

“Utilization of Blends of Biodiesel developed from Jatropha and Karanja in an unmodified diesel Engine – Performance and Emissions Studies.”

**A Major Project Report submitted
Towards the Partial Fulfillment of the Requirements
For the Award of the Degree
Master of Engineering
In
Thermal Engineering**

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11/ME/02**

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CERTIFICATE

This is to certify that the work which is being presented in the dissertation entitled **“Utilization of Blends of Biodiesel developed from Jatropha and Karanja in an unmodified diesel Engine–Performance and Emissions Studies.”** in partial fulfillment of the requirements for the award of degree of **Master of Engineering in Mechanical Engineering** with specialization in **Thermal Engineering**, submitted to the Department of Mechanical Engineering, Delhi College of Engineering, Delhi, is an authentic record of work carried out by Ashish Karnwal , Roll No. 11/ME/02 under my supervision

Further it is also certified that this project has not been submitted to any other institutions/university for the award of any other degree or diploma.

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ACKNOWLEDGEMENT

I express my deep sense of gratitude to my guide **Sh. Naveen Kumar**, Assistant Professor, Mechanical Engineering Department, Delhi College of Engineering, Delhi, for his nurtured vision, unflinching support, encouragement and personal involvement for the successful completion. His valiant efforts, dedicated support & multifunctional approach smoothed the whole process.

I also wish to place my gratitude to Staff, & Laboratory Assistants of Center of Advanced Studies & research in Automotive Engineering, Delhi College of Engineering, Delhi, for assisting me to carry out various Characterization & Engine Testing Experiments in the center. They lend full support to me in performing the experiments and provided all the instruments in best working condition to accomplish the flawless experiments.

I am also thankful to **Dr. Ajay Sharma**, (Director), **Prof. G. S. Sandhu**, (Add. Director), **Sh. Pankaj Kumar**, (Head of Mechanical Engineering Department), faculty members and staff of **Krishna Institute of Engineering and Technology, Ghaziabad** for their whole-hearted support, encouragement and cooperation.

I am also thankful to my friends of Master of Engineering, for their constant support, encouragement and cooperation.

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M.E. (Thermal Engineering)

11/ME /2002

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ABSTRACT

With the stock of fossil fuels diminishing throughout the world and demand for energy based comforts and mobility ever increasing, time is ripe that we strike a balance between energy security and energy usage. Moreover having uplifted to such a sphere of engineering excellence, reverting back to the ages of the bull carts will prove next to impossible thereby compelling us to search for a basket of alternative fuels to derive energy to cater to our needs. Several sources of energy, especially for driving the automotives are being developed and tested. Biodiesel, which is a derivative of vegetable oils, is catching the attention of various nations through its much similar properties to conventional diesel. Biodiesel have the distinct advantages of being renewable, biodegradable, & eco-friendly fuel. Promoting the vision of developed India, by 2020, and envisaging the shortage of fossil fuels, this project ***“Utilization of Blends of Biodiesel developed from Jatropha and Karanja in an unmodified diesel Engine – Performance and Emissions Studies.”*** is just a bead in the garland of projects progressing in this area throughout the world.

The potential of biodiesel derived from Jatropha Curcas & Pongamia Pinnata (‘Honge’ or ‘Karanja’) as a diesel substitute has been explored in this project. They grow in arid & waste lands and needs very little attention. The oil content in both trees is about 30- 40 % (wt %) of the seed (wt) and is non-edible in nature. India is blessed with the environment & type of land required for its growth.

