UTILISATION OF JATROPHA BIODIESEL (ETHYL ESTER) IN SMALL CAPACITY DIESEL ENGINE

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Mechanical Engineering Department
In partial fulfilment of the requirement of the degree of

MASTERS OF TECHNOLOGY
IN
Thermal Engineering

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This is to certify that report entitled **“Utilisation of Jatropha Biodiesel (Ethyl Ester). In Small Capacity Diesel Engine”** by **MR. SURESH KUMAR SAROJ is** the requirement of the partial fulfilment for the award of Degree of **Master of Technology (M.Tech)** in **Thermal Engineering** at **Delhi Technological University, New Delhi.** This work was completed under my supervision and guidance. He has completed his work with utmost sincerity and diligence. The work embodied in this project has not been submitted for the award of any other degree to the best of my knowledge.

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ACKNOWLEDGEMENT

First of all, I would like to express my gratitude to God for giving me ideas and strengths to make my dreams true and accomplish this thesis. I ask God that this thesis and the published works to be a useful guide to help other researchers towards a green world that is utilized by sustainable energy systems.

To achieve success in any work, guidance plays an important role. It makes us put right amount of energy in the right direction and at right time to obtain the desired result. Express my sincere gratitude to **Dr NAVEEN KUMAR,** Professor, in MechanicalEngineering Department for giving valuable guidance during the course of this work, for his ever encouraging and timely moral support. His enormous knowledge always helped me unconditionally to solve various problems.

I am greatly thankful to **Dr R.S. MISHRA** , Professor and Head, Mechanical Engineering Department, Delhi Technological University, for his encouragement and inspiration for execution of the this work. I express my feelings of thanks to the entire faculty and staff, Department of Mechanical Engineering, Delhi Technological University, and Delhi for their help, inspiration and moral support, which went a long way in the successful completion of my report work.

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Abstract

Diesel Engines have proved its utility in transportation, agriculture and power sector of India. These engines also help in developing decentralized systems energy for electrification. However, the concerns about long term availability of petroleum diesel and stringent environmental norms have mandated that renewable alternative to diesel fuel should be expeditely explored to overcome these problems. The major oil varieties, considered suitable for biodiesel making are Jatropha curcas. Biodiesels have always been considered as a good alternative to diesel for last many years and oil derived from Jatropha curcas plant has been considered as a sustainable substitute or extender to diesel fuel.

This study targets at making a comparison of the ethyl esters of non-edible oils in a diesel engine against diesel fuel. The present work aims at developing a dual fuel engine test rig work on dual fuel mode. The performance parameters of the fuels was evaluated in terms of thermal efficiency, specific fuel consumption, power output and mean effective pressure, cylinder pressure, rate of pressure rise, and heat release rates. The emission parameters of carbon monoxide (CO), carbon dioxide (CO2), un-burnt hydrocarbon (HC), oxides of nitrogen (NOx), and smoke opacity with the fuels were also compared. Both varieties of the oil, after trans-esterification, exhibit the major properties within acceptable limits of biodiesel standards set by many countries. Jatropha ethyl ester (JEE) performed better than Jatropha methyl ester (JME), and also the shortest ignition delay is observed with JME. Both the esters performed poorer than diesel, but emissions of HC, NOx, and smoke were found to be lower with biodiesel.

The results from the experiments suggest that biodiesel from non-edible oils like Jatropha could be a good substitute fuel for diesel engine in the near future as far as decentralized energy production is concerned. Considering BTE, BSEC, gaseous emissions and durability and safe operation of the engine without any modification done on the existing Diesel engine.

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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
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
^{0}C	Degree Celsius
CDM	Clean Development mechanism
cc	Cubic centimetre
CI	Compression Ignition
cm^{-1}	Per Centimetre
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
EOI	End of Injection
EV	Electric Vehicle
ºF	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
GDP	Gross Domestic Product
GHG	Green House Gases
GNP	Gross National Product
g/cc	Gram per cubic centimetre
HC	Hydrocarbon
H_2O	Water
HP	Horse Power
Hz	Hertz
IC	Internal Combustion
IDI	Indirect Injection

IR	Infra-Red
IS	Indian Standard
J/CA	Joule per crank angle
JEE	Jatropha ethyl Ester
JEE5	Jatropha ethyl Ester with 5%Blend
JEE10	Jatropha ethyl Ester with 10%Blend
JEE20	Jatropha ethyl Ester with 20%Blend
JEE30	Jatropha ethyl Ester with 30%Blend
JEE100	Jatropha ethyl Ester with 100%
KGOE	Kilogram of oil equivalent
Kg/m^3	Kilogram per cubic meter
kJ/kg	Kilo Joule per kilogram
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

MBOE	Million Barrel oil Equivalent
mg	Milligram
Min	Minute
ml	Milliliter
mm	Millimetres
Mt	Million Tonnes
Mtoe	Million Tonne of Oil Equivalent
NO	Nitric Oxide
Nos.	Numbers
NO_2	Nitrogen Di-oxide
NOx	Oxides of Nitrogen
nPAH	Nitro Poly Aromatic Hydrocarbon
OECD	Organization for Economic Co-operation and Development
O_2	Oxygen
PAH	Poly aromatic Hydrocarbon
PM	Particulate Matter
ppm	Parts per million
RET	Renewable Energy Technologies
rpm	Revolutions Per Minute
SAE	Society of Automobile Engineering
Sfc	Specific Fuel Consumption
TG	Tri-glycerides
TDC	Top Dead Center

CHAPTER 1

INTRODUCTION

1.1 Energy Crises

Energy has always an important role for economic development of any nation in the world. It has a vital role in social development. Growth of a country is measured as per capita energy consumption besides GDP, GNP, etc. While the world has seen as a large industrialisation in the past century, it has also come to face with very dangerous problems arising from the utilization of the energy resources. The concept of the country was ‘More the energy resources, more the development of country’. Low fuel costs did not encourage efficient utilization of energy. During the intensive process of industrialization, the world observed consumption of majority stock of its energy resources and deterioration of the global environment. Energy made up a very small component of the total production cost and monopolized business enabled recovery of high cost of energy.

The Gulf War came as an eye opener for all developed and developing countries. It was then the first time that nations importing petroleum products felt the shock when the petro-nations demanded higher price. This energy crisis forced the world to look for an alternative arrangement to ensure energy sufficiency. This need obviously also pointed at improvement of energy efficiency. The concept changed to ‘More efficiency, more productivity and reduced production cost’. This promised an immediate, long term and multi-faced solution to the problems immerging from increased energy demands against short supplies. Energy management has since become the key word for any profitable industrial unit. As a result of this, positive trends have been noticed over the past decade in the energy use pattern the world over. Countries like the United States, Japan and France have managed to raise their GNP while maintaining the same energy consumption levels. In many cases while the GNP has gone up, the energy consumption has exhibited reducing trends. Introduction of energy efficient technologies and effective energy management has made this possible. Efficiency of energy utilization needs to be a continuous activity as there are lots unproductive energy utilization generally observed in Indian industrial sector.

The world is moving towards a sustainable energy future with an emphasis on energy efficiency and use of renewable energy sources. A finite planet cannot support infinitely increasing consumption of resources and hence the motto of present times must be to "*Reduce*, *Reuse*, and *Recycle*".

The world energy scenario depicts a picture of concern. The adverse effects on environment caused by the production and consumption of energy have resulted in severe environmental impacts across the globe. The supply of energy is expected to remain adequate in coming years. The economic development of many countries is hindered due to "*energy poverty*". Highly volatile fossil fuel prices are creating more and more uncertainty for the global economy while at the same time giving an indirect incentive for investing in renewable energy technologies, which are now booming.

Over the past few years oil prices have gone up and down like a rollercoaster, jumping to a record high in July 2008 of $147.27 and then falling back again to $33.87 in December. Even so, over the whole of 2009 the average oil price was still between $60 and $80 per barrel. In 2009, the total level of annual investment in clean energy was $145 billion, only a 6.5% drop from the record previous year, while the global wind power market grew by an annual 41.5%. The renewable energy industry now employs around two million people worldwide and has become a major feature of national industrial development plans. Meanwhile, the economics of renewables are expected to further improve as they develop technically, as the price of fossil fuels continues to rise and as their saving of carbon dioxide emissions is given a monetary value.

Energy has undergone a major transition from a general field of study of technologies to an important issue in economic planning and international relations. The major sources of energy in the world are oil, coal, natural gas, hydro energy, nuclear energy, renewable combustible wastes and other energy sources. Combustible wastes include animal products, biomass and industrial wastes. Oil is the most important and abundant source of energy in the world. It is also the most highly consumed. However price of crude oil is very volatile and supply is driven by price. Coal is the second most abundant source of energy in the world and is highly used in power generation. Coal ranks quite low in terms of consumption, however its consumption has increased in certain regions. A concern for many developing countries has been the low quality ofCoal. Natural gas has been the energy source with highest rates of growth in recent years. The high end-use efficiency of natural gas has made it a popular choice for power generation projects.Renewable sources of energy are gaining popularity. However, fuel prices and regulatory policies of different countries play an important role in the development of renewable.

1.2 Energy Scenario in India and South Korea

We all know India is a rich country in form of coal and also renewable energy in the form of solar energy, wind energy, hydro power and bio-fuel, Oil reserves in India is 5.8 thousand million barrels at the end of 2009 which is really very small (0.4 per cent of world's oil reserves). India accounts 11.3 % of total primary energy consumption in Asia-Pacific region and 4.2 % of world primary consumption in 2010 **[1]**. Per capita energy consumption remains low as 529 KGOE (Kilogram of oil equivalent) compared with a world average of 1,819 KGOE in 2009 [2]**.** In context of South Korea, oil makes up the greatest share of South Korean total energy consumption, though this percentage has declined gradually in recent years. The decline in the share of oil consumption reflects a faster growth in natural gas availability and to a lesser extent coal over the period. Nuclear energy is the second-largest source of energy in South Korea and supplied nearly 29% of primary energy consumption needs in 2009; this is followed by contributions of coal (24.78%) and natural gas (12.68%).The distribution of primary energy in India, South Korea and the total used in the world at the end of 2010 has been shown in Table 1.1.

Table 1.1: Distribution of Primary Energy in India, South Korea and World (MTOE)

	Oil	**Natural Gas**	**Coal**	**Nuclear Energy**	**Hydro Electric**	**Total**
India	**148.5**	**46.7**	**245.8**	**3.8**	**24**	**468.9**

South Korea	**104.3**	**30.4**	**59.7**	**68.6**	**0.7**	**237.5**
World	**3882.1**	**2653.1**	**3278.3**	**610.5**	**740.3**	**11164.3**

India is fourth largest economy of world and has to extensively use energy to sustain its growth.

Since India does not have huge reserves of petroleum products, it is heavily dependent upon the import of petroleum products to cater to its need for automobiles and other applications despite larger initiatives by government and exploration of new sources. Escalating prices, insufficient supply and limited reserves of petroleum have imposed an enormous burden on country's foreign exchange. In year 2007-08 the indigenous production of crude oil was 34.117 million tonnes whereas consumption was 156.1 million tonnes forcing to import 121.67 million tonnes. India is a country which spend more than Rs.2696.99 billion [3] worth valuable foreign exchange towards import of crude petroleum which could otherwise be utilized for various other development works, that might ultimately prove to be more beneficial to Indian people. 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 regard, the subsidy on traditional fossil fuels must be reduced in a phase manner and efforts must be put to develop and promote the use of renewable sources of energy to meet the energy requirement.

1.3 The Future Forecasting

Projecting fuel-wise energy demand of country is by no means an easy task. As rapid changes in the relative availability and price of the fuel sector, coupled with technological innovations and new policies, the underlying assumptions forming the basis of any projection vary from time to time, thereby revising the estimates. They account for close to 83% of the overall increase in energy demand between 2004 and 2030. Oil remains the single largest fuel in the primary fuel mix in 2030, though its share drops, from 35% now to 33% as shown in figure 1.1.

The supply of commercial energy in India is expected to increase to 7156 Million Barrel Oil Equivalent (MBOE) by the year 2018. About one-third (3l %) of it would be imported. Correspondingly, the demand for domestic coal would increase to 3954 MBOE. It implies that existing coal reserves at that consumption level would last for only 30 more years, beyond 2018, provided no more sources are identified [4]. More than 70% of the increase in world primary energy demand between 2004 and 2030 comes from the developing countries as shown in figure 1.1.

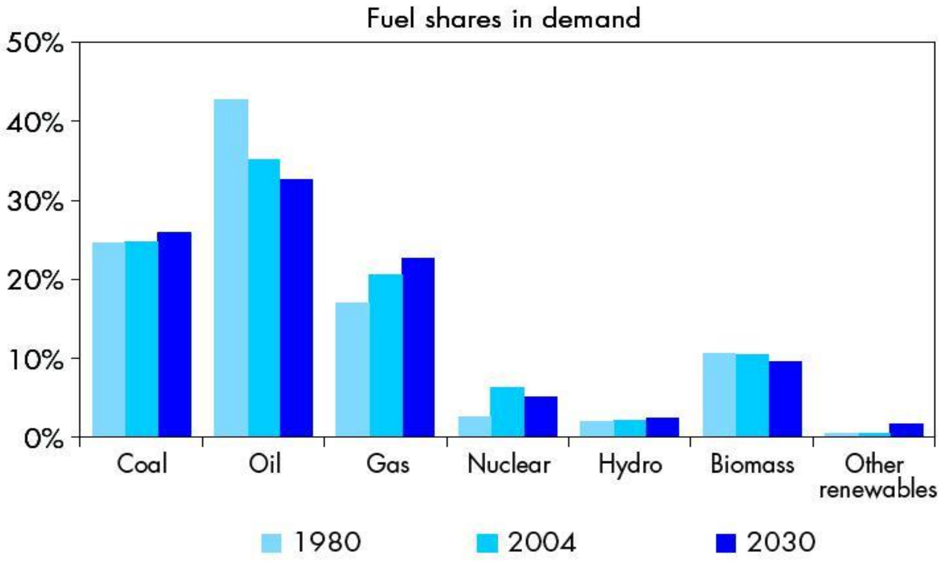

Figure 1.1: Fuel Shares in Primary Energy Demand

OECD countries account for almost one-quarter and the transition economies for the remaining 6%. The increase in the share of the developing regions in world energy demand results from their more rapid economic and population growth. Industrialization and urbanization boost demand for modern commercial fuels.

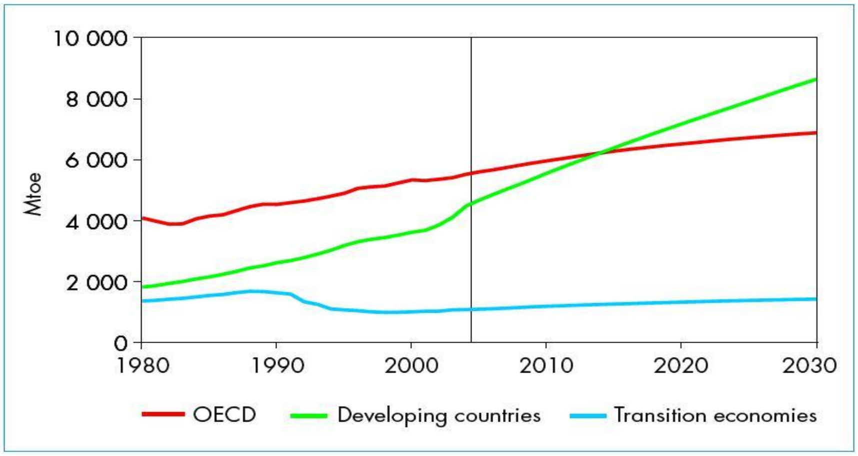

Figure 1.2: Region wise Primary Energy Demand

Global oil demand is expected to continue to grow steadily at an average annual rate of 1.3%. It reaches 99 mb/d in 2015 and 116 mb/d in 2030, up from 84 mb/d in 2005 as shown in Table 1.2. Most increment in oil demand of country comes from developing countries, where economic growth – the main driver of oil demand– is highest. China,India and the rest of developing Asia accounts 46% increase in oil use between 2005 and 2030, in line with rapid economic growth. At 3.0% per year on average, India shall require almost double of oil in 2030 as compared to 2005.

Table 1.2: Global Oil Demand

	1980	**2004**	**2005**	**2010**	**2015**	**2030**	**2005-2030**

OECD	**41.9**	**47.5**	**47.7**	**49.8**	**52.4**	**55.1**	**0.6%**
North America	21.0	24.8	24.9	26.3	28.2	30.8	0.9%
United States	*17.4*	*20.5*	*20.6*	*21.6*	*23.1*	*25.0*	*0.8%*
Canada	*2.1*	*2.3*	*2.3*	*2.5*	*2.6*	*2.8*	*0.8%*
Mexico	*1.4*	*2.0*	*2.1*	*2.2*	*2.4*	*3.1*	*1.6%*
Europe	14.7	14.5	14.4	14.9	15.4	15.4	0.2%
Pacific	6.2	8.2	8.3	8.6	8.8	8.9	0.3%
Transition economies	**8.9**	**4.3**	**4.3**	**4.7**	**5.0**	**5.7**	**1.1%**
Russia	n.a.	2.5	2.5	2.7	2.9	3.2	1.0%
Developing countries	**11.4**	**27.2**	**28.0**	**33.0**	**37.9**	**51.3**	**2.5%**

Developing Asia	4.4	14.2	14.6	17.7	20.6	29.7	2.9%
China	*1.9*	*6.5*	*6.6*	*8.4*	*10.0*	*15.3*	*3.4%*
India	*0.7*	*2.6*	*2.6*	*3.2*	*3.7*	*5.4*	*3.0%*
Indonesia	*0.4*	*1.3*	*1.3*	*1.4*	*1.5*	*2.3*	*2.4%*
Middle East	2.0	5.5	5.8	7.1	8.1	9.7	2.0%
Africa	1.4	2.6	2.7	3.1	3.5	4.9	2.4%
North Africa	*0.5*	*1.3*	*1.4*	*1.6*	*1.8*	*2.5*	*2.4%*
Latin America	3.5	4.8	4.9	5.1	5.6	7.0	1.5%
Brazil	*1.4*	*2.1*	*2.1*	*2.3*	*2.7*	*3.5*	*2.0%*
Int. marine bunkers	**2.2**	**3.6**	**3.6**	**3.8**	**3.9**	**4.3**	**0.6%**

World	**64.4**	**82.5**	**83.6**	**91.3**	**99.3**	**116.3**	**1.3%**
European Union	*n.a.*	*13.5*	*13.5*	*13.9*	*14.3*	*14.1*	*0.2%*

1.4 Environmental Challenge

The threat of climate change, caused by rising global temperatures, is the most significant environmental challenge facing the world at the beginning of the 21st century. It has major implications for the world's social and economic stability, its natural resources and in particular, the way we produce our energy. The Copenhagen Accord, agreed at the climate change summit in December 2009, has the stated aim of keeping the increase in global temperatures to below 2°C, and then considering a 1.5°C limit by 2015. However, the national emissions reduction pledges submitted by various countries to the United Nations coordinating body, the UNFCCC, in the first half of 2010 are likely to lead to a world with global emissions of between 47.9 and 53.6 giga tonnes of carbon dioxide equivalents per year by 2020. This is about 10–20% higher than today's levels. In the worst case, the Copenhagen Accord pledges could even permit emission allowances to exceed a 'business as usual' projection [5].

