.



JATROPHA OIL **JATROPHA BIODIESEL**

Plate 3.2 Physical appearance of jatropha oil and jatropha biodiesel

3.3 PRODUCTION OF N-BUTANOL

Like ethanol, butanol is also a biomass-based fuel or in other words it is a renewable fuel that can be produced by fermentation of biomass feedstocks.

Butanol ($CH_3(CH_2)_3OH$) has a 4-carbon structure and is a more complex alcohol (higher-chain) than ethanol as the carbon atoms can either form a straight chain or a branched structure, thus resulting in different properties. Then, it exists as different isomers depending on the location of the hydroxyl group (–OH) and carbon chain structure, with butanol production from biomass tending to yield mainly straight chain molecules. 1-butanol, also better known as n-butanol (normal butanol), has a straight-chain structure with the hydroxyl group (–OH) at the terminal carbon [52-53].

The production process of butanol has been known to us from over a century. In the year 1862 Louis Pasteur has reported the production of butanol by the fermentation of glucose by using a gram-positive Clostridium anaerobe. Since then this method of fermentation is known as acetone, butanol and ethanol process or the popular name as ABE process, where acetone, butanol and ethanol are the three major products produced [54].

It has been 150 years since the development of the ABE process but the members of Clostridium genus, mainly Clostridium acetobutylicum (CA) and Clostridium biejerinckii (CB), continues itself to be one of the most widely used organisms for fermentation process to produce butanol

Apart from these certain by products like carbon dioxide, acetic acid, butyric acid, and trace amounts of hydrogen gas are also produced The typical ABE process produces a 6 : 3 : 1 ratio of butanol : acetone : ethanol. ABE process gives an yield of 25-33 g/L of acetone, butanol and ethanol [55-58].

3.4 JATROPHA BIODIESEL AND N-BUTANOL FUEL BLEND DEVELOPMENT

The process of blending of jatropha biodiesel with n-butanol is not very complex. It is already seen in the literatures that n-butanol can easily be blended with diesel and other CI engine fuels without phase separation and so similar trend is seem to be followed for the case of jatropha biodiesel and n-butanol blends .

Table 3.1 shows the nomenclature used for naming n-butanol- jatropha biodiesel blends.

Table 3.1 Nomenclature of n-butanol-jatropha biodiesel blends

S.No.	Nomenclature	% of jatropha biodiesel	% of n-butanol
1.	JB100	100	0
2.	95JB 5B	95	5
3.	90JB 10B	90	10
4.	80JB 20B	80	20

Blends are prepared by blending 5% by volume of n-butanol with 95 % jatropha biodiesel which is named as 95JB 5B. Similarly 10 % and 20 % of n-butanol is added to 90 % and 80 % jatropha biodiesel respectively to form blends named as 90JB 10B and 80JB 20B.Neat jatropha biodiesel is notated as JB100 containing 100% jatropha biodiesel. Test fuel samples prepared are shown in Plate 3.3.

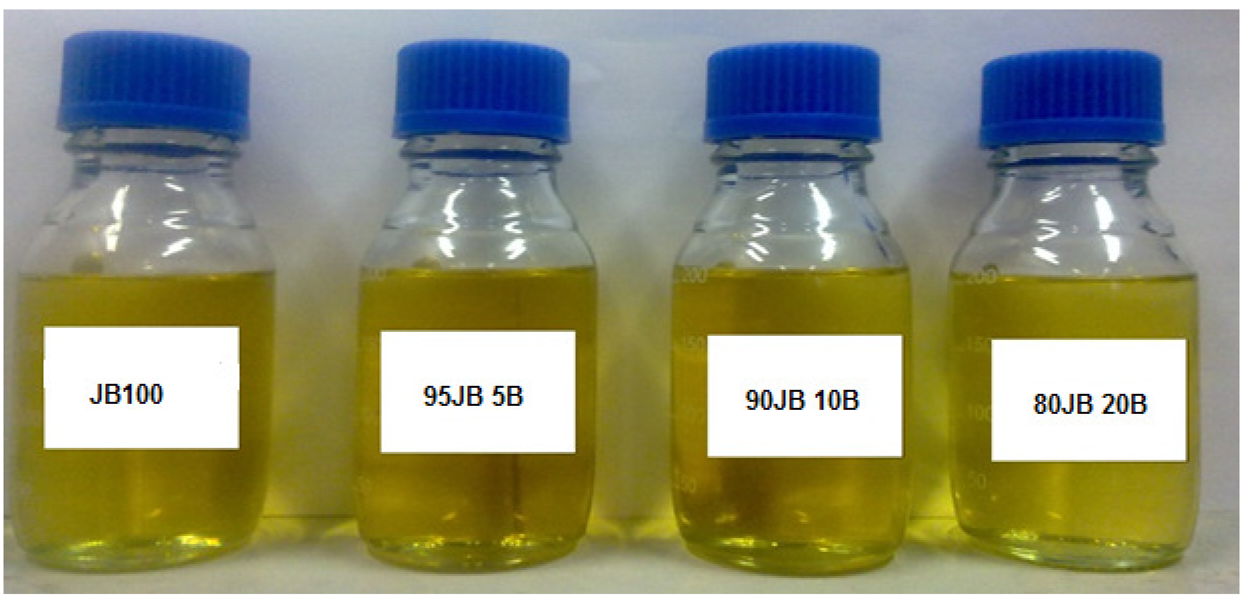


Plate 3.3 Test Fuel Samples

3.5 HOMOGENEITY TEST

All the fuel samples were kept for over two months in closed bottles. They were regularly checked for phase separation and homogeneity.

3.6 PHYSICO-CHEMICAL PROPERTIES

The properties which were evaluated during the present investigation and experimental procedure are summarized below.

PHYSICO CHEMICAL PROPERTIES DETERMINATION

3.6.1 Density and Specific Gravity

For the determination of density various methods are there. A simple U tube oscillating true density meter is one of the instrument to be used in the determination of density and specific gravity. The fuel density is calculated at a temperature of 15^{o}C. The equipment used for the measurement of density and specific gravity is shown in Plate 3.4. Company make of instrument is Anton Paar.

