Major Project II

on

“COMBUSTION, PERFORMANCE AND EMISSION ANALYSIS OF A LIGHT DUTY DIESEL ENGINE ON BLENDS OF MAHUA OIL BIODIESEL AND DIESEL”

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

Master of Technology

In

Thermal Engineering

VIPUL VIBHANSHU

2K11/THE/19

UNDER THE SUPERVISION OF

Dr. Naveen Kumar

Professor and Head
Department Of Mechanical Engineering
Delhi Technological University
Delhi-110042

Department of Mechanical Engineering
Delhi Technological University
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042
July 2013

DECLARATION

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

(VIPUL VIBHANSHU)

M.Tech (Thermal Engineering)

Roll No.: 2K11/THE/19

CERTIFICATE

This is to certify that the work embodied in the dissertation entitled "**COMBUSTION, PERFORMANCE AND EMISSION ANALYSIS OF A LIGHT DUTY DIESEL ENGINE ON BLENDS OF MAHUA OIL BIODIESEL AND DIESEL**" by VIPUL VIBHANSHU, (Roll No.-2K11/THE/19) in partial fulfillment of requirements for the award of Degree of Master of Technology in Thermal Engineering, is an authentic record of student's own work carried by him under my supervision.

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

(Dr. Naveen Kumar)
Professor & Head
Mechanical Engineering Department
Delhi Technological University
Delhi-110042

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge my gratitude to all the people involved, directly or indirectly in completion of this project.

First and foremost, I offer my sincerest gratitude to my supervisor**, Prof. Naveen Kumar**, who has supported me throughout my project with his patience and knowledge whilst allowing me the room to work in my own way. I attribute the level of my Master’s degree to his encouragement and valuable hours for this assignment and providing the motivational guidance during the entire preparation of this project, answering the number of technical queries despite his busy schedule. His valuable suggestions, constructive criticism and timely help proved extremely fruitful. One simply could not wish for a better supervisor.

In the Research Center I have been aided for many years in running the equipment by **Sh. Kamal Nain, Sh. Manoj Kumar and Other Project Staff**. The smooth running of the Research Center is much more a testament to their efforts than my own.

I should give a special mention to my senior colleague **Mr. H.S.Pali, Mr. Sunil Kumar Sinha**, who are always with me and encourage me for this project.

I would also like to thank **Mr. Raghavendra Gautam** and **Dr. Bhupendra Singh Chauhan** for their support. In my daily work I have been blessed with a friendly and cheerful group of fellow friends and colleagues who were always there to lend a helping hand in the hour of need.

Vipul Vibhanshu

2K11/THE/19

ABSTRACT

Ever increasing consumption of petroleum derived fuels has been a matter of grave concern as it involves huge outflow of foreign exchange on one hand and increasing emission causing environmental hazards on other. Public at large are raising their concern over the deteriorating state of environment and health and the rising cost of crude oil in international market has provided an opportunity to look for substitute of fossil fuels. Researchers all over the world are experimenting on variety of renewable fuels for meeting the future energy demands. Biodiesel is fast becoming a potential alternative fuel for the use in agriculture and transport sector.

There are varieties of feedstocks; both edible and non-edible which can be used for biodiesel production. The vegetable oils, derived from oil seed crops or oil seed from tree origin, have around 90 energy value of diesel on volume basis, comparable cetane number and similar engine performance. It seems that plant oil based fuels are better proposition as alternative fuel for diesel engine as they are liquid in nature and have many advantages over other alternative fuel options.

Mahua (Madhuca Indica) seed oil is commonly found in many parts of India and is considered an attractive feedstock for biodiesel production. However, it is relevant to mention that crude mahua oil generally contains very high percentage of free fatty acid and two stage processes comprising of esterification of free fatty acids and subsequent transesterification process was employed to synthesize biodiesel from Mahua Oil. The biodiesel formed conformed to ASTM specifications.

Blends of mahua oil biodiesel with diesel were prepared in 10%, 20% 30% and 40% proportion (v/v). Moreover neat biodiesel derived from mahua and diesel was also used in the present study.

Evaluation of Physico-chemical properties as well as the combustion, performance and emission characteristics was carried for different blends and neat biodiesel along with diesel for a comparative assessment. The Physico-chemical properties of the blends and neat biodiesel were comparable to diesel.

Engine performance parameters such as brake thermal efficiency (BTE), brake specific energy consumption and exhaust temperature and exhaust emissions like CO, HC, NO_x, and smoke opacity were evaluated. Also combustion studies for all blends and neat biodiesel at full load condition were carried and results were compared with base line data of diesel. It has been found that the BTE decreased slightly for all the blends of mahua oil methyl ester. At full load condition CO emission was 38% lower than that of neat diesel. HC emission was 42 ppm for pure mahua biodiesel and 58 ppm for diesel fuel. Smoke opacity for all the blends of mahua oil methyl ester were lower than mineral diesel. However, NO_x was found to be 21 % higher for pure mahua biodiesel Combustion result shows ignition lag for all the blends of mahua oil methyl ester. Ignition delay for D100 is found at 10.5° while for neat mahua oil methyl ester it is 7°. However for M10, M20, M30 and M40 ignition delay varied from 7.3°, 8°, 9.2° and 10° respectively.

At an overall analysis it can be concluded that upto 40 % (v/v) of diesel can be easily substituted by mahua oil biodiesel and can be run on an unmodified single cylinder diesel engine.

CONTENTS

Annexure

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

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
^{o}C	Degree Celsius
CA	Crank Angle
cc	Cubic centimeter
CI	Compression Ignition
cm^{-1}	Per Centimeter
CN	Cetane Number
CO	Carbon Monoxide
CO_2	Carbon Dioxide
cSt	Centi Stoke
Cu	Copper
CV	Calorific Value
D100	Neat Diesel
DI	Direct Injection
DF	Diesel fuel
EOI	End of Injection
EV	Electric Vehicle
^{o}F	Degree Fahrenheit
F/A	Fuel to Air
FFA	Free Fatty Acid
FIT	Fuel Inlet temperature
FIP	Fuel Injection Pump
FT	Fourier Transform
FTIR	Fourier Transform Infra red
g	Gram
g/cc	Gram per cubic centimeter
HC	Hydrocarbon
H_2O	Water
HP	Horse Power
HRR	Heat release rate
Hz	Hertz
IC	Internal Combustion

IDI	Indirect Injection
IR	Infra Red
IS	Indian standard
Kg	Kiligram
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
M10	10% MOME+ 90% Diesel
M20	20% MOME+ 80% Diesel
M30	30% MOME+ 70% Diesel
M40	40% MOME+ 60% Diesel
M100	100% MOME
Min.	Minute
MJ	Mega Joule
ml	Milliliter
mm	Millimeter
MOME	Mahua oil methyl Ester
Mt	Million Tonnes
Mtoe	Million Tonne of Oil Equivalent
NO	Nitric Oxide
Nos.	Numbers
NO_2	Nitrogen Di-oxide
NO_x	Oxides of Nitrogen
O_2	Oxygen
PM	Particulate Matter
ppm	Parts per million
rpm	Revolutions Per Minute
SAE	Society of Automobile Engineering
sfc	Specific Fuel Consumption
TDC	Top Dead Center
THC	Total Hydrocarbon
ULSD	Ultra Low Sulphur Diesel
UBHC	Unburnt Hydrocarbon
Vs	Versus
v/v	Volume/ Volume
ρ	Density
%	Percent
$dQc/d\theta$	Net HRR per ^{0}CA

CHAPTER 1

INTRODUCTION

1.0 ENERGY CRISIS

The growth of human being has travelled a long journey. It was the greatest achievement of primitive man when he discovered fire with the help of a stone. With this human history moved very fast. Later on a number discoveries and inventions were made which changed human life completely. Energy is such a great invention which made life more and more comfortable.

Abundant and economical energy is the life blood of modern civilizations. Adequate availability of inexpensive energy is the most important demand of today. Economic growth and industrialization both are dependent on the availability of energy. Many of the developed Western-European countries as well as developing countries depends a great extent on imports of energy resources to meet the bulk of their requirements. But today the world is facing twin crises of fast depleting world energy sources on one hand and environmental degradation on the other. This has put the world in a grip of energy crisis. [1-3].

There is shortage of energy resources in the world. This problem is related to the insufficient energy resources leading to the shortage in supply which in turn is not able to meet growing demands of energy in the rapidly expanding industrial, transport, agricultural and urban sectors. The condition of India is no better, with growing population and industrialization the demand for energy is increasing day by day.

Oil, coal and natural gas cover most of the world energy needs and not withstanding the many and varied projections as to probable time scales, it must be conceded that present sources of such fossil-derived materials are finite and that whatever quantities remain must become increasingly more difficult (costly) to win. Nevertheless, fossil fuels are not considered sustainable and are also questionable from an economic, ecological and environmental point of view. It should also be realized that, as the more accessible deposits become depleted, the global distribution of those remaining will attract progressively heightened political attention, since not all nations can assume proportional future supplies. The recent increase in petroleum prices and the growing awareness related to the environmental consequences of the fuel over-dependency have stimulated the recent interest in alternative energy sources [3-4]. Alternative fuel source are considered very promising to play an important role in meeting the world's energy requirements [5-6].

1.1 ENERGY SCENARIO

With the dawn of the Bronze Age about 3,000 years ago, mankind started on the path to industrialization. In the industrially advanced world of today, the demand for energy is increasing exponentially. [2]

World is naturally anxious to think about future, because knowing the bitter truth that a day will ultimately come when no more coal or oil will available. It will mean energy crisis. People who have made careful calculation feel that at present level of exploitation, the worldwide coal deposits will last till 2080 and it is also true that poor quality coal with the carbon content of 40 percent only is not conducive for electricity generation.[3]

Energy is one of the most important factors concerned for socio-economic development of any country. Many developing countries are not able to fulfill their energy demand from the resources available in their own country and have to depend on other countries for accomplishing it.

Supply and use to fuel economic development at present,' energy poverty' hinders the economic and social development of very large numbers of people. The Indian economy is at a critical stage of development where energy requirement is increasing at a phenomenal pace. Even though, large part of the developed world is struggling to recover from the recession, the relatively faster emerging countries like, China and India are attempting to meet the requisite demand for Hydrocarbons and other alternative energy resources. India has the limited domestic availability of oil and gas, and is compelled to import over 75%-80% of its domestic requirement and subject to the vagaries of a volatile international price scenario. [7]

India is rich in coal and abundantly endowed with renewable energy in the form of solar, wind, hydro and bio-energy, however, its hydrocarbon reserves represent only 0.3% of the global reserves and India is mainly dependent upon crude import to sustain its growth. The exploitation of these resources is very much limited.

India is amongst the fastest growing economy of world and use energy extensively to sustain its growth. As India does not have huge reserves of petroleum products, it heavily dependent upon the import of petroleum products to cater its need .Despite larger initiatives taken by government; exploration of new sources, rising prices, insufficient supply and limited reserves of petroleum have imposed against burden on country’s forex exchange.

In the year 2011, Indian crude oil production is 40.4 million tonnes which is 3.9 % higher than during the year 2010-11 while the consumption of crude oil in 2011 was 162.3 million tonnes. [8].

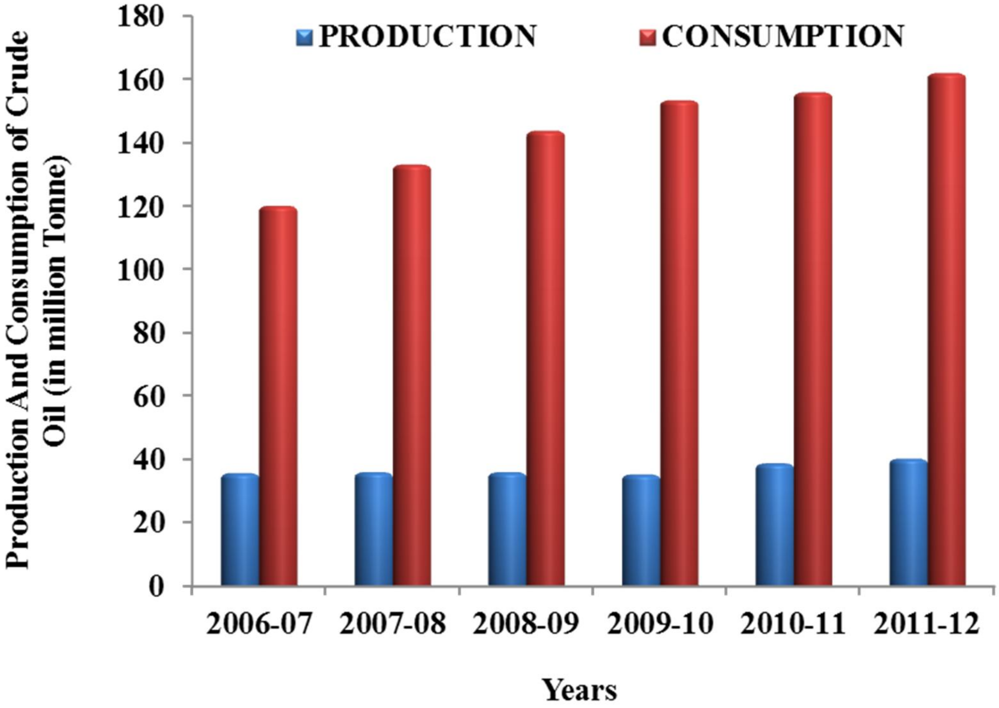


Fig. 1.1 Indian Production and Consumption of Crude oil (in MT) over the year. [7]

It is clearly seen from Fig 1.1 that India is importing around 80% of its crude requirements. In 2010-11, India spent 129 billion US $ (Rs. 6995.39 billion) towards import of crude oil.

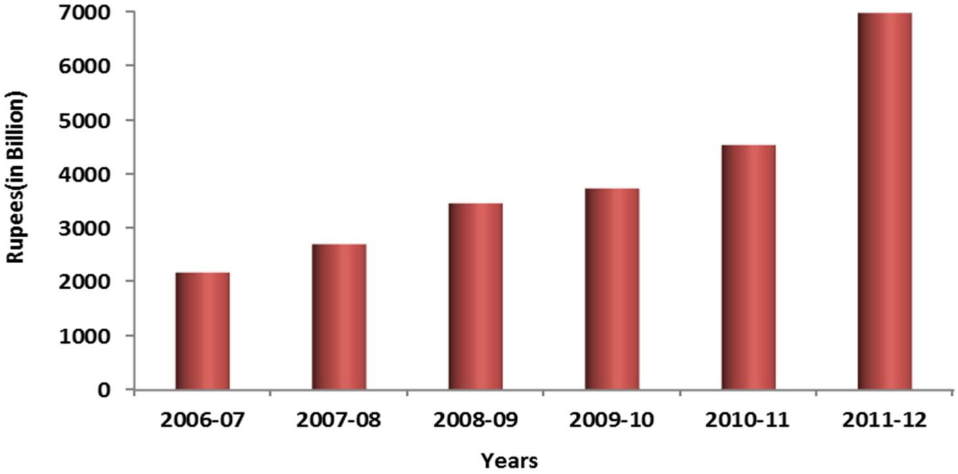


Fig. 1.2 Expenditure incurred in importing Crude oil (in Billion Rupees). [7]

Global energy requirement is mainly derived from fossil fuels comprising of oil, natural gas and coal which constitute nearly 90% of total primary energy requirements. Global primary energy consumption has increased from 11,843.8 mtoe in 2010 to12079.8 in 2011 showing an annual increase of nearly 2%. [7-8].

Table 1.1: World's primary energy consumption in mtoe [7-8]

ENERGY TYPE	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Oil	3911	3940.2	3960	3908.7	4028.1	4059.1
Natural Gas	2558	2652	2717	2661.4	2858.1	2905.6
Coal	3039.1	3184	3286	3305.6	3555.8	3724.3
Hydro Electricity	684.3	696	731	736.3	775.6	791.5
Nuclear Energy	634.9	622	620	614	626.2	599.3
Total	**10827.3**	**11094.2**	**11315.2**	**11226**	**11843.8**	**12079.8**

Increasing population, economic activity and rising income levels with further push the demand for energy in India. The primary energy consumption in India is dominated by coal and hydrocarbons, with less than 10 percent of energy accounted by other sources like hydro, renewable and nuclear. In 2011, oil and gas accounted for around 40 percent of India's total primary energy consumption, next only to coal, which accounts for 53 percent. [9]

India is the fourth largest consumer of energy in the world after USA, China and Russia but it is not endowed with abundant energy resources. It must, therefore, meet its development needs by using all available domestic resources of coal, uranium, oil, hydro and other renewable resources, and supplementing domestic production by imports. High reliance on imported energy is costly given the prevailing energy prices which are not likely to soften; it also impinges adversely on energy security.

Meeting the current energy need to achieve 8 - 9 per cent economic growth and also to fulfill the energy requirements for the population at affordable prices; presents a major challenge. This calls for a sustained effort at increasing energy efficiency to meet the present demand for energy and increasing domestic production as much as possible to keep import dependence at a reasonable level. [10]

Table 1.2 summarizes the primary energy requirement of India in 2009, 2010 and 2011. As already elaborated, India being a developing country, fulfills most of its primary energy demand from fossil fuels including crude oil. The oil consumption level has consistently increased despite volatility is witnessed in the prices on crude petroleum.

Table 1.2 India Primary Energy Consumption for Years 2009, 2010 and 2011 (In mtoe) [3]

ENERGY TYPE	2009	2010	2011
OIL	151	155.5	162.3
NATURAL GAS	45.9	55.7	55.0
COAL	250.6	277.6	295.6
NUCLEAR ENERGY	3.8	5.2	7.3
HYDRO ELECTRICITY	24	25.2	29.8
RENEWABLE ENERGY	4.6	5	9.2
TOTAL	**480**	**524.2**	**559.1**

India’s primary energy consumption has increased from 480 mtoe to 524.2 mtoe between years 2009-10 showing an increase of 9.2 % however, for year 2010-11 it further increases from 524.2 mtoe to 559.1 mtoe showing an increase of 6.2 %. It is relevant to mention that world’s primary energy consumption in 2010 is 11,843.8 mtoe which has increased to 12,079.8 mtoe in 2011 [3].

1.2 RENEWABLE ENERGY RESOURCES

The need to increase total domestic energy production in order to reduce import dependence, combined with the need to move away from fossil fuels in the longer run in view of climate change considerations, points to the need for stronger efforts to increase the production of energy from renewable resources.

All over the world, investment in renewable power sources has been increasing. India has been a late entrant into the field of renewable energy, but it is beginning to make rapid strides in this sector with an annual growth rate of 33 per cent in 2010 against the global growth rate of 26 per cent during the same period. Fig 1.3 shows the renewable energy capacity of top five countries in the world. Since India has a large potential of both wind and solar energy, the exploitation of this potential should play an important role for our long-term energy strategy.