During this study, biodiesel from Jatropha and Karanja Oil were developed. A 50-50% blend by volume of both the biodiesel was prepared to explore the suitability of this blend in a unmodified diesel engine. Further, this blend & Diesel fuel were mixed in varying proportion. The physiochemical characterization of the various samples was done. These samples were than used to fuel a unmodified diesel engine. The results suggest that 20% blends of biodiesel of Jatropha & Karanja oil with Diesel (JKB 20) has shown better performance as compared to conventional Diesel fuel. While fuel sample JKB 20 has proved to be a better fuel, and has the potential to substitute diesel, other samples with low concentration of biodiesel like JKB10 followed closely. The performance of the high percentage blends & pure Biodiesel doesn’t fit the engine atmosphere due to their higher viscosities & low thermal efficiencies and also from economics stand point as well.

CHAPTER 1

INTRODUCTION

1.1 ENERGY CRISIS

Energy has always been a vital resource in the development of any nation. The prosperity of a nation is measured in terms of per capita energy consumption besides GDP, GNP, etc. While the world has seen hectic industrial activity in the past century it has also come face to face with serious problems arising out of haphazard utilization of the energy resources. The concept was 'More the resources (energy), more the development'. Low fuel costs did not encouraged efficient utilization of energy. During the intensive process of industrialization the world observed consumption of majority stock of its energy resources and deterioration of the global environment. Energy made up a very small component of the total production cost and monopolized business enabled recovery of high cost of energy.

The Gulf War came as an eye opener for all developed and developing countries. It was then the first time that nations importing petroleum products felt the shock when the petro-nations demanded higher price. The energy crisis of 1973 forced the world to look for an alternative arrangement to ensure energy sufficiency. This need obviously pointed at improvement of energy efficiency. The concept changed to 'More efficiency, more productivity and reduced production cost'. This promised an immediate, long term and multi-faced solution to the problems immerging from increased energy demands against short supplies. Energy management has since become the key word for any profitable industrial unit. Besides now the 'energy' accounts for a sizable share in the cost of production in most of the industries.

As a result of this, positive trends have been noticed over the past decade in the energy use pattern the world over. Countries like the United States, Japan and France have managed to raise their GNP while maintaining the same energy consumption levels. In many cases while the GNP has gone up the energy consumption has exhibited reducing trends. Introduction of energy efficient technologies and effective energy management has made this possible. Efficiency of energy utilization needs to be a

continuous activity as there are lots unproductive energy utilization generally observed in Indian industrial sector.

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

1.2 ENERGY SCENARIO – INDIAN CONTEXT

India ranks sixth in the world in terms of energy demand accounting for 3.5% of world commercial energy demand in 2001. The energy demand is expected to grow @ of 4.8% per annum. A large part of India's population, mostly in the rural areas, does not have access to it. At 479 kg of oil equivalent the per capita energy consumption is very low. Hence a programme for the development of energy from raw material, which grows in the rural areas, will go a long way in providing energy security to the rural people[c].

Fossil fuels are the foundation of energy needs in India. In 2001, coal contributed to nearly 55% of the primary fuel demand in the country, while oil contributed 34% [4].

1.2.1 COAL

Coal has taken centre-stage in India's energy scenario. Its dominance continues unabated primarily because power generation favours this fuel, given its abundant indigenous availability.

Three quarters of the total coal reserves in India are concentrated in the states of Bihar, Madhya Pradesh, and West Bengal. The total coal resources of the country up to a depth of 1200 m – as per the exploration carried out by the Geological Survey of India – are estimated at 240.78 billion tonnes as on 1 January 2003. Out of this, 37.42% is in the proven category, 46.78% in the indicated category, and 15.8% in the inferred category. Coking coal resources are estimated at 31 977 MT (13.28% of the total resources) and non-coking coal resources are estimated at 208 771 MT (86.72% of the total resources). During 2002/03 (up to December 2002), domestic coal production was 239.76 MT (provisional), while coal dispatch was 244 MT [2].

1.2.2 OIL AND GAS

As the economy grows, demand for hydrocarbons escalates. The transport sector consumed nearly 23.24 MT of petroleum products, while the industrial sector consumed 12.32 MT, during 2000/01 (provisional). Petroleum products to the amount of 5 MT (like high speed diesel, light diesel oil, fuel oil, and low sulphur heavy stock/HHS) were used for power generation. The agricultural sector (including plantation and other food) consumed nearly 7.7 MT [5].