In order to avoid the most catastrophic impacts of climate change, the global temperature increase must be kept as far below 2°C as possible. This is still possible, but time is running out. To stay within this limit, global greenhouse gas emissions will need to peak by 2015 and decline rapidly after that, reaching as close to zero as possible by the middle of the 21st century.

1.5 A Safe Level of Warming

Keeping the global temperature increase to 2°C is often referred to as a ‘safe level’ of warming, but this does not reflect the reality of the latest science. This shows that a warming of 2°C above pre-industrial levels would pose unacceptable risks to many of the world’s key natural and human systems [6]. Even with a 1.5°C warming, increases in drought, heat waves and floods, along with other adverse impacts such as increased water stress for up to 1.7 billion people, wildfire frequency and flood risks, are projected in many regions. Neither does staying below 2°C rule out large scale disasters such as melting ice sheets. Partial de-glaciations of the Greenland ice sheet, and possibly the West Antarctic ice sheet, could even occur from additional warming within a range of 0.8– 3.8°C above current levels [7]. If rising temperatures are to be kept within acceptable limits then we need to significantly reduce our greenhouse gas emissions. This makes both environmental and economic sense. The main greenhouse gas is carbon dioxide (CO2) produced by using fossil fuels for energy and transport.

1.5.1 Kyoto Protocol

The Kyoto Protocol is an agreement under which industrialized countries will reduce their collective emissions of greenhouse gases by 5.2% compared to the year 1990). The goal is to lower overall emissions of six greenhouse gases calculated as an average over the five-year period of 2008-12. National limitations range from 8% reductions for the European Union and some others to 7% for the US, 6% for Japan, 0% for Russia, and permitted increases of 8% for Australia and 10% for Iceland [8].

The five principal concepts of the Kyoto Protocol [9] are:

1. The heart of the Protocol lies in establishing commitments for the reduction of greenhouse gases that are legally binding for Annex I countries, as well as general commitments for all member countries.
2. In order to meet the objectives of the Protocol, Annex I countries are required to prepare policies and measures for the reduction of greenhouse gases in their respective countries. In addition, they are required to increase the absorption of these

gases and utilize all mechanisms available, such as joint implementation, the clean development mechanism and emissions trading, in order to be rewarded with credits that would allow more greenhouse gas emissions at home.

3. Minimizing Impacts on Developing Countries by establishing an adaptation fund for climate change.
4. Accounting, Reporting and Review in order to ensure the integrity of the Protocol.
5. Compliance. Establishing a Compliance Committee to enforce compliance with the commitments under the Protocol.

India and South Korea is the signatory to Kyoto Protocol and committed to adopt recommendation of this protocol. Government of India is looking for renewable, bio-origin fuel produced from locally available resources since these fuels can reduce the atmospheric CO2 which shall ultimately help to clean the environment.

1.6 Historical Background

Biodiesel production is not something new, because the concept of using vegetable oil as fuel dates back to 1895. Rudolf Diesel developed the first diesel engine which was run with vegetable oil in 1900. The first engine was run using groundnut oil as fuel. In 1911, Rudolf Diesel stated that the diesel engine can be fed with vegetable oil and would help considerably in the agricultural development of the countries which use it. In 1912, Rudolf Diesel said, ‘The use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in course of time as important as petroleum and the coal tar products of the present time’’. After eight decades, the awareness about environment rose among the people to search for an alternative fuel that could burn with less pollution. Rudolf Diesel’s prediction is becoming true today with more and more bio-diesel being used all over the world [10].

1.7 Introduction to Biodiesel

Biodiesel is defined as the mono alkyl esters of long-chain fatty acids derived from renewable feedstock, such as vegetable oil or animal fats, for use in compression– ignition engines. Biodiesel has been reported as a possible substitute or extender for conventional diesel and is comprised of fatty acid methyl/ethyl esters, obtained from triglycerides by Trans-esterification with methanol/ethanol, respectively. Biodiesel is compatible with conventional diesel and both can be blended in any proportion. Production of biodiesel from sunflower oil used frying oil, Jatropha oil, Karanja (Pongamia) oil, etc. as a source of triglycerides has been reported [11].

The above points clearly depict the dual problem of fast depletion of fossil fuels and environmental squalor. Alternative fuels are the potential solution to these problems. Alternative fuels are substantially non-petroleum and yield energy security and environmental benefits. They have been with us either in one form or another for more than one hundred years. Identification of alternative to conventional petroleum based fuels has been subjected to various studies throughout the world. Thermodynamic tests, based on engine performance evaluation have established the feasibility of using a variety of alternative fuels such as hydrogen, alcohols, biogas, producer gas and variety of vegetable oils. However, in Indian context, the biomass based fuels like vegetable oils derived fuels can contribute significantly towards the problems related to fuel crisis. Neat vegetable oils are not suitable as a fuel for diesel engine. Therefore, their derivative commonly known as ethyl ester of vegetable oils or biodiesel is more suitable for fuelling the diesel engine. Biodiesel can be used as a CI engine fuel without any major modification in the engine design.

Some of the main advantages of biodiesel are as follows:

- It is plant-derived, not petroleum-derived, and as such its combustion eliminates life cycle carbon-dioxide emissions, a “greenhouse” gas since carbon dioxide emitted during combustion is recycled in the photosynthesis process occurring in the plants used as raw materials for biodiesel production.It can be domestically produced, offering the possibility of reducing petroleum imports.
- The higher Cetane number of biodiesel compared to fossil diesel indicates the potential for higher engine performance.
- It is biodegradable

- Relative to conventional diesel fuel, biodiesel reduces emission of particulate matter by 40%, unburned hydrocarbons by 68%, carbon monoxide by 44%, sulphates by 100%, PAHs (polycyclic aromatic hydrocarbons) by 80%, and carcinogenic nitrated PAHs by 90%, on average. The use of biodiesel complements the working of the catalyst or and can help a current Euro-I vehicles attaining the Euro-III standards, thus significantly reducing the environmental pollution.
- The superior lubricating property of biodiesel increases the engine efficiency.
- The higher flash point of biodiesel makes it safe to store.
- The biodiesel molecules are simple hydrocarbon chains, containing no sulphur which is concern in crude oil derived petroleum products.
- Biodiesel contains higher amount of oxygen (up to 11%), which ensures complete combustion of hydrocarbons.
- Use of biodiesel will lead to increased energy independence as well as increased economic activity from fuel production and utilization.
- Generation of new employment opportunities in cultivation, processing and production of biodiesel.
- Addition to the renewable energy options for decentralized distributed generation (DDG) of electricity and for motive power applications (water pumping, milling, etc.) in energy deficient rural India
- Greening of wastelands and regeneration of degraded forest-lands, thereby helping in eco restoration and preventing further land degradation
- Empowerment of village community through enhanced livelihood opportunities
- Needs no change in refuelling infrastructures and spare part inventories.
- Maintains the payload capacity and range of conventional diesel engines.
- Diesel skilled mechanics can easily attend to biodiesel engines.

- Horsepower, fuel economy and torque are similar to those of conventional diesel fuel engines.
- No engine modification required when used in compression ignition engines.
- Range of vehicle akin to that of conventional diesel vehicles.

1.8 PRESENT WORK

Fuels of bio-origin provide a feasible solution to the twin crises of “fossil fuel depletion” and “environmental degradation” by substituting the petroleum fuels used in internal combustion engines. A significant research effort has been directed toward using vegetable oils and their derivatives as fuels for diesel engines. Non edible vegetable oils in their natural (crude) form, called straight vegetable oils (SVO); methyl or ethyl esters known as esterified vegetable oils referred as biodiesel, fall in the category of bio fuels. Biodiesel made from different feed stocks have been tried by many researchers, and the effect of feedstock on engine performance and emissions are well documented. Jatropha are the major feed stocks that are object of research in India. Looking to the availability and their biodiesel potential, these oils are becoming more and more popular in many other countries as well. Evaluation of Jatropha esters indicates their superiority over many other vegetable oils in terms of engine performance, emissions, ease of use, and availability.

In context to present work, a more elaborate discussion on ethyl ester of Jatropha carcass oil (Ratanjote) is made. In the study, the selected vegetable oils were Trans esterified and the effect on major properties was evaluated. Further, the evaluation of the ethyl esters was done in a compression ignition engine for combustion, performance, and emissions. The results were compared against the diesel fuel results. The practicality of biodiesel oils as diesel fuels has been sufficiently demonstrated to warrant further investigation of their effectiveness and to develop techniques that will permit their incorporation into agricultural operations, particularly in times of energy shortfall [12].

Depending upon the availability and production capability, biodiesel is derived. Biodiesel derived from soybean oil is of primary interest in the United States while many European countries are concerned with rapeseed oil, and countries with tropical climate prefer to utilize coconut oil or palm oil. Other biodiesel from sunflower, safflower, etc., have also been investigated. In India, variety of edible and non-edible oils has been used to fuel the engines. Some of the vegetable oils are available in India easily and in fact some of them underutilized whereas the potential of such oils are very high. If any particular vegetable oil amongst some 250 types of available in India , is to be used as energy crops , then the efforts must be put to increase the yield and oil content of that particular crop. The technologies should be developed to promote the use of biodiesel as a substitute to fossil fuels or an extender of fossil fuels which may result in increased crop production for energy. Thus, taking into considerations several parameters as energy security, green house emission, fast depletion of fossil fuel reserve, potential substitute of existing diesel engine with minimum or without engine modification-biodiesel is most promising renewable fuel for mankind and environment. Physico-chemical characteristics were also analysed to examine the effect of biodiesel derived from these Jatropha oils.

CHAPTER 2

LITERATURE REVIEW

2.1 Domestic Biodiesel Feedstock Production

The Ministry of Food, Agriculture, Forestry and Fisheries (MIFAFF) announced a pilot project last year to begin producing rapeseed in several provinces on an estimated 1,500 hectares. More recently, in August 2008, the program was revised to gradually increase acreage planted from 1,500 hectares to 45,000 hectares by 2012. With this added acreage, MIFAFF projects that rapeseed production will reach 90,000- 100,000 metric tons. Assuming a 40% oil yield ratio, about 45,000 kilolitres (40,000 MT) of oil could be produced from the harvested rapeseed. This, however, represents only 8% of annual biodiesel consumption suggesting that demand for imported feedstock will remain strong. Jeju-do, a small island off the southern coast of Korea, is one of the more proactive regions in the country where rapeseed is currently being produced. This year the biodiesel industry purchased 2,750 tons of Jeju-do rapeseed and extracted 1,300 kilolitres (1,100 MT) of oil.

2.2 Jatropha as a potential compression ignition engine fuel.

While the country is short of petroleum reserve, it has large arable land as well as good climatic conditions (tropical) with adequate rainfall in large parts of the area to account for large biomass production each year. For the reason of edible oil demand being higher than its domestic production, there is no possibility of diverting this oil for production of bio-diesel. Fortunately there is a large junk of degraded forest land and un-utilised public land, field boundaries and fallow lands of farmers where non-edible oil-seeds can be grown. There are many tree species which bear seeds rich in oil. Of these some promising tree species have been evaluated and it has been found that there are a number of them such as *Jatropha curcas*which would be very suitable in all conditions.

2.2.1. Jatropha curcas

Jatropha curcas hitherto considered as a wild oilseed plant of the tropics is now been credited as a most promising bio-fuel crop very much ideally suited for growing in the wasted lands of the country. Jatropha curcas of physic nut is a large multi-purpose oil-yielding shrub. Belonging to Euphorbiaceous (castor family), this tropical and sub-topical crop can thrive well in low rainfall regions and problem soils. It is a hardy, drought-tolerant crop, and this quick growing crop can be established easily without much care. Jatropha crop is widely propagated through seeds and vegetative means. Mass propagation through stem cuttings will ensure uniformity and early establishment. The plants reach a height of three meters within three years. Jatropha does not thrive in wetland conditions.

The plants grow luxuriantly even in marginal, stony and sandy tracts. It can be grown in the hedges at a spacing of 15 to 20 CM by 15 to 25 CM in single or double-rows for conserving soil. For commercial plantations, the crop can be grown at an escapement of about 2 M by 1.5 M or even 3 M by 3 M. A dry climate has been found to greatly improve the oil yields of the seeds. However, three to four irrigations a month during summer will help in improving the growth of the plants. Plants raised from the seeds take 3 to 4 years to yield seeds. However, the stem cuttings with rapid growth will start yielding in less than a year of planting. Seed production varies from 0.4 tonnes initially to ten tonnes per hectare per year, as the bushes grow larger. The plants respond well to the addition of small quantities of calcium, magnesium and sulphur. It does well when rich organic nutrition is provided.

2.2.2 Jatropha Plant Description

The Jatropha plant (Jatropha Curcas) or physic nut is a shrub or a small tree belonging to the genus Euphorbiaceous. The Jatropha plant originated from South America, but now the plant can be found worldwide in arid and semi-arid tropical and sub-tropical countries. It is claimed that probably the plant was distributed from South America by Portuguese seafarers via Cape Verde Islands and Guinea Bissau to Africa and Asia. The Jatropha plant can be grown in almost all types of soils. It can even be grown in very poor soil and still produce a high average yield of seeds. However, light sandy soil is the most favourable. The Jatropha plant is a multiple use plant. The different uses of Jatropha will be presented in another section of this chapter. The root system of Jatropha plant comprises 3 – 4 lateral roots and a vertical one that reaches 5m down in the ground. The Jatropha Curcas is a drought resistant plant that can live up to 50 years. Jatropha Curcas tolerates a minimum annual rainfall of 250 mm and a maximum annual rainfall of 3000 mm. The minimum depends on the humidity, the higher the humidity the less the minimum rainfall Jatropha can tolerate. Jatropha can be found from sea level to 1800m altitudes. The tree grows to a maximum height of nearly 8m. The Jatropha fruit maturation takes 45 – 50 days. The plant starts producing yield 4 – 5 months after planting. The Jatropha trees produce a round fruit with a soft brownish skin, which have 1.5 – 3 cm in diameter and weigh 1.5 – 3 g. The seeds contain about 30-35% oil. The oil is pale yellow to brown in colour. The oil contains a toxic substance curcas in that has strong purging effects.

The harvesting period of Jatropha seeds differ in different countries depending on the humidity of the weather. For instance, Jatropha seeds are only harvested once in most regions of Africa, during the period of August to September, while in Cape Verde the Jatropha seeds are harvested twice, in June or July and October or November. In general, fruits are picked from the plant or sometimes the fruits ripen in the tree and fall down, and thereafter are picked for processing. Jatropha can be propagated from seeds as well as from cuttings. Seeds or cutting can be directly planted in the main field. Otherwise, seedlings grown in poly bags are transplanted in the main field.

2.2.3. Toxicity of the Jatropha plant

The toxicity of the Jatropha Curcas is an advantage on one hand and disadvantage on the other. The advantage emanates from the fact that the plant could not be browsed by animals and could act as an excellent fence. The disadvantage comes from the fact that the equipment, such as ram presses that are used to press Jatropha seeds, could not be used to press other edible seed oil from plants like sunflower unless a thorough cleaning is done which would take a lot of environmental resources. The main source of the toxicity is the phorbol esters contents of the seeds that could also promote tumour and inflammation. However, it has been observed that it is possible to detoxify the phorbol esters by de-acidification and bleaching in order to use the seedcake for animal feed. The DE acidification could reduce the phorbol esters up to 55%. The claims that there are some varieties of non-toxic Jatropha plants need more investigation.

2.2.4 Jatropha Oil as a Renewable Fuel for Road Transport

The history of using Jatropha oil instead of diesel goes back to the Second World War when Madagascar, Cape Verde and Benin used Jatropha oil as a diesel substitute. The recent tests of unmodified and modified Jatropha oil for diesel engines in Mali, Nicaragua and India make Jatropha oil a potential renewable fuel for road transport as a replacement or an extender of diesel fuels. Jatropha oil could also be used as cooking fuel or lighting fuel in rural areas. The focus of this study is for using Jatropha oil as a fuel for decentralized energy production. Jatropha oil is a very promising fuel for this application due to several advantages: Jatropha oil is a renewable fuel that could last for many years without any problem. Jatropha oil is environmentally friendly fuel and could be produced easily in rural areas. The major disadvantage of Jatropha oil as a fuel for road transport 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. The literature further notes that in the long term the high viscosity may develop gumming, the formation of injector deposits, and ring sticking. Therefore, the reduction of viscosity in order for Jatropha oil to be used for road transport is paramount.

The greatest difference to be considered in using Jatropha oil as fuel for road transport or agriculture sector is the amount of viscosity, which could contribute to carbon deposit in the engines and the above-mentioned issues. The high viscosity could also cause incomplete fuel combustion and may result in reducing the life of an engine and have environmental drawbacks such as producing carcinogenic particles. However, the high cetane number andcalorific value that is approximately equal to diesel fuel make it possible to use Jatropha oil in diesel engines. Additionally, the high flash point of Jatropha oil makes it safer to store, use and handle than petroleum diesel; 210ºC is the temperature at which it will ignite when exposed to a flame while diesel is only 45 – 55 ºC.

2.2.5 Advantages of Selection of Jatropha curcas*:*

The advantages in favour of Jatropha advantages due to the following reasons [13]

- It can be grown in areas of low rainfall (200 mm per year) and in problematical soils. In high rainfall and irrigated areas too it can be grown with much higher yields. Therefore, it can be grown in most parts of the country.
- Jatropha is easy to establish, grows relatively quickly and is hardy.
- Jatropha lends itself to plantation with advantage on lands developed on watershed basis and on low fertility marginal, degraded, fallow, waste and other lands such as along the canals, roads railway tracks, on borders of farmers' fields as a boundary fence or live hedge in the arid/semi-arid areas and even on alkaline soils. As such it can be used to reclaim wastelands in the forests and outside.
- Jatropha seeds are easy to collect as they are ready to be plucked before the rainy season and as the plants are not very tall.
- Jatropha is not browsed by animals.
- Being rich in nitrogen, the seed cake is an excellent source of plant nutrients.
- Seed production ranges from about 0.4 tons per hectare per year to over 12 t /ha.
- The plant starts giving seed in a maximum period of two years after planting.
- Raising plants in nurseries, planting and maintaining them and collection of seed are
- Labour intensive activities. Except for the cost of fertiliser and transportation of the plants from the nursery, all the activities in the nurseries and in planting consist of labour. The cost of seed is entirely in the form of wage for labour.
- Various parts of the plant are of medicinal value, its bark contains tannin, the flowers attract bees and thus the plant has honey production potential.
- Like all trees, Jatropha removes carbon from the atmosphere, stores it in the woody tissues and assists in the build-up of soil carbon. It is thus environment friendly.
- Jatropha can be established from seed, seedlings and vegetative from cuttings. Use of branch cutting for propagation is easy and results in rapid growth.

It can meet a number of objectives such as meeting domestic needs of energy services including cooking and lighting; as an additional source of household income and employment through markets for fuel, fertilizer, animal feed medicine, and industrial raw material for soap, cosmetics, etc. in creating environmental benefits – protection of crops or pasture lands, or as a hedge for erosion control, or as a windbreak and a source of organic manure. Thus it can be concluded that promotion of Jatropha plantation can generate tremendous job opportunities among the rural masses. Simultaneous production of indigenous biodiesel from its oil will resist the outflow of valuable foreign exchange caused by the import of crude petroleum [14]. It may lead to a revolutionary transformation of the current gloomy economic and energy scenario with an era of economic bloom and prosperity for all sections of society.