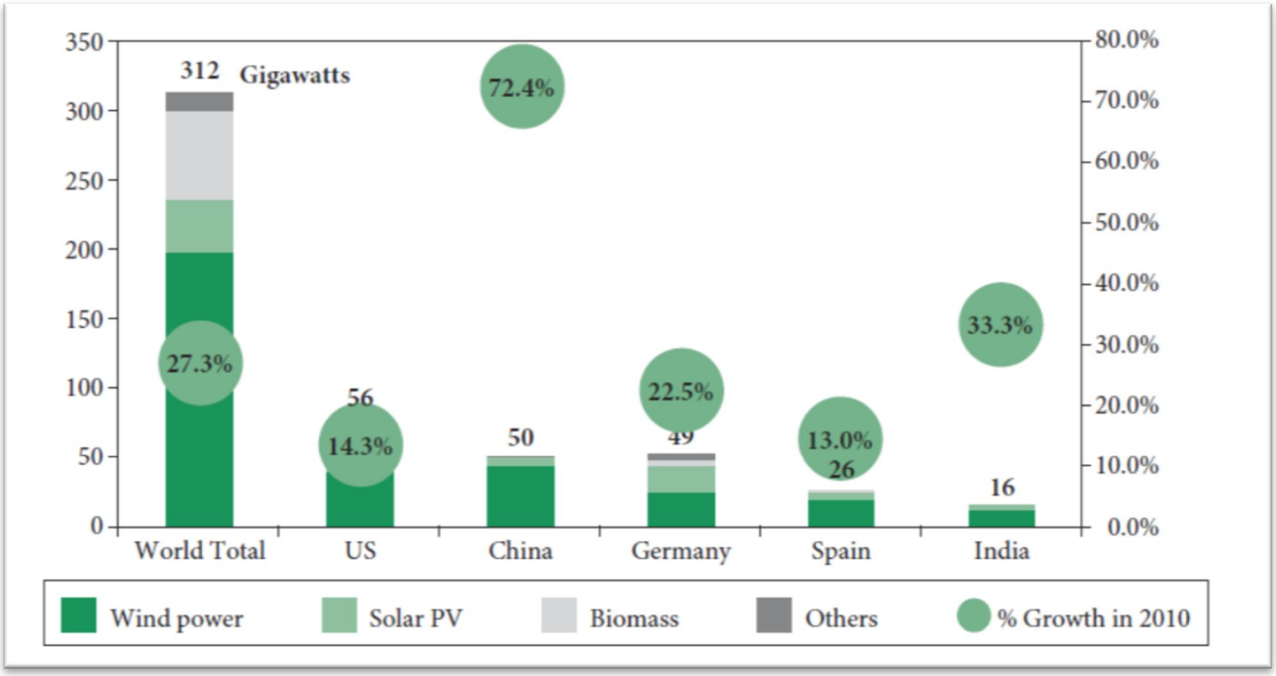


Fig. 1.3 Renewable Power Capacities, Top Five Countries

The potential for renewable power has been revised upward over time. In the early 80s, India was estimated to have renewable energy potential of about 85 GW from commercially exploitable sources, viz. (i) Wind: 50 GW (at 50 m mast height) (ii) Small Hydro: 15 GW (iii) Bio-energy: 20 GW and (iv) solar radiation sufficient to generate 50 MW/sq. km using solar photovoltaic and solar thermal energy. [10, 11]

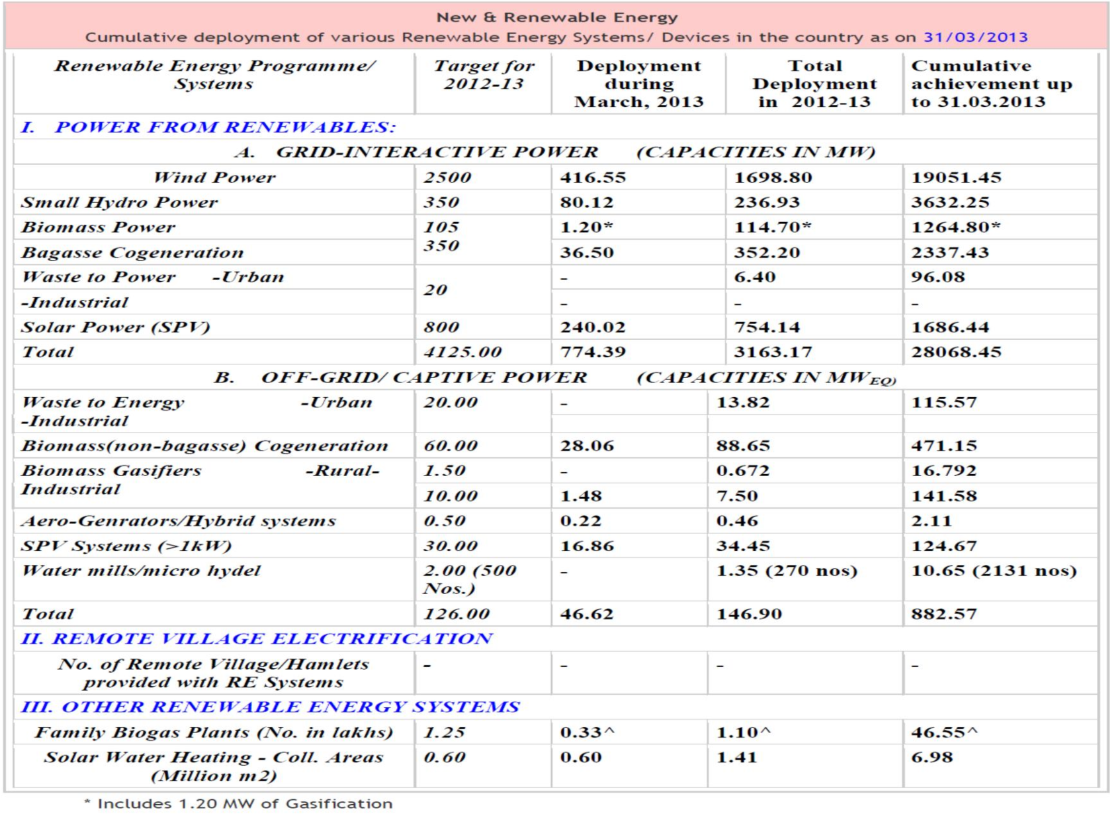
Renewable energy has to play an expanding role in achieving energy security and access in the years ahead. Government of India along with various private organizations has now taking front step for maximum utilization of renewable energy resources in rural as well as commercial sector. During the Twelfth Plan attention will be taken in following areas:

- Grid interactive and off-Grid/Distributed Renewable Power
- Renewable Energy for Rural Application

- Renewable Energy for Urban, Industrial and Commercial Applications
- Research, Design and Development for New and Renewable Energy
- Strengthening of Institutional Mechanism for enhanced deployment and creation of public awareness.

Presently Ministry of New and Renewable energy released the renewable energy potential achieved till 31.03.2013 shown in Table 1.3.

Table 1.3 Renewable Energy Potential and Achievements in India as on 31.03.2013 [11]



New & Renewable Energy
Cumulative deployment of various Renewable Energy Systems/ Devices in the country as on 31/03/2013

Renewable Energy Programme/ Systems	*Target for 2012-13*	**Deployment during March, 2013**	**Total Deployment in 2012-13**	**Cumulative achievement up to 31.03.2013**
I. POWER FROM RENEWABLES:				
A. GRID-INTERACTIVE POWER (CAPACITIES IN MW)				
Wind Power	*2500*	416.55	1698.80	19051.45
Small Hydro Power	*350*	80.12	236.93	3632.25
Biomass Power	*105*	1.20*	114.70*	1264.80*
Bagasse Cogeneration	*350*	36.50	352.20	2337.43
Waste to Power -Urban	*20*	-	6.40	96.08
-Industrial		-	-	-
Solar Power (SPV)	*800*	240.02	754.14	1686.44
Total	*4125.00*	774.39	3163.17	28068.45
B. OFF-GRID/ CAPTIVE POWER (CAPACITIES IN MW_{EQ})				
Waste to Energy -Urban	*20.00*	-	13.82	115.57
-Industrial				
Biomass(non-bagasse) Cogeneration	*60.00*	28.06	88.65	471.15
Biomass Gasifiers -Rural-	*1.50*	-	0.672	16.792
Industrial	*10.00*	1.48	7.50	141.58
Aero-Genrators/Hybrid systems	*0.50*	0.22	0.46	2.11
SPV Systems (>1kW)	*30.00*	16.86	34.45	124.67
Water mills/micro hydel	*2.00 (500 Nos.)*	-	1.35 (270 nos)	10.65 (2131 nos)
Total	*126.00*	46.62	146.90	882.57
II. REMOTE VILLAGE ELECTRIFICATION				
No. of Remote Village/Hamlets provided with RE Systems	-	-	-	-
III. OTHER RENEWABLE ENERGY SYSTEMS				
Family Biogas Plants (No. in lakhs)	*1.25*	0.33^	1.10^	46.55^
Solar Water Heating - Coll. Areas (Million m2)	*0.60*	0.60	1.41	6.98

* Includes 1.20 MW of Gasification

1.3 THE FUTURE OUTLOOK

The global primary energy consumption is projected to increase from 11843.8 in the year 2010 to 12079.8 mtoe in 2011 showing an increase of 1.96 % per year.

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

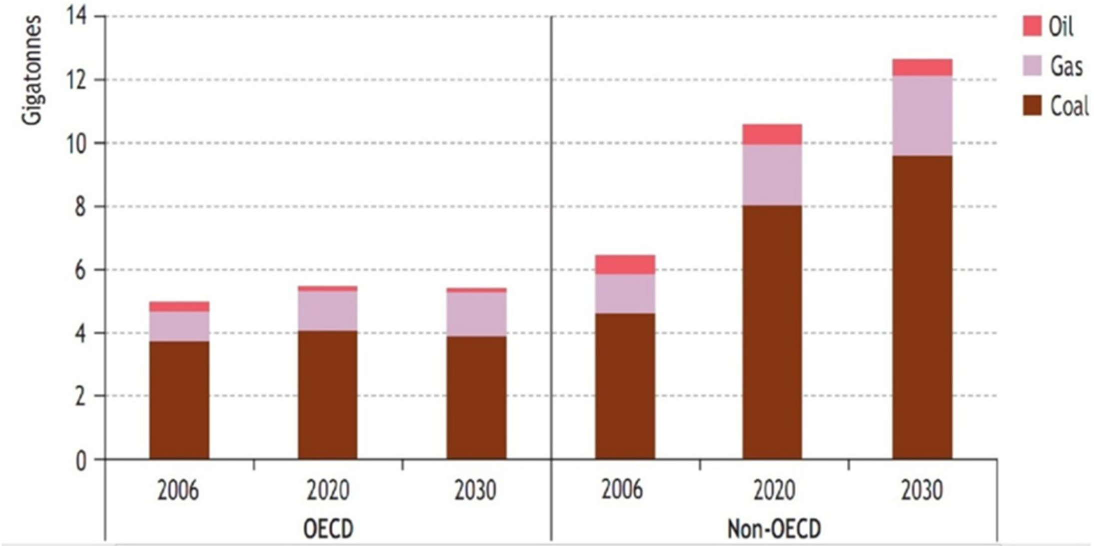


Fig 1.4 Dependence on different fuels for OECD and non-OECD countries [12]

Fossil fuels remain the world’s prominent fuel, accounting for 33.1% of global energy consumption in 2011. [8]

Global energy demand grows by more than one-third over the period to 2035 in the New Policies Scenario with China, India and the Middle East accounting for 60% of the increase. Energy demand barely rises in OECD countries, although there is a pronounced shift away from oil, coal (and, in some countries, nuclear) towards natural gas and renewable. Despite the growth in low carbon sources of energy, fossil fuels remain dominant in the global energy mix, supported by subsidies that amounted to $523 billion in 2011, up almost 30% on 2010 and six times more than subsidies to renewable. [12]

The renewable energy technologies, including biofuels, wind, solar, geothermal, wave and tidal energy, see the fastest increase in demand. Renewable become the world’s secondlargest source of power generation by 2015 (roughly half that of coal) and, by 2035, they approach coal as the primary source of global electricity. Consumption of biomass (for power generation) and biofuels grows four-fold, with increasing volumes being traded internationally. Global bioenergy resources are more than sufficient to meet our projected biofuels and biomass supply without competing with food production, although the land use implications have to be managed carefully.

The rapid increase in renewable energy is underpinned by falling technology costs, rising fossil-fuel prices and carbon pricing, but mainly by continued subsidies: from $88 billion globally in 2011, they rise to nearly $240 billion in 2035.

1.4 ENVIROMENTAL DEGRADATION AND ITS GLOBAL EFFECT

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

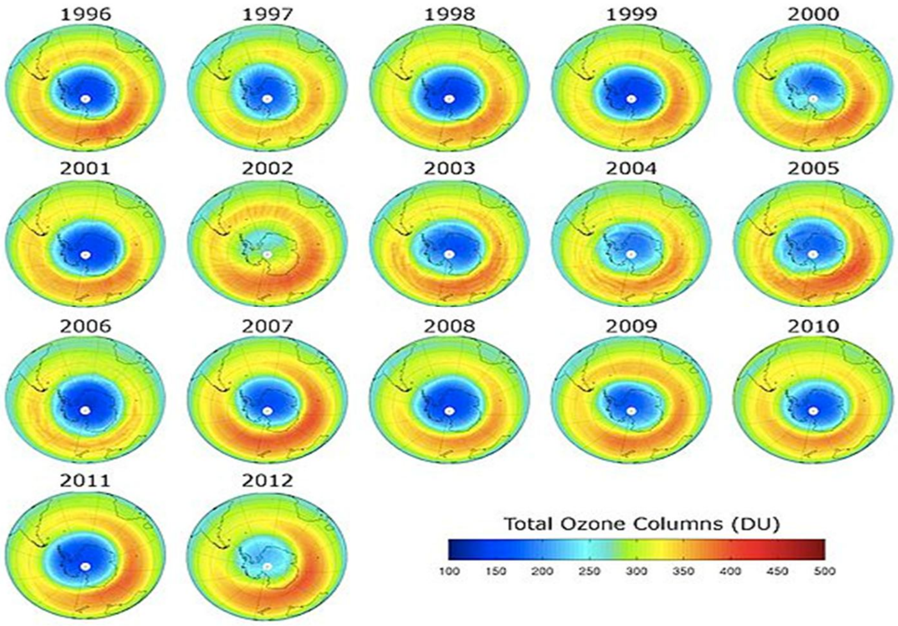


Fig. 1.5 Ozone layer depletions over Antarctica from 1996 to 2012 [13].

The ozone layer is a layer in Earth's atmosphere which contains relatively high concentrations of ozone (O_3). The distribution of ozone in the stratosphere is a function of altitude, latitude and season. It is determined by photochemical and transport processes. The ozone layer is located between 10 and 50 km above the Earth's surface and contains 90% of all stratospheric ozone, though the thickness varies seasonally and geographically. This layer absorbs 97–99% of the Sun's high frequency ultraviolet light, which potentially damages the life forms on Earth. Measurements carried out in the Antarctic have shown that at certain times, more than 95% of the ozone concentrations found at altitudes of between 15 - 20 km and more than 50% of total ozone are destroyed. The ozone layer can be depleted by free radical catalysts, including nitric oxide (NO), nitrous oxide (N_2O), hydroxyl (OH), atomic chlorine (Cl), and atomic bromine (Br) [9, 14].

The main potential consequences of this ozone depletion are:

- Increase in UV-B radiation at ground level: a one percent loss of ozone leads to a two percent increase in UV radiation. Continuous exposure to UV radiation affects humans, animals and plants, and can lead to skin problems (ageing, cancer), depression of the immune system, and corneal cataracts (an eye disease that often leads to blindness). Increased UV radiation may also lead to a massive die-off of photoplankton (a CO_2 "sink") and therefore to increased global warming.
- Disturbance of the thermal structure of the atmosphere, probably resulting in changes in atmospheric circulation.
- Reduction of the ozone greenhouse effect: ozone is considered to be a greenhouse gas. A depleted ozone layer may partially dampen the greenhouse effect. Therefore efforts to tackle ozone depletion may result in increased global warming.
- Changes in the tropospheric ozone and in the oxidizing capacity of the troposphere. [14].

Usage to renewable fuels and strict government regulations and global policies has certainly reduced the depletion of ozone layer. A study has revealed that Antarctica ozone levels have already recovered by an amount of 15% since the late 1990s [14].

1.5 GLOBAL WARMING

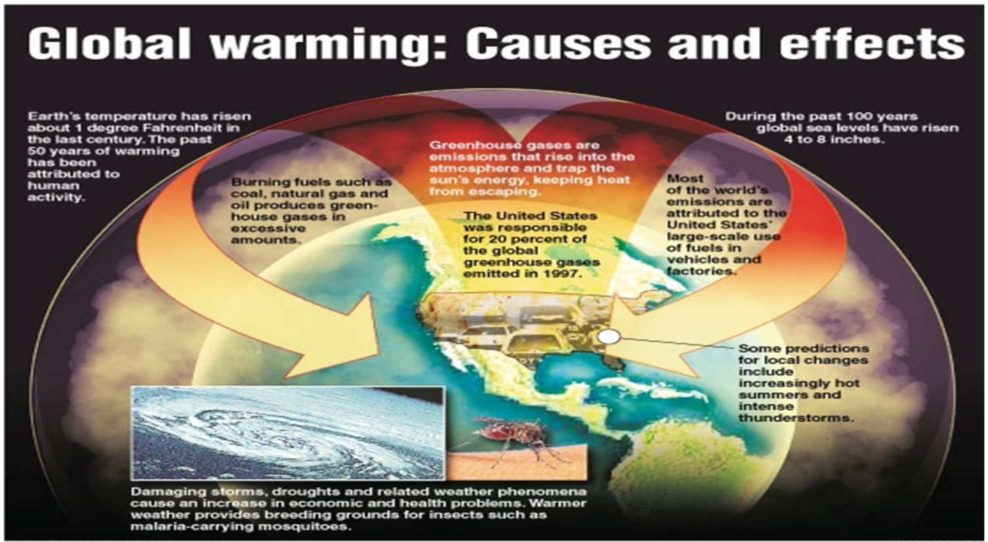
Global Warming effects on the natural balance of environment. Global Warming is the increase of Earth's average surface temperature due to effect of greenhouse gases, such as carbon dioxide emissions from burning of fossil fuels or from deforestation, which trap heat that would otherwise escape from earth.

There are many causes of Global Warming. The destruction and burning down of tropical forests, traffic clogging up the city streets , rapid growth of unplanned industries, the use of CFCs in packaging and manufacturing products, the use of detergents etc. cause Global

Warming. Besides all theses, over population, deforestation are the causative factors of Global Warming. The setting up of mills and factories in an unplanned way has a great effect on environment. These mills and factories produce black smoke which gets mixed with air and increases the amount of CO_2. [16]

For last few decades, it effect has increased mainly due to industrialization and modernization. From the three main greenhouse gases liberated in the atmosphere i.e. CO_2, NO_X and methane; CO_2 is produced in abundance and it plays a major role in causing global warming. [17]

Raising sea levels, glacier retreat, Arctic shrinkage, and altered patterns of agriculture are cited as direct consequences, but predictions for secondary and regional effects include extreme weather events, an expansion of tropical diseases, changes in the timing of seasonal patterns in ecosystems, and drastic economic impact. Concerns have led to political activism advocating proposals to mitigate, eliminate, or adapt to it.[17, 18].Fig. 1.6 shows the cause and its effect of global warming.



Source: Environmental Protection Agency NATE OWENS/STAFF

Fig. 1.6 cause and its effect of global warming. [18]

Although, being a greenhouse gas CO_2has adverse effects on environment which are the possible consequences of global warming. The greenhouse effect refers to the interaction between the Earth's atmosphere and surface to absorb, transfer, and emit energy as heat, cycling it through the atmosphere and back to the surface. The natural greenhouse effect is necessary for life as it exists on Earth today [13].