India's balance recoverable reserves of crude oil and natural gas stood at 732 MT and 763 BCM (billion cubic metre), respectively, by March 2002. Crude oil and natural gas production were 32 MT and 29.7 BCM, respectively, for 2001/02. The import dependency reached 73.3% as the country imported 78.7 MT of crude oil for refinery throughput of 107.2 MT. However, the effects of global slowdown were reflected in the Indian economy too and manifested in postponement of several planned refinery capacity additions/ pipelines, and work-in-progress of grassroots refineries. The demand for petroleum products declined by 0.6% from the previous level of 100.75 MT, and the country exported 3 MT of petroleum products.

The discovery of 7 TCF (trillion cubic feet) of natural gas by Reliance in its KG-DWN-98/3 block in the KG (Krishna–Godavari) basin was the highlight of 2002. It not only improved the energy security of the country by boosting possible gas production by 50%, but also raised the prospects of Indian sedimentary basins in the international arena.

1.2.3 POWER

India has at present, an installed generating capacity of nearly 107 GW [1]. This comprises 70% of thermal (coal, gas, liquid fuel); 25% hydro; 3% nuclear; and 2% wind. Out of the total installed capacity, 90% is owned by the public sector (60% under state governments and 30% under the Central Government) and the balance of about 10% by the private sector.

The capacity addition of 19 015 MW during the Ninth Plan represents 47% of the targeted addition [6]. At the beginning of the Ninth Plan, the energy shortage was 11.5% and peak deficit 18%. The actual power supply position as on March 2002 indicates

energy deficit of 7.5% and peak deficit of 12.6%. This improvement is partly due to a marked improvement in PLF (plant load factor) of thermal plants as well as higher inter-regional transfer of power through the national grid in spite of major shortfalls in the capacity addition during the Ninth Plan period.

1.2.4 RENEWABLE ENERGY SOURCES

Due to depleting fossil fuel resources, renewable energy sources such as solar, wind, biomass, small hydro power, etc. are emerging as alternative energy options. The potential for expanding the use of RETs (renewable energy technologies) for energy generation is vast in India and awaits exploitation.

Table 1.1 Renewable energy potential and achievements in India [b]

Sources/technologies	Units	Approximate potential	Achievements (till February 2000)	As on March 2003
Wind Power	MW	45,000	1,736.0	1,870.0
Small hydro power (upto 25 MW)	MW	15,000	1,475.0	1,509.0
Biomass power/cogeneration	MW	19,500	478.0	483.9
Biomass gasifiers		–	53.0	53.4
Urban and Industrial waste-based power	MW	1,700	17.1	25.8
Solar photovoltaics	MW/km ²	20	107.0	121.0
Solar water heating	million m ² (collector area)	140	0.6	0.7
Waste-to-energy	MW	2500	25.0	25.8
Biogas plants	million	12	3.5	3.5
Improved biomass chulhas (cookstoves)	million	120	35.2	35.2

Though environmentally friendly, the high initial cost of RET has been a major deterrent in harnessing the renewable resources.

1.3 THE FUTURE FORECASTING

Projecting fuel-wise energy demand is by no means an easy task. With rapid changes in the relative availability and price in the fuel sector, coupled with technological

innovations and new policies, the underlying assumptions forming the basis of any projection vary from time to time, thereby revising the estimates.

The supply of commercial energy in India is expected to increase to 7156 Million Barrel Oil Equivalent (MBOE) by the year 2018. About one-third (31%) of it would be imported. Correspondingly, the demand for domestic coal would increase to 3954 MBOE. It implies that existing coal reserves at that consumption level would last for only 30 more years, beyond 2018, provided no more sources are identified [9].