2.3 Literature review

An exhaustive literature review has been carried out from several national and international journals and other sources before identification of the research problem. A critical review of all the relevant literature is being summarized below.

Gumus et al. [15] study apricot (Prunusarmeniaca) seed kernel oil was Trans esterified with methanol using potassium hydroxide as catalyst to obtain apricot seed kernel oil ethyl ester. Neat apricot seed kernel oil ethyl ester and its blends with diesel fuel were tested in a compression ignition diesel engine to evaluate performance and emissions. Apricot seed kernel oil ethyl ester and its blends can be successfully used in diesel engines without any modification. Lower concentration of apricot seed kernel oil ethyl ester in blends gives a better improvement in the engine performance and exhaust emissions. Therefore lower per cent of apricot seed kernel oil ethyl ester can be used as additive. Canakci et al. [16] study, the applicability's of Artificial Neural Networks (ANNs) have been investigated for the performance and exhaust-emission values of a diesel engine fuelled with biodiesels from different feedstock's and petroleum diesel fuels. The engine performance and emissions characteristics of two different petroleum diesel-fuels (No. 1 and No. 2), biodiesels (from soybean oil and yellow grease), and their 20%blends with No. 2 diesel fuels were used as experimental results. The fuels were tested at full load (100%) at 1400-rpm engine speed, where the engine torque was 257.6 Nm. To train the network, the average molecular weight, net heat of combustion, specific gravity, kinematic viscosity, C/Hratio and cetane number of each fuel are used as the input layer, while outputs are the brake specific fuel-consumption, exhaust temperature, and exhaust emissions. The back-propagation learning algorithm with three different variants, single layer, and logistic sigmoid transfer function were used in the network. By using weights in the network, formulations have been given for each output. The network has yielded R2 values of 0.99 and the mean % errors are smaller than 4.2 for the training data, while the R2 values are about 0.99 and the mean % errors are smaller than 5.5 for the test data. The performance and exhaust emissions from a diesel engine, using biodiesel blends with No. 2 diesel fuel up to 20%, have been predicted using the ANN model.

Kegl[17] discusses the influence of biodiesel on the injection, spray, and engine characteristics with the aim to reduce harmful emissions. The considered engine is a bus diesel engine with injection M system. The injection, fuel spray, and engine characteristics, obtained with biodiesel, are compared to those obtained with mineral diesel (D2) under various operating regimes. The considered fuel is neat biodiesel from rapeseed oil. Its density, viscosity, surface tension, and sound velocity are determined experimentally and compared to those of D2. The obtained results are used to analyse the most important injection, fuel spray, and engine characteristics. The injection characteristics are determined numerically under the operating regimes, corresponding to the 13 mode ESC test. The fuel spray is obtained experimentally under peak torque condition. Engine characteristics are determined experimentally under 13 mode ESC test conditions. The results indicate that, by using biodiesel, harmful emissions (NOx, CO, smoke and HC) can be reduced to some extent by adjusting the injection pump timing properly.

Sahoo et al. [18] find non-edible filtered high viscous (72 cSt at 40^0C) and high acid value (44 mg KOH/gm.) polanga (Calophylluminophyllum L.) oil based mono esters (biodiesel) produced by triple stage trans esterification process and blended with high speed diesel (HSD) were tested for their use as a substitute fuel of diesel in a single cylinder diesel engine. HSD and polanga oil ethyl ester (POME) fuel blends (20%, 40%, 60%, 80%, and 100%) were used for conducting the short-term engine performance tests at varying loads (0%, 20%, 40%, 60%, 80%, and 100%). Tests were carried out over entire range of engine operation at varying conditions of speed and load. The brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE) were calculated from the recorded data. The engine performance parameters such as fuel consumption, thermal efficiency, exhaust gas temperature and exhaust emissions (CO, CO2, HC, NOx, and

O2) were recorded. The optimum engine operating condition based on lower brake specific fuel consumption and higher brake thermal efficiency was observed at 100% load for neat biodiesel. From emission point of view the neat POME was found to be the best fuel as it showed lesser exhaust emission as compared to HSD. Agarwal et al. [19] shown that biodiesel-fuelled engines produce less carbon monoxide (CO), unburned hydrocarbon (HC), and particulate emissions compared to mineral diesel fuel but higher NOx emissions. Exhaust gas recirculation (EGR) is effective to reduce NOx from diesel engines because it lowers the flame temperature and the oxygen concentration in the combustion chamber. However, EGR results in higher particulate matter (PM) emissions. Thus, the drawback of higher NOx emissions while using biodiesel may be overcome by employing EGR. The objective of current research work is to investigate the usage of biodiesel and EGR simultaneously in order to reduce the emissions of all regulated pollutants from diesel engines. A two-cylinder, air-cooled, constant speed direct injection diesel engine was used for experiments. HCs, NOx, CO, and opacity of the exhaust gas were measured to estimate the emissions. Various engine performance parameters such as thermal efficiency, brake specific fuel consumption (BSFC), and brake specific energy consumption (BSEC), etc. were calculated from the acquired data. Application of EGR with biodiesel blends resulted in reductions in NOx emissions without any significant penalty in PM emissions or BSEC. Labeckas et al.[20] presents the comparative bench testing results of a four stroke, four cylinder, direct injection, unmodified, naturally aspirated Diesel engine when operating on neat REE and its 5%, 10%, 20% and 30% blends with Diesel fuel. The purpose of this research is to examine the effects of REE inclusion in Diesel fuel on the brake specific fuel consumption (bsfc) of a high speed Diesel engine, its brake thermal efficiency, emission composition changes and smoke opacity of the exhausts. The brake specific fuel consumption at maximum torque (273.5 g/kW h) and rated power (281 g/kW h) 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 REE and from 0.373 to 0.383 for Diesel fuel. The highest fuel energy content based economy (9.36– 9.61 MJ/kW h) is achieved during operation on blend B10, whereas the lowest ones belong to B35 and neat REE. The maximum NOx emissions increase proportionally with the mass per cent of oxygen in the biofuel and engine speed, reaching the highest values at the speed of 2000 min^{-1}, the highest being 2132 ppm value for the B35 blend and 2107 ppm for REE. 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 B30blends and neat REE. The emissions of unburned hydrocarbons, HC, for all biofuels are low, ranging at 5–21 ppm levels.

Canakci [21] study, the combustion characteristics and emissions of two different petroleum diesel fuels (No. 1 and No. 2) and biodiesel from soybean oil were compared. The tests were performed at steady state conditions in a four-cylinder turbocharged DI diesel engine at full load at 1400-rpm engine speed. The experimental results compared with No. 2 diesel fuel showed that biodiesel provided significant reductions in PM, CO, and unburned HC, the NOx increased by 11.2%. Biodiesel had a 13.8% increase in brake-specific fuel consumption due to its lower heating value. However, using No. 1 diesel fuel gave better emission results, NOx and brake-specific fuel consumption reduced by 16.1% and 1.2%, respectively. The values of the principal combustion characteristics of the biodiesel were obtained between two petroleum diesel fuels. The results indicated that biodiesel may be blended with No. 1 diesel fuel to be used without any modification on the engine

Kwanchareon et al. [22] studied the phase diagram of diesel–biodiesel–ethanol blends at different purities of ethanol and different temperatures. Fuel properties (such as density, heat of combustion, cetane number, flash point and pour point) of the selected blends and their emissions performance in a diesel engine were examined and compared to those of base diesel. It was found that the fuel properties were close to the standard limit for diesel fuel; however, the flash point of blends containing ethanol was quite different from that of conventional diesel. The high cetane value of biodiesel could compensate for the decrease of the cetane number of the blends caused by the presence of ethanol. The heating value of the blends containing lower than 10% ethanol was not significantly different from that of diesel. As for the emissions of the blends, it was found that CO and HC reduced significantly at high engine load, whereas NOx increased, when compared to those of diesel. Taking these facts into account, a blend of 80% diesel, 15% biodiesel and 5% ethanol was the most suitable ratio for diesohol production because of the acceptable fuel properties (except flash point) and the reduction of emissions.

Reyes et al. [23] studied power response and level of particulate emissions was assessed for blends of Diesel-crude Biodiesel and Diesel-refined Biodiesel. Crude Biodiesel and refined

Biodiesel or ethyl ester were made from salmon oil with high content of free fatty acids, throughout a process of acid esterification followed by alkaline trans-esterification. Blends of Diesel-crude Biodiesel and Diesel-refined Biodiesel were tested in a diesel engine to measure simultaneously the dynamometric response and the particulate material (PM-10) emission performance. The results indicate a maximum power loss of about 3.5% and also near 50% of PM-10 reduction with respect to diesel when a 100% of refined Biodiesel is used. For blends with less content of either crude Biodiesel or refined Biodiesel, the observed power losses are lower but at the same time lower reduction in PM-10 emissions are attained.

Labeckas [24] presents the comparative bench testing results of a naturally aspirated, four strokes, one cylinder, air cooled, direct injection Diesel engineoperating on Diesel fuel and cold pressed rapeseed oil. The purpose of this research is to study rapeseed oil flow through the fuelling system, the effect of oil as renewable fuel on a high speed Diesel engine performance efficiency and injector coking under various loading conditions. Test results show that when fuelling a fully loaded engine with rapeseed oil, the brake specific fuel consumption at the maximum torque and rated power is correspondingly higher by 12.2 and 12.8% than that for Diesel fuel. However, the brake thermal efficiency of both fuels does not differ greatly and its maximum values remain equal to 0.37–0.38 for Diesel fuel and 0.38–0.39 for rapeseed oil. The smoke opacity at a fully opened throttle for rapeseed oil is lower by about 27–35%, however, at the easy loads its characteristics can be affected by white colourvapours. Oil heating to the temperature of 60 ^{0}C diminishes its viscosity to 19.5 mm^2 /s ensuring a smooth oil flow through the fuel filter and reducing the brake specific energy consumption at light loads by 11.7–7.4%. Further heating to the temperature of 90 ^{0}C offers no advantages in terms of performance. Special tests conducted with modified fuel injection pump revealed that coking of the injector nozzles depends on the engine performance mode. The first and second injector nozzles that operated on pure oil were more coated by carbonaceous deposits than control injector nozzles that operated simultaneously on Diesel fuel.

Labeckas [25] presents the bench testing results of a four stroke, one cylinder, direct injection, unmodified, diesel engine operating on pure rapeseed oil (RO) and its 2.5 vol.%, 5 vol.%, 7.5 vol.% and 10 vol.% blends with ethanol (ERO), petrol (PRO) and both improving agents applied in equal proportions as 50:50 vol.% (EPRO). The purpose of the research is to examine the effect of ethanol and petrol addition into RO on diesel engine emission characteristics and smoke opacity of the exhausts. The biggest NOx emissions, 1954 and 2078 ppm, at 2000 min_1 speed generate blends PRO10 (9.72%) and EPRO5 (11.13%) against, 1731 and 1411 ppm, produced from ERO5 (12%) and ERO10 (13.2% oxygen) blends. The carbon monoxide, CO, emissions emitted from a fully loaded engine fuelled with three agent blends EPRO5–7.5 at maximum torque and rated speed are higher by 39.5–18.8% and 27.5–16.1% and smoke opacity lower by 3.3–9.0% and 24.1– 17.6% comparing with RO case. When operating at rated 2200 min_1 mode, the carbon dioxide, CO2, emissions are lower, 6.9–6.3 vol.%, from blends EPRO5–7.5 relative to that from RO, 7.8 vol.%, accompanied by a slightly higher emission of unburned hydrocarbons HC, 16 ppm, and residual oxygen contents O2, 10.4–12.0 vol.%, in the exhausts.

Arkoudeas et al.[26] studied the first jet fuels were aviation gasoline (avgas), and the characteristics of subsequent jet fuels have evolved from this original choice, the available supply infrastructure, and the refiners' capabilities. Earlier on, it was evident that avgas would have to be altered to operate satisfactorily in jet powered aircraft. The present contribution outlines the various requirements that led to development of various operational jet fuels, including United States Jet A (European Jet A-1), JP-4 (NATO code, F-40), JP-5 (NATO code, F- 44), JP-7 (US only), JP-8 (F-34), JP-TS (US only), and JP-8 þ 100. To reduce this fuel logistic burden, the NATO Armed Forces are advancing the use of a single fuel for both aircraft and ground equipment. To this end, F-34 is replacing distillate Diesel fuel in many applications. In order to make this type of fuel compatible with direct injection compression engines, the Fuels and Lubricants Laboratory of the National Technical University of Athens, used a stationary Diesel engine fuelled with fuel blends containing two different types of biodiesel, at proportions up to 50%. In this paper, fuel consumption and exhaust emission measurements from a single cylinder, stationary, Diesel engine are described. The two types of biodiesel appeared to have equal performance, and irrespective of the raw material used for their production, their addition to the JP-8 aviation fuel improved the particulate matter emissions.

2.4 Statement of the problem

On the strength of an exhaustive literature survey and analysis of the reported results by several researchers in India and abroad it has been found that most of the studies concerning biodiesel usage in diesel engine have been carried out in unmodified diesel engines. The fuel injection pressure, fuel injection timing and compression ratio which are an important engine parameters were kept constant throughout the trial. Since, properties of biodiesel are significantly different from diesel fuel and effect of these variables on engine performance, emission and combustion parameters is expected to be substantial, the proposed work wish to investigate all these parameters in details for biodiesel using a variable compression ratio engine. The following objectives are envisaged to be accomplished during the course of proposed study.

1. Comprehensive literature survey to identify the non-edible oils for utilization as a fuel.
2. Preparation of biodiesel from these oils.
3. Production Process optimization.
4. Determination of various physico-chemical properties of diesel, biodiesel and different blends in accordance to appropriate ASTM standards.
5. Instrumentation of the engine and system development for fuel testing.
6. Performance and emission tests on the engine with diesel to generate baseline data for reference in all subsequent tests. Performance and emission tests on the engine with different biodiesel/diesel blends for a comparative evaluation of the optimal blend.

CHAPTER 3

SYSTEM DEVELOPMENTS& EXPERIEMNTAL PROCEDURE

INTRODUCTION

As the increases in world human population, more land may be needed to produce food and shelter for human consumption. The problem already exists in Asia. Vegetable oil prices are relatively very high there. The same trend will eventually happened in the rest of the world. This is the potential challenge to alternative fuel. From this point of view, biodiesel can be used most effectively as a supplement to other energy forms, not as a primary source. Biodiesel is particularly useful in mining and marine situations where lower pollution levels are important. Trans-esterification is not a new process. Scientists E. Duffy and J. Patrick conducted it as early as 1853. One of the first uses of Trans-esterified vegetable oil was powering heavy-duty vehicles in South Africa before World War II. In the 1930s and 1940s vegetable oils were used as diesel fuels from time to time, but usually only in emergency situations. Recently, because of increases in crude oil prices, limited resources of fossil oil and environmental concerns there has been a renewed focus on vegetable oils and animal fats to make biodiesel fuels. Beginning in 1980, there was considerable discussion regarding use of vegetable oil as a fuel. Bartholomew (1981) addressed the concept of using food for fuel, indicating that petroleum should be the ``alternative" fuel rather than vegetable oil and alcohol being the alternatives and some form of renewable energy must begin to take the place of the non-renewable resources. The most advanced work with sunflower oil occurred in South Africa because of the oil embargo. Caterpillar Brazil, in 1980, used pre-combustion chamber engines with a mixture of 10% vegetable oil to maintain total power without any alteration or adjustments to the engine. At that point, it was not practical to substitute 100% vegetable oil for diesel fuel, but a blend of 20% vegetable oil and 80% diesel fuel was successful. Some short-term experiments used up to a 50/50 ratio. The first International Conference on Plant and Vegetable Oils as fuels was held in Fargo, North Dakota in August 1982. The primary concerns discussed were the cost of the fuel, the effects of vegetable oil fuels on engine performance and durability and fuel preparation,Specifications and additives. Oil production, oilseed processing and extraction also were considered in this meeting.

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

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 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.

3.1 Source of Jatropha oil

The plant that is generally cultivated for the purpose of extracting jatropha oil is Jatropha carcass. The seeds are the primary source from which the oil is extracted. Owing to the toxicity of jatropha seeds,they are not ingested by humans. The major goal of jatropha cultivation, therefore, is performed for the sake of extracting jatropha oil since the recognition of jatropha as an alternative energy sources (namely, biofuel), jatropha oil extraction methods have also gained due importance in the market. Since jatropha oil is the primary ingredient required in the production of biofuels, the development of oil extraction methods and the optimization of existing methods of extracting the oil have become significant.

Plate 3.1: Jatropha plant and Seed

3.2 Biodiesel Methodology

Fats and oils are primarily water-insoluble, hydrophobic substances in the plant and animal kingdom that are made up of one mole of glycerol and three moles of fatty acids and are commonly referred to as triglycerides. Fatty acids vary in carbon chain length and in the number of unsaturated bonds (double bonds). The fatty acids found in vegetable oils are summarized in **Table 3.1.** Considerable research has been done on vegetable oils as diesel fuel. Some methods applicable to vegetable oils are not applicable to animal fats because of natural property differences. Oil from algae, bacteria and fungi also has been investigated [27]. Microalgae have been examined as a source of ethyl ester diesel fuel Terpenes and latexes also were studied as diesel fuels. The name ‘‘biodiesel’’ has been given to Trans esterified vegetable oil to describe its use as a Diesel fuel. The process of converting vegetable oil into biodiesel fuel is called trans-etherification and is less complex than it sounds. Chemically, trans-etherification means taking a triglyceride molecule or a complex fatty acid, neutralizing the free fatty acids, removing the glycerine and creating an alcohol ester. This is accomplished by mixing ethanol with sodium hydroxide to make sodium eth-oxide. The entire mixture then settles. Glycerine is left on the bottom and methyl esters, or biodiesel, is left on top. The glycerine can be used to make soap (or any one of 1600 other products) and the ethyl esters is washed and filtered. The resulting biodiesel fuel when used directly in a Diesel engine will burn up to 75% cleaner than petroleum Diesel fuel. Ethyl esters of vegetable oils have several outstanding advantages among other new-renewable and clean engine fuel alternatives. There are more than 350 oil bearing crops identified as potential alternative fuels for Diesel engines.

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 un-branched chain unsaturated hydrocarbons, but the later are not present in large amounts to make oxidation a problem [28]. Vegetable oils consist of triglycerides to about 97%, the other 3% distribute among di- and mono glycerides and furthermore 3 fatty acids and the fat accompanying which are mostly removed with refining [29]. Structurally, a triglyceride is a reaction product of one molecule of glycerol with three fatty acid molecules to yield three molecules of water and one molecule of triglyceride as shown in **Figure 3.1** [30].