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

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

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

1. Rise in Sea level – The densely settled coastal plains could become uninhabitable with just a small rise in sea level, which could be a result of melting of ice from the ice caps
2. Deplation of ozone layer - Warming would result in increase in high cloud cover during winter, giving chemical reactions a platform in the atmosphere, which could result in depletion of the ozone layer

3. Increased extreme weather - A warmer climate could change the weather systems of the earth, meaning there would be more droughts and floods, and more frequent and stronger storms
4. Impacts on agriculture - Global warming could have major effects on agricultural productivity
5. Spread of diseases - Diseases would be able to spread to areas which were previously too cold for them to survive in
6. Ecosystem change - As with the diseases, the range of plants and animals would change, with the net effect of most organisms moving towards the North and South Poles

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

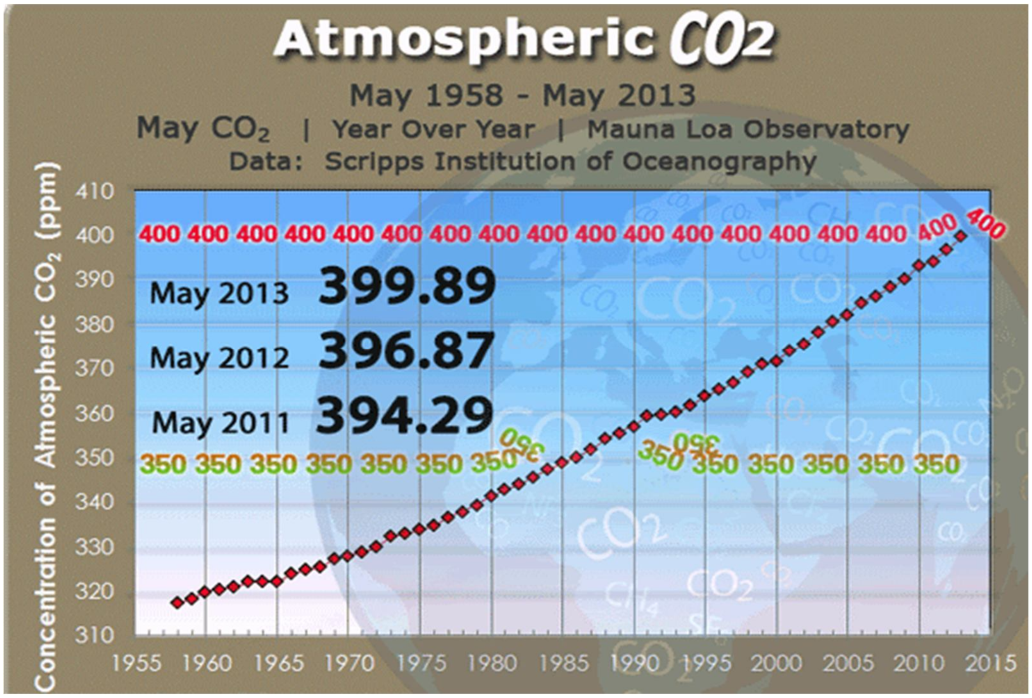


Fig 1.7 Atmospheric CO_2 at Mauna Lao observatory for last six decades [21].

Fig. 1.7 shows that the concentration of CO_2 in atmosphere has constantly increased which needs to be prevented for decreasing the effects of global warming. In May 2013, CO_2 level is estimated at Mauna Lao observatory as 399.89 ppm [21].

1.6 CO_2 EMISSION OUTLOOK

The world is not on track to meet the target agreed by governments to limit the long term rise in the average global temperature to 2 degrees Celsius (°C). Global greenhouse gas emissions are increasing rapidly and, in May 2013, carbon-dioxide (CO_2) levels in the atmosphere exceeded 400 parts per million for the first time in several hundred millennia. Despite positive developments in some countries. Global energy-related CO_2 emissions increased by 1.4% to reach 31.6 Gigatonnes (Gt) in 2012, a historic high. Non-OECD countries now account for 60%of global emissions, up from 45% in 2000.

Energy-related CO_2 emissions reached 31.6 Gt in 2012, an increase of 0.4 Gt (or 1.4%) over their 2011 level, confirming rising trends. The global increase masks diverse regional trends, with positive developments in the two-largest emitters, China and the United States. US emissions declined by 200 Mt, mostly due to low gas prices brought about by shale gas development that triggered a switch from coal to gas in the power sector. China’s emissions in 2012 grew by one of the smallest amounts in a decade (300 Mt), as almost all of the 5.2% growth in electricity was generated using low-carbon technologies, mostly hydro and declining energy intensity moderated growth in energy demand. Despite an increase in coal use, emissions in Europe declined (-50 Mt) due to economic contraction, growth in renewable and a cap on emissions from the industry and power sectors. OECD countries now account for around 40% of global emissions, down from 55% in 2000 [12]. So it is a matter of concern for the world to inhibit the quantity of CO_2 emissions to atmosphere.

Table 1.4 CO_2 Emissions Based On Region (Gigatonnes) [12]

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

1.7 DIESEL ENGINE AND INDIAN ECONOMY

Diesel Engine plays a crucial role in Indian economybut also contributes to pollution significantly. During April-May 2013, diesel consumption grew 5.9% compared to period 2012. The overall diesel consumption growth for 2012-13 was 6.8%, compared to 7.8% during 2011-12.[22].

According to the data provided by the Petroleum Planning and Analysis Cell, petrol consumption in India in April-January this fiscal was 12.35 million tonnes. India is expected to end up consuming 14.82 million tonnes of petrol in the year, registering growth of 4.41% in FY12. Consumption of diesel is expected to be 63.91 million tonnes, registering growth of 6.4%.[23]

The diesel engine is typically more efficient than the gasoline engine due to higher compression ratio. Diesel engines also do not suffer from size and power limitations, which the SI engine is prone to. In India, diesel engines are used in heavy trucks, city transport buses, locomotives, electric generators, farm equipment, underground mine equipment etc. The dual problem of fast depletion of petroleum based fuels and air pollution can be judiously handled by switching from fossil fuel based economy to renewable source of energy.

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

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

1.8 NECESSITY OF ALTERNATIVE FUELS

Alternative fuels are a compelling necessity in industries and automobiles not only because fossil fuel reserves are fast depleting, but also to combat pollution.Emissions from automobiles and industries such as carbon dioxide, carbon monoxide and sulphur had led to phenomena like global warming. However, since a world without these sectors was unthinkable, there was an urgent need to find eco-friendly alternative fuels.

With more advanced technology, we still use staggering amounts of fuels and it seems that nothing will change it in the near future. As today’s fuel sources will not be enough for humankind to further develop or even survive, scientists have been looking for alternatives.It might be surprising for many but the fact is that world need desperately a substitute for fossil fuels as available alternative energy sources , this might not be simply enough to secure our uncertain future, taking into account the speed of technological progress. Therefore there is an increasing necessity of developing the fuel of the future which will have the best qualities and at the same time it will not endanger the environment.

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

1.8.1 BIO FUELS

Bio-fuels are renewable liquid fuels derived from biological raw material and have been proved to be worthy substitutes for oil in the transportation and agriculture sector. Bio- fuels are gaining worldwide recognition as a sustainable solution for problems like environmental degradation, energy security, restricting imports, rural employment and agricultural economy. Other than having the potential to solve the energy crisis of the world, biofuels also have the advantage of lower emissions of HC, CO and PM as compared to fossil diesel fuel. The most promising biofuel and closest to being competitive in current markets without subsidy, are:

- Straight vegetable oils
- Ethanol
- Methanol
- Biodiesel.

Straight vegetable oil is oil derived from oil seeds of oil-bearing plants. This can be successfully used as fuel for the diesel engine for short term. However, long term use causes problems such as injector deposits and subsequent coking, sticking of seals,lubricating oil dilution, among others.

Ethanol is used as fuel or as oxygenate to gasoline. Raw material used for producing ethanol varies from sugar in Brazil, cereals in USA, sugar beet in Europe to molasses in India. Brazil uses ethanol as 100 %fuel in about 20% of vehicles and 25% blend with gasoline in the rest of the vehicles. USA uses 10% ethanol-gasoline blends whereas a 5% blend isused in Sweden. Australia uses 10% ethanol-gasoline blend. Use of 5%ethanol-gasoline blend is already approved by BIS and is dispensed inmany Indian states. Government of India is also planning to enhance it to 10% ethanol gasoline blend.

Methanol could conceivably be made from grain, but its most common source is natural gas. Use of natural gas is better for reducing carbon dioxide production in comparison to other fossil fuels, but use of renewable fuels instead of natural gas would be still better. It can be made from coal or wood with more difficulty and lower efficiency than from natural gas.

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

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

Emissions of CO_2, which results into a green house effect, are a feature of most fuels. However, if biomass energy is used instead of fossil fuels there is anet reduction in CO_2 emissions. SO_2 emissions from using biomass energy tend to be considerably lower because relevant plants and trees contain only tracequantities of sulphur compared to higher emissions from coal, gasoline and natural gas. This drop in SO_2 is accompanied by a fall in the level of the other traditional motor pollutant emissions such as carbon monoxide, unburned hydrocarbons and particulates, but these reductions are lesser quantifiable.However, there is an increase in the release of nitrogen oxides and aldehydes.There is no clear advantage to any one of the liquid biofuels, and choices between them will depend on local priorities.

1.9 RATIONALE OF BIOFUELS IN INDIA

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

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

1.10 ATTRIBUTES FOR ALTERNATIVE FUELS

Adaptation of an alternative fuel for any existing engine depends on certain very important and essential parameters which includes : no or minimum modification required in design of engine, use of same storage and transportation infrastructure, biodegradable and non-toxic assuring safe handling and transportation, capability of being produced locally and having low investment cost.[24, 25].

In economic point of view alternative fuels like edible and non-edible vegetable oils, ethanol and related alcohol and other bio origin fuels are having marginal variation in terms of cost compared to the traditional petroleum resources.

Government policies need to be revised to encourage the development and utilization of these fuels. Land for production need to be explored, an extraction and transesterification plant would be required, distribution and storage facilities constructed and monitoring of major users for detection of problems in large scale use are all needed before the technology can be recommended for general use. The magnitude of our energy needs provides an inexhaustible market of our total agriculture production capacity at the highest possible level.We could put the farm back to work providing for our food needs and also growing crops and livestock for energy. Energy is the only crop that we could never grow in surplus [26].

1.11 PRESENT WORK

In the present framework, a more elaborative discussion on the adoptation of vegetable oil is made. Oil seed crops can provide a fuel grade product using easy extaction and processing.Vegetable oils are seems to be a worthy fuels particularly for diesel engine applications. The practicality of using vegetable oils as diesel fuels has been sufficiently demonstrated to permit further exploration of their effectiveness to develop techniques that will authorize their incorporation into agricultural operations, particularly in times of energy shortfall.Biodiesel despite being a biofuel is also having added advantage over that of its oil in the form of viscosity, calorific value, volatility level.Vegetable oil returns about ten calories of output for each calorie of input. Numerous different vegetable oils have been tested as a fuel in engines. [27]

A two stage transesterification is carried out to convert vegetable oil to corresponding biodiesel which displays fairly similar properties to that of mineral diesel fuel. Biodiesel can be prepared from bothedible as well as nonedible oil depending upon its availability in a country. In the United States Soybean oil is of primary interest while many European countries are concerned with rapeseed oil, and countries with tropical climate prefer to utilize coconut oil or palm oil. Other vegetable oils, including sunflower, safflower, etc., have also been investigated.

In India, variety of non-edibleoil has been used as a fuel to propel the engines. The current prices of vegetable oil in India arecomparable with petroleum fuels. Some of the vegetable oils are available in India easily and infact some of them underutilized whereas the potential of such oils are very high. If any particular vegetable oil amongst some 450 types of species available in India , is to be used as energy crops , thenthe 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 vegetable oils as a replacement to fossilfuel which may result in increased crop production for energy.[29].

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

As already elaborated in previous chapter, rapidly increasing prices and uncertainties concerning petroleum availability has mendate the researchers to search for sustainable alternative fuel sources for diesel engine applications that are superior to conventional fossil fuels in terms of performance, emissions and combustion characteristics.

Bio origin fuels spacialy biodiesel due to its advantage of being renewable and enviromental friendly attributes is getting limelight for quite sometime. Vegetable oils , both edible as well as non-edible found in rural area can be utilize for biodiesel production. Not only the vegetable oils but also animal fats can be used to produce biodiesel, but due to food security issues non-edible oils are more preffered over edible oils for production of biodiesel.

The idea of using vegetable oils as fuel for diesel engines is not radically new. In1900 Rudolph diesel used peanut oil to fuel one of his engines at the Paris Exposition. For quite some times systematic efforts have been taken by the scientists all over the globe for better utilization of biodiesel in diesel engine application.

2.1 VEGETABLE OILS AS A POTENTIAL C. I. ENGINE FUEL

Various alternative fuels viz biodiesel, ethanol, metenol,vegetable oils and other related biofuels had already been proposed for diesel engine application. Biodiesel is a derivative of vegeable oil and can be made by virgin or used vegetable oil (both edible and non-edible) and animal fats by a chemical process named transesterification.

Biodiesel produced from transesterification process exhibit improved properties compared to its corresponding oil. Biodiesel shows improved volatility approaching thoes of petrolium derived diesel fuel.[29]. Improved volatility and physico-chemical properties lead to an improved cetane number(CN). [30]

The properties of biodiesel are insignificant to neat diesel and therefore, biodiesel shows a potential candidate to replace the diesel fuel if need arises. The conversion of triglyceried into ester through transesterification process reduce the moleculer weight to one third that of triglycerieds, viscocity by a factor of about eight and marginal increase in volatility. These vegetable oil esters contains 10-15% more oxygen by weight which may boost combustion process than hydrocarbon based diesel fuel.

The characteristics of variety of available vegetable oils fall within a fairly a narrow band and are closer to those of Diesel Oil. The Kinematic viscosity of vegetable oils varies in the range of 30-40 cSt at 38ºC. High viscosity of these oils is due to larger molecular mass and chemical structure. Vegetable oils have high molecular weights in the range of 600-900, which are three or more times higher than diesel fuel The flash point of vegetable oils are very high (above 200º C).The heating value of these oils are of the range of 39-43 MJ/Kg which are low compared to diesel fuels (about 45 MJ/Kg).The presence of chemically bond oxygen in vegetable oils lower the heating value by about 10%. The Cetane number of biodiesl is in the range of 50 depends on the feedstocks. The iodine value ranges from 0 to 200 depending upon un- saturation. These esters have 15-25ºc higher cloud point and pour point than diesel fuel.[31].

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

Table 2.1: Tests and Limits for Fuel Properties [32]

Fuel Property	**Diesel**	**Biodiesel (B100)**	**Units**
Fuel Standard	**ASTM D975**	**ASTM D6751**	
Lower Heating Value	~129,050	~118,170	Btu/gal
Kinematic Viscosity @ 40° C	1.3 - 4.1	1.9 - 6.0	mm 2/s
Specific Gravity @ 60° C	0.85	0.88	kg/l
Density	7.079	7.328	lb/gal
Water and Sediment	0.05 max	0.05 max	% volume
Carbon	87	77	wt. %
Hydrogen	13	12	wt. %
Oxygen	0	11	
Sulfur	0.0015 max	0.0 to 0.0024	wt. %
Boiling Point	180 to 340	315 to 350	° C
Flash Point	60 to 80	130 to 170	° C
Cloud Point	-15 to 5	-3 to 12	° C
Pour Point	-35 to -15	-15 to 10	° C
Cetane Number	40 to 55	47 to 65	
Lubricity SLBOCLE	2,000 to 5,000	>7,000	grams
Lubricity HFRR	300 to 600	<300	microns

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

It is clear that the use of the vegetable oils as fuels for diesel engines depends on their physico-chemical properties, and on their combustion characteristics as well as the type of engine use and the conditions of operation. They also have a higher Kinematic viscosity and density and higher cetane number, than the diesel fuel. Though the properties vary from one type of oil to another this general comparison with the diesel fuel is valid for all. [32].

Various vegetable oils are distinguished by their fatty acid compositions. Triglyceride molecules have molecular weights between 800 and 900 and are thus nearly four times larger than typical diesel fuel molecules [34]. Chemical structure of common fatty acids is given in table 2.2.

Table 2.2Chemical Names and Descriptions of some Common Fatty Acids [35]

Common Name	Carbon Atoms	Double Bonds	Scientific Name
Butyric acid	4	0	butanoic acid
Caproic Acid	6	0	hexanoic acid
Caprylic Acid	8	0	octanoic acid
Capric Acid	10	0	decanoic acid
Lauric Acid	12	0	dodecanoic acid
Myristic Acid	14	0	tetradecanoic acid
Palmitic Acid	16	0	hexadecanoic acid
Palmitoleic Acid	16	1	9-hexadecenoic acid
Stearic Acid	18	0	octadecanoic acid
Oleic Acid	18	1	9-octadecenoic acid
Ricinoleic acid	18	1	12-hydroxy-9-octadecenoic acid
Vaccenic Acid	18	1	11-octadecenoic acid
Linoleic Acid	18	2	9,12-octadecadienoic acid
Alpha-Linolenic Acid (ALA)	18	3	9,12,15-octadecatrienoic acid
Gamma-Linolenic Acid (GLA)	18	3	6,9,12-octadecatrienoic acid
Arachidic Acid	20	0	eicosanoic acid
Gadoleic Acid	20	1	9-eicosenoic acid
Arachidonic Acid (AA)	20	4	5,8,11,14-eicosatetraenoic acid
EPA	20	5	5,8,11,14,17-eicosapentaenoic acid
Behenic acid	22	0	docosanoic acid
Erucic acid	22	1	13-docosenoic acid
DHA	22	6	4,7,10,13,16,19-docosahexaenoic acid
Lignoceric acid	24	0	tetracosanoic acid

There are various problems associated with the utilization of straight vegetable oil in diesel engine application. They can be categorized as operational and durability problems. The former included the ignition quality characteristics, e.g. poor cold engine start-up, misfire, and ignition delay, and the latter include characteristics demonstrating incomplete combustion, e.g.

nozzle coking, deposit formation, carbonization of injector tips, ring sticking and lubricating oil dilution and degradation [36].

Problems faced on using the neat vegetable oil are:

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

b) The clogging of the fuel system.

c) Polymerization during storage.

d) Blow-by causing polymerization of the lubricating oil [37].

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

f) Oil ring sticking.

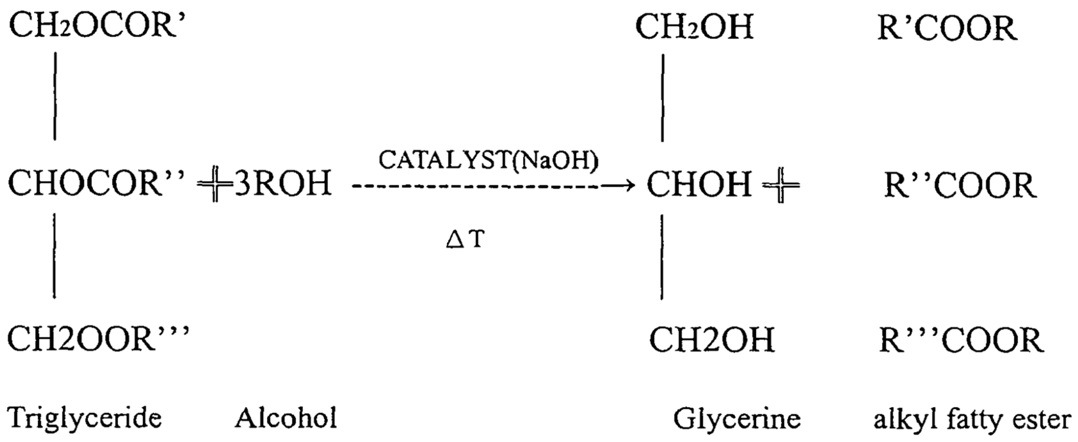
g) Carbon deposits around the nozzle orifice, the upper piston ring grooves and on the piston rings [38].

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

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

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

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



$$\begin{matrix} \mathrm{CH_2OCOR'} & & & \mathrm{CH_2OH} & & \mathrm{R'COOR} \\ | & & & | & & \\ \mathrm{CHOCOR''} & +\ \mathrm{3ROH} & \xrightarrow[\Delta T]{\mathrm{CATALYST(NaOH)}} & \mathrm{CHOH} & + & \mathrm{R''COOR} \\ | & & & | & & \\ \mathrm{CH2OOR'''} & & & \mathrm{CH2OH} & & \mathrm{R'''COOR} \end{matrix}$$

Fig. 2.1 Chemical Structure of biodiesel

Here R',R'',R''' and R represent various alkyl groups of different carbon chain lengths and –COO- is a carboxyl group. [39].

Effect of different parameters like temperature, molar ratio of alcohol to oil, catalyst, reaction time have been investigated by several researchers and it was found that for base catalysed transesterification at atmospheric pressure, 60-70 °C temperature, 45 min to 1 hr. reaction time and 6:1molar ratio of alcohol to oil the yield is optimum.

In rural and remote areas of developing countries, where grid power is not available, vegetable oils can play a vital role in decentralized power generation for irrigation and electrification. In these remote areas, different types of vegetable oils are grown/produced locally but it may not be possible to chemically process them due to logistics problems in rural settings. Hence using heated vegetable oils as petroleum fuel substitutes is an attractive proposition. Keeping these facts in mind, a set of engine experiments were conducted using Madhuca Indica (locally known as mahua) oil on an engine, which is typically used for agriculture, irrigation and decentralized electricity generation. Heating was used to lower the viscosity of mahua oil in order to eliminate various operational difficulties.