Plate 3.4 Density Meter

3.6.2 Kinematic Viscosity

Viscosity describes a fluid's internal resistance to flow and it is a measure of fluid friction. A fluid when subjected to external forces, resists flow due to internal friction.. The viscosity of the fuel affects atomization and fuel delivery rates. It is an important property because atomization and mixing of air and fuel in combustion chamber gets affected by its change. Viscosity measurements were conducted for different blends under consideration. Kinematic viscosity of liquid fuel samples were measured using kinematic viscometer Plate at 40^{o}C as per the specification given in ASTM D445. A suitable capillary tube was selected, and a measured quantity of sample was allowed to free flow through the capillary tube. Time is noted for passing of fuel from the capillary tube’s upper level and lower level mark. Plate 3.5 shows the kinematic viscometer used for the experimental purpose.

Plate 3.5 Kinematic Viscometer

$$\nu = k \times t$$

Where, ν = Kinematic viscosity, mm^2/sec

k = constant; mm^2/sec^2

t = time, in seconds

3.6.3 Calorific Value

The Bomb calorimeter is the device used for the determination of calorific value. Calorific value is a measure of amount of heat released by the combustion of unit amount of substance or fuel in the presence of oxygen in a bomb calorimeter. The calorific value of fuel was determined by the use of Isothermal Bomb Calorimeter as per the specifications given in ASTM D240. The calorimeter model used is "Parr 6100 Oxygen Bomb Calorimeter". The sample of fuel was burned electrically by the use of electrodes fitted in bomb. Higher calorific value is measured in the calorimeter which is the amount of heat abstracted during the formation of steam in the process of combination of hydrogen and oxygen.

Plate 3.6 Bomb Calorimeter

Plate 3.6 shows the bomb calorimeter used for the determining the HCV of jatropha biodiesel and the blends formed.

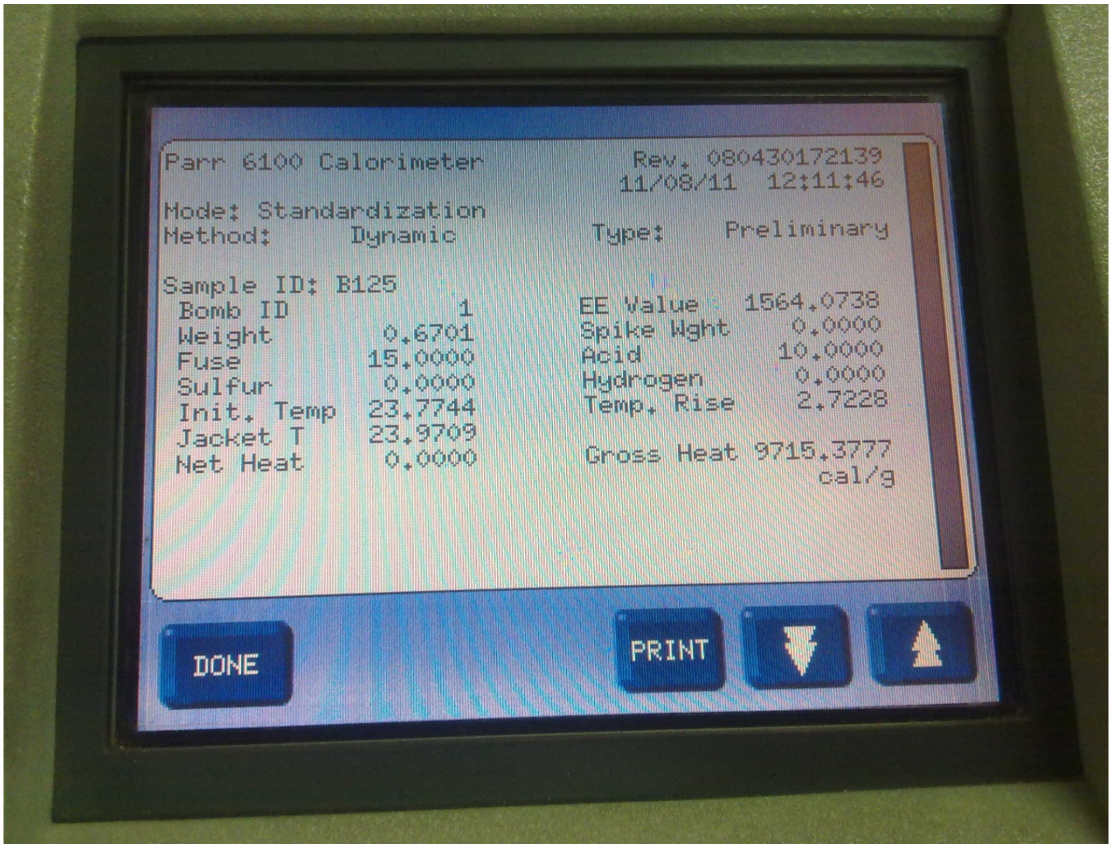


Plate 3.7 Test Reading in Bomb Calorimeter

Results can be shown by the instrument either in MJ/kg or Cal/gm.

3.7 SELECTION OF DIESEL ENGINE

Due to the robustness and high load carrying capacity diesel engines are preferred more than the petrol engine in agriculture, marine and other load carrying locomotives like trucks. Also the fuel economy and cheap diesel fuel than petrol has attracted the manufacturers to make vehicles having diesel engine.

Air Pollution created by diesel engine is also more severe than the petrol engine. Also due to bulkiness in terms of more storage capacity of engine for moving more goods at the same time they consume more fuel and so create more air pollution. Due to this reason by changing some trend in the decrease of air pollution or harmful emissions by changing the fuel can bring considerable changes 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 DEVELOPMENT OF EXPERIMENTAL TEST RIG

A Kirloskar Model number CAF 8 make, single cylinder, air cooled, direct injection, diesel engine was selected for the present research work, which is mainly used for agricultural activities and as a household electricity generator.