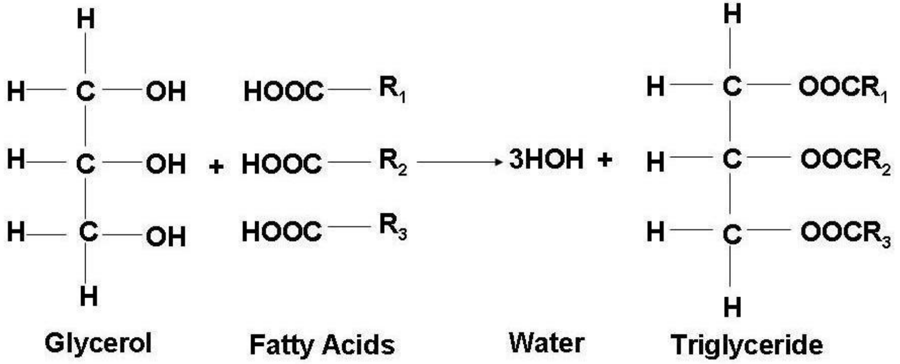

Figure: 3.1 Chemical Structures of Vegetable Oils

Where R, R' and R'' are the alkyl groups of different carbon chain lengths (varyingbetween12-18), and -COO- is a carboxyl group. Vegetable oils have different chemical structure as shown in **Figure: 3.2** [32]: -

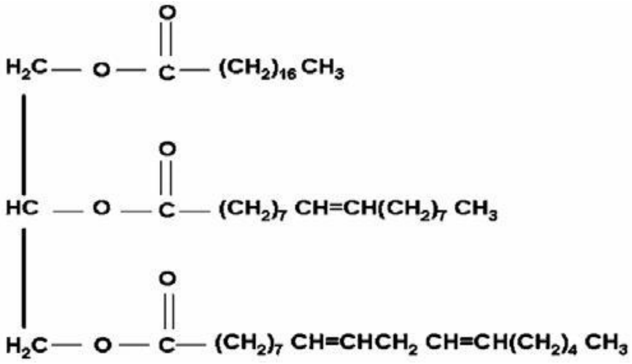

Figure 3.2 Structure of a Typical Triglyceride Molecule

The large size of the vegetable oil molecules and the presence of oxygen in the molecules suggest that some fuel properties of the vegetable oils would differ markedly from those of hydrocarbon fuels [31]. Table 3.2 shows various chemical structures of common fatty acids found in different edible and non-vegetable oils

3.2.1 Esterification process optimisation using taguchi approach

Esterification process is the reaction of triglyceride (fat/oil) with an alcohol in the presence of acidic as a catalyst to reduce free fatty acid number of oil. The presence of strong acid accelerates the reaction. The main purpose of esterification is to reduce FFA. In this study, FFA is reduced by reacting Jatropha oil with ethanol in the presence of acid catalyst (P-T-S-A). The Jatropha oil is first filtered to remove solid impurities then it is preheated at100oC for half an hour to remove moisture. A two stage process is used for producing biodiesel of Jatropha oil. The first stage is esterification to reduce free fatty acid content in Jatropha oil with ethanol (99% pure) and acid catalyst (98% pure) heated for two hour at 65oC in magnetic stirrer to reduce FFA below 2%. After esterification, the esterified oil washed using water. The washing is carried out in a separating funnel. The hot water having temperature as that of esterified oil added in a separating funnel. Impurities like dust, carbon content; sulphur content is washed away with water.

Table 3.1.**Four parameter and three variables for design of experiment**

Parameter	Level		
	1	2	3
Time(min)	60	90	120
Temp (°C)	55	60	65
Catalyst conc. (% wt.)	0.5	1.0	1.5
Molar ratio	4:1	5:1	6.67:1

3.2.1.1 Design of Experiment

Although, in the taguchi software there is a different type of Array but I have used L-9 Array that is suitable for four parameter and three level which is used in this thesis. The columns of an orthogonal array represent factors to be studied and the rows represent individual experiments. This study is associated with four factors with each at three levels. The orthogonal array used to find the effects of four parameters namely the molar ratio of oil to ethanol, time, catalyst, and concentration and reaction temperature on the reduction of FFA. The four selected parameters at three levels i.e. L-9 experimentally studied are shown in this table I. Table 3.2 shows the orthogonal array used to design experiments with four parameters at three levels. In this study, Taguchi approach is software for automatic design was used to analyse the results and optimize the experimental conditions for setting the control variables.

$$\frac{S}{N_{(Smaller)}} = -10 \log\left(\frac{\sum y_i^2}{n}\right)$$

If smaller is better then used this formula.

Where n is no. of experiment perform for one solution, in this case it is equal to 1 and y is the S/N ratio for the each set L-9 array.

Table 3.2

Exp.no.	Molar ratio (Oil/ethanol)	Catalyst conc.(wt.%)	Temp(°C)	Time(min)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3

5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3.3Trans esterification

Trans esterification (also called alcoholises) [32] is the reaction of a fat or oil with an alcohol to form esters and glycerol. The reaction is shown in Fig.3 3. A catalyst is usually used to improve the reaction rate and yield. Because the reaction is reversible, excess alcohol is used to shift the equilibrium to the products side. Alcohols are primary and secondary monohydric aliphatic alcohols having 1-8 carbon atoms. Among the alcohols that can be used in the Trans esterification process are methanol, ethanol, propanol, butanol and amyl alcohol. Methanol and ethanol are used most frequently, especially methanol because of its low cost,high yield and its physical and chemical advantages (polar and shortest chain alcohol). It can quickly react with triglycerides and NaOH is easily dissolved in it. To complete a Trans-esterification's toichiometrically, a 5:1molar ratio of alcohol to triglycerides is needed. In practice, the ratio needs to be higher to drive the equilibrium to a maximum ester yield.

The reactions can be catalysed by alkalis, acids, or enzymes. The alkalis include NaOH, KOH, carbonates and corresponding sodium and potassium alkoxides such as sodium ethnocide, sodium ethnocide, sodium prop oxide and sodium but oxide. Sulphuric acid, sulfonic acids and hydrochloric acid are usually used as acid catalysts. Lipases also can be used as biocatalysts. Alkali-catalysedtrans esterification is much faster than acid-catalysedtrans-esterification and is most often used commercially. For an alkali-catalysedtrans-esterification, the glycerides and alcohol must be substantially anhydrous because water makes the reaction partially change to saponification, which produces soap. The soap lowers the yield of esters and renders the separation of ester and glycerol and the water washing difficult. Low free fatty acid content in triglycerides is required for alkali-Catalysed trans-esterification. If more water and free fatty acids are in the triglycerides, acid catalysedtrans-esterification can be used. The triglycerides can be purified by saponification (known as alkali treating) and then Trans esterified using an alkali catalyst.

The boiling points and melting points of the fatty acids, ethyl esters, mono-, di-and triglycerides increase as the number of carbon atoms in the carbon chain increase, but decrease with increases in the number of double bonds. The melting points increase in the order of tri-, di- and mono glycerides due to the polarity of the molecules and hydrogen bonding. After trans- esterification of triglycerides, the products are a mixture of esters, glycerol, alcohol, catalyst and tri-, di- and mono glycerides. The mono glycerides caused turbidity (crystals) in the mixture of esters. This problem was very obvious, especially for trans- esterification of animal fats such as beef tallow. The impurities raised the cloud and pour points. However, the saturated components have other value-added applications in foods, detergents and cosmetics. The co-product, glycerol, needs to be recovered because of its value as an industrial chemical such as CP glycerol, USP glycerol and dynamite glycerol. Glycerol is separated by gravitational settling or centrifuging. Trans-esterification is the process used to make biodiesel fuel also used to make ethyl esters for detergents and cosmetics. There are numerous trans- esterification citations in the scientific and patent literature (The mechanism and kinetics trans- esterification consists of a number of consecutive, reversible reactions. The triglyceride is converted stepwise to di-glycerides, mono glycerides and finally glycerol. A mole of ester is liberated at each step. The reactions are reversible, although the equilibrium lies towards the production of fatty acid esters and glycerol. **Figure 3.3**summarizes the mechanism of alkali-catalysedtrans-esterification. The reaction mechanism for alkali-catalysedtrans-esterification was formulated as three steps:-

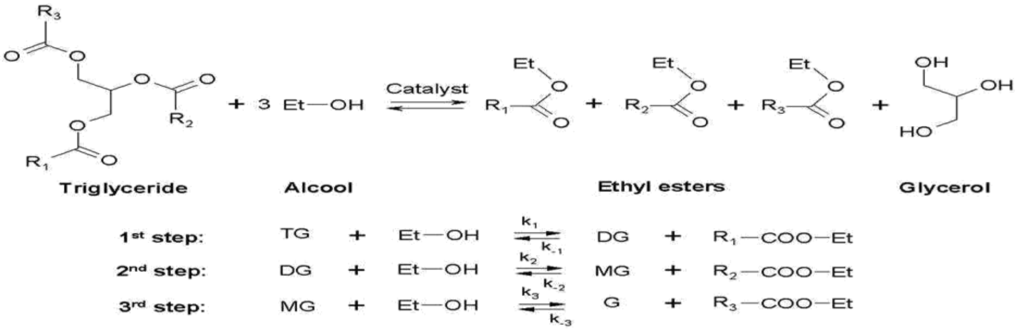

Figure 3.3: Mechanism of Alkali-CatalysedTrans-esterification

The first step is the conversion of triglycerides to di glycerides followed by the conversion of di glycerides to mono glycerides and of mono glycerides to glycerol yielding one ethyl ester molecule from each glycerides at each step The first step is an attack on the carbonyl carbon atom of the triglyceride molecule by the anion of the alcohol (ethnocide ion) to form a tetrahedral intermediate. In the second step, the tetrahedral intermediate reacts with an alcohol (methanol) to regenerate the anion of the alcohol (ethnocide ion). In the last step, rearrangement of the tetrahedral intermediate results in the formation of a fatty acid ester and di glycerides. When NaOH, KOH, K2CO3 or other similar catalysts were mixed with alcohol, the actual catalyst, alkoxide group is formed. A small amount of water, generated in the reaction, may cause soap formation during trans-esterification. The process of ethyl ester process is as shown in figure 3.4.

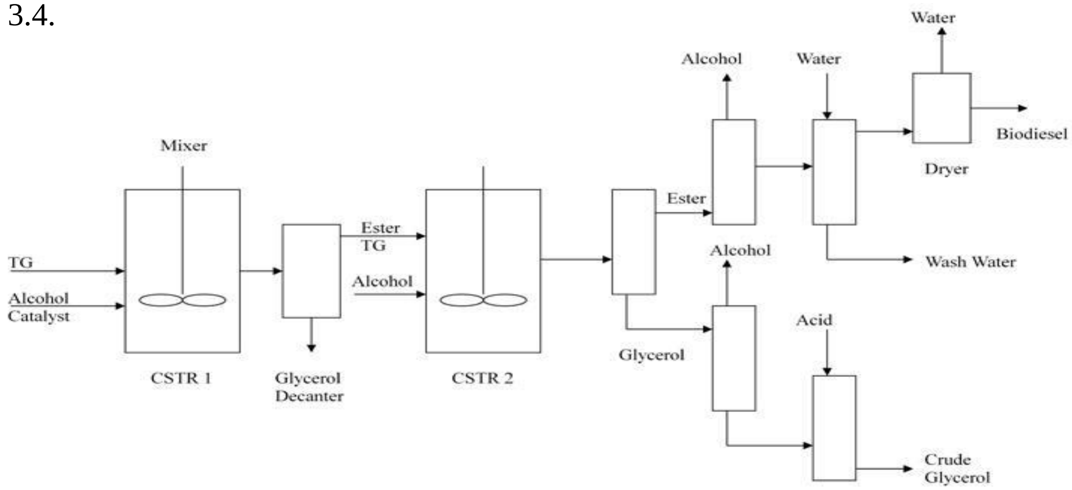

Figure-3.4: Flow Diagram of ethyl Ester Production Process.

In the present study the trans-esterification of Jatropha oil samples was carried out in the lab using standard procedures commonly used. As Jatropha oil contains more FFA (more than 5%), ethanol with KOH as catalyst was used. After separation of glycerol, the ester was water washed to remove un-reacted ethnocide. It was then heated to remove the water traces to obtain clear biodiesel. The ethyl ester (biodiesel) thus produced by this process was totally miscible with mineral diesel in any proportion. Plate 3.2 shows photograph of Jatropha derived Biodiesel after trans-esterification.

Plate 3.2: Jatropha ethyl ester biodiesel

3.4Trans-esterification process optimisation using taguchi approach

3.4.1Taguchi Approach

The Taguchi method helped to understand the effect of control parameter and to optimize the experimental conditions from a limited number of experiments and contribution of each noise factor calculated by ANOVA. Finally the yield of Jatropha ethyl ester could be improved using control parameter which was obtained by Taguchi method.In Taguchi method, the signal to noise ratio is used to measure the quality characteristics deviating from the desired value. S/N ratio developed by GenichiTaguchi is a predictor of quality loss after making certain simpleadjustments to the product's function. It isolates the sensitivity of the product's function to noise factors. The signal to noise ratios (S/N) are log functions of desired output, serve as the objective functions for optimization, help in data analysis and the prediction of the optimum results.

3.4.2Trans-esterification Process

Trans-esterification process is the reaction of triglyceride (fat/oil) with an alcohol in the presence of acidic, alkaline or lipase as a catalyst to form mono-alkyl ester that is biodiesel and glycerol. The presence of strong acid or base accelerates the reaction. The main purpose of trans-esterification is to reduce the high viscosity of oil which is suitable for CI engine. In this study, Jatropha ethyl ester is obtained by reacting Jatropha oil with ethanol in the presence of base catalyst. The Jatropha oil is first filtered to remove solid impurities then it is preheated at100oC for half an hour to remove moisture. A two stage process is used for trans-esterification of Jatropha oil. The first stage is esterification to reduce free fatty acid content in Jatropha oil with ethanol (99% pure) and acid catalyst (98% pure) heated for one hour at 60-65oC in magnetic stirrer. After esterification, the esterified oil washed using water. The washing is carried out in a separating funnel. The hot water having temperature as that of esterified oil added in a separating funnel. Impurities like dust, carbon content; sulphur content is washed away with water. After washing, the esterified oil was fed to the trans-esterificationprocess. The basic catalyst was dissolved in ethanol and added into esterified Jatropha oil while heating. This mixture is heated for 60 minutes. Once the reaction is complete, it is allowed for settling for 10-12 hours in a separating funnel. The products formed during trans-esterification were Jatropha oil ethyl ester and glycerine. The bottom layer consists of glycerine, excess alcohol, catalyst impurities and traces of unreacted oil. The upper layer consists of cleanamber coloured Jatropha oil ethyl ester. After settling, the glycerol layer is removed. The separated biodiesel is taken for characterization.

3.4.3Design of Experiments

Design of experiment consists of a set of experiments which is the setting of several products or process parameters to be studied that are changed from one experiment to another. Design of experiments is also called matrix experiment, parameters are also called factors and parameter settings are also called levels. Conducting matrix experiment using orthogonal array is an important technique. It gives more reliable estimates of factor effects with fewer numbers of experiments when compared with the traditional methods such as one factor at a time experiments. The design of experiment via Taguchi method uses a set of orthogonal array for performing of the fewest experiments. Taguchi method involves the determination of large number of experimental situation, described as orthogonal array, to reduce errors and enhance the efficiency and reproducibility of experiments. The columns of an orthogonal array are pair wise orthogonal that is for every pair of column, all combination of factor levels occur at an equal numbers of times.

Table3.3. Design experiments with five parameters at five levels, for the production of Jatropha ethyl esters.

Parameters	**Levels**				
	1	2	3	4	5
Molar ratio	3.33:1	4:1	5:1	6.67:1	10:1
Time (min)	40	50	60	70	80
Temp (˚c)	50	55	60	65	70
Catalyst Conc.	0.4	0.6	0.8	1.0	1.2
Speed (rpm)	125	250	375	500	625

The columns of an orthogonal array represent factors to be studied and the rows represent individual experiments. This study is associated with five factors with each at five levels. The orthogonal array used to find the effects of four parameters namely the molar ratio of oil to ethanol, reaction time, speed,and catalyst concentration and reaction temperature on the production of Jatropha oil ethyl ester. The five selected parameters at five levels i.e., L-25 arrays, experimentally studied are shown in Table 3.1. Table 3.2 shows the orthogonal array used to design experiments with five parameters at five levels.

Table 3.4Orthogonal array used to design experiments with four parameters at three levels,L-25(55)

S.No.	**Molar Ratio**	**Time (min)**	**Temperature ˚C**	**Catalyst conc. (wt. %)**	**Speed (rpm)**
1	1	1	1	1	1

2	1	2	2	2	2
3	1	3	3	3	3
4	1	4	4	4	4
5	1	5	5	5	5
6	2	1	2	3	4
7	2	2	3	4	5
8	2	3	4	5	1
9	2	4	5	1	2
10	2	5	1	2	3
11	3	1	3	5	2
12	3	2	4	1	3
13	3	3	5	2	4
14	3	4	1	3	5
15	3	5	2	4	1
16	4	1	4	2	5
17	4	2	5	3	1
18	4	3	1	4	2
19	4	4	2	5	3
20	4	5	3	1	4
21	5	1	5	4	3

22	5	2	1	5	4
23	5	3	2	1	5
24	5	4	3	2	1
25	5	5	4	3	2

In this study, Minitab15, which is software for automatic design, was used to analyse the results and optimize the experimental conditions for setting the control variables.

3.4.4 Determination of optimal experimental condition by the design of experiment.

The yield ofJatropha oil ethyl ester, prepared under twenty five sets of experimental conditions are shown in table. All experiments were performed, under the same experimental conditions(e.g., molar ratio of methanol to oil, catalyst concentration, reaction time, and speedand reaction temperature). This study is associated with four parameters with each at three levels. Above table indicates that the best suitable orthogonal array is L9. Table II shows the design matrix for L25. After conducting all the twenty five experiments and measuring the percentage yields so that there are twenty five observations in total for each experiment. According to the analysis for the case of larger the better the mean squared deviations (MSD) of each experiment were evaluated using the following equation

$$\mathrm{MSD} = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{1}{y_i}\right)^2$$

Where n is the number of repetitions of each experiment and $y_i$theyield of Jatropha ethyl ester.

Then the S/N ratio was evaluated using the equation. S/N ratio = -10Log(MSD)

The effect of parameter level is defined as the deviation it causes from the S/N ratio.

3.5PHYSICO-CHEMICAL PROPERTIES

3.5.1 Density

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

Plate 3.3: U-Tube Oscillating True Density Meter

3.5.2 Viscosity

When a fluid is subjected to external forces, it resists flow due to internal friction. Viscosity is a measure of internal friction. The viscosity of the fuel affects atomization and fuel delivery rates. It is an important property because atomization and mixing of air and fuel in combustion chamber gets affected. Viscosity studies were conducted for different test fuels. Absolute viscosity sometimes called dynamic or simple viscosity is the product of Kinematic viscosity and fluid density. Kinematic viscosity of liquid fuel samples were measured using Kinematic viscometer shown in plate 3.4 at 40^0 C as per the specification given in ASTM D445. A suitable capillary tube was selected, and then a measured quantity of sample was allowed to flow through the capillary. Efflux time was measured for calculating Kinematic viscosity using the formula given below:

$$\nu = c^{*}\, t \qquad \ldots (3.1)$$

Where,

ν= Kinematic viscosity, or mm^2/sec,

T = time, second

C = constant; mm^2/sec^2

Plate 3.4: Kinematic Viscometer

3.5.3 Flash and Fire point

Flash point is the minimum temperature at which the oil vapour, which when mixed with air forms an ignitable mixture and gives a momentary flash on application of a small pilot flame. The flash and fire point of the test fuels were measured as per the standard of ASTM D 93. The sample was heated in a test cup at a slow and constant rate of stirring for proper and uniform heating. A small pilot flame was directed into the cup through the opening provided at the top cover at the regular intervals. The temperature at which these vapour catches flash is observed and called as the flash point of that liquid. Fire point is an extension of flash point in a way that it reflects the condition at which vapour burns continuously for at least for 5 seconds. Fire point is generally higher than the flash point by 5-8° C. A Pen sky Martens apparatus used in the study for determination of flash point is shown in Plate 3.5.