Oil can be extracted from a variety of plants and oilseeds. Under Indian condition only such plant sources can be considered which is essentially non edible oil and available is in appreciable quantity and can also be grown on large-scale on wastelands.

Moreover, some plants and seeds in India have tremendous medicinal value, considering these plants for biodiesel production may not be a viable and wise option. Considering all the above options, probable biodiesel yielding trees or crops in India are [40]:

- Jatropha curcas or Ratanjot
- Pongamia pinnata or Karanj
- Madhuca Indica or Mahua
- Calophylluminophyllum or Nagchampa
- Heveabrasiliensis or Rubber seeds
- Calotropisgigantia or Ark
- Euphorbia tirucalli or Sher
- Boswelliaovalifololata.
- Orizyasativa or Rice bran oil
- Animal tallow
- Fish oil

All the above prospective plant candidates as biodiesel yielding sources. One of the critical issues to be resolved for vegetable oil fuels as they seek status as replacements for petroleum diesel fuel is how they perform in a standard diesel engine. This literature review examines many of the tests that have been conducted in the past several years related to performance & emissions of vegetable oil fuels.

2.2 LITERATURE REVIEW

Labeckas et al (2006) studied an unmodified, naturally aspirated Diesel engine operating on neat rape seed methyl ester (upto 35 %) and diesel fuel blends. The maximum brake thermal efficiency varied from 0.356 to 0.398 for RME and from 0.373 to 0.383 for Diesel fuel. The maximum NOx emissions increased proportionally with the increase of mass percent of oxygen in the biofuels and also with engine speed. CO emissions and visible smoke emerging from the biodiesel over all loads and speed ranges were lower by up to 51.6% and 60.3%, respectively. The emissions of unburned hydrocarbons, HC, for all biofuels were low, ranging at 5-21 ppm levels [41].

Kumar et al (2008) conducted engine tests to get the comparative measures of brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC) and emissions such as CO, CO_2, HC, NOx to evaluate the behaviour of PPME and diesel in varying proportions. The results reveal that blends of PPME with diesel up to 40% by volume (B40) provide better engine performance (BSFC and BSEC) and improved emission characteristics. [42]

Lapuerta et al (2008) compared the diesel engine emissions of biodiesel fuels as opposed to conventional diesel fuels. Special attention was paid to nitric oxides and particulate matter and it was observed that sharp reduction in particulate emissions in case of biodiesel fuel in comparison to diesel fuel [43].

Adailehet et al (2012) presented the combustion and emissions characteristics of waste vegetable oil biodiesel at variable engine speed between 1200-2600 rpm. The results showed significant reductions in CO, and unburned HC, but the NOx was increased. Biodiesel has a 5.95 % increase inbrake-specific fuel consumption. The fuel consumption rate, brake thermal efficiency, and exhaust gas temperature increased while the BSFC, emission indices of CO_2, CO decreased with an increase of engine speed[44].

Yang et al (2012) investigated the performance, combustion and emission characteristics of diesel engine fuelled by biodiesel at partial load conditions. Experiments were conducted on a common-rail fuel injection diesel engine using ultra low sulphur diesel, biodiesel (B100) and their blend fuels of 10%, 20%, and 50% under various loads. The results showed that biodiesel/blend fuels had significant impacts on the engine's brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE) at partial load conditions[45].

Qi et al (2009) examined the performance, emissions and combustion characteristics of diesel and biodiesel as fuels in the compression ignition engine. The power output of biodiesel was almost identical with that of diesel. The brake specific fuel consumption was higher for biodiesel due to its lower heating value. Biodiesel provided significant reduction in CO, HC, NOx and smoke under speed characteristic at full engine load. Based on this study, biodiesel can be used as a substitute for diesel in diesel engine [46].

Nabi et al (2009) investigated different parameters for the optimization of biodiesel production and carried out the performance test of a diesel engine with neat diesel fuel and biodiesel mixtures. The engine experimental results showed that exhaust emissions including carbon monoxide (CO)particulate matter (PM) and smoke emissions were reducedfor all biodiesel mixtures. However, a slight increase in oxides of nitrogen (NOx) emission was experienced for biodiesel mixtures [47].

Hoekman et al (2012) has studied “biodiesel NOx effect, and theories to explain this effect. The biodiesel NOx effect can be mitigated by modifying engine control settings particularly by retarding injection timing and increasing exhaust gas recirculation (EGR). The absolute magnitude of the biodiesel NOx effect appears to be reduced with modern engines, although there are cases where the percentage change is still substantial.[48]

Hoekman et al (2012) have found that differences in chemical and physical properties among biodiesel fuels can be explained largely by the fuels' FA profiles. Two features that are especially influential are the size distribution and the degree of unsaturation within the FA structures. For the biodiesel types reviewed, it was found that several fuel properties - including viscosity, specific gravity, cetane number, iodine value, and low temperature performance metrics - are highly correlated with the average unsaturation of the FAME profiles [49].

Yanowitz et al (2009) found that the use of a common biodiesel blend (B20) consistently reduces emissions of particulate matter, hydrocarbons, and carbon monoxide by 10-20% and B20 show varying effects on oxides of nitrogen (NOx). The emissions effect of B20 on heavy-duty diesel truck emissions did not show any correlation with model year or type of fuel injection equipment as per their study [50].

Qi et al (2010) conducted experiment to evaluate the effects of using methanol as additive to biodiesel– diesel blends on the engine performance, emissions and combustion characteristics of a diesel engine under variable operating conditions. BD50 (50% biodiesel and

50% diesel in vol.) was prepared as the baseline fuel. Methanol was added as an additive by volume percent of5% and 10% (denoted as BDM5 and BDM10). The results indicate ignition delay forBDM5 and BDM10 than for BD50 at low engine load. At low engine load BDM5 and BDM10 showed similar peak cylinder pressure and higher peak of heat release rate than that of BD50. At low engine load of 1800 r/min, the peak cylinder pressure and the peak of pressure rise rate of BDM5 and BDM10 was lower than those of BD50, and the peak of heat release rate was similar to that of BD50. At high engine load, the peak cylinder pressure, the peak of pressure rise rate and peak of heat release rate of BDM5 andBDM10 was higher than those of BD50, and the crank angle of peak values for all tested fuels was almost same. BDM5and BDM10 show dramatic reduction of smoke emissions. CO emissions were slightly lower; NOx and HC emissions were almost similar to those of BD50.

Muralidharan et al(2011)found the performance, emission and combustion characteristics of a single cylinder four stroke variable compression ratio multi fuel engine fuelled with waste cooking oil methyl ester and its 20%, 40%, 60%and 80% blends with diesel (on a volume basis) and compared with standard diesel. Experiment has been conducted at a fixed engine speed of 1500 rpm, 50% load and at compression ratios of18:1, 19:1, 20:1, 21:1 and 22:1. The results indicate longer ignition delay, maximum rate of pressure rise, lower heat release rate and higher mass fraction burnt at higher compression ratio for waste cooking oil methyl ester compared to that of diesel. B40 is found to give maximum thermal efficiency at 50 % loading condition. The blends when used as fuel results in reduction of carbon monoxide, hydrocarbon and increase in nitrogen oxides emissions.

DAS et al(2009) has investigated on filtered Jatropha (Jatropha curcas), Karanja (Pongamia pinnata) and Polanga (Calophyllum inophyllum) oil based mono esters (biodiesel) tested for their use as substitute fuels of diesel engines.. Diesel; neat biodiesel from Jatropha, Karanja and Polanga; and their blends (20 and 50 by v%) were used for conducting combustion tests at varying loads (0, 50 and 100%).Combustion analysis revealed that neat Polanga biodiesel that results in maximum peak cylinder pressure was the optimum fuel blend as far as the peak cylinder pressure was concerned. The ignition delays were consistently shorter for neat Jatropha biodiesel neat Karanja and Polanga biodiesel and found lower than diesel with the difference increasing with the load.

Devan et al(2009) studied on methyl ester of paradise oil and eucalyptus oil to study the performance and emission characteristics of these fuels. Various proportions of paradise oil and eucalyptus oil are prepared on a volume basis and used as fuels in a single cylinder, four-stroke DI diesel engine, methyl ester derived from paradise oil was considered as an ignition improver. The results show a 49% reduction in smoke, 34.5% reduction in HC emissions and a 37% reduction in CO emissions for the Me50–Eu50 blend with a 2.7% increase in NOx emission at full load. There was a 2.4% increase in brake thermal efficiency for the Me50–Eu50 blend at full load. The combustion characteristics of Me50–Eu50 blend are comparable with those of diesel.

Labecki et al (2012) found combustion and emission characteristics of rapeseed plant oil (RSO) and its blends with diesel fuel in a multi-cylinder direct injection diesel engine. An attempt had been made to reduce soot emissions from the combustion of RSO to exploit the advantage of its low NOx emissions. Variation in injection parameters such as injection pressures and injection timings had been used in this work to reduce the soot emissions for blends of 50% and 30% RSO in diesel fuel. Under diesel equivalent soot emission levels, it was also possible to achieve a further reduction in NOx emissions by up to 22% for 30% RSO blend, this was achieved at the expense of THC, CO and BSFC. However, when compared to diesel, the exhaust soot particle number concentration for 30% RSO blend was still higher, even after diesel equivalent level of soot emission was achieved. The heat release shapes are almost the same for all cases, except for a shift towards the expansion stroke for 30% RSO case under diesel equivalent soot operating condition.

Ren et al (2008) evaluate combustion and emissions of a DI diesel engine fuelled with diesel-oxygenate blends. The results showed that there exist the different behaviours in the combustion between the diesel-diglyme blends and the other five diesel-oxygenate blends. The smoke concentration decreases regardless of the types of oxygenate additives, and the smoke decreases with the increase of the oxygen mass fraction in the blends without increasing the NOx and engine thermal efficiency. CO and HC concentrations were found to decrease with the increase of oxygen mass fraction in the blends. Unlike conventional diesel engines fueled with pure diesel fuel, engine operating on the diesel-oxygenate blends presents a flat NOx/Smoke trade off curve versus oxygen mass fraction.

Gill et al (2011) found condensed overview of Gas-to-Liquid (GTL), Biomass-to-Liquid (BTL) and Coal-to- Liquid (CTL) theory and technology by the use of Fischere-Tropsch (FeT) processes. FeT diesel fuels typically have a number of very desirable properties, including a very high cetane number. This review focused on how fuel properties impact pollutant emissions and draws together data from various studies that have been carried out over the past few years. Reduced emission levels as demonstrated in several publications have been attributed to several chemical and physical characteristics of the FeT diesel fuels including reduced density, ultra-low sulphur levels, low aromatic content and high cetane rating, but not all of them contribute to the same extent to the emissions reduction.

Selim et al (2003)carried out investigation to examine for the first time the performance and combustion noise of an indirect injection diesel engine running with new fuel derived from pure jojoba oil, jojoba methyl ester, and its blends with gas oil. A Ricardo E6 compression swirl diesel engine was fully instrumented for the measurement of combustion pressure and its rise rate and other operating parameters. Results showed that the new fuel derived from jojoba is generally comparable and good replacement to gas oil in diesel engine at most engine operating conditions, in terms of performance parameters and combustion noise produced.

Agarwal et at (2013)studied, performance, emission and combustion characteristics of Karanja oil blends (K10,K20, K50 and K100) with mineral diesel in unheated conditions in a direct injection CI engine at different engine loads and constant engine speed (1500 rpm) and compared to baseline data from mineral diesel. Detailed combustion analysis revealed that the combustion duration increased significantly even with smaller concentration of Karanja oil in the fuel blend. HC, CO and Smoke emissions were found to decrease for 20e50% (v/v) Karanja oil content in the fuel blends.

Chauhan et al(2011) compared performance, emission and combustion characteristics of biodiesel derived from Jatropha oil in a dual fuel diesel engine with base line results of diesel fuel. The brake thermal efficiency of Jatropha methyl ester and its blends with diesel were lower than diesel and brake specific energy consumption was found to be higher. However, HC, CO and CO_2 and smoke were found to be lower with Jatropha biodiesel fuel. NOx emissions on Jatropha biodiesel and its blend were higher than Diesel.

Above studies were conducted on either neat vegetable oils or blends of vegetable oil with diesel. The vegetable oil fuels were not subjected to any preheating arrangement. As already elaborated in preceding section, operational and durability problems have been experienced in diesel engine with vegetable oil as a fuel. The high viscosity of the vegetable oil has been the main reason behind these problems. The preheating of vegetable oil before introduction into the diesel engine either by exhaust gases or some other means has been found to be one option of utilizing vegetable oil in diesel engine since at high temperature viscosity of vegetable oil shall lower down.

2.3 STATEMENT OF THE PROBLEM

From the above mentioned literature review it is clear that vegetable oil can be used either as an extender or complete replacement to diesel fuel. But some researchers have reported difficulties encountered with use of vegetable oil in diesel engine. These difficulties are mainly due to high viscosity of vegetable oil. Mahua oil is a sustainable replacement of diesel in India. However its high viscosity issue is to be resolved for its long term utilization in diesel engine. Blending of mahua oil with diesel is one of the methods to decrease the viscosity of the mahua oil which produce methyl esters through transesterification process that could be used straight instead of diesel.

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

1. Comprehensive literature survey.
2. Identification of non-edible oil for biodiesel production.
3. Preparation of biodiesel
4. Development of dual fuel mode experimental diesel engine test rig.
5. Determination of important Physico-chemical properties of mahua oil biodiesel.
6. Conducting exhaustive experiments on the test rig to evaluate performance and emission characteristics of pure diesel and mahua oil methyl ester blend with different proportion in crude diesel.
7. Evaluation of combustion characteristics of different blends of mahua oil methyl ester and neat diesel
8. Analysis of Result.

CHAPTER 3

SYSTEM DEVELOPMENT & EXPERIEMNTAL PROCEDURE

3.0 INTRODUCTION

Diesel engines are amongst the most useful and efficient prime movers amongst all power producing machines. Due to this reason it has becomes necessary to develop alternative fuels with properties comparable to petroleum based diesel fuels with the view of protecting global environment and concerns for long-term energy security.

For countries like India and many other developing countries; fuels of bio-origin provide a feasible solution to the above twin crisis. Bio-fuels are getting a worldwide attention because of global stress on reduction of greenhouse gases (GHGs) and clean development mechanism (CDM).

The fuels of bio-origin may be alcohol, vegetable oils, animal tallow, biomass, and biogas. Amongst all Vegetable oils have comparable Physico-chemical properties with mineral diesel and they are biodegradable, non-toxic, and have a potential to significantly reduce pollution.

In many countries the qualities of this fuel, environmentally as well as technically, have pushed this fuel close to the final stages of commercialization. Each country can proceed in the production of particular oil, depending upon the climate and economy. In recent years many 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 indifferent parts of the country to promote large scale cultivation of oilseed bearing plants. Amongst the various plant species, oil extracted from seeds of Mahua tree has been found very suitable as a substitute to diesel fuel.

3.1 MAHUA PLANT DESCRIPTION

Mahua (Madhuca Indica) is one of the forest-based tree-borne non-edible oils with large production potential of about 60 million tons per annum in India [61]. It belongs to the family of sapotaccac. The two major species of Madhuca found in India are Madhuca Indica (latifolia) and Madhuca longifolia (longifolia). Mahua is deciduous tree of dry region and native of India. It is found in abundance in the forests of Asian and Australian continents and is adapted to arid environments. It is a prominent tree in tropical mixed deciduous forests of West Bengal, Bihar, Orissa, Madhya Pradesh, Punjab and Uttar Pradesh and sub mountainous region of the Himalayas in India. Mahua is much planted in the plains of Northern India and Deccan peninsula and propagates mostly by seeds. This tree species has been domesticated by tribal people in India and Pakistan for its wide variety of uses from its flower, leaves, bark, seed oil, seed cake etc., since the ancient times. Mahua grows well on a wide variety of soils specially on alluvial soil in Indo-gangetic plain. Mahua being hardy thrives well on rocky, gravelly red soils and also on saline and sodic soils. It grows even in pockets of soil between crevices of barren rock. For its better growth and productivity, well deep loam or sandy-loam soils with good drainage are ideal. It also occurs on shallow boulder, clayey and calcareous soils. It usually attains about 20 m height with spreading crown. Bark is grey to brown. Leaves are elliptic, 7-20 x 3-7 cm, slightly hairy and coppered when young, glabrous at length. Mahua seed contain 30-40 percent of oil. The mahua tree starts bearing seeds from seventh year of planting. The oil is obtained from the seed kernels and is a pale yellow, semi-solid fat at room temperature. Crude mahua oil generally contains high % Free Fatty Acid (FFA).

Fig: 3.1 Mahua Tree, Dry and Raw fruit of mahua

Historically mahua has been the single largest indigenous source of natural hard fat in soap manufacture both by the small scale and organized sector. However the quantities of fat available do not commensurate the requirement, white mahua fat is satisfactory for production of washing soaps, its utility as virgin fat in toilet soap.

Seed Oil is used as ointment, in rheumatism and to prevent crack in the skin in winter. It is used for edible purposes culinary, hair oil, illumination, lighting, keeps body glossy and warm.

The presence of toxic and bitter saponins in mahua cake/meal preludes its utilization in poultry/animal feeds. Mahua cake can be used as cheap organic manure. It contains N=3.5%, Pro 50.51% and it can be used as cattle feed when treed from bitters and saponins, since it contains 20% crude protein. To be used as feed it must be supplemented with essential amino acids e.g. Arginine and try to phan. The saponin in the cake is a powerful fish poison and the cake can be used to control predatory fish present in the pounds and lakhs. The cake is a cheap and effective wormicide to maintain the turf, lawn and golf ground, free from earth warms.

The flowers are used as vegetable, for making cake, liquor; flower juice is used in the treatment of enlargement of axillary grand, neurotic disorder and taken with cow’s milk as an aphrodisiac, in cough and bronchitis. The derived liquor desired from the fermentation of flowers is considered to be a tonic and nutritive.

Seed paste is applied to curve muscle fatigue and relieve pain in the muscle and joints to improve the texture and vigor of skin. Bark decoction is used in curing bleeding gums and ulcers.

3.2 PRODUCTION OF BIODIESEL FROM MAHUA OIL

Biodiesel from mahua seed is important because most of the states of India are tribal where it is found abundantly. Mahua seed contain 30-40 percent fatty oil called mahua oil. The mahua tree starts bearing seeds from seventh year of planting. Mahua seed oil is a common ingredient of hydrogenated fat in India. It is obtained from the seed kernels and is a pale yellow, semi-solid fat at room temperature. It is also used in the manufacture of various products such as soap and glycerin. Crude mahua oil generally contains high % Free Fatty Acid (FFA) and conversion of FFA to biodiesel is very important Properties of biodiesel depend on the nature of the vegetable oil used for preparation of biodiesel by esterification and/or transesterification.

From the chemical composition it is found that Mahua oil is almost similar to that of other non-edible oils.

Bio diesel was produced from Mahua (Madhuca Indica) oil through esterification followed by transesterification.

3.2.1 ESTERIFICATION

Mahua Oil free from water and contaminants was taken in the flask. Heat was supplied to the setup. Measured amount of p-toluene sulphonic acid and Methanol were added to the oil .Heat was supplied and stirred continuously maintaining a steady temperature. Reaction time was conducted for 1hours. Intermittently samples were collected at regular intervals and FFA was determined. After the confirmation of complete reduction of FFA to less than 2%, the heating was stopped this oil sample was further treated for transesterification step to obtain methyl esters.

3.2.2 TRANSESTERIFICATION

Solution of known amount of catalyst potassium hydroxide was prepared in methanol. The solution and the rest required amount of methanol was added to the oil sample and was put on mantle heater. The system was maintained airtight to prevent the loss of alcohol. The reaction mix was maintained at temperature just above the boiling point of the alcohol i.e. around 70°C to speed up the reaction. Recommended reaction times varied till around 1 hour. Excess alcohol was normally used to ensure total conversion of the oil to its esters. After the confirmation of completion of methyl ester formation, the heating was stopped and the products were cooled and transferred to a separating funnel. The ester layer containing mainly methyl ester and methanol and the glycerol layer containing mainly glycerol and methanol were separated. The methyl ester was washed and dried under vacuum to remove traces of moisture.