Plate 3.8 Test Engine

Table 3.2 describes the specifications of diesel engine used for the experiments.

Table 3.2 Diesel Engine Specifications

Make	Kirloskar
Model	CAF 8
Rated Brake Power	5.9 KW/8 HP
Rated Speed (rpm)	1500
Number of Cylinder	One
Bore X Stroke (mm)	95 x 110
Compression Ratio	17.5:1
Cooling System	Air Cooled
Lubrication System	Forced Feed
Cubic Capacity	0.78 Lit
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

This engine is coupled to an electrical alternator used to produce the electric current. This supply is given to the electrical loads (bulbs). The engine is to be started by hand lever. A decompression lever is used for the combustion chamber to be vented and results in low compression ratio.

Various instruments and components are mounted and coupled with the engine to give us the desired experimental data required for the calculation purposes.

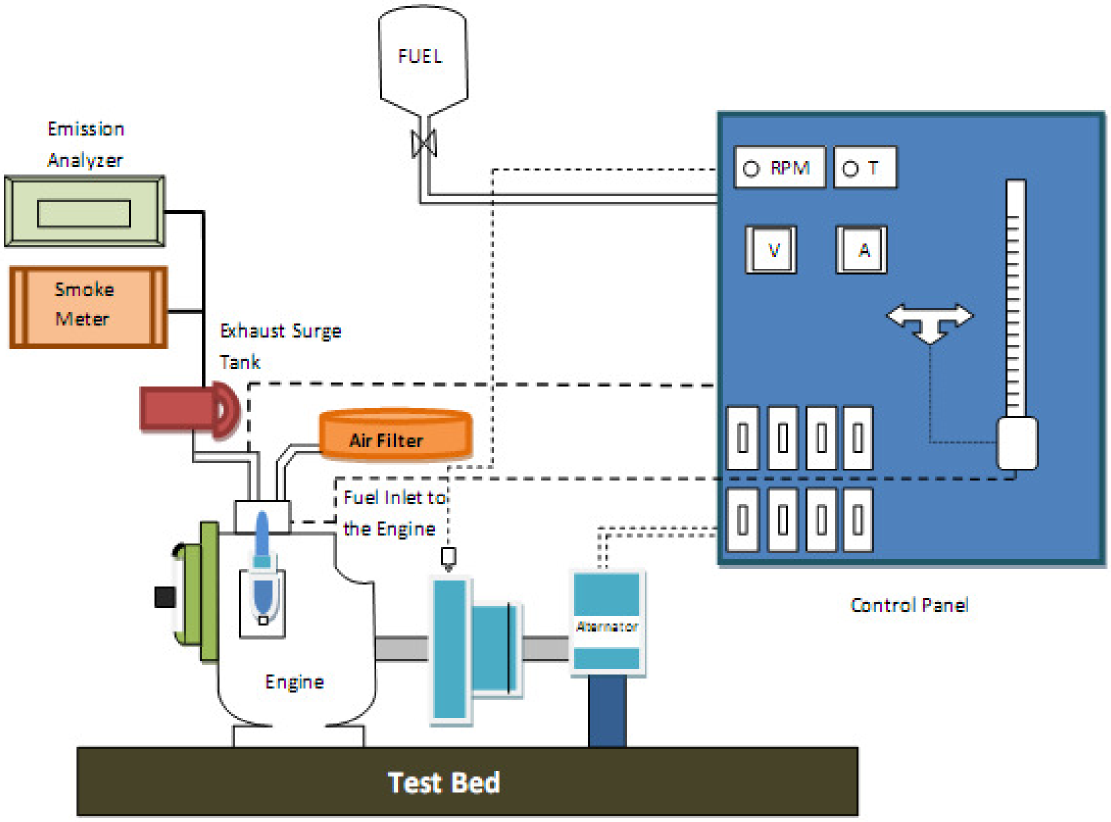


Fig 3.2 Schematic of Test Rig

Fig 3.2 shows the schematic of the test rig used in experiments for the determination of performance and emission characteristics of the engine working at different electrical loads.

Plate 3.9 shows the actual test rig used for the experimental purpose

Plate 3.9 Test Rig

3.9 CONTROL PANEL INSTALLATION

After the Test rig has been developed, the control panel is made and connected to the engine.

Plate 3.10 Fuel Tank

Plate 3.11 Control Panel (Indicators & Meters)

The contol panel is mounted with the burette, electrical loads, ammeter, voltmeter, temperature indicator, rpm indicator, switches, mcb, fuel lines and contol valves as shown in the plates 3.11 and plates 3.12. Fuel tank is also mounted to prove undisturbed supply of fuel to the engine.

Plate 3.12 Burette & Valves

Plate 3.13 Electrical Load Bank

The engine is loaded by using electrical load bank comprising of twelve 500 W tungsten electrode bulbs. The load on the engine is varied through a series of individual switches. Electrical load banks, i.e., 12 bulbs each of 500 watts, were mounted on the rear side of the Bakelite sheet as shown in plate 3.13 and their switches provided on the front side of the control panel.

3.10 RPM MEASUREMENT OF THE ENGINE

For the RPM measurement a Digital tachometer of MTC company is being used is mounted. A nut was welded on the flywheel face of the engine and tachometer was mounted on a bracket near the flywheel at a distance less than 5 mm. The display unit is mounted on the control panel board.

Plate 3.14 Digital Tachometer

3.11 EXHAUST EMISSION ANALYSIS

The major pollutants appearing in the exhaust of a diesel engine are Unburned Hydrocarbons, Carbon Monoxide, smoke and NO_X. For the measurement of UBHC, CO and NO_X, AVL 4000 Light Di-Gas Analyzer was used. Smoke is also to be measured as smoke is a primary sign of incomplete combustion since it is mainly composed of very small unburnt carbon particles; therefore it is important to determine the smoke content of the flue gas. For measuring the smoke opacity, AVL 437 smoke analyzer was used. 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.