Plate 3.5: pen sky Marten Flash Point Apparatus

3.5.4 Cloud and Pour Point

Cloud and Pour points are important for determining the feasibility of using the fuel in engine at lower ambient temperatures. Fuels with high pour points give flow problems at lower temperature, therefore it cannot be recommended for use in engine at low temperatures. Pour point for fuel oils, lubricating oils and diesel fuels is used as criteria in cold surroundings. The cloud and pour point of the fuel were measured as per the specification given of ASTM D2500 and ASTM D97 respectively. The cloud and pour point apparatus used for determination of these properties is shown in plate 3.6

The cloud point is the temperature at which a solid material, usually paraffin waxes and similar compounds in the case of petroleum liquid begins to separate when the sample is cooled under carefully controlled conditions. Likewise, the pour point is the lowest temperature at which the liquid will flow in a specific way when cooled under controlled conditions. The cessation of flow results from an increase in viscosity or from the crystallization of wax from the oil. Fuel oils of wax bearing crude oils have much higher pour point then those derived from crude oils of low wax content. A low pour point is a desired property of oil in respect of handling in cold atmosphere.The pour point is determined by cooling a sample of the oil in a test jar, to a temperature when the jar is displaced from the vertical to the horizontal position, no perceptible movement of the oil will occur within the first 5 second.

Plate 3.6: Cloud and Pour Point Apparatus

3.5.5 Calorific Value

The calorific value is defined in terms of the number of heat units liberated when unit mass of fuel is completely burnt in a calorimeter under specified conditions. Higher calorific value of fuel is the total heat liberated in kJ per kg or m^3. All fuels containing hydrogen in the available form will combine with oxygen and form steam during the process of combustion. If the products of combustion are cooled to its initial temperature, the steam formed as a result will condense. Thus maximum heat is abstracted. This heat value is called the higher calorific value. The calorific value of the fuel was determined with the Isothermal Bomb Calorimeter as per the specification given in ASTM D240. The combustion of fuel takes place at constant Volume in a totally enclosed vessel in the presence of oxygen. The sample of fuel was ignited electrically. The water equivalent of bomb calorimeter was determined by burning a known quantity of benzoic acid and heat liberated is absorbed by a known mass of water. Then the fuel samples were burnt in bomb calorimeter and the calorific value of all samples were calculated. The Bomb Calorimeter used for determination of Calorific value is shown in plate 3.7

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

$$H_c = (W_c * \Delta T)/M_s \qquad \ldots (3.2)$$

$\triangle$

Where,

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

W_c = Water equivalent of the calorimeter assembly, kJ/ ^{o}C

T = Rise in temperature, ^{o}C

$\triangle$

M_s = Mass of sample burnt, kg

Plate 3.7: Bomb Calorimeter

3.6 Engine Selection

There is no difference of opinion that India is going to face a severe fuel crisis in future because fuel consumption has increased in all the vital sectors specially transportation and agricultural sector. As diesel engines plays an indispensable role in transportation and agriculture sector and as such diesel consumption will increase Multifood in time to come. The diesel engine continues to dominate the agriculture sector in our country in comparison to spark ignition engine and have always been preferred widely because of power developed, specific fuel consumption and durability. A through description of combustion mechanism in diesel engine is beyond the scope of this study. However, it would be worthwhile to inform that the fuel is burnt in diesel engine by self-ignition at higher temperature and pressure conditions of the order of 600°C and 40 bar, respectively. Diesel as a fuel is injected into the combustion chamber at the end of compression stroke and after certain ignition delay; it burns to give the motive power. In India, almost all irrigation pump sets, tractors, mechanized farm machinery and heavy transportation vehicle are powered by direct injection diesel engines. Keeping the specific features of diesel engine in mind, a typical engine system has been selected for the present experimental investigations.

3.6.1 Development of an Experimental Test Rig

A Kirloskar make, single cylinder, air cooled, direct injection, DAF 8 model diesel engine was selected for the present research work, which is primarily used for agricultural activities and household electricity generations as shown in Plate 3.8.

Plate 3.8: Test Engine

It is a single cylinder, naturally aspirated, four stroke, vertical, air-cooled engine. It has a provision of loading electrically since it is coupled with single phase alternator through flexible coupling. The engine can be hand started using decompression lever and is provided with centrifugal speed governor. The cylinder is made of cast iron and fitted with a hardened high-phosphorus cast iron liner. The lubrication system used in this engine is of wet sump type, and oil is delivered to the crankshaft and the big end by means of a pump mounted on the front cover of the engine and driven from the crankshaft. The inlet and exhaust valves are operated by an overhead camshaft driven from the crankshaft through two pairs of bevel gears. The fuel pump is driven from the end of camshaft. The detailed technical specifications of the engine are given in Table 3.5.

Table 3.5: Specifications of the Diesel Engine

Make	**Kirloskar**
Model	DAF 10
Rated Brake Power (bhp/kW)	10 / 7.4
Rated Speed (rpm)	1500
Number of Cylinder	One
Bore x Stroke (mm)	102 x 116
Compression Ratio	17.5:1
Cooling System	Air Cooled (Radial Cooled)
Lubrication System	SAE 30/SAE 40, Forced feed
Cubic Capacity	0.78 Lit
Injection pressure (bar)	200-205
Length (mm)	531
Width (mm)	546
Height (mm)	878
Weight (kg)	194

For conducting the desired set of experiments and together required data from the engine, it is essential to get the various instruments mounted at the appropriate location on the experimental setup. Apart from this, a dual fuel system has been developed for diesel and biodiesel. The schematic diagram of the experimental setup along with all instrumentation is shown in Figure 3.1. Overall pictorial view of the test rig along with instrumentation used in the present investigations is shown in Plate 3.9.

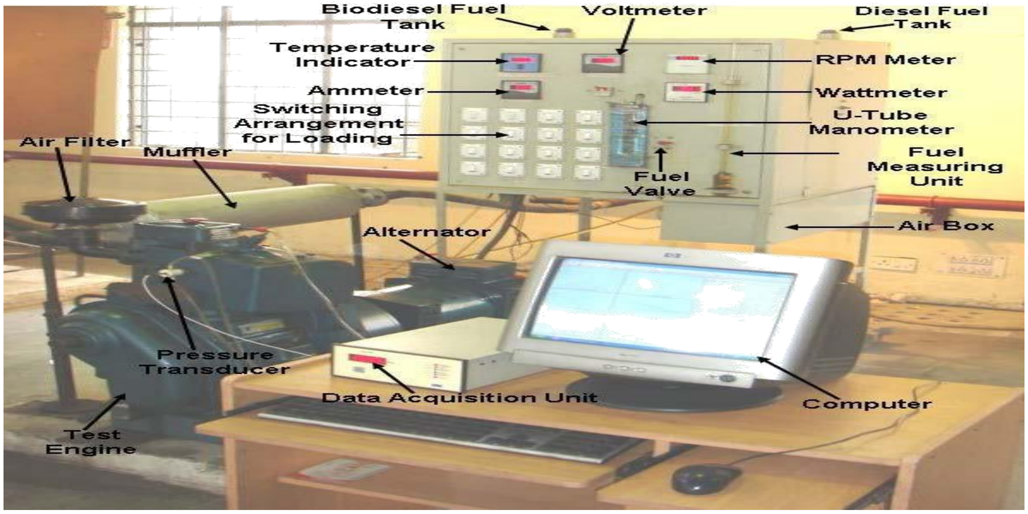

Plate 3.9: Photograph of the Experimental Set Up

3.7 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 (rpm)
3. Fuel consumption

4. Exhaust gas temperature
5. Exhaust gas analysis
6. Crank angle measurement
7. In-cylinder gas pressure measurement

8. Heat release rate

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

7. Voltage generated by the alternator
8. Current generated by the alternator
9. RPM of the engine
10. Air inlet temperature
11. Fuel consumption rate
12. AVL 437 smoke meter
13. AVL Di Gas analyser
14. Pressure
15. Signals from pressure transducer and crank encoder

Once the parameters were selected, the essential instruments required for sensing these parameters were installed at the appropriate points in the experimental set-up as shown in figure 3.5.

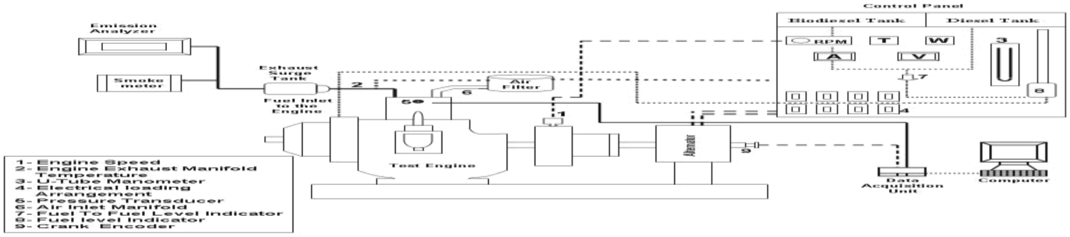

Fig. 3.5 Schematic Diagram of the Experimental Set Up

3.8 Installation of the Instrument Control Panel

After finalizing the procedures for data collection and procurement of the desired instruments, they were put on a panel. A control panel was fabricated and instruments such as voltmeter, ammeter, speed counter, six channels digital temperature display, U-tube manometer was mounted on the front side of the control panel (Plate 3.10). Electrical load banks, i.e., 16 bulbs each of 500 and 300 watts, were mounted on the rear side of the control panel which is shown in Plate 3.10 and their switches provided on the front side of the control panel.

Plate 3.10: Control Panel

Plate 3.11: Load Bank

One burette with stop cock and two way valves were also mounted on the front side of the panel for fuel flow measurements and selecting between both diesel fuel and biodiesel. The two fuel tanks of 10 litter’s capacity were mounted for storing the fuels on the rear side of the panel at highest position as shown in plate 3.12

Plate 3.12: Two Tanks System

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 in-cylinder gas pressure was measured by piezo-electric pressure transducer (Plate-13). Crank encoder was also used so that the angular position of the piston over the complete cycle can be determined. The piezo-electric pressure transducer was too provided with cooling system since it has to withstand high temperature and pressure. The AVL 437 smoke meter and AVL Di Gas Analyser were also kept in proximity for the measurements of various exhaust gas parameters. Thus, such a system was chosen to examine the practical utility of biodiesel 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.

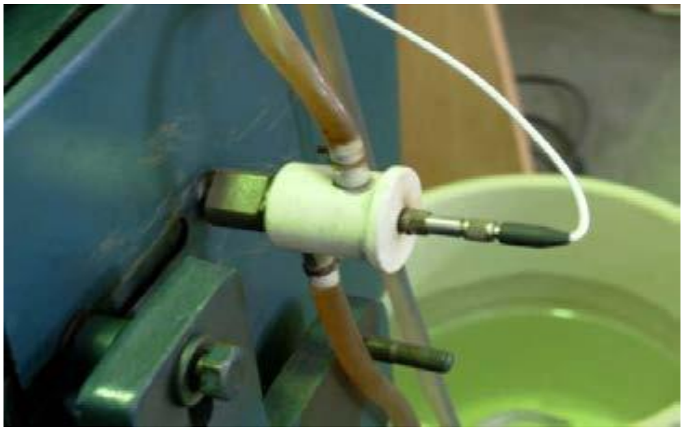

Plate 3.13: Piezo-Electric Pressure Transducer

3.9 Measurement Methods

As already elaborated, the main components of the experimental setup are two fuel tanks (Diesel and Jatropha biodiesel), Fuel consumption measuring unit, Electrical loading arrangement, voltmeter, ammeter, RPM meter, and Temperature indicator and emissions measurement equipment. The engine is started with diesel for at least 30 minutes. For switching the engine from diesel to biodiesel, a two way valve is provided on the control panel. Both the fuels from the two tanks can be feed to the engine through this valve separately. One end of the valve is connected to oil and the other end is connected to diesel. The fuel from the valve enters into the engine through this fuel measuring unit. With the help of this fuel measuring unit, the volumetric flow of the fuel can be easily measured. The fuel from the fuel measuring unit than enter in to the fuel filter before entering to the engine.

3.9.1 Brake Power

The brake power is among the most important parameter in testing of an engine. The power developed by the engine was measures with the help of an electric alternator type of dynamometer. The dynamometer was coupled to the engine with the help of a flexible coupling. The output lead of this mechanically coupled alternator was connected to the control panel along with an ammeter and voltmeter of range in series and thus by measuring voltage and current, the power developed by the electric generator was known as brake power. The lamp load was connected in series with the generator to act as a resistive load bank. Carbon brushes were checked and replaced when worn out. Lamp load consisted of 4 rows in parallel with 4 bulbs in series. The ratings of incandescent lamps were 250 Volts, 500 and 300 Watt. The dynamometer used in this study was an “Anchor” makes, 220 Volts, 7.5kVA, single phase alternator. A Voltmeter, 0-415 Volts AC and an ammeter, 0-30 Ampere were selected for the measurements.

3.9.2 Fuel Flow Measuring System

The fuel consumption of an engine is measured by determining the time required for consumption of a given volume of fuel. The mass of fuel consumed can be determined by multiplication of the volumetric fuel consumption to its density. In the present set up volumetric fuel consumption was measured using a glass burette. The time taken by the engine to consume a fixed volume was measured using a stopwatch. The volume divided by the time taken for fuel consumption gives the volumetric flow rate. The test facilities were built up for measuring oil consumption rates. For this, two separate tanks, one burette, and a number of valves were provided on the panel as shown in the Plate 3.14

Plate 3.14: Fuel Flow Measuring System

This test was carried out only after the preliminary run. After stable operating conditions were experimentally achieved, the engine was subjected to similar loading conditions. Starting from no load, observations were recorded at 20%, 40%, 60%, 80% and 100% of the rated load. The brake specific fuel consumption was calculated by using the relationship given below:

$$\text{Bsfc} = (V_{cc} \times \ell \times 3600) / (hp \times t) \qquad (3.3)$$

Where, bsfc = Brake specific fuel consumption, g/kW-h

Vcc = Volume of fuel consumed, cc

ℓ = Density of fuel, g/cc

Hp = Brake horsepower, kW

T = Time taken to consume, cc of fuel, sec.

The brake thermal efficiency of the engine on different fuel blends at different operating conditions was determined using the equation as given below:

$$Hth = Ks / (HV \times bsfc) \qquad (3.4)$$

Where, Hth = Brake thermal efficiency, %

Ks = Unit constant, 3600

HV = Gross heat of combustion, kJ/kg

Bsfc=Brake specific fuel consumption, g/kW-h

3.9.3 Rpm of the Engine

An ‘MTC’ make digital panel tachometer with proximity/photo reflective sensor was used for measurement of RPM. The instrument is capable of functioning in the range of 1 to 9,999 rpm with a sampling time of 1 second. For measurement, a nut was welded on the flywheel face and sensor was mounted on a bracket near the flywheel in such a way that the distance was less than 5 mm. The display unit is digital and mounted on the panel board. The engine speed measurement arrangement is shown in plate 3.15.

Plate 3.15: Engine Speed Measurement

3.9.4 Temperature Measurement

Chromel-Alumel K-type thermocouples were connected to a 6 channel digital panel meter to measure temperatures of exhaust as shown in Plate 16. Temperature of oil is also observed at various points. The meter was calibrated by a mille Volt source up to 800^{o} C. Thermocouples were provided in the exhaust line to measure the temperature of the exhaust gases at the outlet and inlet section.

Plate 3.16: Temperature Measurement Arrangement

3.9.5 Rate of Heat Release and Combustion Characteristics

Cylinder pressure versus crank angle data over the compression and expansion strokes of the engine operating cycle can be used to obtain quantitative information on the progress of combustion and value of rate of release of fuel's chemical energy or heat release rate can be computed from these data. Heat release analysis compute the amount of heat would have to be added to the cylinder content in order to get the observed pressure variation. The rate of heat release is very important parameters since this has a very significant influence on combustion noise, pressure rise rate and NOx emissions. For a D.I. compression ignition engine, the cylinder contents are a single open system. The only mass flows across the system are the fuel and the crevice flow between inlet and exhaust valves are closed. The model described in Heywood was used to calculate the apparent net heat transfer rate from the cylinder pressure history. The model is a single zone model and does not distinguish between burned and unburned zones. The model neglects the crevice flow effects. Multi-zone models also exist, but the developer must approximate multiple equilibrium zones and keep track of the burned and unburned areas for the heat transfer calculation. The benefits from an apparently more rigorous, multi-zone analysis may be negligible in view of the uncertainties in defining the evolution of zones, the computational intensity, and the fact that a single pressure is measured in the cylinder. The above model has been used by many previous researchers. The ignition Delay is the period between the start of fuel injection into the combustion chamber and the start of combustion (from a heat release analysis/ p-θ diagram). In this study, the ignition delay was computed from the time interval from the static fuel injection timing to the start of rapid pressure rise from heat release analysis. The rapid combustion duration is the time interval from the start of rapid pressure rising to the end of rapid pressure rise and the total combustion duration is the time interval from the start of heat release to the end of heat release. Different test fuels were used in the engine and the combustion characteristics and heat release rate based on recorded in cylinder pressure data were analysed at the same load for all the test fuels.

3.9.6 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, CO2 and NOx. For measuring the smoke opacity, AVL 437 smoke analyser 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. The technical detailed specifications have been given in Appendix I. For measurement of UBHC, CO, CO2 and NOx, AVL 4000 Light Di-Gas Analyser was used. The detailed specification of AVL Di-gas Analyser has been given in Appendix II. Both the AVL 437 Smoke meter and AVL Di Gas Analyser are shown in Plate 3.17.

Plate 3.17 Smoke and Emissions Measuring System

3.10 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, NOx, HC , CO2 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 neat biodiesel was used to evaluate its suitability as a fuel. The performance and emission characteristics of neat biodiesel were evaluated and compared with diesel fuel. These data were than compared with both the diesel fuel and the biodiesel. The engine was always started with diesel as a fuel and after it was run for 20-25 minutes, it was switches over to biodiesel. The preliminary run on the engine was conducted at rated speed of 1500 rpm to ensure that the engine is made trouble free for its exhaustive test run. This was done in accordance with IS: 10,000 Part V. During the preliminary run, attention was paid to vibration and quietness of the engine, and the oil pressure was checked from time to time. It was ensured that the temperature of the engine lubricating oil should be reached within 5°C of the room temperature before starting the next cycle. Oil and fuel leaks were monitored and rectified wherever necessary. The complete record of such problems and running time of components changed was maintained. After completion of the rating test, subsequent performance and emission tests on the engine was carried in accordance with IS: 10,000 (Part VIII) and observations were recorded at the various loads starting from no load to full load conditions: **No load, 20%, 40%, 60%, 80%, 100%.** The engine was run initially on neat diesel for generation of baseline data. Thereafter, the engine was run on different biodiesel based fuels. Various performance and emission characteristics were recorded only when stabilized working conditions were achieved. The performance and emission data were duly corrected according to the procedure specified in IS: 10000 (Part IV)-1980 for all the test fuels. Before turning the engine off, the biodiesel was replaced with diesel and it was run on diesel till all biodiesel in fuel filter and pipe line is consumed.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.0 Introduction

The objectives of the present work was to evaluate the optimum process variable for the maximum yielding of biodiesel production and feasibility of using this biodiesel (ethyl ester) derived from Jatropha oils in different proportions with diesel in small capacity diesel engine. Performance and emission characteristics were evaluated during the observation. Blends of Jatropha biodiesel (B5, B10, B20, B30 and B100) were prepared to find out the optimal blend based on the performance and emission characteristics with respect to mineral diesel.