Flow diagram represents the two step transesterification process of conversion of vegetable oil into methyl ester.

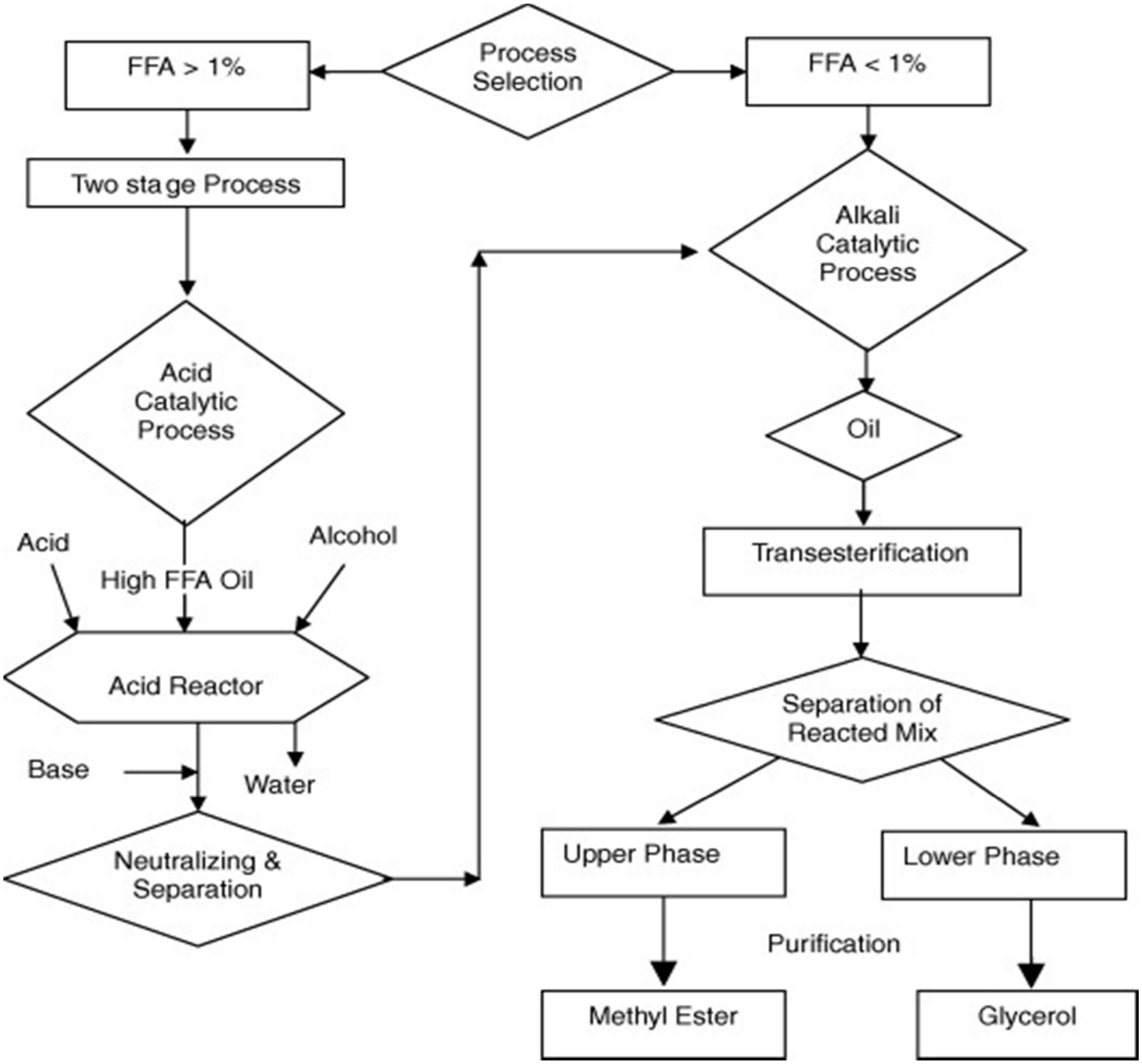


Plate 3.1 Mahua oil Methyl Ester

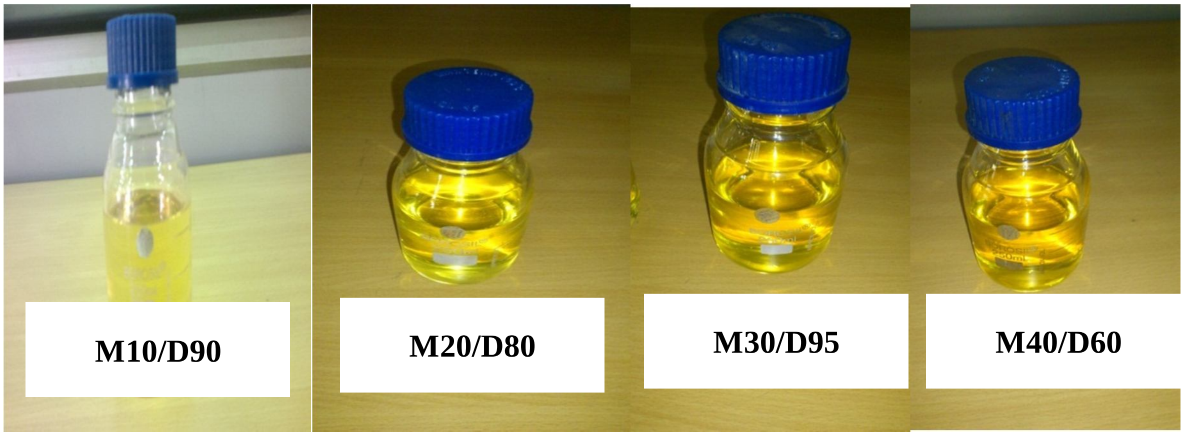


Plate 3.2 Various Blends of Mahua Oil Methyl Ester

3.3 DETERMINATION OF PHYSICO-CHEMICAL PROPERTIES

3.3.0 EQUIPMENTS

The following equipments were used in the laboratory for determination of Physico-chemical properties of the fuel for the specified project. These are used in CASRAE of Delhi Technological University, Delhi.

3.3.1 BIODIESEL RANCIMAT

Rancimat is an instrument used to measure the oxidation stability of biodiesel and biodiesel blends. The oxidation stability is the ability of a biodiesel sample to resist oxidation under conditions of heat and continuous air flow. Oxidation stability is one of the limiting factors in the use of bio-fuels, as this determines the shelf life of fuels. If the bio-diesel oxidizes, it forms fatty acids, which being acidic, corrodes the fuel injection system, and the engine cylinder. The Rancimat operation is based on air bubbling through the given fuel sample and testing for acidity by electrical conduction through the sample, between two electrodes. The equipment in CASRAE is of Metrohm brand, and has been acquired. The instrument is used extensively in determining the detrimental effects of metallic contaminants and the ameliorating effects of chelators and antioxidants.

PLATE 3.3: Biodiesel Rancimat

3.3.2 KINEMATIC VISCOSITY

Viscosity is an important property of fuel and it can be defined as measure of the resistance of a fluid which is being deformed by either shear stress or tensile stress. Viscosity describes a fluid's internal resistance to flow and may be thought of as a measure of fluid friction. In general too viscous fuel tends to form scum and deposits on cylinder walls, piston head etc., and cause atomization problems. So it is desirable that viscosity of fuel should be low. The different blend samples are prepared are investigated for viscosity at 400 C using a kinematic viscometer as per the specification given in ASTM D445. It consists of a capillary tube in which sample to be test is filled. The capillary tube has two marks engraved on it. The time for flow of fuel sample from upper mark to lower mark is measured and kinematic viscosity is calculated using time taken by each sample. The plate of the kinematic viscometer apparatus is shown below.

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

$$\upsilon = k \text{ x } t$$

Where,

υ= kinematic viscosity of sample;

k = constant for viscometer;

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

PLATE 3.4Kinematic Viscometer

3.3.3 Gas Chromatograph

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

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

The instrument present here is equipped with a FID (flame ionization detector), enabling us to quantify the quantities of various organic compounds present in the sample being tested. Hence, we can find out precisely the percentage of different fatty acid present in the biodiesel.

PLATE 3.5 Gas Chromatograph

3.3.4 Bomb Calorimeter

The calorific value is defined in terms of the number of heat units liberated when unit mass of fuel is completely burnt in a calorimeter under specified conditions. Higher calorific value of fuel is the total heat liberated in kJ per kg or m^3. All fuels containing hydrogen in the available form will combine with oxygen and form steam during the process of combustion. If the products of combustion are cooled to it initial temperature, the steam formed as a result will condense. Thus maximum heat is abstracted. This heat value is called the higher calorific value.

The calorific value of the fuel was determined with the Isothermal Bomb Calorimeter as per the specification given in ASTM D240. The combustion of fuel takes place at constant volume in a totally enclosed vessel in the presence of oxygen. The sample of fuel was ignited electrically. Then the fuel samples were burnt in bomb calorimeter and the calorific value of all samples were calculated. Parr Model 6100EF was used in laboratory for measuring calorific value of biodiesel. The Bomb Calorimeter used for determination of Calorific value is shown in plate 3.6

Plate 3.6 Parr 6100 calorimeter

3.3.5 Density meter

Density meter used in laboratory is DMA 4500AntoParr model. This density meter works on the principle of oscillating U-tube. The oscillating U-tube is a technique to determine the density of liquids and gases based on an electronic measurement of the frequency of oscillation, from which the density value is calculated. This measuring principle is based on the Mass-Spring Model.

The sample is filled into a container with oscillation capacity. The Eigen frequency of this container is influenced by the sample’s mass. This container with oscillation capacity is a hollow, U-shaped glass tube (oscillating U-tube) which is electronically excited into undamped oscillation (at the lowest possible amplitude). The two branches of the U-shaped oscillator function as its spring elements.

The direction of oscillation is normal to the level of the two branches. The oscillator's Eigen frequency is only influenced by the part of the sample that is actually involved in the oscillation. The volume involved in the oscillation is limited by the stationary oscillation knots at the bearing points of the oscillator. If the oscillator is at least filled up to its bearing points, the same precisely defined volume always participates in the oscillation, thus the measured value of the sample's mass can be used to calculate its density.

PLATE 3.7 Density Meter

3.3.6 COLD FILTER PLUGGING POINT (CFPP)

Cold Filter Plugging Point (CFPP) is defined as the minimum temperature at the fuel filter does not allow the fuel to pass through it. At low operating temperature fuel may thicken and does not flow properly affecting the performance of fuel lines, fuel pumps and injectors.

Cold filter plugging point of vegetable oils reflects its cold weather performance. It defines the fuels limit of filterability. The apparatus for CFPP measurement is shown in plate 3.9

Plate 3.8 Cold Filter Plugging Point Apparatus

3.4 SELECTION OF DIESEL ENGINE

Due to robustness and high load carrying diesel engines are preferred more than the gasoline engine in almost every sector like agriculture, marine, and other load carrying locomotives. Also due to economic point of view diesel engine attracted the manufacturers to make diesel engines.

Air pollution created by diesel engine is also more severe than the petrol engine. Also due to bulkiness in terms of more storage capacity of engine for moving more goods at same time they consume more fuel and so create more air pollution. Due to this reason by changing some trends to reduce the air pollution or harmful emissions by changing the fuel may bring considerable changes in the environment. Keeping all these specific features of diesel in mind, a typical engine system has been selected for present experimental investigations.

3.5 EXPERIMENTAL TEST RIG

The test rig consists of single cylinder, four stroke, VCR (Variable Compression Ratio) Diesel engine connected to eddy current type dynamometer for loading. The compression ratio can be changed without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. Setup is provided with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The setup has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement. The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance. Lab view based Engine Performance Analysis software package "Engine soft” is provided for on line performance evaluation. The detailed technical specifications of the engine are given in Table 3.1

Plate 3.9 Test Engine

Table 3.1: Specifications of the Diesel Engine

Make	**Kirloskar**
Model	VCR test setup 234
Rated Brake Power (kW)	3.5
Rated Speed (rpm)	1500
Number of Cylinder	One
Bore X Stroke (mm)	87.5 x 110
Compression Ratio	17.5:1
Variable compression ratio	12 to 18
Cooling System	Water Cooled
Dynamometer	Eddy current
Piezo sensor	Range 5000 PSI, with low noise cable
Crank angle sensor	Resolution 1 Degree, Speed 5500 RPM with TDC pulse
Load sensor	type strain gauge, range 0-50 Kg
Cubic Capacity	661cc
Air flow transmitter	Pressure transmitter, Range (-) 250 mm WC
Inlet Valve Open (Degree)	4.5 BTDC
Inlet Valve Closed (Degree)	35.5 ABDC
Exhaust Valve Open (Degree)	35.5 BBDC
Exhaust Valve Closed (Degree)	4.5 ATDC
Fuel Injection Timing (Degree)	26 BTDC

The engine is to be started by hand lever. 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. The schematic diagram of the experimental setup with all instrumentation is shown in Figure 3.1.

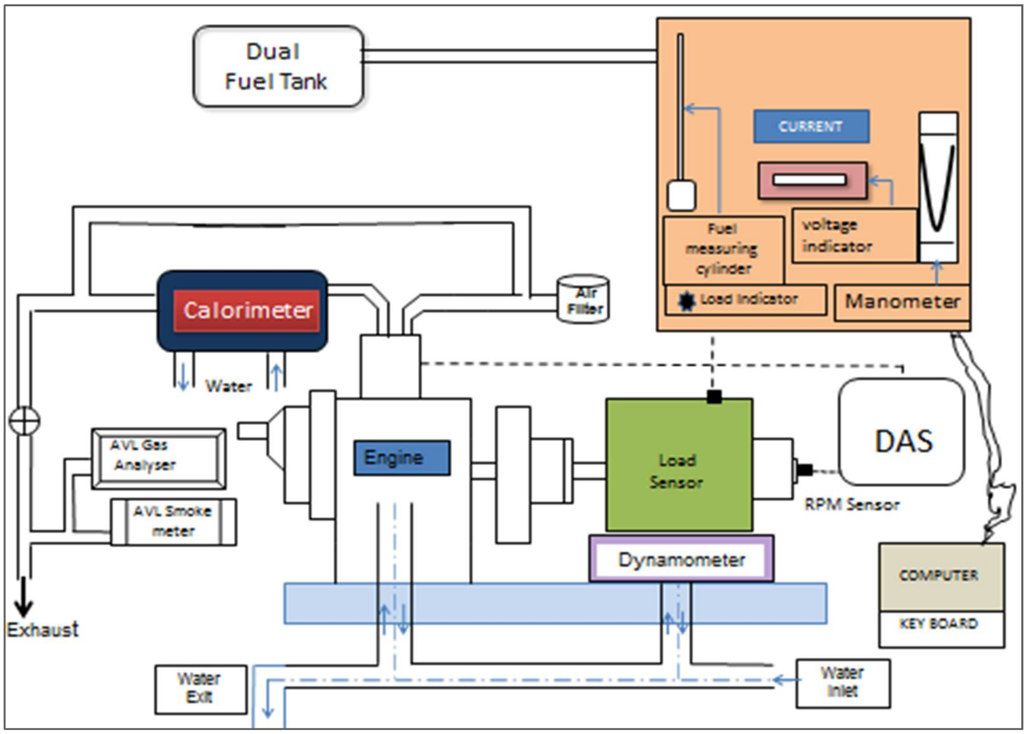


Fig. 3.1 Schematic Diagram of the Experimental Set Up

A voltmeter, ammeter and wattmeter were connected between alternator and load bank. A nut was welded on the flywheel and the photo reflective sensor was mounted on a bracket attached to engine body. The thermocouples were mounted in the exhaust manifold to measure the exhaust temperature. The AVL 437 smoke meter and AVL Di Gas Analyzer were also kept in proximity for the measurements of various exhaust gas parameters.

Thus such a system was chosen to examine the practical utility of mahua oil 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 a water cooled engine it was suitable for hot climate.

3.6 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 analyzer was utilized. This instrument gave reading in terms of percentage opacity. Of the light beam projected across a flowing stream of exhaust gases, a certain portion of light is absorbed or scattered by the suspended soot particles in the exhaust. The remaining portion of the light falls on a photocell, generating a photoelectric current, which is a measure of smoke density. For measurement of UBHC, CO, CO_2 and NOx, AVL 4000 Light Di-Gas Analyzer was used. Both the AVL 437 Smoke meter and AVL Di Gas Analyzer are shown in Plate 3.10.The details of test rig instrumentation are shown in table 3.2.The engine trial was conducted as specified in IS: 10,000.

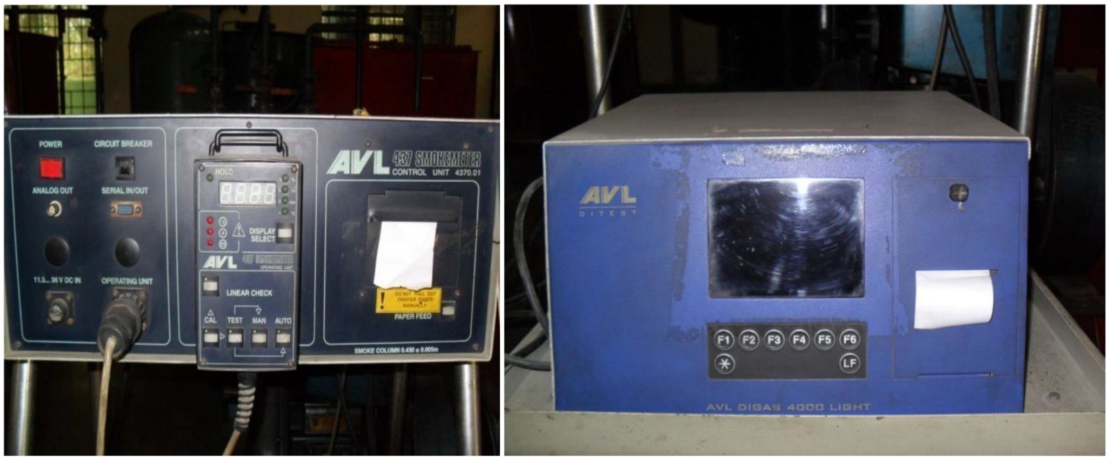


Plate 3.10 AVL Smoke analyzer and AVL Di-Gas Analyzer

Table 3. 2 Test rig specification

S.N	Instrument Name	Measurement Range	Resolution	Measurement Technique	% uncertainty
	AVL DI GAS ANALYSER				
1	CO	0 – 10 % Volume	0.01 %volume	Non dispersive infra-red sensor	0.2%
2	HC	0 – 20.000 ppm Volume.	1ppm	Flame ionization detector-FID	0.2%
3	NO_x	0-5,000 ppm volume	1 ppm	Chemi-luminescence principle, electrochemical sensor	0.2%
	AVL SMOKE METER	**0 - 100%**	**±1 % volume**	**Hatridge principle**	**0.1%**

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. Brake Specific Energy Consumption
3. Brake Mean Effective Pressure
4. Engine speed (Rev/min)
5. Fuel consumption
6. Temperature
7. Exhaust Gas Emissions
8. Exhaust Gas Temperature

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

1. Voltage generated by the alternator
2. Current generated by the alternator
3. RPM of the engine.
4. Fuel consumption rate
5. AVL 437 smoke meter reading
6. AVL Di Gas analyzer reading

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

3.8 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 , CO_2 and power output were also measured. The engine was loaded gradually keeping the speed with in the permissible range and the observations of different parameters were evaluated. The performance and emission characteristics of various blends of mahua oil methyl ester and diesel were evaluated and compared with baseline diesel fuel. The engine was always started with diesel as a fuel and after it was run for 20-25 minutes, it was switches over to mahua oil methyl ester blends. Before turning the engine off, the mahua oil methyl ester was replaced with diesel oil and it was run on diesel oil till all mahua oil methyl ester in fuel filter and pipe line is consumed.