Plate 3.13 Smoke Meter & Di- Gas Analyzer

In addition a simple surge tank is also mounted at the exhaust of the engine to receive consistent exhaust emissions.

3.12 DETERMINATION OF IMPORTANT PARAMETERS

Various parameters are selected and determined with the help of experimental data for the analysis of the blends prepared.

These parameters are

1. Brake Power produced by the engine

2. Brake Specific Energy consumption

3. Brake Mean Effective Pressure

4. Exhaust emissions i.e. CO, HC, smoke content and NO_X.

5. Exhaust gas temperatures

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

1. Voltage generated by the alternator

2. Current generated by the alternator

3. Fuel consumption rate

4. RPM of the engine

5. AVL 437 Smoke meter readings

6. AVL Di Gas Analyzer readings

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

3.13 EXPERIMENTAL PROCEDURE

All electrical and flow connections are checked before starting the engine. If any problem is observed it is corrected. The engine to be used in the determination of performance characteristics i.e. Kirloskar CAF 8 is started by hand cranking it at no load by the use of decompression lever. Then the flow valves are set to control the flow and the engine is allowed to run for nearly 30 minutes to attain steady conditions. With the help of stop watch the time elapsed for the consumption of 10, 20 and 30 ml of the fuel quantity is measured and the average of time is taken. Voltage, Current, RPM, CO, HC, NO_X, smoke density and exhaust gas temperature are measured by the various devices connected to the engine. Then the engine is loaded at different electrical loads gradually and all the parameters mentioned above are again determined and noted down. The performance characteristics and emission characteristics were evaluated for different blends and neat jatropha biodiesel. Comparison is made and studied after these characteristics are plotted in the graph. Before turning the engine off, the fuel was replaced with diesel oil and it was run on diesel till all the fuel in fuel filter and pipe line is consumed.

CHAPTER 4

RESULTS AND DISCUSSION

4.0 INTRODUCTION

The present study was done on an unmodified diesel engine and the main objective of the study was to fuel an unmodified diesel engine with jatropha biodiesel and n-butanol blends and evaluate the performance and emission characteristics of the diesel engine and compare the results with baseline data of jatropha biodiesel.

4.1 PHYSICO-CHEMICAL PROPERTIES

The comparative assessment of physico-chemical properties of blends of jatropha biodiesel and n-butanol was made with neat jatropha biodiesel. The results summarized in Table 4.1 depicts that the density, specific gravity, calorific value and kinematic viscosity of n-butanol- jatropha biodiesel blends decreases with an addition of n-butanol in jatropha biodiesel. Greater is the amount of n-butanol in blend lesser is the density, specific gravity, calorific value and kinematic viscosity. Decrease in viscosity is an advantage in terms of increase in volatility and these properties are in accordance to results of Lujaji et.al. [1] and Mehta et.al.[46].

Table 4.1 Physico-Chemical Properties

FUEL/PROPERTY	DENSITY (g/cm^3)	SPECIFIC GRAVITY	CALORIFIC VALUE (kJ/kg)	KINEMATIC VISCOSITY (cSt)
JB100	0.89031	0.8911	40676.34	6.321
95JB 5B	0.88629	0.8871	40105.56	5.334
90JB 10B	0.88245	0.8832	39626.35	5.124
80JB 20B	0.87485	0.8756	38871.82	4.460

4.2 PHASE SEPARATION & HOMOGENEITY

No phase separation was observed in the blends even after three months. Blends were regularly observed for homogeneity and they remained homogenous even after three months and no significant change was observed.

4.3 PERFORMANCE CHARACTERSTICS

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

4.3.1 Brake Thermal Efficiency

The variation of brake thermal efficiency of the engine with brake mean effective pressure for different blends is shown in the Fig. 4.1. From the experimental test results it is seen that there is a slight increase in BTE of engine for all the blends. The increase in BTE is observed with increase in quantity of n-butanol in jatropha biodiesel.