ENPEP (Energy and Power Evaluation Programme) Module is a versatile and fairly easy to use computer-based software though it requires voluminous inputs. Considering various constraints, the study is confined to the two most important modules of the model viz. 'Balance' and 'Impacts'. The base year assumed in the study is 1994 and the terminal year is 2018. Two scenarios have been generated in the study. The Business As Usual (BAU) assumes a moderate economic growth rate of 6 to 7 per cent during the planning horizon and, another, a lower growth rate but with the assumptions that Free Market Conditions (FMC) would apply in the selection of energy sources.

The particulate emissions are projected to increase by 540% in BAU and 410% in FMC cases during the terminal year (ESP) compared to the base year. Considering the use of Electro state Precipitation and other measures in the new coal thermal power projects, the cost of controlling the particulate emissions during the planning horizon is projected to be US \$33 billion for BAU and US \$25 billion for FMC cases. It may, however be noted that, these costs would be in the higher range as a Generic Facility database of impact module has been used and the figures are applicable to the USA conditions.

Table 1.2 Comparison of the Commercial Energy Flow for the study period			
Particulars	Base Year	BAU Year	FMC Year
	1994	2018	2018
Energy Flow (MBOE)	1696	7156	5639
Imports(%)	19	31	43
Conversion & Transmission losses(%)	34	33	32
Coal Demand (MBOE)			
Domestic	997	3954	2924
Import	30	00	224
Total	1007	3954	3148
Crude Oil (MBOE)			
Domestic	235	300	10
Import	200	1907	1752
Total	435	2207	1762
Petroleum Products (MBOE)			
Domestic	-	-	-
Import	84	330	258
Total	84	330	258
Nuclear Fuel (MBOE)			
Domestic	12	195	0.2
Import	-	-	196
Total	12	195	196
Import Bill US \$ Billion	5.17	35.5	88.8

The CO₂ emissions also increase by more than 400% in BAU and 300% in the FMC case during the study's timeframe. About 85% of these emissions are discharges from coal thermal power stations.

The study points out the urgent need to develop viable and reliable alternate energy source for the long term, particularly, nuclear power. The study recommends that:

- Integrated Energy Planning should be taken up on a continuous basis, so that decision makers are kept informed of options and implications of decisions taken in this field. This should cover all aspects of the energy cycle - right from extraction of resources, their use in various sectors and finally disposal of residual wastes.
- Efforts have to stepped up on the exploration and development of new sources of primary energy namely, Coal, Oil and Gas.

- Alternative sources of energy need to be explored and since INDIA is a agriculture based country so efforts should aim so that to find out some alternate fuel which can be used in place of diesel.
- Tightening of pollution limits and enforcing the applicable regulations, in the industry, power and transport sectors, should be taken up.

1.4 DEGRADATION OF GLOBAL ENVIRONMENT

Besides this the environmental implications of haphazard energy utilization also need to be closely studied. The process of energy generation, transport and utilization leads to environmental pollution. In-efficient use of energy has stretched the global environment to its limits as can be seen from the unprecedented and unpleasant responses of the nature in the past few years. Green house effect, global warming, acid rain, smog, deforestation, shift in climatic conditions, etc., are some of the indications. The Carbon Dioxide level in the atmosphere increased from 280 ppm in 1850 to 360 ppm at present [7]. The average temperature of the earth's atmosphere is likely to increase by 1.5 to 4 °C in the next 50 years. Such temperature rises may lead to unpredicted consequences.

Setting up additional generating capacities to meet increasing energy demands would not only cost dearly but it would also add to further degradation of the environment while Energy Conservation would act as a 'double sided sword'. Energy Conservation promises solutions to the approaching double trouble of Energy & Environment. Implementation of an effective energy management program, as far as India is concerned, would lead to energy sufficiency and environmental safety.