CHAPTER 4

RESULT AND DISCUSSION

4.0 INTRODUCTION

The present study was done on an unmodified VCR diesel engine which run on a dual mode operation. The main objective of the study was to fuel the diesel engine with blends of mahua oil methyl ester and diesel. The combustion, performance and emission studies on various blends were evaluated and compare with the results with baseline diesel fuel.

4.1 Results of physicochemical properties

4.1.1 Gas Chromatograph

Fatty acid profile of the biodiesel was determined by gas chromatography.Figure 4.1 shows the gas chromatogram of mahua oil methyl ester. The peak of the graph indicates retention time. Table 4.1 indicates the composition of different fatty acid present in the mahua oil. The saturated fatty acid in the present biodiesel is higher than the unsaturated fatty acid, so its cetane number is higher; however, this biodiesel has poor cold flow property.

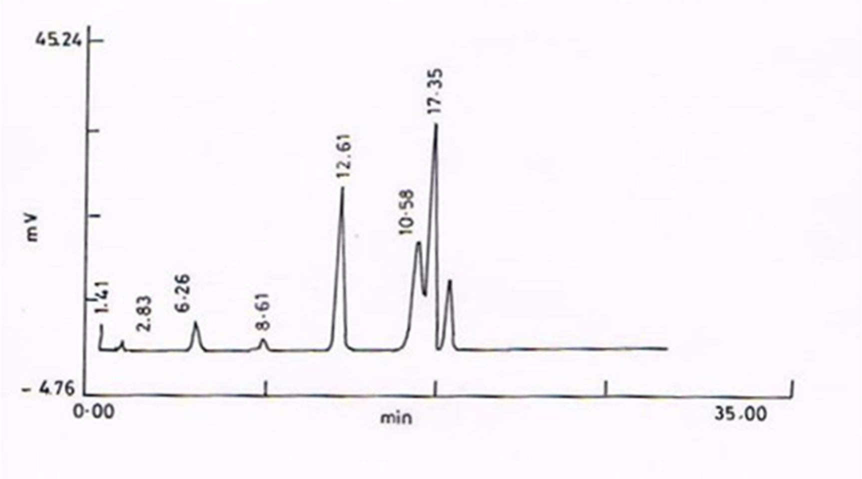


Fig 4.1 Graph obtained from Gas Chromatograph for Mahua oil biodiesel

Table 4.1 Trivial names and percentage composition of fatty acids present in the Mahua oil biodiesel

Trivial Name (C: D)	**Composition (%)**
MYRISTIC ACID (C: 0)	1.14
PALMITIC ACID (C16:0)	24.43
STEARIC ACID (C18:0)	23.47
OLEIC ACID (C18:1)	37.17
LINOLEIC ACID (C18:2)	9.57

4.1.2 Oxidation Stability

The results obtained using Rancimat Test for different blends of Mahua Oil Methyl Esters are obtained in the form of graphs, in between conductivity and time (in hours) is as follows:

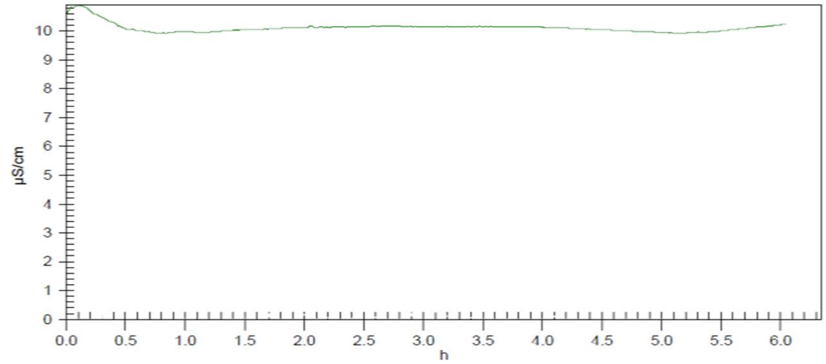


Fig 4.2 Oxydation Stability of M10

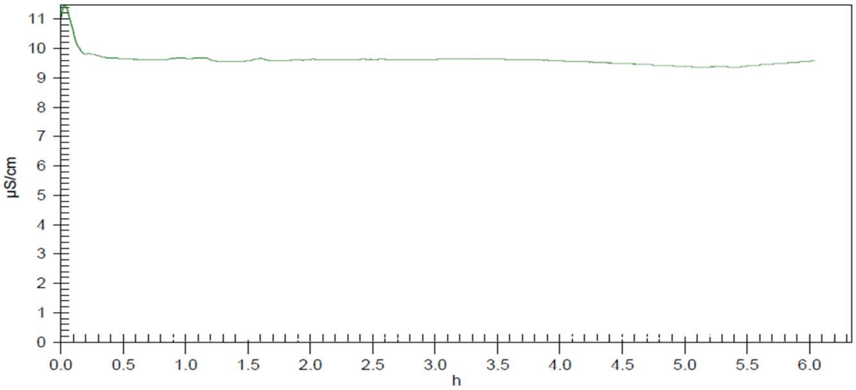


Fig 4.3 Oxydation Stability of M20

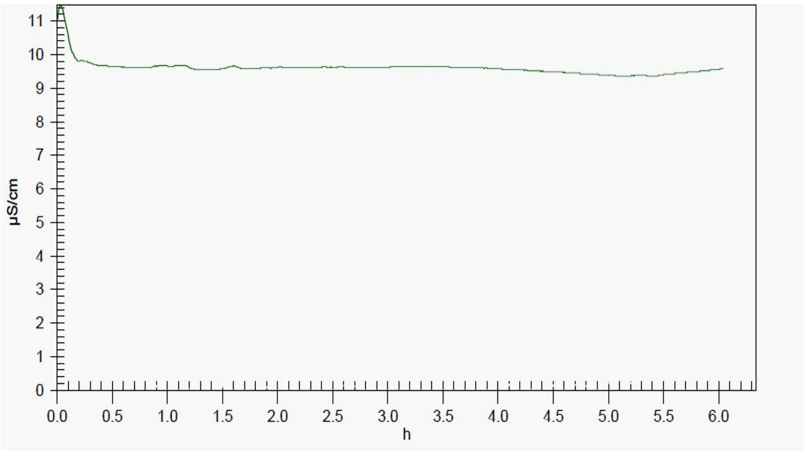


Fig 4.4 Oxydation Stability of M30

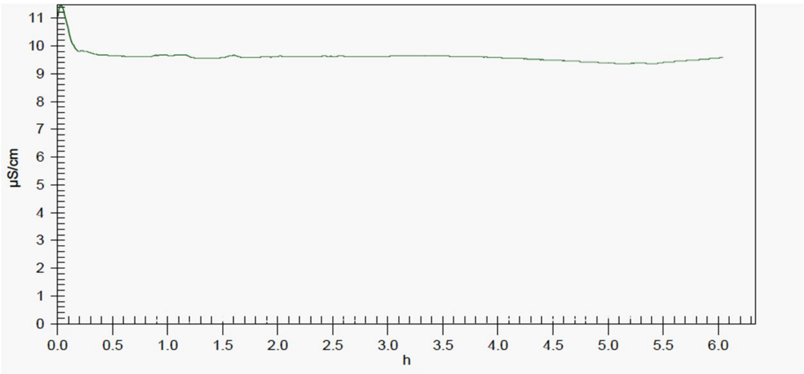


Fig 4.5 Oxydation Stability of M40

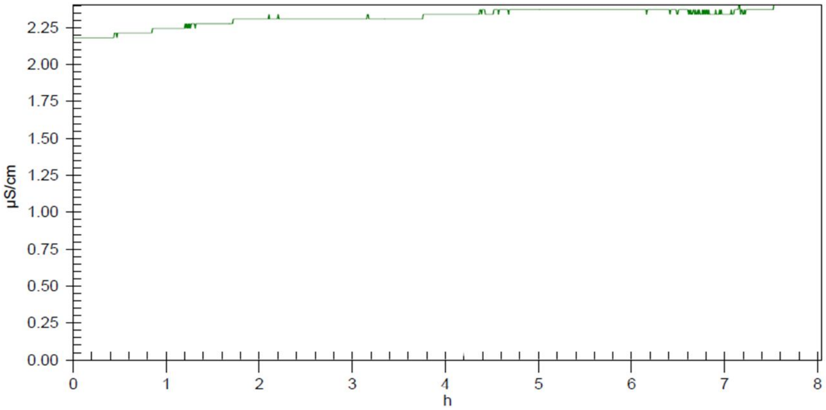


Fig 4.6 Oxydation Stability of M100

Clearly, all the samples prepared passed through IP of 6 hours, satisfying the condition required for Rancimat Induction Test. Hence, the mahua oil methyl Ester can be blended with

Diesel in optimum percentage, as it will maintain its Physico-chemical characteristics, over a certain period of time.

From this experiment it was clear that as oxidation deterioration advances with respect to time. From the above detailed experimental study, it can be concluded that Mahua Oil with wonderful characteristics as a fuel, can be utilized in form of Methyl Ester as it satisfies the parameters and standards like EN-14214, EN-14112 and ASTM standard D-6751 with IP greater than 6 hours.

4.1.3 OTHER PHYSICO-CHEMICAL PROPERTIES

Physico-chemical properties of mahua oil methyl ester and its blend (in different volumetric proportion) with mineral diesel were evaluated using standard test facilities Neat mahua oil biodiesel has lower calorific value than that of mineral diesel but having high viscosity and density. The different blends prepared are as follows: D 100(mineral diesel), M 10 (10 % mahua biodiesel and 90 % pure diesel), M 20 (20% mahua biodiesel and 80 % pure diesel), M 30 (30% mahua biodiesel and 70 % pure diesel), M 40 (40% mahua biodiesel and 60 % purediesel) and M100 (neat mahua biodiesel).Kinematic viscosity and density increases with increase in percentage of biodiesel. But lower calorific value decreases as biodiesel content increases in the mixture, due to the presence of oxygen in the fuel and it requires more fuel to be burnt for a particular heat release. The Physico-chemical properties evaluated in respect of different blends are summarized in Table 4.2

Table 4.2 Physico-chemical properties of different blends of diesel and Mahua biodiesel

Properties(unit)	D 100	M 10	M 20	M 30	M 40	M 100	ASTM Method
Density(kg/m^3)	827	828.43	831.56	838.50	839.86	876.67	D-4052
Kinematic viscosity at 40ºC (centistokes)	2.8	3.20	3.36	3.65	3.70	5.85	D-445
Calorific value (MJ/Kg)	45.486	44.769	44.112	43.718	43.357	39.281	D-4809
CFPP Result (ºC)	-14	-12	-7	1	5	8	

4.2 PERFORMANCE CHARACTERISTICS

Various performance characteristics were analyzed for different test fuels and they are summarized in this section. The results obtained for different blends of mahua oil methyl ester and diesel are compared with baseline diesel fuel.

4.2.1 BRAKE THERMAL EFFICIENCY (BTE)

The variation in brake thermal efficiency (BTE) is shown in Fig 4.7. From the experimental tests result it is observed that there is slight decrease in BTE for all the blends. At full load condition, the BTE is 1.2%, 3.2%, 6.2%, 7.3%, and 9.6% lower for M10, M20, M30, M40 and M 100 compare to diesel. This is due to the fact that biodiesel have higher viscosity and lower heating value than diesel fuels. Reduction in lower calorific value and high viscosity cause improper atomization of the blends as compared to diesel fuel. Also BTE is found to decrease because of increase in fuel consumption rate compare to baseline diesel fuel. These results are in agreement with the result obtained by Agrawal et al. (2013) [59] and Chauhan et al (2012) [61].

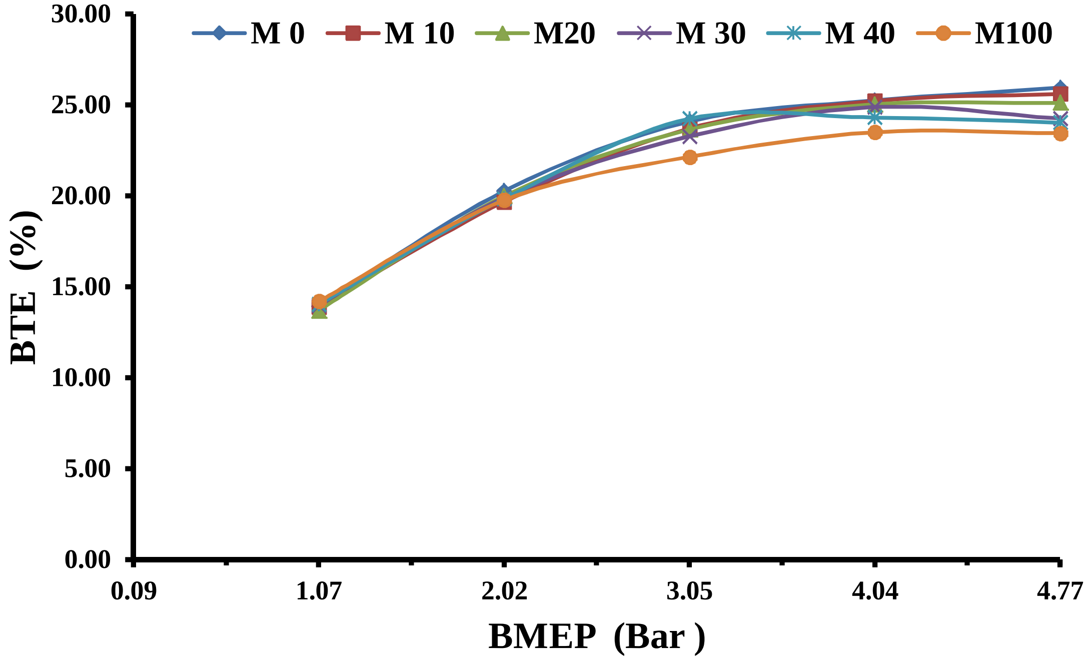


Fig4.7 Effect of BMEP on BTE

4.2.2 BRAKE SPECIFIC ENERGY CONSUMPTION (BSEC)

Brake specific energy consumption (BSEC) measures the amount of input energy required to develop one-kilo watt power. The BSEC is an important parameter of an engine because it takes care of both mass flow rate and heating value of the fuel. Basic specific energy consumption is an essential and ideal parameter for comparing engine performance of the fuels having different calorific value and density. Fig 4.8 shows the variation of BSEC for neat diesel and mahua oil biodiesel blends. It is observed that the BSEC is lower for D100as compared to all the blends of mahua biodiesel. At full load condition, the BSEC is lowest for D100 (13.88 MJ/Kwh) and highest for M100 (15.36 MJ/Kwh). These results are similar with the results obtained by Adaileh et al. [44] and Chauhan et al (2012) [60].

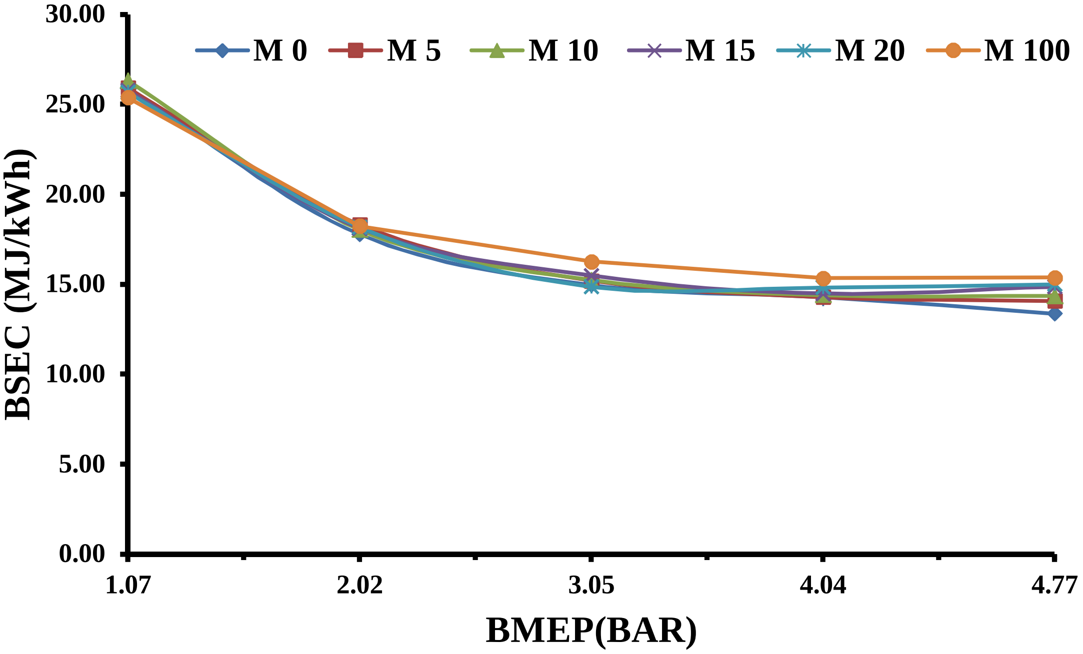


Fig 4.8 Effect of BMEP on BSEC

4.2.3 EXHAUST TEMPERATURE

Fig. 4.9 shows the variation of exhaust temperature with brake mean effective pressure of diesel fuel and Mahua biodiesel and its blends. It shows that the exhaust gas temperature increased with increase in load in all cases. The highest value of exhaust gas temperature of 612^{o}C was observed with the M100, whereas the corresponding value with diesel was found to be 570^o C. This is due to the poor combustion characteristics of the mahua biodiesel and its blends because of its viscosity variation and lower heating value. These results are in agreement with the result obtained by Agrawal et al. (2013) [59] and Chauhan et al (2012) [60].

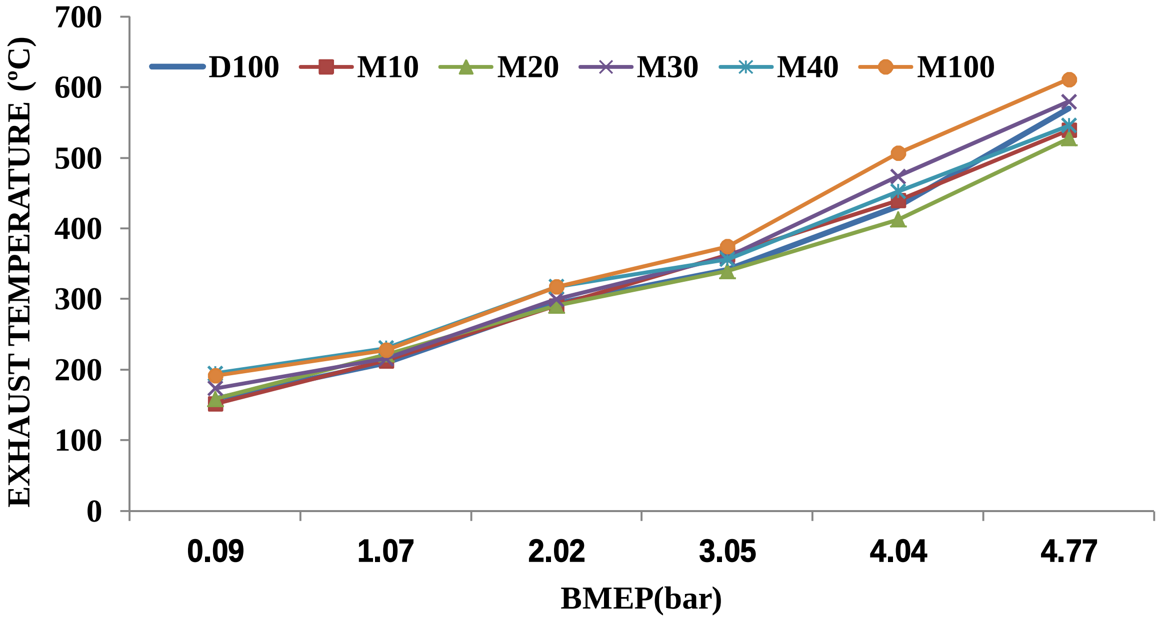


Fig 4.9 Effect of BMEP on Exhaust Temperature

4.3 EMISSION CHARACTERISTICS

The emission characteristics of various blends of mahua oil biodiesel and diesel are summarized in this section. Main exhaust emissions are CO, UBHC, NO_x and smoke opacity.