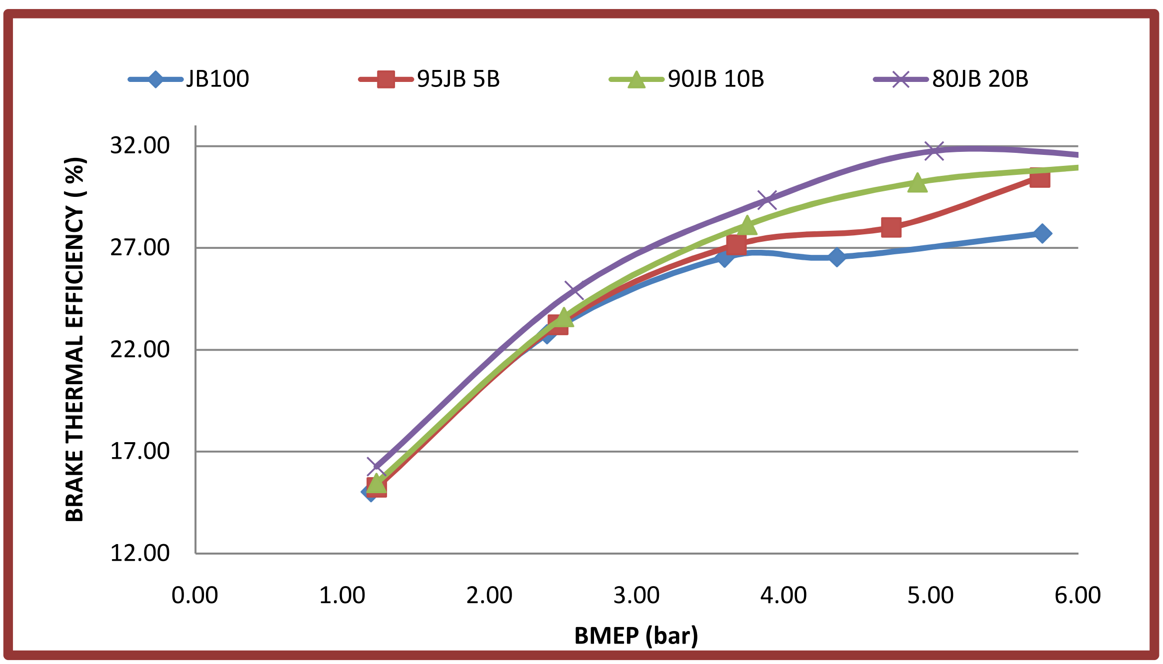


Fig. 4.1 BTE vs BMEP

The maximum thermal efficiency observed in the engine for the blends 95JB 5B, 90JB 10B and 80JB 20B are 30.46 %, 30.98 % and 31.76 % respectively whereas that for neat biodiesel is 27.71%. In the test operations with blends, the engine yields relatively high BTE values for the blends ,which can be attributed to the promoted combustion due to the oxygen content of the blends. Furthermore, blends up to 20% do not cause a significant decrease in the energy content and cetane number of the fuel. The results are in similar to the results obtained by Dogan [43] and Rakopoulos et al. [44].

4.3.2 Brake Specific Energy Consumption

Brake specific fuel consumption is not a very reliable parameters to be considered for comparing the performance of n-butanol- jatropha biodiesel blends and neat biodiesel since density and calorific value of both type of fuels are significantly different. Therefore, brake specific energy consumption is considered as a better parameter to compare the energy requirement for producing unit power for the different test fuels.

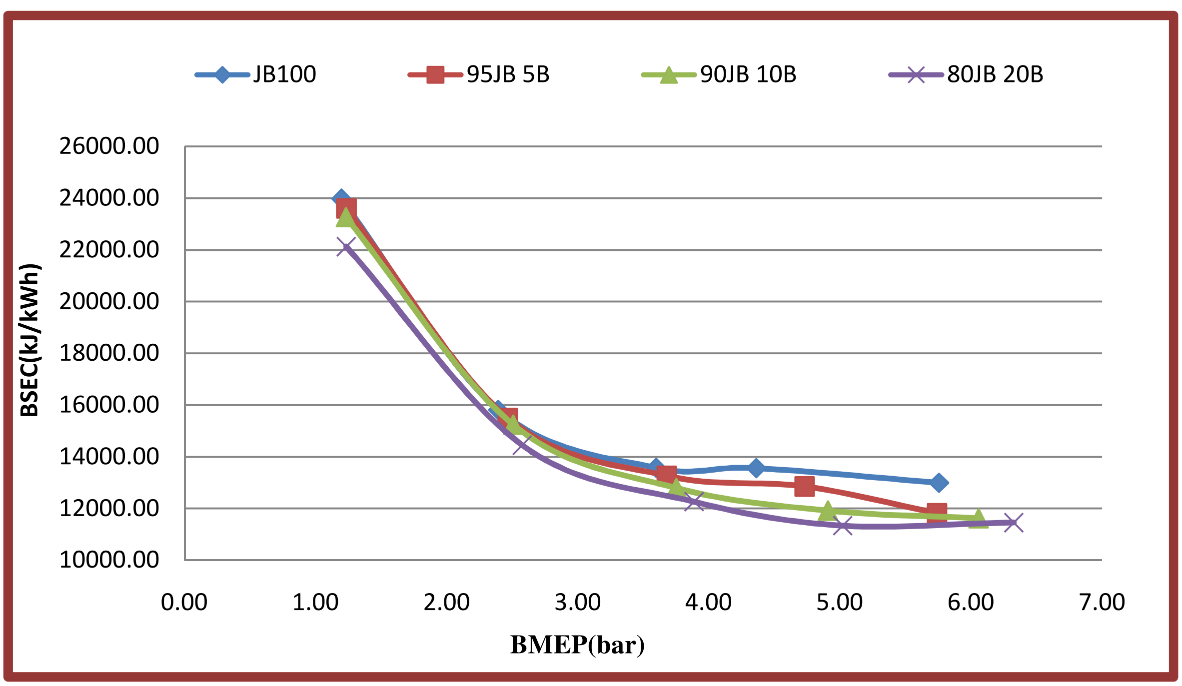


Fig. 4.2 BSEC vs BMEP

As seen from Fig. 4.2 , the BSEC reduces with the increase in BMEP. Brake specific energy consumption of n-butanol-jatropha biodiesel blends is lower than that of jatropha biodiesel. This is mainly because of presence of oxygen in butanol in addition to biodiesel which in turn helps in better comubustion in case of n-butanol-jatropha biodiesel blends. Due to better combustion of fuel blends, requirements for energy is reduced and hence, BSEC of blends decreases in comparison to baseline result . Decrease in viscosity of blends due to presence of n-butanol also helps in better atomisation on fuel and subsequent better consumption.

4.3.3 Exhaust Temperature

Fig. 4.3 shows the variation of exhaust gas temperature with brake mean effective pressure for different blends of n-butanol and jatropha biodiesel and neat jatropha biodiesel. The result shows that the exhaust gas temperature decreased with increase in brake power in all cases. The highest value of exhaust gas temperature of 381°C which was observed with neat jatropha biodiesel (JB100) and the lowest value of exhaust gas temperature was achieved with the blend 80JB 20JB of about 341°C.