1.5 Global Warming and Climate Change

Global warming and climate change refer to an increase in average global temperatures. [i] Natural events and human activities are believed to be contributing to an increase in average global temperatures. This is caused primarily by increases in "greenhouse" gases such as Carbon Dioxide (CO₂).

1.5.1 Greenhouse Effect

The term *greenhouse* is used in conjunction with the phenomenon known as the *greenhouse effect*.

Energy from the sun drives the earth's weather and climate, and heats the earth's surface, in turn, the earth radiates energy back into space; some atmospheric gases (water vapor, carbon dioxide, and other gases) trap some of the outgoing energy, retaining heat. These gases are therefore known as greenhouse gases;

Six main gases considered to be contributing to global climate change are carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O), plus three fluorinated industrial gases: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF₆). Water vapor is also considered a greenhouse gas.

Many of these greenhouse gases are actually life-enabling, for without them, heat would escape back into space and the Earth's average temperature would be a lot colder. However, if the greenhouse effect becomes stronger, then more heat gets trapped than needed, and the Earth might become less habitable for humans, plants and animals.

1.5.2 Impacts of Global Warming

For decades, greenhouse gases, such as carbon dioxide have been increasing in the atmosphere. But why does that matter? Won't warmer weather be nicer for everyone?

1.5.2.1 Rapid changes in global temperature

Increased greenhouse gases and the greenhouse effect is feared to contribute to an overall warming of the Earth's climate, leading to a global warming (even though some regions may experience cooling, or wetter weather, while the temperature of the planet on average would rise).

However, it is the *rapid* pace at which the temperature will rise that will result in many negative impacts to humans and the environment and this why there is such a world-wide concern.

1.5.2.2 Extreme Weather Patterns

Most scientists believe that the warming of the climate will lead to more extreme weather patterns such as:

- More hurricanes and drought;
- Longer spells of dry heat or intense rain

- Scientists have pointed out that Northern Europe could be severely affected with *colder* weather if climate change continues, as the Arctic begins to melt and send fresher waters further south. It would effectively cut off the Gulf Stream that brings warmth from the Gulf of Mexico, keeping countries such as Britain warmer than expected;
- In South Asia, the Himalayan glaciers could retreat causing water scarcity in the long run.

1.5.2.3 Super-storms

Interviewing a biological oceanography professor at Harvard University, IPS notes that the world's oceans are approaching 27 degrees C or warmer during the summer. This increases the odds of major storms.

- When water reaches such temperatures, more of it evaporates, priming hurricane or cyclone formation.
- Once born, a hurricane needs only warm water to build and maintain its strength and intensity.

Furthermore, “as emissions of greenhouse gases continue to trap more and more of the sun's energy, that energy has to be dissipated, resulting in stronger storms, more intense precipitation and higher winds.”

1.5.2.4 Ecosystem Impacts

With global warming on the increase and species' habitats on the decrease, the chances for various ecosystems to adapt naturally are diminishing. These some of the points that global warming will lead to the following situations, amongst others:

- Rapid global heating according to a US National Academy of Science warning;
- Dramatic increase in greenhouse gas emissions;
- Ozone loss aggravated by global warming;
- Ozone loss likely to aggravate global warming;
- Warming of the oceans leads to increased greenhouse gases;
- Permafrost thawing will aggravate global warming;
- Oceanic changes observed that may aggravate the situation;

- A vicious circle whereby each problem will exacerbate other problems which will feedback into each other;
- Massive extinction of species will aggravate the environmental crisis;
- Sudden collapse of biological and ecological systems may occur, but will have a very slow recovery;
- While effective measures can decrease global warming and other problems the World community has repeatedly failed to establish cooperation.

1.5.2.5 Rising Sea Levels

Water expands when heated, and sea levels are expected to rise due to climate change. Rising sea levels will also result as the polar caps begin to melt. Rising sea levels is already affecting many islands.