4.1 Optimisation technique for esterification process using taguchi

4.1.1 S/N plot

From the figure 4.1 it is observed that the optimum level of molar ratio, reaction time, and reaction temperature and catalyst concentration are 3, 2, 3, 1,i.e. 6.67:1, 90 min, 65°C, and 1.0% of oil (chapter 3, table 3.1). Hence we can conclude that it can give the lowest FFA of oil i.e.0.8

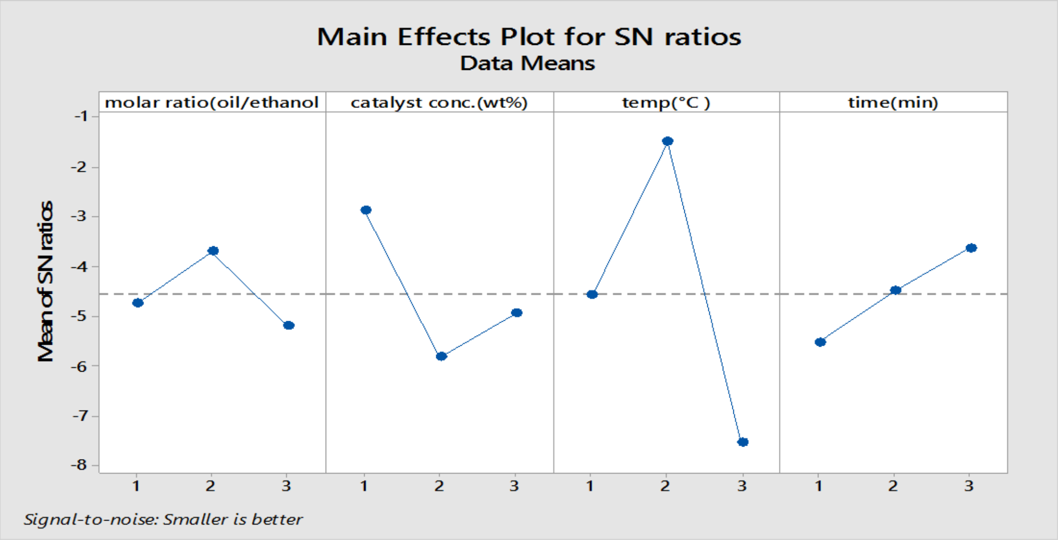

Figure 4.1. Main effects plot of the control parameters

4.1.2 Anova table

Different parameters affect the free fatty acid of oil to a different degree. The relative magnitude of the parameter effects are listed in table. A best feel for the relative effect of the different factors is obtained by the decomposition of variance, which is generally called as analysis of variance (ANOVA). This is obtained by the formula given below.

Total sum of squares = Sum of square due to parameter A [(total number of experiments at level A1) x (mA1-m)] + [(total number of experiments at level A2) x (mA2-m)] + [(total number of experiments at level A3) x (mA3-m)].

Now all these sum of squares are listed in Table 4.1. This is known as the ANOVA table.

4.1.2.1 Analysis of Variance

Source	**DF**	**Adj. SS**	**Adj. MS**	**F-value**	**P-value**
Molar ratio(oil/ethanol)	2	0.01556	0.00778	78.34	0.00012
Catalyst conc. (Wt. %)	2	0.42889	0.21444	6.33	0.042
Temp(°C)	2	2.06889	1.03444	21.33	0.022
Time(min)	2	0.16222	0.08111	0.06	0.18
Error	0	0	0		
Total	8	2.67556			

Table 4.1

The larger the contribution of a particular parameter to the total sum of squares, the larger the ability is of that factor to affect the S/N ratio. More ever, the lower P- value, the larger will be the factor contribution in the reduction of FFA. For the molar ratio, catalyst conc. and reaction temperature P-value is very small; hence it has more contribution in the reduction of FFA.

4.2 Optimisation technique for trans-esterification process (biodiesel production) using taguchi

The process variables affecting trans-esterification of oil are amount of catalyst, oil to alcohol 11(molar ratio), reaction temperature, speed of stirring and reaction time. In the present study the optimization condition for trans-esterification of Jatropha oil such as catalyst concentration, molar ratio, reaction time, reaction temperature, and rate of mixing (stirring speed) was determined. The details of optimisation condition for trans-esterification of Jatropha oil are shown in (Tables 4.2 to 4.6) and (Figure. 4.2 to 4.6).

Table 4.2 Variation of molar ratio on biodiesel yield

S. No.	Molar ratio	Biodiesel yield (%)
1	3.33:1	48
2	4:1	58
3	5:1	65.5
4	6.67:1	71
5	10:1	82.5

Table 4.3 Variation of catalyst concentration on biodiesel yield

S. No.	Catalyst (mg of KOH/gm. of oil)	Biodiesel yield (%)
1	0.4	65
2	0.6	66
3	0.8	65.75
4	1.0	67.25
5	1.2	64

Table 4.4 Variation of stirring speed on biodiesel yield

S. No.	**Speed(rpm)**	**Biodiesel yield (%)**
1	125	64.5
2	250	66.8
3	375	67.7
4	500	64
5	625	64.7

Table 4.5 Variation of time on biodiesel yield

S. No.	**Time(min)**	**Biodiesel yield (%)**
1	40	66.4
2	50	64.8
3	60	64.6
4	70	65.6
5	80	66.3

Table 4.6 Variation of reaction temperature on biodiesel yield

S. No.	**Reaction temperature (°C)**	**Biodiesel yield (%)**
1	50	61.5
2	55	61
3	60	66
4	65	68.1
5	70	70.1

4.2.1 Effect of oil to alcohol (molar ratio)

Most important variables which affect the yield of ethyl ester is the molar ratio of jatropha oil to alcohol. Ethanol is the common alcohol used for trans-esterification process due its high yielding and safety storage. The stoichiometry trans-esterification reactions require 3 moles of ethanol and 1 mole of triglycerides to give 3 moles of fatty acid ethyl ester and 1 mole of glycerol. The reaction consists of three consecutive reversible reactions with intermediate formation of diglycerides and monoglycerides. Since the trans-esterification reaction is an equilibrium reaction where excess of amount of ethanol is always required to drive the reaction close to completion in a forward direction. To study the effects of molar ratio, five different level of molar ratio, i.e., 3.33:1, 4:1, 5:1, 6.67:1 and 10:1 was taken as variable. For all the different molar ratio, the reaction parameters such as speed, catalyst conc., reaction time and reaction temperature were kept constant as; 250 rpm, 0.5%, one hours and 65°C respectively. Figure 4.2 shows the effect of molar ratio on the yield of biodiesel. From the figure, it is observed that the yield of ethyl ester (biodiesel) is maximum at the level 5 of molar ratio i.e. 10:1. For the molar ratio less than 9:1, it takes more time to complete the reaction. Similarly, for the molar ratio higher than 9:1, the separation of glycerol from ethyl ester (biodiesel) was very difficult and the yield of ethyl ester (biodiesel) decreases. This may be due to some portion of glycerol remains in the biodiesel phase.

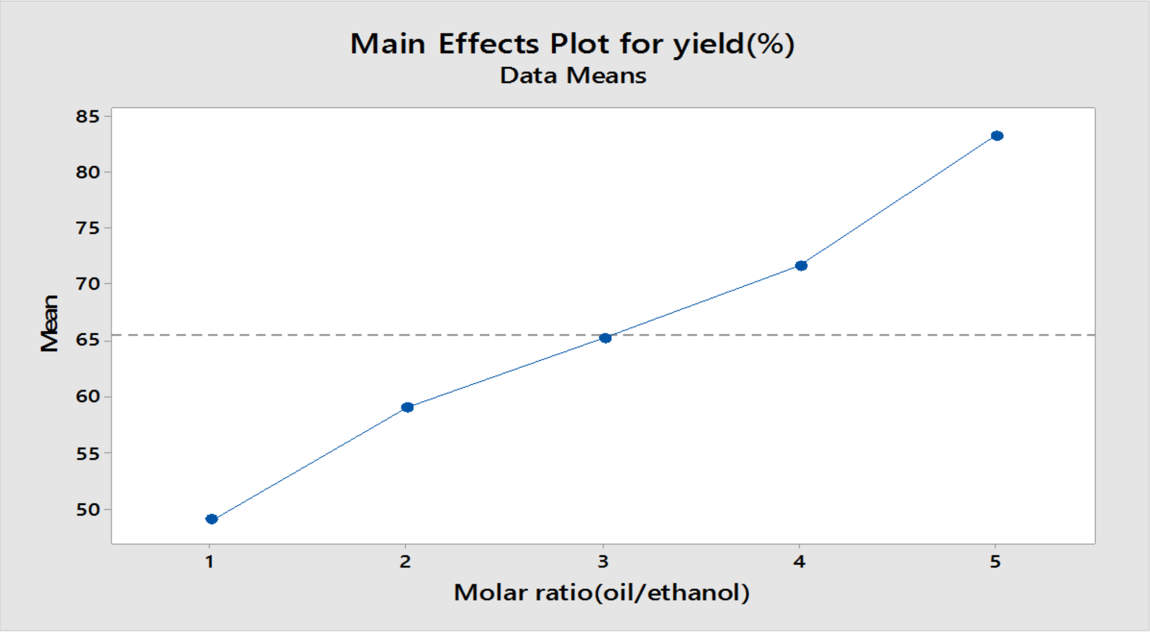

Figure.4.2 Effect of molar ratio on biodiesel yield with constant, reaction time, reaction temperature, catalyst conc. and stirring speed

4.2.2 Effect of catalyst concentration on biodiesel yield

Trans-esterification of triglycerides is catalysed by strong acids or alkali. The alkali catalysts instead of acid were selected for biodiesel production. The alkaline catalyst like KOH, NaoH is mostly used due to its high esters conversion, minimum side reactions and less corrosion problems. This catalyst increases the reaction rate many times faster than acid catalysts. Figure. 4.3 show the effect of catalyst conc. on biodiesel yield. In the study, five different catalyst amounts i.e., 0.4%, 0.6%, 0.8%, 1.0% and 1.2% was taken. The oil to ethanol (molar ratio) of 5:1, constant reaction temperature of 65°C and reaction time of one hour, stirring speed 250 rpm were used with different amounts of catalyst for production of ethyl ester (biodiesel). The maximum yield of ethyl ester (biodiesel) was observed at level 4 of catalyst conc. i.e. 1.0wt%. With the increase in catalyst conc. there was decrease in the yield of ethyl esters. Moreover this leads to more extra costs because it was necessary to remove it from the reaction medium at the end. Further the addition of excess amount of catalyst gave rise to the formation of an emulsion, which increased the viscosity and led to the formation of gel. This is in accordance with the results obtained by [32]. It was observed that trans-esterification reaction does not take place due to insufficient amount of catalyst conc.

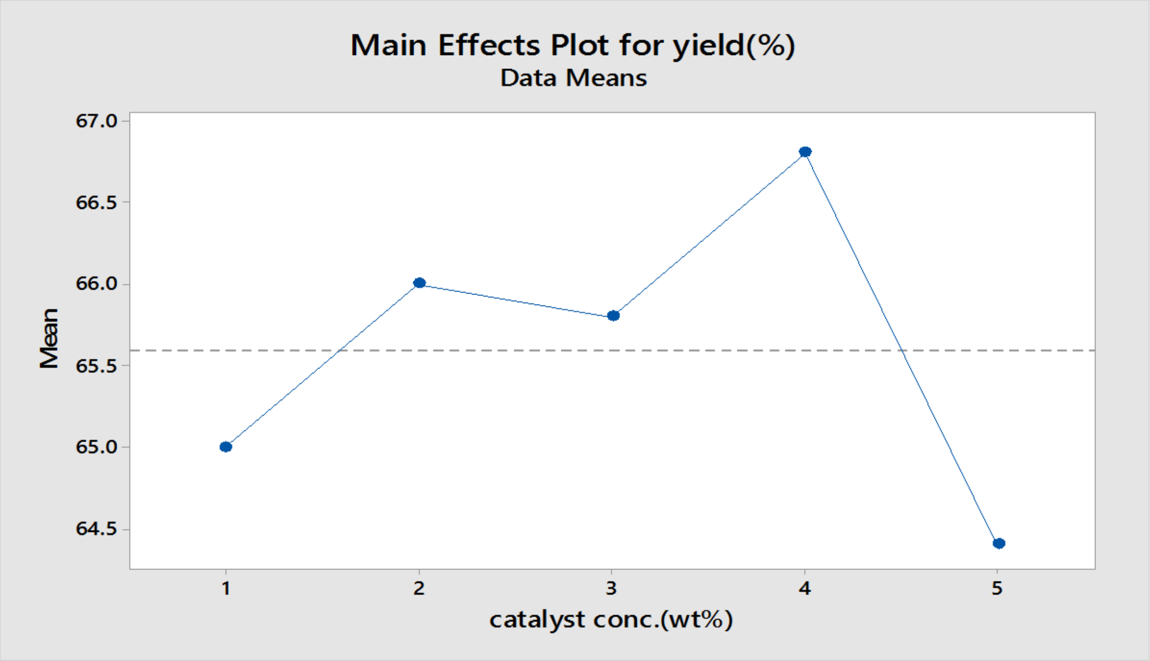

Figure 4.3 Effect of catalyst conc. on biodiesel yield with constant molar ratio, reaction time, reaction temperature and stirring speed

4.2.3 Effect of stirring speed

To achieve effective interaction between the catalyst and oil during trans-esterification, it is essential that they must be stirred well for proper mixing at constant rate. Mixing is very important in this reaction, as oils or fats are immiscible with ethanol forming two layers [33]. Figure 4.4 show the effect of stirring speed on biodiesel yield. The stirring speed was varied from 125 to 625 rpm to observe the yield of biodiesel. For all the different stirring speeds, the reaction parameters such as molar ratio, catalyst conc., reaction time and reaction temperature were kept constant as; 5:1, 0.5%, one hours and 65°C respectively. It was observed that the reaction was incomplete with 375 rpm and rate of mixing was insignificant for ethanolysis.

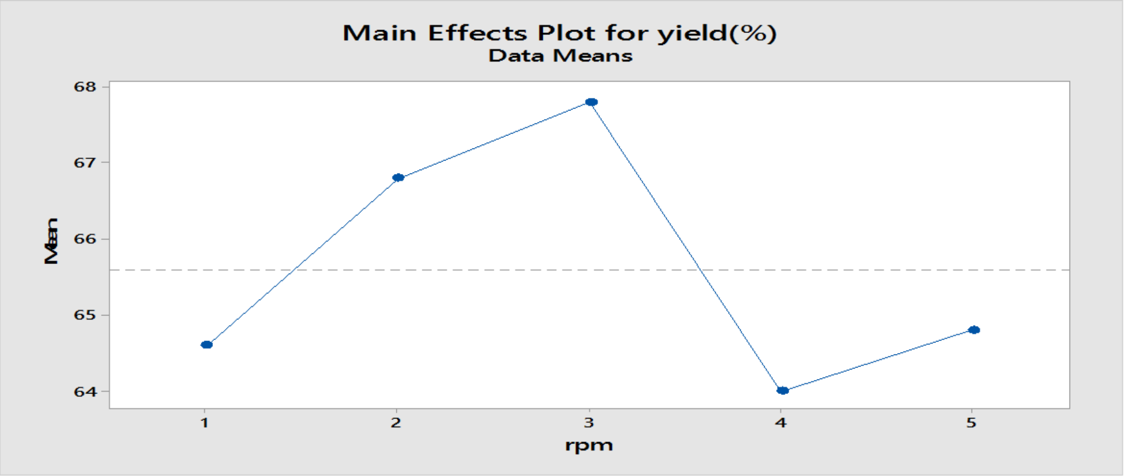

Figure 4.4 Effect of stirring speed on biodiesel yield with constant reaction time, reaction temperature, catalyst conc. and molar ratio

4.2.4 Effect of reaction duration

Fig. 4.5 shows the effect of reaction duration on jatropha ethyl ester yield. To study the effect of reaction time, five different times i.e., 40 minutes, 50 minutes, 60 minutes, 70 minutes and 80 minutes was taken as variable. For all the different reaction times, the reaction parameters such as molar ratio, catalyst conc., reaction time reaction temperature and stirring speed were kept constant as 5:1, 0.5%, one hour 65°C and 250rpm respectively. From the Figure 4.5, it is observed that the conversion rate decreases with reaction time. The maximum yield of Jatropha biodiesel was observed at reaction time of 40 minutes and further increased of reaction duration increases the biodiesel yield but more than that which was at 40 min. Results from the present investigation concluded that reaction duration of 40 minutes is sufficient for the completion of based catalyst trans-esterification.

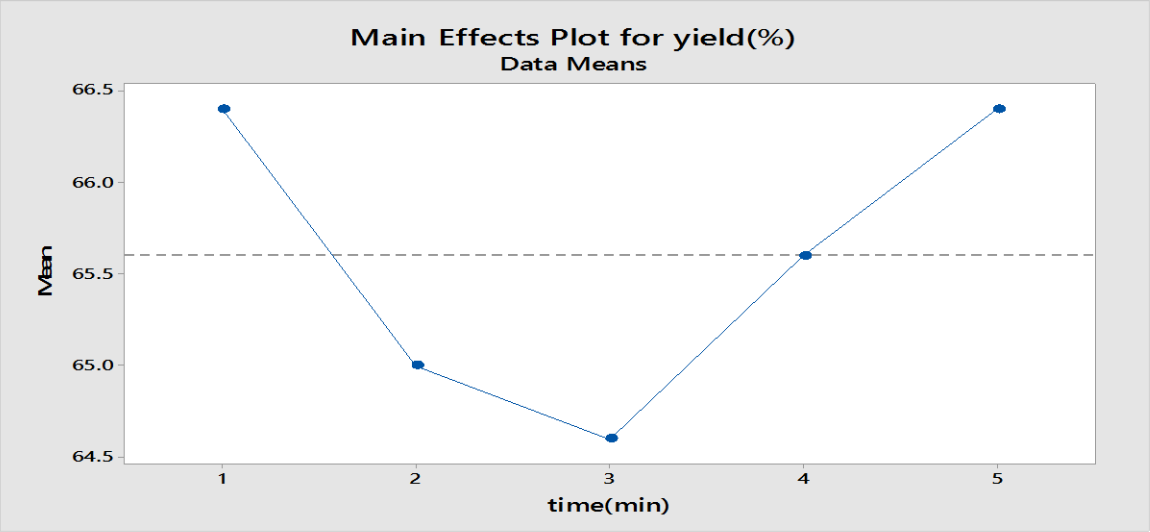

Fig. 4.5 Effect of reaction duration on biodiesel yield with constant temperature and stirring speed

4.2.5 Effect of reaction temperature

The rate of trans-esterification reaction is strongly influenced by the reaction temperature. In the present investigation the reaction temperature was varied from 50°C to 70°C. For all the different reaction temperatures, the reaction parameters such as molar ratio, catalyst, reaction time and stirring speed were kept constant as 5:1, 0.5%, one hours and 250 rpm respectively. It was observed that reaction temperature have positive influence on ethanolysis of Jatropha oil. This is in accordance with [34]; the reaction temperature is linked to the reaction time. From Figure 4.6, it is observed that the percentage yield of biodiesel increased with increased in temperature up to 70°C. The maximum biodiesel yield was obtained at 70°C temperature. Further increases in reaction temperature have negative effect on ester conversion. This may be due to the saponification (side reaction) of the triglycerides that is favoured at high temperature. The free fatty acid neutralisation (side reaction) also produces soap and therefore constitutes another cause of yield loss.