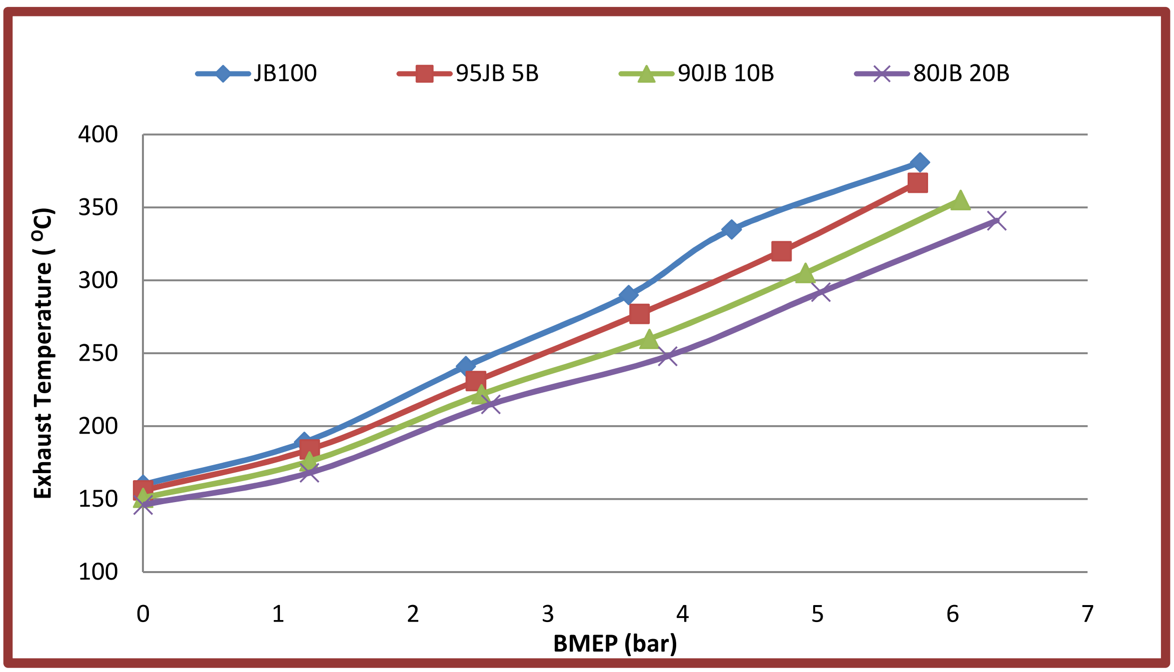


Fig.4.3 Exhaust Temperature vs BMEP

The reduction in exhaust temperature with butanol addition in biodiesel may be due to quenching effect produced by n-butanol presence in n-butanol-jatropha biodiesel blends. This results in lower exhaust temperature. These results are in agreement with the results of Dogan [43] and Rakopoulos et.al [44]. The lower exhaust temperature with n-butanol-jatropha biodiesel blends is an indication of higher thermal efficiencies of the engine. At higher thermal efficiency, more of the energy input in the fuel is converted to work, thereby decreasing exhaust temperature.

4.4 EMISSION CHARACTERISTICS

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

4.4.1 CO Emissions

Carbon Monoxide emission is toxic in nature and has to be controlled. CO emissions are produced mainly due to the lack of oxygen, poor air entrainment, mixture preparation and incomplete combustion during the combustion process [59].

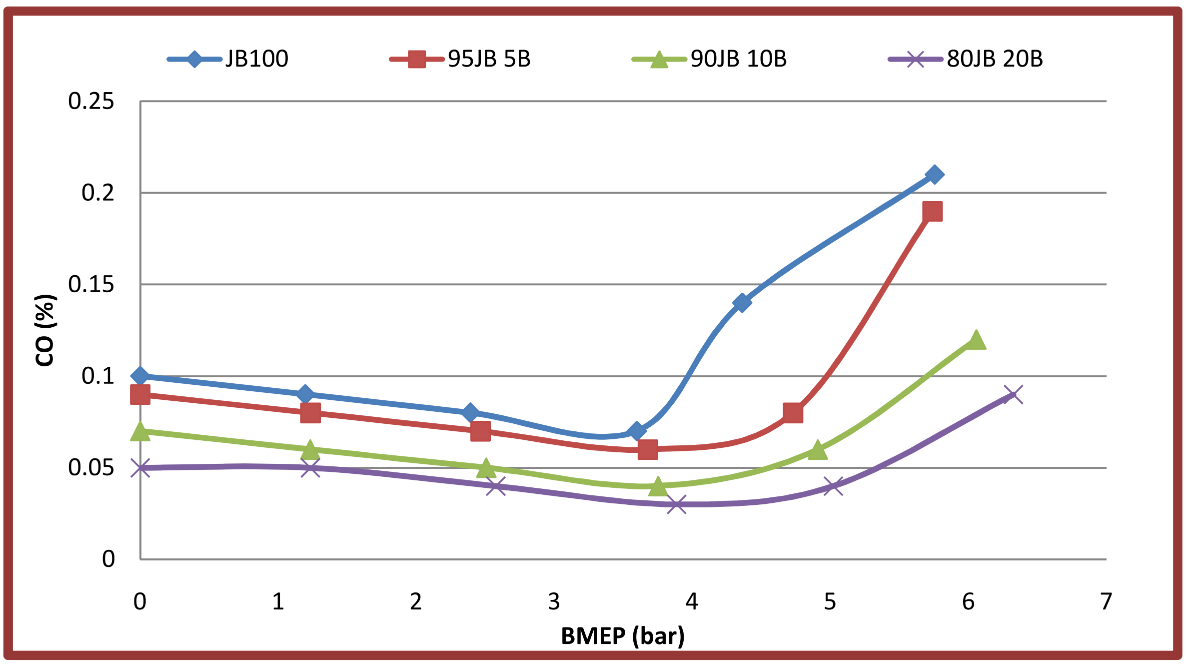


Fig. 4.4 CO vs BMEP

Fig. 4.4 clearly indicates that n-butanol addition in jatropha biodiesel results in decrease in CO emissions. There is appreciable decrease in CO at high loads over the base line data of biodiesel as a fuel.

The main reason for decrease in CO emissions is mainly due to decrease in viscosity and density of fuel. There is a considerable increase in volatility due to decrease in viscosity which helps in proper atomisation of fuel.

Decrease in CO emissions is also due to the increase in amount of oxygen locally in n-butanol-jatropha biodiesel blends. These results are in agreement with the results of Dogan [43], Rakopoulos et.al [44], Altun et.al. [42] and Lujaji et.al.[1].

4.4.2 NO_X Emissions

The variation of NO_X emissions for all the test fuels is shown in.Fig.4.5. The NO_X emissions decreased with the increasing engine load, due to a lower combustion temperature. This proves that the most important factor for the emissions of NO_X is the combustion temperature in the engine cylinder and the local stoichiometry of the mixture.