1.5.2.6 Increase in Pests and Disease

An increase in pests and disease is also feared. A report in the journal *Science* in June 2002 described the alarming increase in the outbreaks and epidemics of diseases throughout the land and ocean based wildlife due to climate changes.

One of the authors points out that, “Climate change is disrupting natural ecosystems in a way that is making life better for infectious diseases.”

1.5.3 Greenhouse gases and emissions resulting from human activity

Leading climate scientists now agree that human pollution, mainly from fossil fuels, has added substantially to global warming in the past 50 years. A 1000-page document from the UN's Intergovernmental Panel on Climate Change (IPCC) reveals far bleaker predictions that the Earth will get far hotter than predicted[j].

1.5.4 Differences in Greenhouse Gas Emission Around the World

As the *World Resources Institute* highlights there is a huge contrast between developed/industrialized nations and poorer developing countries [k] in greenhouse emissions, as well as the reasons for those emissions. For example:

- In terms of historical emissions, **industrialized countries account for roughly 80% of the carbon dioxide buildup in the atmosphere to date.** Since 1950, the

U.S. has emitted a cumulative total of roughly 50.7 billion tons of carbon, while China (4.6 times more populous) and India (3.5 times more populous) have emitted only 15.7 and 4.2 billion tons respectively (although their numbers will rise).

- **Annually, more than 60 percent of global industrial carbon dioxide emissions originate in industrialized countries**, where only about 20 percent of the world's population resides.
- Much of the growth in emissions in developing countries results from the provision of **basic human needs for growing populations**, while emissions in industrialized countries contribute to growth in a standard of living that is already far above that of the average person worldwide. This is exemplified by the large contrasts in per capita carbon emissions between industrialized and developing countries. Per capita emissions of carbon in the U.S. are over 20 times higher than India, 12 times higher than Brazil and seven times higher than China.
- The United States is the world's largest emitter [1] of greenhouse gases. It:
 - Accounts for roughly four percent of the world's population;
 - Accounts for approximately 23% of global emissions and 42% of industrialized country emissions;

At the 1997 Kyoto Conference, industrialized countries were committed to an overall reduction of emissions of greenhouse gases to 5.2% below 1990 levels for the period 2008 - 2012. The treaty Kyoto Protocol was result of the conference. The Kyoto Protocol is an international agreement to reduce greenhouse gas emissions by using the global marketplace to protect the environment. The Kyoto Protocol [m]:

- Sets binding emission limits, which vary from nation to nation
- Emission limits are based on a % of their 1990 emission values
- Nations have a 5-year window (2008-2012) to meet these limits
- Activities that absorb GHGs (e.g., planting trees) will be offset against emissions target
- Emissions permits can be traded between nations

- Countries can get emissions credits by reducing emissions in other countries (e.g., building an environmentally sound power plant in a developing country)
- Certified emissions reductions achieved starting in 2000 will count toward the first budget period (2008-2012)
- Military emissions are largely exempt
- Requires all countries to establish programs to address GHG emissions and to report on progress

Since India has already signed Kyoto Protocol and under this it is bound accordingly. Thus Government of India is looking for alternative fuels and Biodiesel is the most happening area since in this we get oil from seeds of plants so this will give promotion to plantation of such type of trees which give oil and plantation will ultimately reduces the amount CO₂ present in the atmosphere which ultimately helps to clean the environment.

1.6 RURAL ELECTRIFICATION IN INDIA

It is a matter of shame for all of us that even after 55 years of independence there are 63% of total rural households in India which use only kerosene for lighting [f]. Majority of the kerosene lamps are hurricane type lamps, which produce very poor light of about 60-70 lumens (lm) [g](a 100 W bulb produces ~ 1300 lm). In some states like Bihar, Assam etc. there are about 90-95% rural households which use only kerosene for lighting. Thus there are estimates that 90-100 million rural households do not have electricity and with frequent blackouts and brownouts even larger number probably use kerosene for lighting. With electricity shortfall of about 15,000 MW/year in India; poor grid infrastructure in rural areas [h], and with ever increasing petroleum imports for the country it is safe to say that the lives of rural poor will remain in a primitive state for a long time to come.