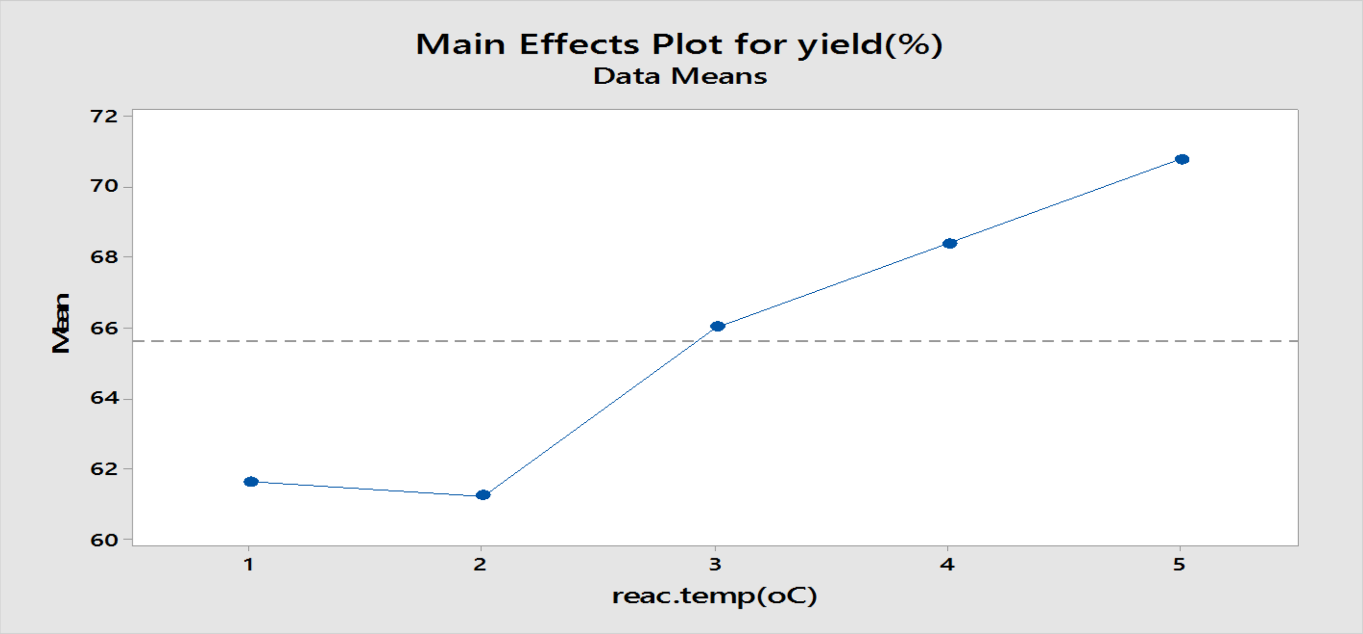

Figure 4.6 Effect of reaction temperature on biodiesel yield with constant reaction time, and stirring speed

4.2.6 S/N plot

From the figure 4.7 it is observed that the optimum level of molar ratio, reaction time, reaction temperature and catalyst concentration for maximum S/N ratio are 5, 5, 5, 4, 3 i.e.10:1, 40 min, 70°C, 1.0 wt.% and 375 rpm. Hence we can conclude that it can give the highest η or the highest percentage yield i.e.94%.

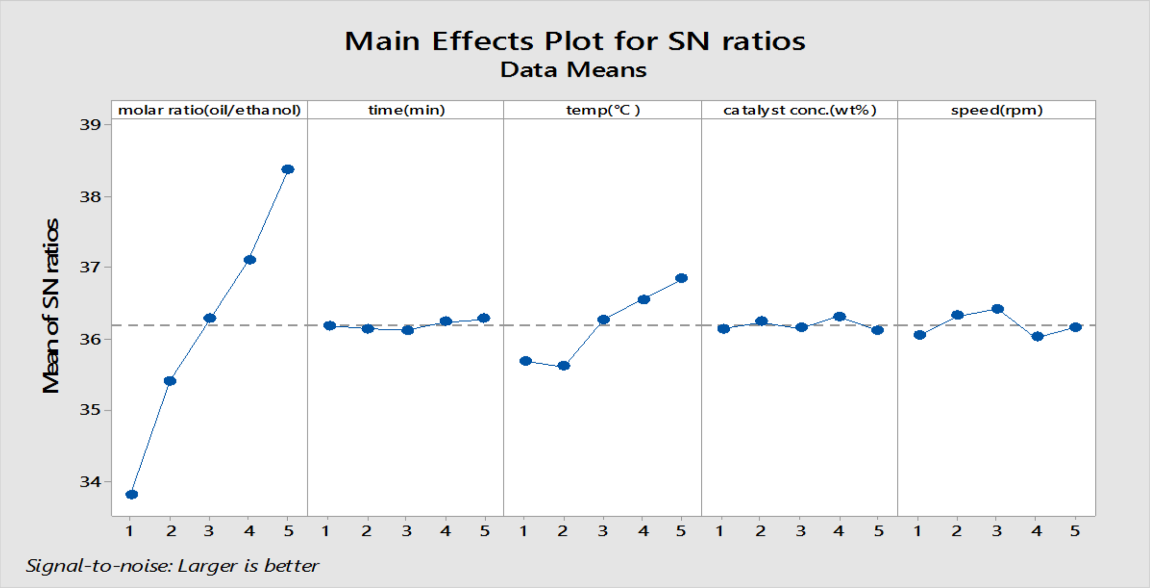

Figure4.7. Main effects plot of the control parameters

4.2.7 Anova table

Different parameters affect the yield of ethyl ester to a different degree. The relative magnitude of the parameter effects are listed in table 4.7. A better feel for the relative effect of the different factors is obtained by the decomposition of variance, which is commonly known as analysis of variance (ANOVA). This is obtained by

Total sum of squares = Sum of square due to parameter A [(number of experiments at level A1) x (mA1-m)]+ +[(number of experiments at level A2) x (mA2-m)] +[(number of experiments at level A3) x (mA3-m)].

Now all these sum of squares are tabulated in Table. This is called as the ANOVA table.

4.2.7.1Analysis of Variance

Source	**DF**	**Adj. SS**	**Adj. MS**	**F-value**	**P-value**
Molar ratio(oil/ethanol)	4	3325.20	831.300	69.28	0.001
Reaction	4	13.20	3.300	0.27	0.881

time(min)					
Reaction temp(°C)	4	352.00	88.000	7.33	0.040
Catalyst conc.(wt%)	4	17.20	4.300	0.36	0.828
Speed(rpm)	4	52.40	13.100	1.09	0.467
Error	4	48.00	12.000		
Total	24	3808.00			

Table 4.7

In the present study, the degrees of freedom for the error are zero. Hence an approximate estimate of the error sum of squares is obtained by pooling the sum of squares corresponding to the factors. The larger the contribution of a particular parameter to the total sum of squares, the larger will be the ability is of that factor to influence S/N ratio. Moreover, the lower P-value, the larger will be the factor effect in comparison to the error mean square. For the molar ratio and reaction temperature P-value is very small, hence it has more contribution in the yielding of biodiesel.

4.3.1: Physico-Chemical Characterization

The different physico-chemical properties of Diesel, Jatropha biodiesel are summarized in **Table 4.8**. The oil samples were subjected to several property tests in accordance with ASTM D-6751.

Table 4.8: Physico-Chemical Properties of Diesel and Jatropha and Karanja Biodiesel Oil

Property	Diesel oil	Jatropha oil	Jatropha biodiesel (JOEE100)
Higher Calorific Value(kJ/kg)	42232	39584	39594
Density (kg/m^3)	0.831	0.921	0.881
Kinematic Viscosity@ 40°C(mm^2/s)	3.21	3.8	4.12
Acid No. (Mg.KOH/gm.)	0.2	2.32	0.3
Cloud Point, °C	-12	-1	-4
Pour Point °C	-17	-6	-8
CFPP, °C	-14	-	-6

Table 4.8: Physico-Chemical Properties of Diesel and Jatropha and Karanja Biodiesel Oil

Flash Point, °C	76	235	162
Water Content (Karl Fisher)Ppm	**120**	-	**282**
Copper Strip Corrosion	**1A**	-	**1A**
Rams bottom Carbon Residue , % wt.	**0.05**	-	**0.036**
Cetane number	**47.2**	-	-
Sulphur Content (Ppm)	**340**	-	**8**
API Gravity	38.77	-	29.11
Cetane Index	47.14	-	48.13

4.4 Combustion characteristics

The analysis of combustion characteristic of diesel, biodiesel of Jatropha were carried out. It is clear from **Figure 4.8** and **Figure 4.9** that ignition of fuel starts earlier for jatropha biodiesel based fuels in comparison to diesel fuel. Maximum cylinder gas pressure was found to be lower for biodiesel based fuels. In diesel engine, cylinder pressure depends on the burnt fuel fraction during the premixed burning phase, i.e., initial stage of combustion. Cylinder pressure characterizes the ability of the fuel to mix well with air and burn. High peak pressure and maximum rate of pressure rise corresponding to large amount of fuel burnt in premixed combustion stage. The value of maximum cylinder pressure was found lowest for JME100 fuel. It may be due to higher cetane index of this fuel in comparison to Jatropha ethyl ester and diesel fuels resulting in shorter ignition delay and more fuel burnt in diffusion stage.The ignition delay in a diesel engine is defined as the time between the start of fuel injection and the start of combustion. Rapid premixed burning followed by diffusion combustion is typical for naturally aspirate diesel engines. After the ignition delay period, the premixed air fuel mixture burns rapidly releasing heat at a very high rate, after which diffusion combustion takes place, where the burning rate is controlled by the availability of combustible air –fuel mixture. The ignition quality of a fuel is usually characterized by its cetane number or cetane index. Higher cetane number means shorter ignition delay. In the entire set of test it was found that biodiesel have higher cetane number than conventional diesel fuel. Shorter ignition delay causes lower peak heat release rate to lower accumulation of the fuel. Therefore premixed combustion heat release is higher for conventional diesel, which is responsible for higher peak pressure and higher rate of pressure rise in comparison to different biodiesel and diesel. The ignition delay depends on fuel viscosity with result in poor atomization, slower mixing, increased mixing and reduced cone angle. Higher engine speed leads to faster mixing between fuel and air and shorter ignition delay occur. The reaction time for each engine cycle was shorter so the residence time of the gas temperature with in cylinder decreases, this leads to lower NOx under full speed.

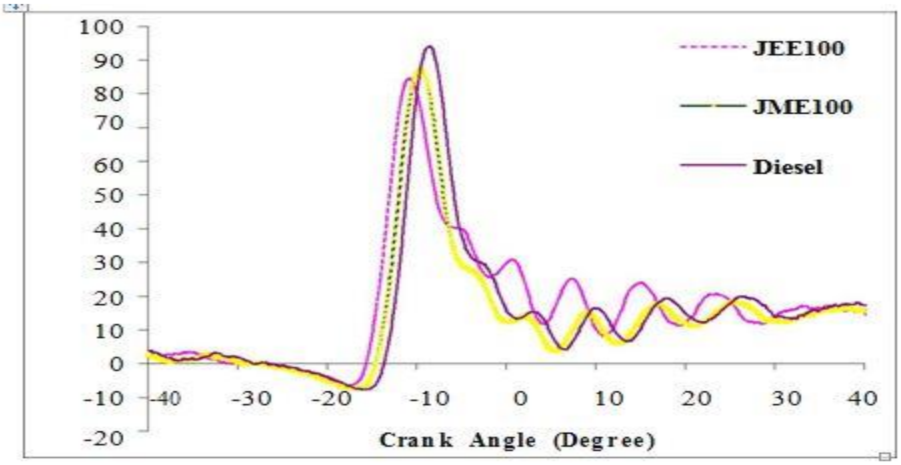

Figure 4.8: Variation of Heat Release Rate with Change in Crank Angle

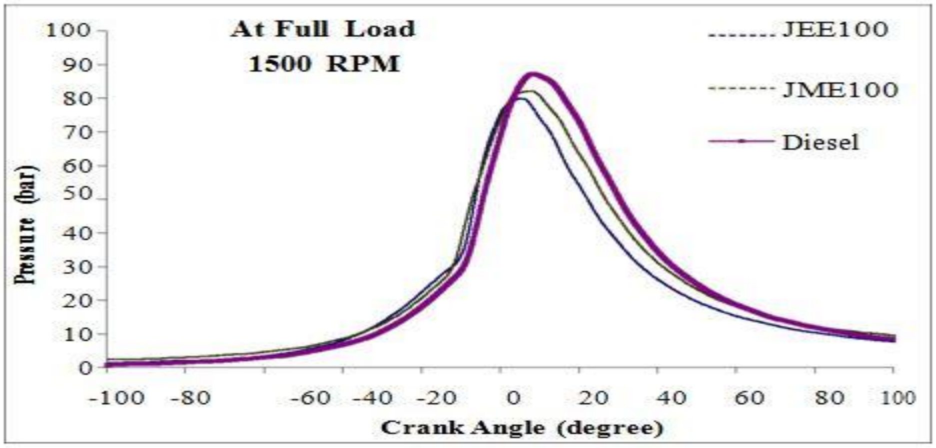

Figure 4.9 Variation of Pressure with Change in Crank Angle

4.5 Formula Used For Calculation of Various Engine Performance Parameters

4.5.1 Mass Flow Rate of the Fuel:

If the volume flow rate (for the 20 ml.) of the fuel is known then multiplying it by the density of the fuel to get the mass flow rate of the fuel.

Mass flow rate (m) = volume flow rate (v) x density (ρ) x 3600

Where m– mass flow rate in kg/hr.

v - Volume flow rate in m^3/sec

ρ - Density in kg/m^3

4.5.2 Power:

If the torque on the shaft of the engine is known then Power output of the engine can be calculated by the brake drum dynamometer. By knowing the torque we get the power output of the engine by the following relationship:

Power (P) = $2\pi NT/60$

Where N - speed in RPM

T- Torque in N-m= (Load applied - spring coefficient) x diameter of drum/2

4.5.3 Brake Specific Energy Consumption:

Brake specific energy consumption is defined as the energy used by the engine to produce unit power. It is calculated by the following relationship –

BSEC (kJ/kW-hr) = BSFC (kg/kW-hr) x Calorific Value (kJ/kg)

4.5.4 Brake Thermal Efficiency:

Brake thermal efficiency is definedas the ratio of the power output of the engine to the rate of heat liberated by the fuel during the combustion.

$$\text{Brake thermal efficiency } (\eta bth\ \%) = \frac{\text{Power output of the engine}}{\text{Mass flow rate of fuel x Calorific Value}} \times 100$$

4.5.5 Brake Mean Effective Pressure:

It is the average value of pressure inside the cylinder of an internal combustion engine based on the measured power output

$$\text{BMEP (k Pa)} = \frac{60{,}000 \text{ x B.P}}{\text{L A n K}}$$

Where,

B.P = Brake Power (kW)

L = Length of Stroke (m),

A = Cross Sectional Area of the cylinder

N = N/2 for 4-Stroke Engine, and N for 2-Stroke Engine

N = Engine Speed (RPM)

= No of Cylinders.

4.6 Engine Performance Characteristics

The different fuel sample was used to test a diesel engine at different load conditions at rated speed of 1500rpm. The experimental data was used to compute brake mean effective pressure (BMEP), brake specific consumption (BSEC) and brake thermal efficiency (BTE) of the engine. All observations were recorded thrice and the average was taken to ensure reliable data. The graphs representing BSEC, BTE and exhaust gas temperature Vs. BMEP for different biodiesel and their blends with diesel were drawn.

4.6.1 Brake Thermal Efficiency

The variation of brake thermal efficiency (BTE) with respect to mean effective pressure is shown in the **Figure 4.10**. From the test results of Jatropha derived biodiesel and their blends in the ratio of 5%, 10%, 20%, 30%, neat Jatropha ethyl ester biodiesel (100%) and diesel were used. It was observed that initially with increasing brake power, the brake thermal efficiencies of Jatropha ethyl ester and its blends also increases together with diesel. The maximum BTE for diesel obtained as 28.54% at 80 % loading and 25.33% for JEE100, 27. 65% for JEE5, 26.71 for JEE 10, 25.82% for JEE20 and 25.71% for JEE30 at same load.The brake thermal efficiencies of the Jatropha ethyl ester oil and its blends were found to be lower than diesel fuel throughout the entire range. The possible reasons for this reduction are lower calorific value and increase in fuel consumption of JEE and its blends as compared to diesel fuel.

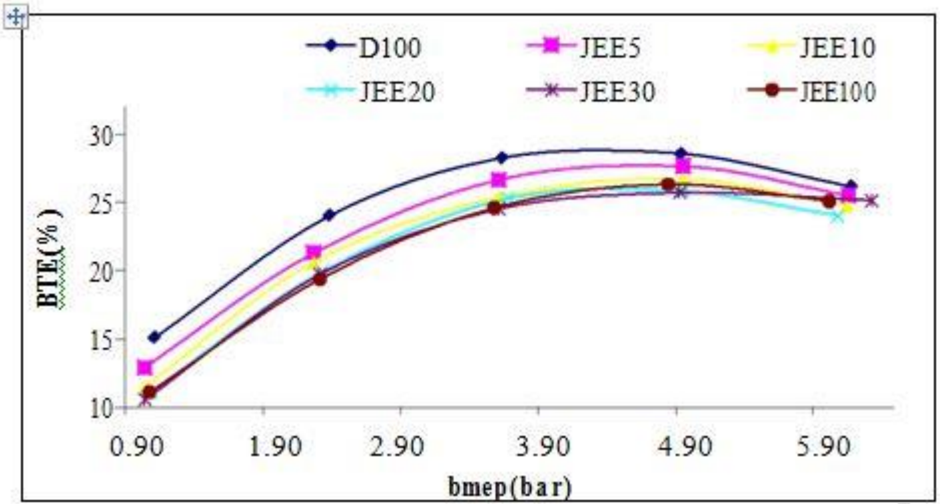

Figure 4.10: Variation of Brake Thermal Efficiency (BTE) With Brake Mean Effective Pressure (Bmep)

4.6.2 Brake Specific Fuel Consumption

The brake specific fuel consumptions (BSFC) in case of Jatropha ethyl ester and its blends were also found to be higher than diesel fuel as evident from **Figure 4.11**.This is mainly due to the combined effects of the relative fuel density, viscosity and heating value of the jatropha biodiesel blends. The higher density of Jatropha biodiesel has led to more discharge of fuel for the same displacement of the plunger in the fuel injection pump, that why increasing the specific fuel consumption. The results obtained during the test shows that the brake specific consumption of Jatropha ethyl ester and its blends, when used in an unmodified small capacity diesel engine was higher than the diesel fuel.