From Fig. 4.5, it can be seen that by using the blends of n-butanol-jatropha biodiesel, quenching effect is produced which results in decrease in exhaust gas temperature. As a result of this decrease in temperature, there is slight decrease in NO_X emissions from engine.

For JB100, the highest NO_X emission was 2326 ppm, but in case of 95JB 5B, 90JB 10B and 80JB 20B, the highest value of NO_X was 2318, 2257 and 2183 ppm respectively.

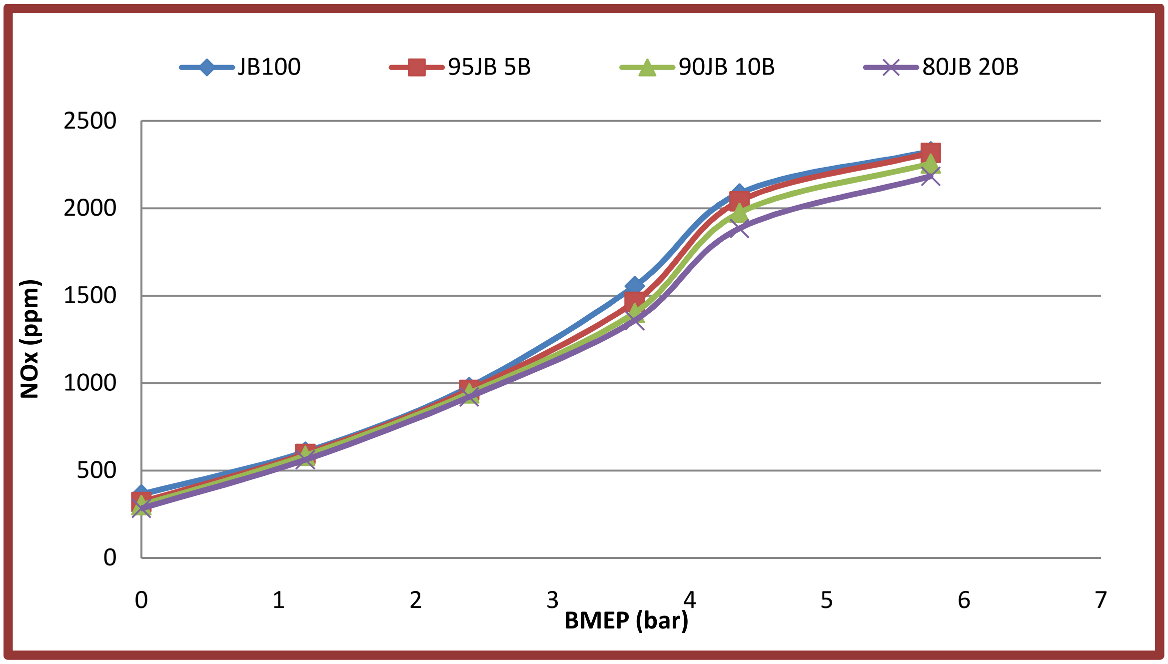


Fig. 4.5 NO_X vs BMEP

The results obtained from the study show that by using blends of n-butanol with jatropha biodiesel in diesel engine, NO_X emissions reduces and these results are in agreement with Dogan [43] and Rakopoulos et.al. [44].

4.4.3 Un-burnt Hydro Carbon Emissions

The variation in unburnt hydrocarbon (HC) for n-butanol and jatropha biodiesel is shown in Fig. 4.6. HC emissions were found to increase with the increase in engine load. However, for blends of n-butanol and jatropha biodiesel, the HC emissions were found to increase. The low cetane number of n-butanol is the main reason for higher HC emissions with blends.

The low cetane number deteriorates self-ignition characteristics of the blends and promotes quenching effect in the leaner mixture zone of the cylinder [45]. The results obtained in the present investigation are in accordance to results obtained by Dogan [43], Rakopollos et.al. [44] and Karabektas et.al. [45].

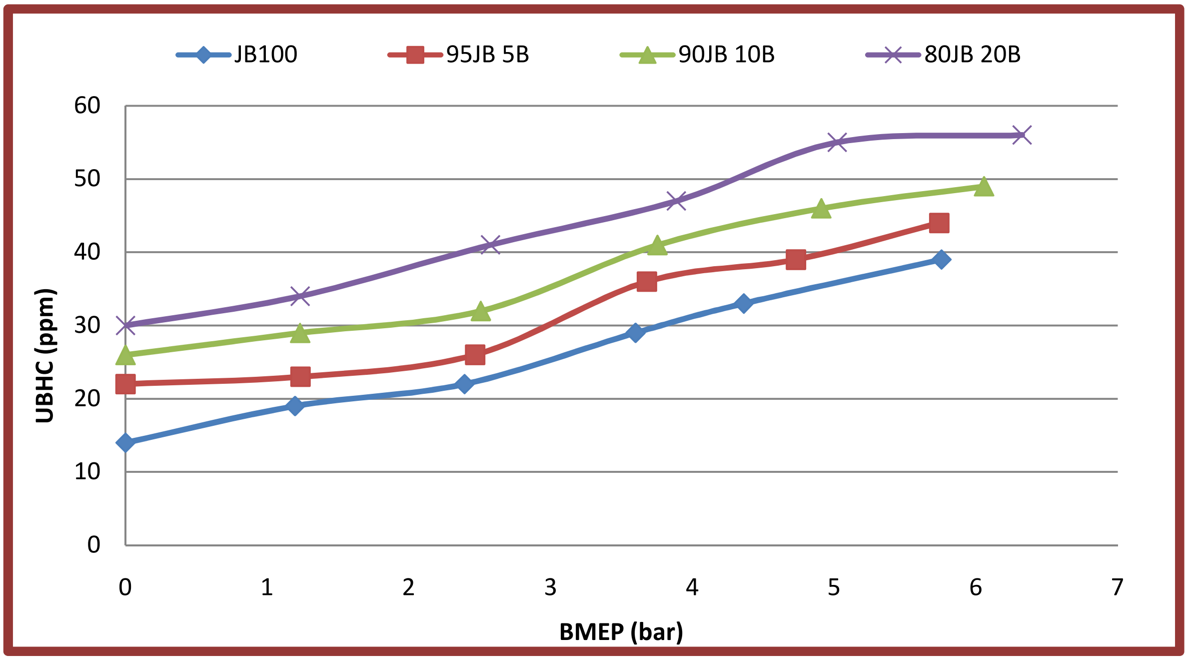


Fig. 4.6 UBHC vs BMEP

4.4.4 Smoke Opacity

Fig. 4.7 represents the variation of smoke opacity for different test fuels.