4.3.1 CO EMISSION

The variation of carbon monoxide (CO) emission of blends of diesel and Mahua oil biodiesel is shown in Fig 4.10. It has been observed that the CO emission is lower for all the blends of mahua oil methyl ester than that of neat diesel. The CO emissions are found to be increasing with increase in load since the air-fuel ratio decreases with increase in load such in internal combustion engines. The engine emits less CO using biodiesel blends as compared to that of diesel fuel under all loading conditions. With increasing biodiesel percentage, CO emission level decreases as amount of oxygen content in biodiesel helps in complete combustion and proper oxidation. The higher cetane number of blend as compared to that of mineral diesel is also one of the reasons of better combustion. For the experimental investigation it has been found that M100 has lowest CO emission than other blends and baseline diesel fuel. At part load condition variation in CO emission for all the blends and baseline diesel is insignificant however, at full load condition diesel has 38.8 % more CO emission than neat mahua oil methyl ester i.e. M100. These results are in confirmation with the result by], Nabi et al (2009) [47] and Godiganur et al (2009) [61].

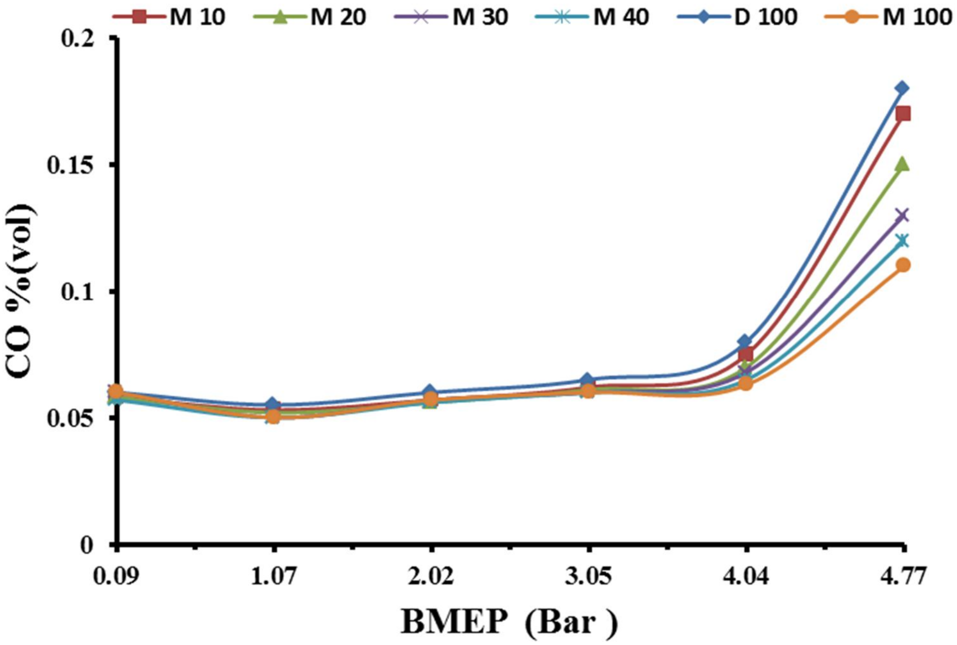


Fig4.10 Effect of BMEP on CO

4.3.2 HYDROCARBON (HC)

The HC emissions of different blends are shown in Fig.4.11. It is found that the hydrocarbon (HC) emission is lower for all the blends of mahua oil methyl ester as compared to neat diesel fuel. As percentage of biodiesel increase in the blend, HC emission decreases. At peak load condition Variation in HC is 58, 55, 52, 50, 45, and 42 ppm respectively for D100, M10, M20, M30, M40 and M100 respectively. However, at part load condition the variation is comparable for all the blends of mahua biodiesel and diesel compare to the baseline diesel fuel. The significant decrease in HC emission is due to the complete combustion as the oxygen content in M100 enhances the combustion process to form CO_2. This result is in confirmation with the result obtained by Labeckaset al (2006) [41], Kumar et al (2008) [42], and Yang et al(2012) [45].

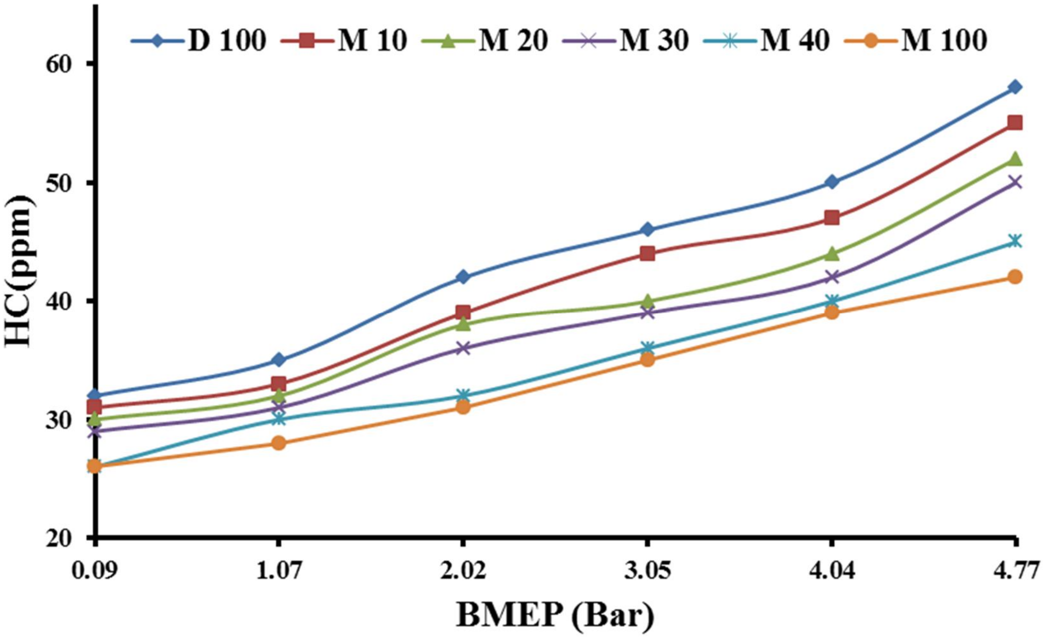


Fig 4.11 Effect of BMEP on HC

4.3.3 NITROGEN OXIDE (NO_X)

The NOx values as parts per million (ppm) for different fuel blends of diesel and M100 in exhaust emissions are plotted in Fig 4.12. The amount of NOx produced at peak load condition for D100, M10, M20, M30, M40 and M100 are 650, 700, 750, 810 and 832 ppm respectively. From this Fig 4.12 it can be seen that the increasing proportion of biodiesel in the blends was found to increase NOx emissions slightly when compared with that of pure diesel. This could be attributed to the increased exhaust gas temperatures and the fact that biodiesel had some oxygen content in it which facilitated NOx formation. In general, the NOx concentration varies linearly with the load of the engine. NOx emissions are a direct function of engine loads. With increasing load, the temperature of the combustion chamber increases and NOx formation is enhanced because NOx formation is strongly dependent on the temperature. Another point is that the NOx emissions of biodiesel are higher than diesel fuel in spite of any blending rates. This is in accordance with their port on biodiesel from National Biodiesel Board of USA.As the load increases, the overall fuel-air ratio increases resulting in an increase in the average gas temperature in the combustion chamber and hence NOx formation, which is sensitive to temperature increase. This result is in consistent with the results obtained by Nabi et al (2009) [47] and Adaileh et al (2012) [61].

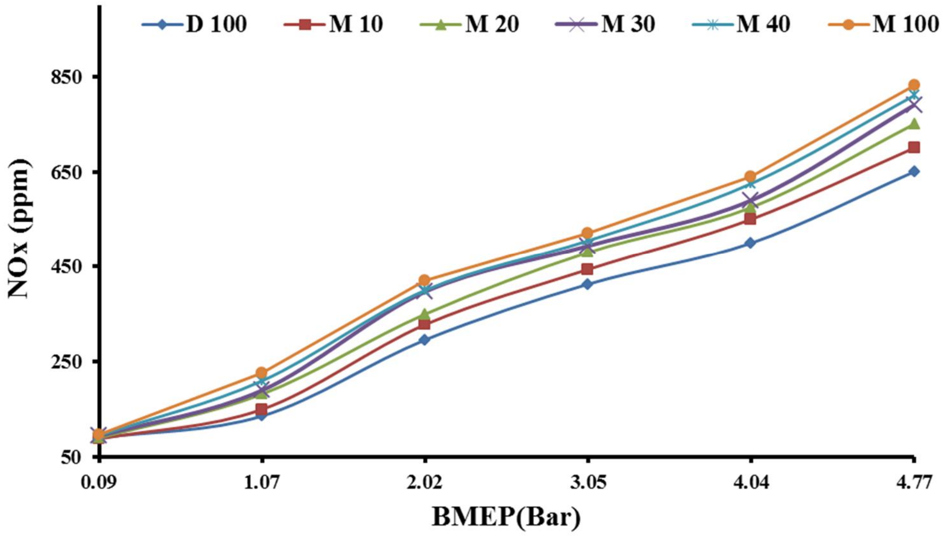


Fig 4.12 Effect of BMEP on NOx

4.3.4 SMOKE OPACITY

The highest smoke emissions of all fuels are obtained at high loads (Fig. 4.13), thus the formation of smoke strongly depends upon the engine load. As the load increases, more fuel is injected, causing an increase of diffusion combustion duration. This reduces the oxidation of soot during the expansion stroke because there is less time after the end of diffusion combustion and there is also less oxygen. Thus, higher loads lead to a higher formation of smoke. At almost all engine loads, the smoke decreases with a higher content of biodiesel. This is due to the complete and stable combustion of the biodiesel, which contains more number of oxygen atoms. This occurs due to longer ignition delay period (keeping all parameters constant) because of more fuel injection before ignition, higher temperature in the cycle and earlier termination of combustion process. The residence time is therefore increased. All these factors have found to reduce smoke opacity in exhaust. However, earlier injection may results in more combustion noise and nitrogen oxide emission. This result is in confirmation with Agrawal et al (2008) [62] and Sayin et al (2010) [63].

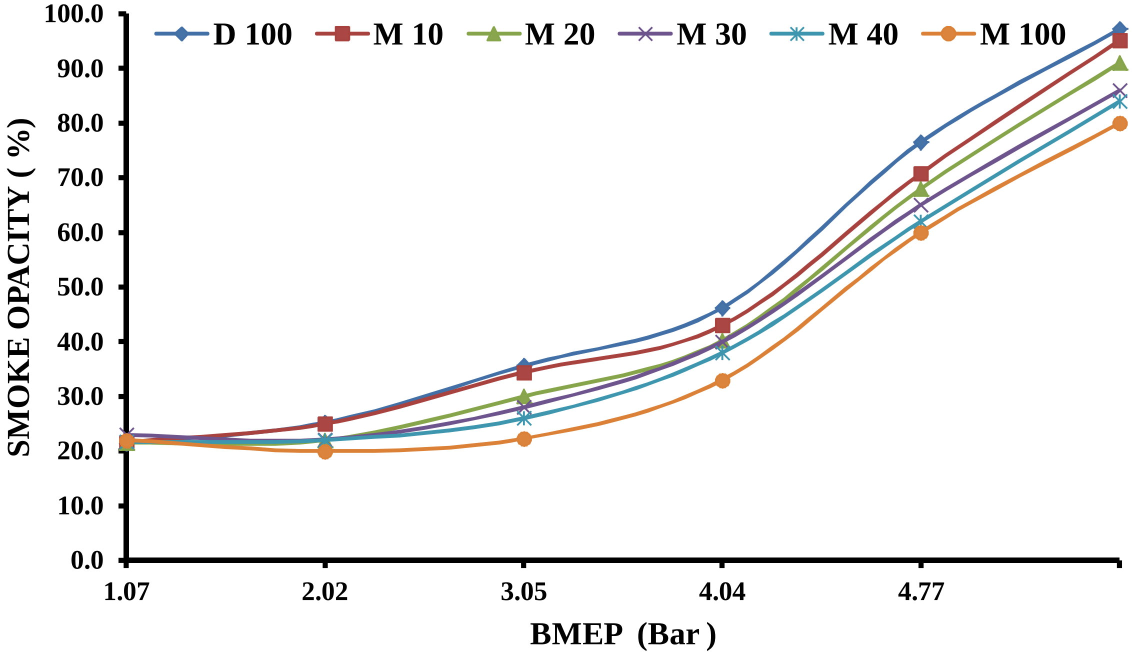


Fig 4.13 Effect of BMEP on Smoke Opacity

4.4 COMBUSTION ANALYSIS

4.4.1 ESTIMATION OF THE EXPERIMENTAL HEAT RELEASE RATE

For each operating condition, 91 engine pressure cycles were recorded, and the mean cylinder pressure trace was estimated. Evaluation of cyclic heat release is very much significant for combustion study. Various heat release models have been developed by researchers for determining critical combustion parameters like heat release rate, pressure rise rate etc. In the present study Sorenson's [68] zero dimensional heat release model was used for heat release characterization. It is a thermodynamic model based upon energy conservation principle.

Neglecting the heat loss through piston rings [69] the energy balance inside the engine may be written as

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

Now the universal gas equation is given by

$$\mathbf{PV = mRT} \qquad (2)$$

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

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

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

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

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

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

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

The heat transfer coefficient “h”was evaluated by using the correlation formula given by Woschni [69].

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

Here w is the average cylinder gas velocity .Cp and C_V is specific heat and is temperature dependent parameters. The primary data used for heat release calculation was the pressure crank angle data obtained during experiment. Equation (5) was used for the determination of heat release rate. Pressure rise rate and cumulative heat release was calculated by standard mathematical operations in the HRR spread sheet database.

4.4.2 COMBUSTION CHARACTERISTICS

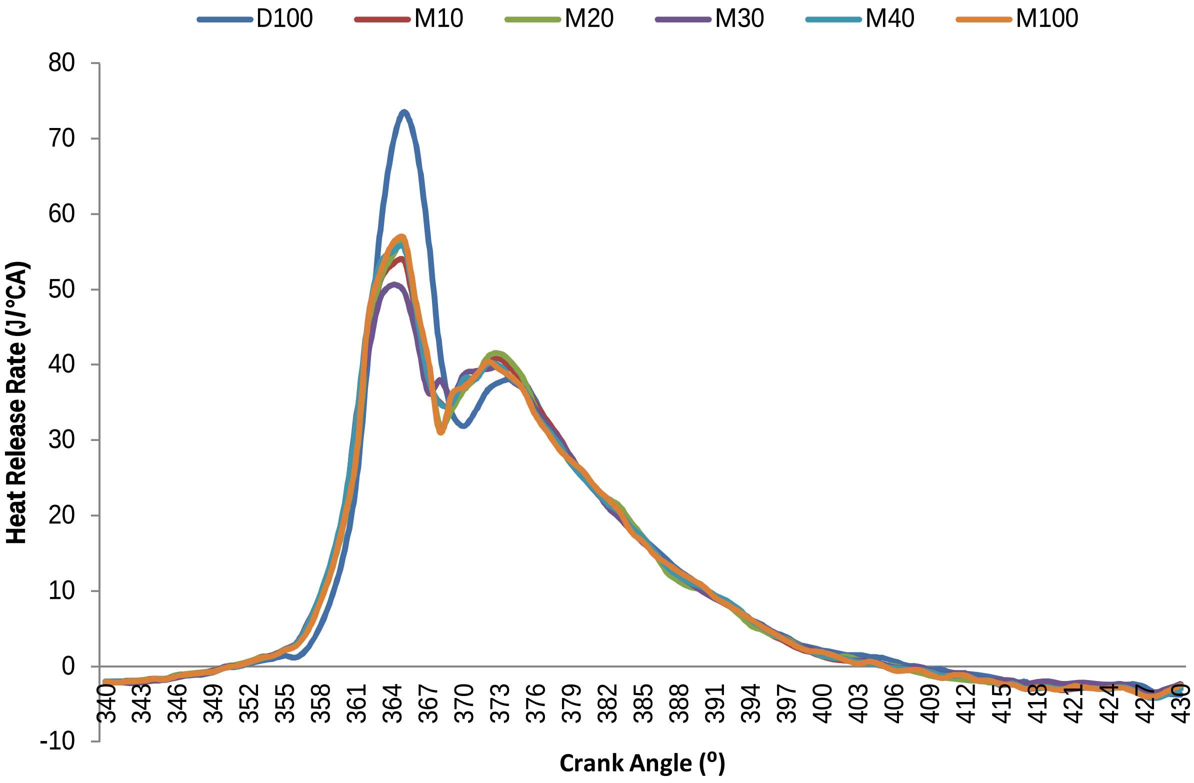


Fig 4.14 Heat Release Rate

Analysis of combustion characteristic of Mahua biodiesel and diesel were carried out in the subsequent phase of investigation. It is clear from Figs. 4.14 and 4.15 that ignition of fuel starts earlier for 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 correspond to large amount of fuel burnt in premixed combustion stage. Combustion duration for mineral diesel is found to be lower than M30, M40 and M100 blends. However, M10 and M20 blend showed lower combustion duration than that of diesel fuel. This may be due to the lower exhaust temperature of M10 and M20 blends compare to baseline diesel. Whereas other blends including neat mahua methyl ester showed higher exhaust temperature.

Higher cetane index of Mahua biodiesel 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 onset of combustion. Rapid premixed burning followed by diffusion combustion is typical for naturally aspirated diesel engines. Fuel injection was observed to start at 337º in engine cylinder and crank angle corresponding to heat release rate is about 5 º of the peak heat release. Crank angle difference between injection of fuel and heat release rate is equivalent to 5 % of peak heat release rate. Ignition delay for D100 is found at 10.5º CA while for neat mahua oil methyl ester it is 7ºCA. However for M10, M20, M30 and M40 ignition delay varied from 7.3º, 8º, 9.2º and 10º CA respectively.

After the ignition delay period, the premixed fuel air mixture burns rapidly releasing heat at a very rapid rate, after which diffusion combustion takes place, where the burning rate is controlled by the availability of combustible fuel-air mixture.

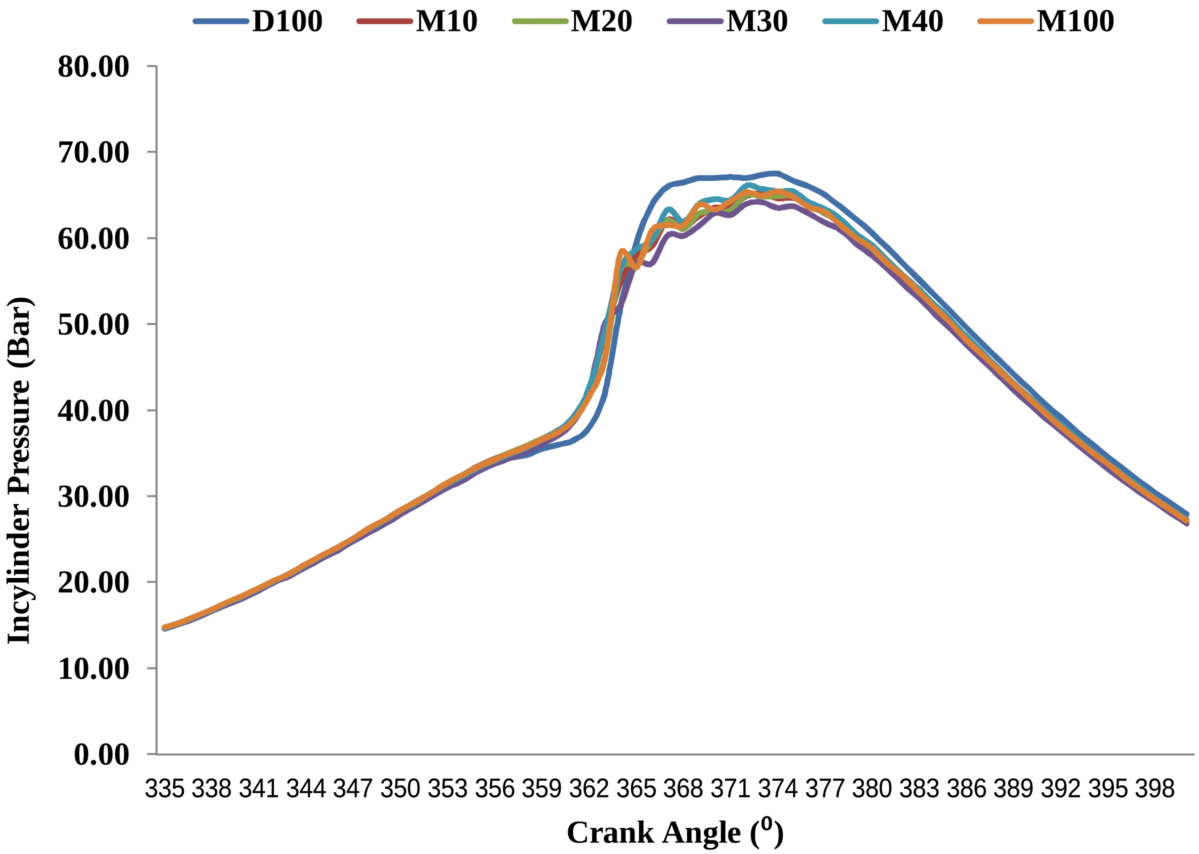


Fig 4.15 variation of In-cylinder pressure (Bar)

The ignition quality of a fuel is usually characterized by its cetane number or cetane index. Higher cetane index/number generally means shorter ignition delay. In the entire set of test, it was found that biodiesel has higher cetane index 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 diesel, which is responsible for higher peak pressure and higher rate of pressure rise in comparison to biodiesel. The ignition delay also 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 occur. This result is in accordance with Agrawal et al [59] and Chauhan et al [61].