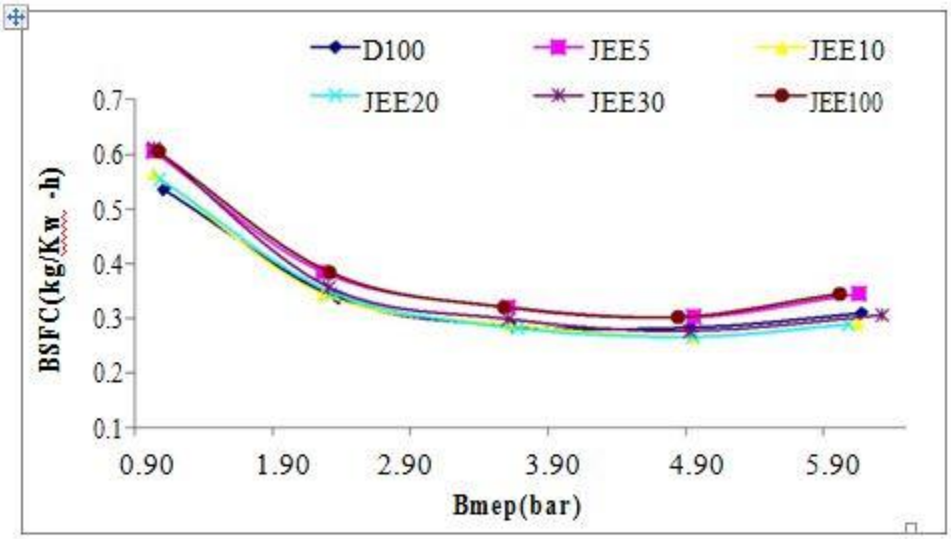

Figure 4.11: Variation of brake specific fuel consumption with brake mean effective pressure

4.6.3 Brake Specific Energy Consumption

The variations of BSEC with respect to change in brake mean effective pressure (BMEP) for Jatropha ethyl ester, its blends and diesel fuels is shown in **Figure 4.12**. It is clear from the figure that the brake specific energy consumption of Jatropha ethyl ester oil and its blends is higher than diesel which is due to high density and lower calorific value of the fuel.

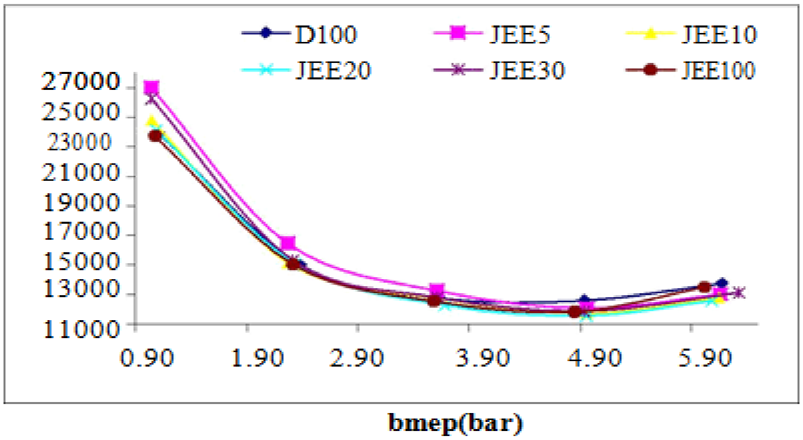

Figure 4.12: Variation of Brake Specific Energy Consumption with Brake Mean Effective Pressure

4.6.4 Exhaust Temperature

The variations of exhaust temperature with brake mean effective pressure of diesel fuel and Jatropha ethyl ester and its blends with diesel is shown in Figure **4.13.** It shows that the exhaust gas temperature increased with increase in brake power in all cases. The highest value of exhaust gas temperature of 505°C was observed with the Jatropha ethyl ester, whereas the corresponding value with diesel was found to be 610°C. It is due to the poor combustion characteristics of the Jatropha ethyl ester and its blends because of its viscosity variation.

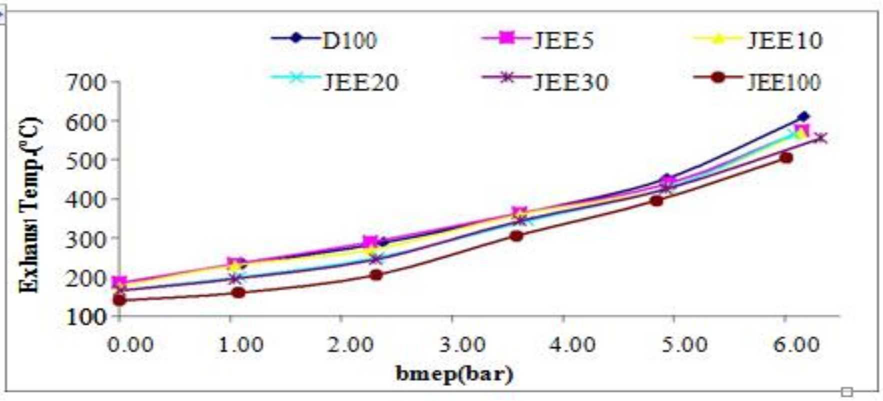

Figure 4.13: Variation of Exhaust Temperature with Brake Mean Effective Pressure

4.7 Emission Characteristics

Emission characteristic of biodiesel was examined with the help of AVL 437 Smoke meter and AVL 4000 light 5-Gas Analyser. All observation recorded was replicated thrice to ensure the reliable data. The graphs representing CO, CO2, HC, NOx and Smoke opacity Vs. BMEP for different ethyl ester samples and their blends with diesel were drawn.

4.7.1 CO2 Emissions

The variation in CO2 emissions are shown in **Figure 4.14**. In the range of whole engine load, the CO2 emissions of diesel fuel are all lower than that of the other Jatropha ethyl ester and its blended fuels. This is because Jatropha ethyl ester oil contains oxygen element; the carbon content is relatively lower in the same volume of fuel consumed at the same engine load, consequently the CO2 emissions from the vegetable oil and its blends are lower. The result shows that there was a slight increase in CO2 emissions when using jatropha ethyl ester oil.

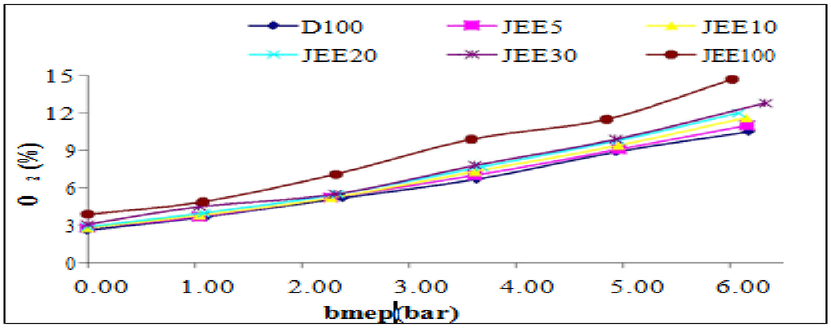

Figure 4.14: Variation of Carbon Di Oxide with Brake Mean Effective Pressure

4.7.2 CO Emissions

Within the experimental range, the CO emission from the Jatropha ethyl ester and its blends is lower than neat diesel fuel as seen in **Figure 4.15**. Diesel engine emits more CO using diesel as compared to that of ethyl ester biodiesel blends under all loading conditions. With increase in ethyl ester percentage CO decreases, as biodiesel is oxygenated fuel and contain oxygen which help for complete combustion. Hence CO emission decreases with increasing biodiesel percentage in fuel.

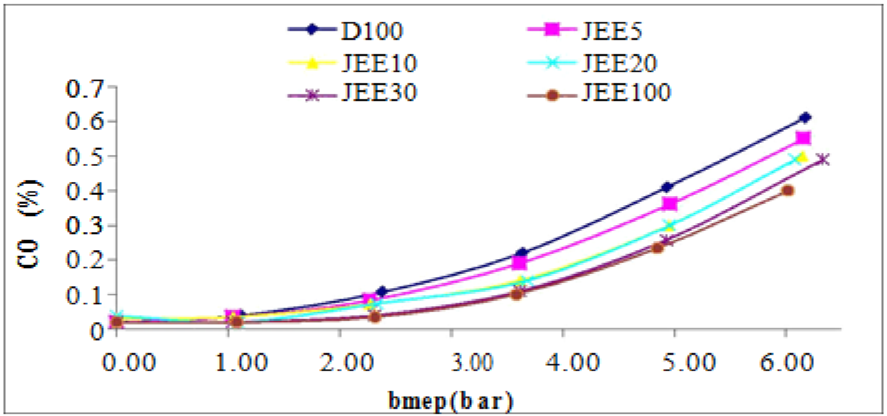

Figure 4.15: Variation of Carbon Mono Oxide with Brake Mean Effective Pressure

4.7.3 UBHC Emissions

The values of unburned hydrocarbon emission from the diesel engine in case of Jatropha ethyl ester and its blends is less than diesel fuel as evident from **Figure 4.16**. HC emissions are lower at partial load, but tend to increases at higher loads for both the fuels. This is due to lack of oxygen resulting from engine operation at higher equivalence ratio. Thus, high percentage of O2 leads to low HC.

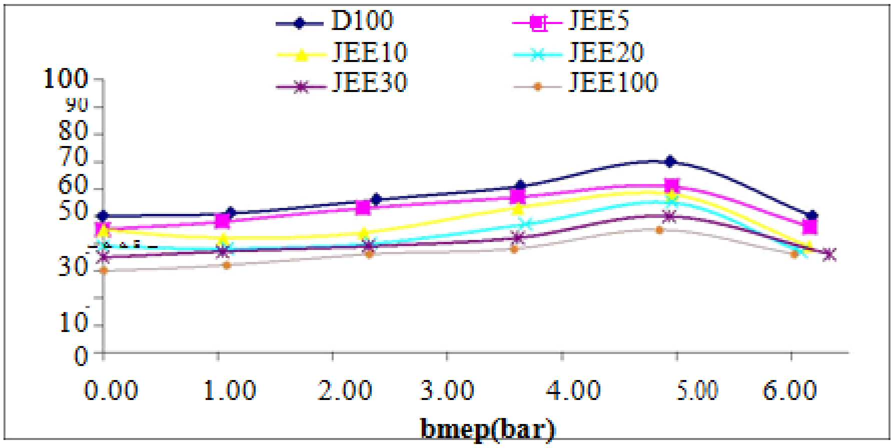

Figure 4.16: Variation of Hydrocarbon with Brake Mean Effective Pressure

4.7.4 NOx Emissions

The variation of NOx emissions from Jatropha ethyl ester and its blends with respect to diesel fuel are shown in **Figure 4.17**. The NOx emission increases with the increasing engine load, due to a higher combustion temperature. This proves that the most important factor for the emissions of NOx is the combustion temperature in the engine cylinder and the local stoichiometric of the mixture. It can be seen that within the range of tests, the NOx emissions from the Jatropha ethyl ester and its blends are lower than that of diesel fuel. The reductions of the NOx emissions are from 3120 ppm to 2108 ppm at full load. The reason is possibly due to the smaller calorific value of ethyl ester. The reaction time for each engine cycle was shorter so the residence time of the gas temperature within the cylinder decreases, this leads to lower NOx. This is the most important emission characteristic of biodiesel oil as the NOx emission is the most harmful gaseous emissions from engines, the reduction of it is always the target for engine researchers and engine makers. This emission character of NOx for biodiesel oil is a very useful character for the application of ethyl ester oil to diesel engines as a kind of alternative fuel for the petroleum-based ordinary diesel fuel. The results obtained from the experiment clearly show that using Jatropha ethyl ester oil in small diesel engine reduces NOx emissions.

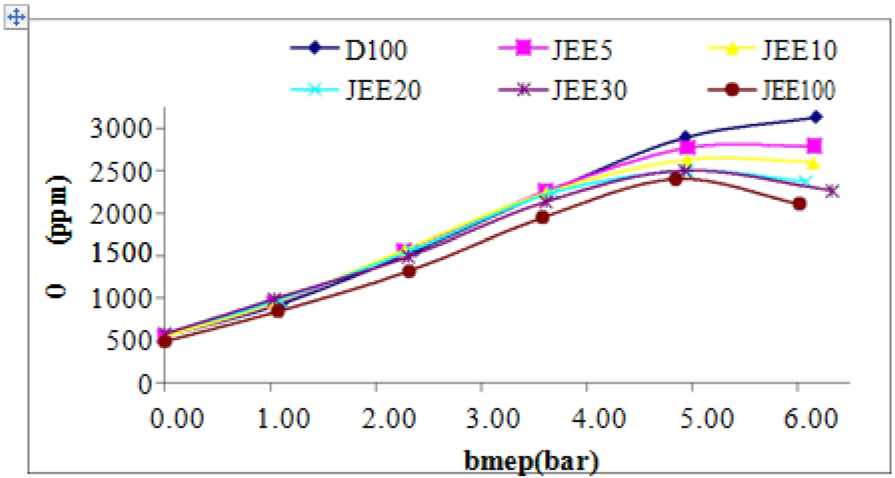

Figure 4.17: Variation of NOx with Brake Mean Effective Pressure

4.7.5 Smoke Opacity

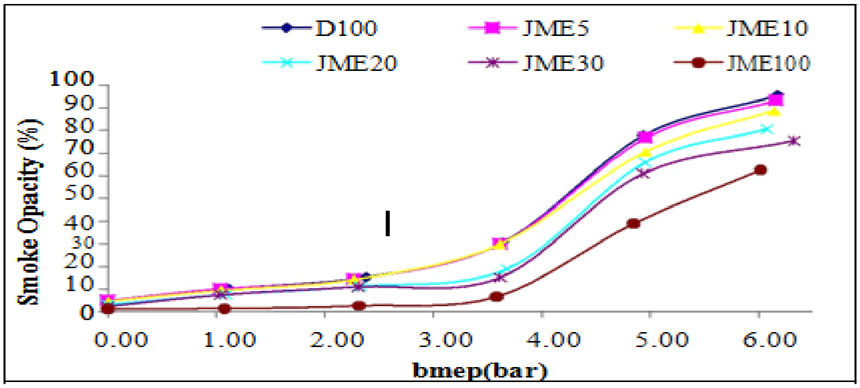

Figure 4.18: Variation of Smoke Opacity with Brake Mean Effective Pressure

Figure 4.18shows the variation of the smoke opacity of Diesel and Jatropha ethyl esters and its blended fuels at different brake mean effective pressure (bmep). It can be observed that the smoke density has reduced with the use of biodiesel in diesel engine in comparison to the diesel, it can be seen that at low load, the smoke density is lower for all blends as the load on the engine increases the smoke density increases. Within most of the experimental range, the smoke opacity from the Jatropha ethyl ester and its blends is lower than diesel fuel. This is possible because of the viscosity difference of ethyl ester biodiesel and diesel fuel and subsequent improvement in spray and fuel- air mixing. It results in incomplete combustion and more smoke formation.

CHAPTER 5

CONCLUSIONS AND SCOPE FOR FUTURE WORK

The present study was carried on an unmodified small capacity diesel engine which was converted to run on a dual mode (biodiesel& diesel) operation. The main objective of the present investigation was to evaluate suitability of Jatropha curcas oil as a raw oil to extract biodiesel and to use as a fuel for a C.I. engine and to evaluate the performance and emission characteristics of the engine. The two oils that is used fall in the category of non-edible oil and hence it will create no threat to the debt going for fuel versus food. After esterification of Jatropha oil the kinematic viscosity and specific gravity is significantly reduced. Higher flash point of esterified Jatropha oil and its blend with diesel fuel made it as safe storage and handling. The raw oils of Jatropha seed have very higher relative density but lower calorific value than that of diesel oil. The kinematic viscosity and flash point of these raw oils are very high than that of conventional diesel oil. The FFA contents of jatropha oil are usually higher than 12%, whereas Jatropha biodiesel contains even less than 2%.

The experimental results show that the engine performance with biodiesel of Jatropha was slightly inferior to the performance with diesel fuel. The oxide of nitrogen (NOx) from Jatropha ethyl ester during the whole range of experiment was lower than that of diesel fuel. This is the most important gaseous emission characteristic of jatropha ethyl ester. However, for higher load, the NOx emission was increased. These NOx emissions can be reduced by several methods such as EGR. While emissions like CO, smoke density and NOx were reduced for ethyl ester oil and its blends as compared to diesel oil. These reductions of emissions are due to complete combustion of fuel. The Carbon monoxide (CO), Hydrocarbon (HC), Carbon dioxide (CO2) from the unheated Jatropha ethyl esters was found higher than that of diesel fuel during the whole experimental range. With the increase load for Jatropha ethyl ester biodiesel, the value of Carbon monoxide (CO), Hydrocarbon (HC) and smoke opacity were decreased and Carbon dioxide (CO2) emissions were slightly increased.

For all the fuels which is tested, the brake thermal efficiency increased with increase in load. Maximum brake thermal efficiency in case of Jatropha biodiesel was found to be higher than diesel and it decreased with increase in biodiesel percentage in the blend. From all these observations,itcouldbe concluded that the blends of Jatropha ethyl ester with diesel up to 20% by volume could replace diesel for running the diesel engine fewer emissions and without sacrificing the power output. Thus this will help in controlling air pollution to a great extent. Brake specific fuel consumption for Jatropha ethyl ester was higher than diesel and for blends lie between the two. Brake specific energy was higher for Jatropha ethyl ester than diesel fuel during all range of loadings and for blends lie between intermediates because of reduction in calorific value and power output with increase in ethyl ester percentage in the blend oil. The exhaust temperature of diesel fuel at full load was very high than biodiesel this is due to the poor combustion characteristics of the Jatropha biodiesel and its blends because of its large viscosity variation.

Considering the emission and performance of Jatropha biodiesel and conventional diesel, jatropha biodiesel is a good. Thus, Jatropha is the promising alternative fuel for future in the category of biofuels to overcome diesel fuel shortage, if happens.

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APPENDIX – I

TECHNICAL SPECIFICATION OF AVL 437 SMOKE METER

Accuracy and Reproducibility : ± 1% full scale reading.

Measuring range : 0 - 100% capacity in %

0 - ∞ absorption m^{-1}.

Measurement chamber : effective length 0.430 m ± 0.005 m

Heating Time : 220 V …… 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 Temperature at entrance : 250ºC

APPENDIX – II

TECHNICAL SPECIFICATION OF AVL Di-GAS ANALYZER

Measurement principle	CO, HC, CO2	Infrared measurement
Measurement principle	O2 NO (option)	Electrochemical measurement
Operating temperature	+5 ……. +45º C	Keeping measurement accuracy
	+1 ……. +50ºC	Ready for measurement
	+5 ……. +35º C	with integral NO sensor (Peaks of : +40ºC)
Storage temperature	-20 ….. +60º C	
	-20 ….. +50º C	With integrated O2 sensor
	-10 ….. +45º C	With integrated NO sensor
	0 ….. +50º C	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	