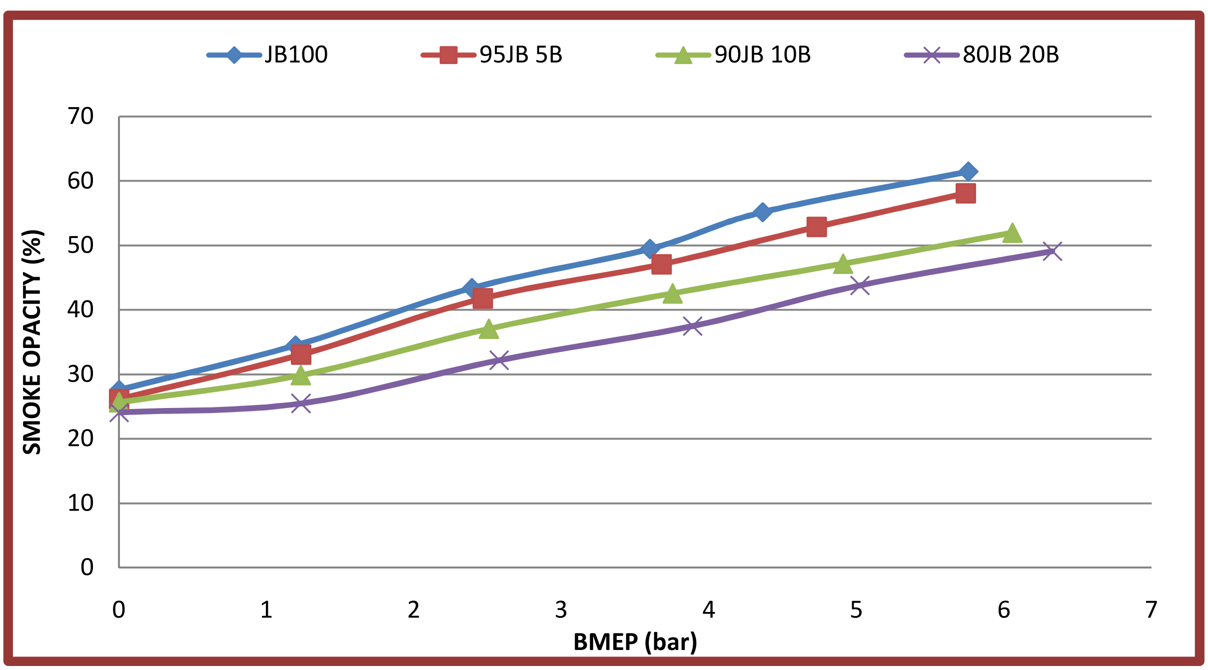


Fig. 4.7 Smoke Opacity vs BMEP

Jatropha biodiesel has the maximum level of smoke content under all loads conditions whereas 20% butanol and 80% jatropha biodiesel blend had exhibited lowest smoke opacity. Blending of butanol in biodiesel have resulted in reduction in smoke at all loads. This has been because of additonal oxygen in butanol which have resulted in better combustion of n-butonol-jatropha biodiesel blends. Further, lower viscosity of butanol-biodiesel blend have also resulted in better atomisation resullting in improved combustion and hence lower smoke opacity. These results are in agreement with the results of Dogan [43] and Rakopoulos et.al [44].

CHAPTER 5

CONCLUSION AND SCOPE FOR FUTURE WORK

5.1 CONCLUSIONS

The present study was carried on an unmodified diesel engine. The main objective of the present investigation was to evaluate suitability of n-butanol as a fuel blended with jatropha biodiesel for use in a C.I. engine and to evaluate the performance and emission characteristics of the engine. The experimental results show that the engine performance with blends has improved in comparison to performance with biodiesel.

The calorific value, kinematic viscosity, density and specific gravity of blends decrease by increase the blending percentage. The thermal efficiency of the engine was higher with blends. BTE increases by increasing the percentage of n-butanol mixture in the blend and the brake specific energy consumption of the engine were lower and continued to decrease by increasing the percentage of n-butanol in the blends. Carbon monoxide (CO), the oxides of nitrogen (NO_X) and smoke opacity of blends were found lower than jatropha biodiesel during the whole experimental range. However, Unburnt Hydrocarbon (HC) emission was found to have slightly increased.

The results from the experiments suggest that n-butanol is a potential alternative fuel to be blended with jatropha biodiesel for diesel engine application.

5.2 SCOPE FOR FUTURE WORK

On the basis of experience gained during the present series of investigation, the following directions are indicated for further investigations and developments:

In the present study, butanol concentration was limited upto 20%. It is suggested that higher concentration of butanol may be explored in the future work.

In the present study, an unmodified diesel engine was used, however, it is expected that certain modifications may be required for better performance than unmodified one. Therefore, the engine design may be modified specially the injection system for using blends of n-butanol and biodiesel.

The short term trial of engine was carried in the present work. There is an urgent need to carryout long term endurance test to assess the suitability of n-butanol-jatropha biodiesel blends on engine hardware.

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APPENDICES-I

Technical Specifications of AVL Di-Gas Analyzer

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

Measurement Ranges of AVL Di-Gas Analyzer

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

Technical Specifications of AVL 437 Smoke Meter

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