CHAPTER 5

CONCLUSION AND SCOPE FOR FUTURE WORK

5.0 CONCLUSION

In the present study, the experiments were conducted using blends of mahua oil methyl ester and diesel. Subsequently combustion, performance, and emission studies were carried out .

Based on the experimental results, the following major conclusions have been drawn:

1. Full load brake thermal efficiency was found to decrease with increase in MOME percentage in the blend due to lower heating value of biodiesel. Full load BTE of M10 was found very near to baseline data of diesel.
2. Brake specific energy consumption of 13.88 MJ/kWh was observed for diesel at full load. With increase in percentage of MOME in the blend, a steady increase in BSEC was observed. For M10, BSEC was 14.06 MJ/kWh where as for M100, BSEC was 15.36 MJ/kWh. The BSEC for rest of the blends were in between M10 and M100.
3. Carbon monoxide was found to get reduced with increase in MOME percentage in the blends. At part loads, CO emission was found to be low for all the test fuels, however, substantial increase was observed after 60% load. Reduction in carbon monoxide emissions for higher blends may be attributed to improved combustion of high cetane and oxygenated fuel such as MOME.
4. Hydrocarbon emissions were found to decrease for all the blends of mahua oil methyl ester compared to neat diesel fuelconfirming better combustion characteristics.
5. Due to higher cetane rating of MOME and improved combustion, the in-cylinder temperature was increased resulting in higher NOx emission for blended fuels as compared to baseline data. Full load NOx emission was steeply increased by 23% for

M100 as compared to diesel baseline. Lower blends exhibited marginal increase in NOx emissions.

6. Variation in smoke opacity was insignificant at lower loads for all the test fuels. However, at higher loads, MOME blends showed reduction in smoke opacity as compared to neat diesel operation .
7. Heat release rate was found higher for neat diesel, which is responsible for higher peak pressure and higher rate of pressure rise in comparison to mahua biodiesel. This may be due to the higher exhaust temperature and higher cetane rating of mahua oil biodiesel blends compare to baseline diesel fuel. Higher cetane index of Mahua biodiesel resulting in shorter ignition delay
8. It was observed that even small quantity of Mahua oil in the fuel blend significantly alters the in-cylinder combustion process due to bulk changes in fuel atomization and fuel- air mixing processes.

As a fair conclusion of the exhaustive engine trial, it may be stated that a blending of 40% MOME in diesel will result inbetter engine performance and emissions of HC,CO and smoke opacity .However, emission of NOx was found to get enhanced withaddition of MOME which may be addressed throughadequate catalytic converters. Furthermore Long-term runand wear analysis of biodiesel fueled engine is also necessary along with injection timing and duration for better combustion of biodiesel in diesel engines.

5.1 FUTURE WORK

On the basis of experience gained during the present experimental studies, the following diections are indicated for further investigation and development.

1. Utilization of blends of biodiesel-alcohol-diesel is suggusted for improvement in performance characteristic and NO_x emission.

2. In the present investigation, an unmodified diesel engine was used havig compression ratio 17.5. It is recommended that further work may be carried at variable compression ratios and injection angles.
3. Some computational and simulation analysis may be carried by further researchers..
4. There is urgent need to carry out long term endurance test to access the sutability of mahua oil methy ester on engine hardware.

REFERENCES

[1]. http://planetforlife.com/ assessed on 11 May 2013.

[2]. http://www.publishyourarticles.net/eng/articles/energy-crisis-essay.html assessed on 11 May 2013.

[3]. http://www.preservearticles.com/2011081410495/572-words-sample-essay-on-energy-crisis-worldwide.html assessed on 11 May 2013.

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

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

[6]. Berrios M., Martín M.A., Chica A.F., Martín A., Purification of biodiesel from used cooking oils, Applied Energy 88 (2011) 3625-3631.

[7]. Basic Statistics on Indian Petroleum & Natural Gas, 2011-12, Ministry Of Petroleum & Natural Gas ,Government Of India New Delhi (Economic Division)

[8]. BP Statistical Review Of World Energy 2012.

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

[10]. 12th five year plan, Government Of India.

[11]. http://www.mnre.gov.in/mission-and-vision-2/achievements/ accessed on June 10, 2013.

[12]. World energy outlook, IEA 2013

[13]. http://webtv.accuweather.com/en/home-garden-articles/earth-and-you/ozone-hole-shrinks-to-record-l/6058589. Accessed on June 15, 2013.

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

[15]. http://en.wikipedia.org/wiki/Ozone_depletion accessed on 15th June 2013.

[16]. http://www.nmsea.org/Curriculum/Primer/Global_Warming/fossil_fuels_and_global_warming.htm Accessed on 15th June 2013.

[17]. http://www.worldbank.org/en/topic/climatechange/overview accessed on 15th June 2013.

[18]. http://ralphdeeds.hubpages.com/hub/Global_Warming__Where_we_are_now accessed on 15th June 2013.

[19]. Dr. Kerr Casper; Global warming: Green house gases; ISBN 978-1-4381-2740-8 (ebook), 2009

[20]. http://www.carboncalculator.co.uk/effects.php accessed on June 20, 2013.

[21]. http://co2now.org accessed on June 20, 2012

[22]. http://timesofindia.indiatimes.com/business/india-business/Demand-for-diesel-falls-amid-slowdown/articleshow/20672793.cms? Accessed on June 20, 2013.

[23]. http://www.livemint.com/Politics/F5G9nfaQUUvGvMe5qH3xbM/Petrol-consumption-may-decelerate-in-FY12.html accessed on June 20, 2013.

[24]. Edward Crabbe, Nolasco-HipolitoCirilo and Genta Kobayashi; Biodiesel production from crude palm oil and evaluation of butanol extraction and fuel properties; Process Biochemistry, Vol-37, pp 65-71, 2001

[25]. Naveen Kumar, SachinChugh and Vijay Kumar; Biodiesel – A Bridge for Sustainable Development for India; proceedings of International Conference on “Energy and Environment-Strategies for Sustainable Development”, JamiaMiliaIslamia, Delhi, 2004.

[26]. C. L. Peterson, M. E. Casada, L. M. Safley and J. D. Broder; Potential Production of Agriculture Produced Fuels; Applied Engineering in Agriculture, Vol-11, pp 767-772, 1995.

[27]. A. Farsaie, J. V. Debarhte and W. J. Kenworthy; Analysis of producing the vegetable oil as an alternate fuel; Energy in Agriculture, Vol-4, pp 189-205, 1985.

[28]. T.Eseji, N Qureshi, H.P.Bleschek; Production of acetone- butanol-ethanol (ABE) in a continuous flow bioreactor using degemed corn and clostridium beijernickii; process Biochemistry, Vol-42,pp 34-39, 2007.

[29]. A.G.Souza, H.J.Danta, M.C.D. Silva, I.M.G. Santos, V.J. Fernandesjr, F.S.M. Sinfronio, L.S.G. Teixeira and C.S.Novak, Thermal and kinetic evaluation of cotton oil biodiesel; Journal of Thermal Analysis, Vol-90, Issue:3;pp 945-949,2007.

[30]. Angelo C. PintoI; Lilian L. N. Guarieiro; Michelle J. C. RezendeI; Núbia M. Ribeiro; Ednildo A. Torres; Wilson A. Lopes; Pedro A. de P. Pereira; Jailson B. de Andrade; Biodiesel: an overview; Journal of the Brazilian Chemical Society;Vol. 16, No. 6B, 1313-1330, 2005.

[31]. A.K. Agarwal; Biofuels(alcohols and biodiesel) applications as fuels for internal combustion engines; Progress in Energy and Combustion Science, Vol-3,pp 233-271,2007.

[32]. http://www.crimsonrenewable.com/specs.php accessed on JUNE 23, 2013.

[33]. J. Roy Crookes, FarriborzKiannejad and A. A. NazhaMarouan; Systematic assessment of combustion characteristics of biofuels and emulsions with water for use as diesel engine fuel; Energy Conversion & Management, Vol-38, pp1785-1795, 1997.

[34]. Yousaf Ali Hana and M. A. Khan; Alternative diesel fuels from vegetable oils, Bioresource Technology, Vol-50, pp 153-163, 1994.

[35]. http://www.scientificpsychic.com/fitness/fattyacids.html accessed on June 22,2013.

[36]. W Thomas Ryan and O. MaurinBagby; Identification of chemical change occurring during the transient injection of selected vegetable oils; SAE-paper No. 930933, pp 201-210, 1993.

[37]. S. M. Geyer, M. J. Jacobus and S. S. Lestz; Comparison of diesel engine performance and emissions from neat and transesterified vegetable oils; ASAE, Vol-27, pp 375-381, 1984.

[38]. M. A. Fangrui and A Milford Hanna; Biodiesel Production: A Review; Bioresource Technology, Vol-70, pp 1-15, 1999.

[39]. A. Demirbas; Biodiesel A Realistics Fuel Alternative for Diesel Engines, Springer-verlag London Limited, e-ISBN 978-1-84628-995-8 9ebook0,2008.

[40]. G. Knothe, R.O. Dunn and M. O. Bagby; Biodiesel: The use of vegetable oils and their derivatives as alternative diesel fuels. Biodiesel News Letter published by Central Pollution Control Board, New Delhi. ACS Symposium Series, 666, pp 172-208, 1997.

[41]. Labeckas Gvidonas, SlavinskasStasys. The effect of rapeseed oil methyl ester on direct injection Diesel engineperformance and exhaust emissions. Energy Conversion andManagement 47 (2006) 1954-1967.

[42]. Kumar K. Suresh, Velraj R., Ganesan R. Performance and exhaust emission characteristics of a CI engine fueled with Pongamiapinnata methyl ester (PPME) and its blendswith diesel. Renewable Energy 33 (2008) 2294-2302.

[43]. LapuertaMagín, Armas Octavio, Rodríguez-Fernández José. Effect of biodiesel fuels on diesel engine emissions.Progress in Energy and Combustion Science 34 (2008)198-223.

[44]. Adaileh Wail M. and AlqdahKhaled S. Performance of Diesel Engine Fuelled by a Biodiesel Extracted From AWaste Cocking Oil, Energy Procedia 18 (2012) 1317-1334.

[45]. An H., Yang W.M., Chou S.K., Chua K.J. Combustion and emissions characteristics of diesel engine fueled bybiodiesel at partial load conditions Applied Energy 99 (2012)363-371.

[46]. Qi D.H., Geng L.M., Chen H., BianY.ZH., Liu J., Ren X.CH. Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crudeoil, Renewable Energy 34 (2009) 2706-2713.

[47]. NurunNabi Md., Rahman Md. Mustafizur, Akhter Md. Shamim, Biodiesel from cotton seed oil and its effect onengine performance and exhaust emissions, Applied ThermalEngineering 29 (2009) 2265-2270.

[48]. Hoekman S. Kent, Robbins Curtis Review of the effects of biodiesel on NOx emissions Fuel Processing TechnologyVolume 96, April 2012, Pages 237-249.

[49]. Hoekmana S. Kent, Brocha Amber, Robbinsa Curtis, Cenicerosa Eric, Natarajanb Mani, Review of biodieselcomposition, properties, and specifications Renewable andSustainable Energy Reviews Volume 16, Issue 1, January2012, Pages 143-169.

[50]. Yanowitz Janet, McCormick Robert L., Effect of biodiesel blends on North American heavy-duty diesel engineemissions European Journal of Lipid Science and TechnologyVolume 111, Issue 8, pages 763-772, No. 8 August 2009.

[51]. D.H. Qi , H. Chen, L.M. Geng, Y.ZH. Bian, X.CH. Ren, Performance and combustion characteristics of biodiesel–diesel–methanolblend fuelled engine, Applied Energy 87 (2010) 1679–1686

[52]. K. Muralidharan , D. Vasudevan, Performance, emission and combustion characteristics of a variablecompression ratio engine using methyl esters of waste cooking oil and diesel blendsApplied Energy 88 (2011) 3959–3968.

[53]. P.K. Sahoo, L.M. Das , Combustion analysis of Jatropha, Karanja and Polangabased biodiesel as fuel in a diesel engine, Fuel 88 (2009) 994–999

[54]. P.K. Devan , N.V. Mahalakshmi, A study of the performance, emission and combustion characteristics of a compression ignition engine using methyl ester of paradise oil–eucalyptus oil blend, Applied Energy 86 (2009) 675–680.

[55]. L. Labecki, A. Cairns, J. Xia, A. Megaritis, H. Zhao, L.C. Ganippa, Combustion and emission of rapeseed oil blends in diesel engine, Applied Energy 95 (2012) 139–146

[56]. Yi Ren, Zuohua Huang , Haiyan Miao, Yage Di, Deming Jiang, KeZeng,Bing Liu, Xibin Wang, Combustion and emissions of a DI diesel enginefuelled with diesel-oxygenate blends, Fuel 87 (2008) 2691–2697

[57]. S.S. Gill, A. Tsolakis , K.D. Dearn , J. Rodríguez-Fernández , Combustion characteristics and emissions of Fischere-Tropsch diesel fuels in IC engines, Progress in Energy and Combustion Science 37 (2011) 503-523.

[58]. M.Y.E. Selim , M.S. Radwan , S.M.S. ElfekyCombustion of jojoba methyl ester in anindirect injection diesel engine, Renewable Energy 28 (2003) 1401–1420.

[59]. Avinash Kumar Agarwal, AtulDhar, Experimental investigations of performance, emission and combustioncharacteristics of Karanja oil blends fuelled DICI engine, Renewable Energy 52 (2013) 283-291

[60]. Bhupendra Singh Chauhan , Naveen Kumar , HaengMuk Cho,A study on the performance and emission of a diesel engine fueled with Jatrophabiodiesel oil and its blends, Energy 37 (2012) 616-622

[61]. Godiganur, Sharanappa b Murthy C.H. Suryanarayana, Reddy RanaPrathap 6BTA 5.9 G21 Cummins engineperformance and emission tests using methyl ester mahua(Madhuca indica) oil/diesel blends, Renewable Energy 34(2009) 2172-2177.

[62]. Agarwal Deepak, Kumar Lokesh, AgarwalAvinash Kumar, Performance evaluation of a vegetable oil fuelled compressionignition engine, Renewable Energy 33 (2008)1147-1156.

[63]. Ng HoonKiat, GanSuyin Combustion performance and exhaust emissions from the non pressurised combustion of palm oil biodiesel blends, Applied Thermal Engineering 30(2010) 2476-2484.

[64]. JFaletti, S. C. Sorenson, C. E. Goering. “Energy release rates from hybrid fuels”.
Transactions of the ASAE (1984); 27(2): 322-325.

[65]. Z.HHuang, D.MJiang, K. Zeng, B. Liu, Z.LYang. “Combustion characteristics and heat release analysis of a DI compression ignition engine fueled with diesel-dimethyl carbonate blends”. ProcInstMechEng, Part D, J Automobile Eng (2003); 217(D7):595–606.

[66]. Heywood JB. Internal combustion engine fundamentals. New York: McGraw-Hill Book Company; 1988.

ANNEXURE 1

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

Brake Thermal Efficiency (η_{th}):

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

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

Where:

η_{th} = thermal efficiency;

BP = brake power [kW];

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

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

ρ = relative density of fuel [kg/L].

Brake Fuel Energy Consumption:

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

Where:

m_f= mass flow rate [Kg/sec];

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

BP = brake power [KW].

ANNEXURE 2
List of Publications

S.N.	Title Of The Paper	Name of The journal/ Proceeding	Date Of Issue	Single/ Joint
Papers In Journal				
1	An Experimental Investigation on Performance and Emission Studies of a Single Cylinder Diesel Engine Fuelled with Blends of Diesel and Mahua oil Methyl Ester	SAE International Paper id: 13SDP-0056/2013-01-1041.	April, 8,2013	Joint
2	Performance Evaluation and Emission Studies of a Single Cylinder diesel Engine fuelled with Isopropyl Alcohol and Diesel	SAE International Paper id: 13PFL-1015/2013-01-1132	April, 8,2013	Joint
3	Experimental investigation of Diesel engine fueled with Jatropha oil blend with ethanol	SAE Journal of Fuel and Lubricants Paper id:2013-24-0105	Approved for Publication	Joint
	Experimental Investigation of Orange Peel oil methyl Ester on Single cylinder Diesel Engine	SAE Journal of Fuel and Lubricants Paper id: 2013-24-0171	Approved for Publication	Joint
Papers In Conferences				
3	An Experimental Investigation on Performance and Emission Studies of a Single Cylinder Diesel Engine Fuelled with Blends of Diesel and Mahua oil Methyl Ester	SAE World Congress, 2013,!6-18th April,2013, Detroit, USA	April, 8,2013	Joint
4	Performance Evaluation and Emission Studies of a Single Cylinder diesel Engine fuelled with Isopropyl Alcohol and Diesel	SAE World Congress, 2013,16-18th April,2013, Detroit, USA	April, 8,2013	Joint
5	Mahua oil: As a potential feedstock of biodiesel production	Proceedings of 1st International Conference on Innovative Technologies in Mechanical Engineering, KIET, Ghaziabad Paper id: ITME201227	August 17,2012	Joint
6	Preparation and Characterisation of Nanofuel: A future potential Nano Energetic Fuel	Proceedings of 1st International Conference on Innovative Technologies in Mechanical Engineering, KIET, Ghaziabad Paper id: ITME201226	August 17,2012	Joint

7	Potential Utilization of Higher Alcohols in Unmodified Diesel Engine	ASME 2013 International Mechanical Engineering Congress & Exposition	Approved for publication	Joint
9	Experimental investigation of Diesel engine fueled with Jatropha oil blend with ethanol	11th International Conference on Engines & Vehicles The Use of Non-Traditional Fuels in Engines	Approved For Publication	Joint
10	Experimental Investigation of Orange Peel oil methyl Ester on Single cylinder Diesel Engine	11th International Conference on Engines & Vehicles Emissions Measurement and Testing	Approved For Publication	Joint
11	Utilization of Blends of Jatropha Oil & N-Butanol in a Naturally Aspirated Compression Ignition Engine	SAE/KSAE 2013 International Power trains, Fuels & Lubricants Meeting Fuel & Additive Effects on CI Engine Performance	Under review	Joint
12	Emission Studies on A VCR Engine Using Stable Diesel Water Emulsion	SAE/KSAE 2013 International Powertrains, Fuels & Lubricants Meeting Fuel & Additive Effects on CI Engine Performance	Under review	Joint
13	Performance Analyses of Diesel Engine at Different Injection Angles Using Water Diesel Emulsion	SAE 2013 AeroTech Congress & Exhibition Environment - Alternative Fuels and Energies	Under review	Joint