1.6.1 Lighting Energy

It can safely be said that the history of present civilization is the history of lighting. Without the increase in waking hours for mankind all the major developments of this world might not have taken place. Adequate lighting during evening and night helped

increase the productivity of people and enterprises. Adequate lighting should therefore be a part of minimum needs program of any government for its people.

Presently mankind knows two methods to produce light. One is via thermal route where the fuel (like kerosene or oil) is used to produce an incandescent flame so that yellow light results from the soot particles. This type of light is produced from open flame, candles and hurricane lanterns. Another example of thermal light is that produced by the use of thermo luminescent mantles made of rare earth oxides which are heated by high temperature flame. Most of the pressurized and non-pressurized mantle lanterns (generically called Petromax) fall in this category.

All the remaining lighting is effected by electricity. This includes incandescent bulbs, fluorescent tubes, high-pressure discharge lamps, etc. Since in rural areas of India the grid electricity will not be available for a long time to come, it is safe to assume that the lighting will remain dependent mostly on liquid fuels or at most on decentralized electricity sources. Therefore there is a need for R&D in these areas to make such devices affordable and efficient.

Recently there has been a thrust on bio-diesel in the country. Basically this is produced from edible or non-edible oils after esterification. Non-edible oils derived from tree borne oilseeds have been used in India for centuries as lighting fuels in earthen lamps. Using edible oils for bio-diesel production is not feasible in India at least under present circumstances of edible oil shortage. Bio-diesel produced from non-edible oil, and which is similar to diesel oil, can also be used for lighting.

With the above developments it is quite possible that liquid and gaseous fuel based lighting systems may provide a near term solution for distributed lighting in rural areas and may be far better than electricity based units.

1.7 TRANSPORT SECTOR & ALTERNATIVE FUELS

Transport sector is the major oil-consuming arena in India. An extensive research is going on for diminishing its harmful impacts on the environment. Under the cause, the prominent work is advancing in the field of alternative fuels.

1.7.1 ALTERNATIVE FUELS [9]

1.7.2 COMPRESSED NATURAL GAS (CNG)

Natural gas is a mixture of hydrocarbons-mainly methane and is produced either from gas wells or in conjunction with crude oil production. Due to its lower energy density for use as a vehicular fuel, it is compressed to a pressure of 200-250 bar to facilitate storage in cylinders mounted in vehicle and so it is called Compressed Natural Gas.

India's recoverable resources of more than 690 billion cubic meters make it a long-term substitute fuel for use in petrol & diesel engines. Low exhaust emissions, low noise, less maintenance, not prone to adulteration, driver's comfort etc are some of the attractive features of CNG as an automotive fuel.

CNG is now established as a very successful alternative fuel for automobiles throughout the world. Infrastructure, onboard storage & issues on safety need proper attention for this fuel.

1.7.3 LIQUIFIED PETROLEUM GAS (LPG)

LPG is a byproduct of Natural Gas processing or product that comes from crude oil refining and is composed primarily of propane and butane with smaller amounts of propylene and butylenes. Since LPG is largely propane, the characteristics of propane sometimes are taken as a close approximation to those of LPG.

Reduction in emissions, very less carbon build-up increases life of engine parts like spark plugs, little or no damage to soil or water if it is spilled, due to its rapid evaporation, higher octane number are some of the advantages of LPG fuel.

In the initial stages of introduction of this fuel, issues like safety, storage and handling, extreme volatility of the fuel etc. needs proper attention.

1.7.4 DIMETHYL ETHER (DME)

DME is an ether compound having a molecular structure in which one oxygen atom and two methyl groups are bonded. It is chemically synthesized from natural gas, coal-associated, etc. DME is a gas looking colourless and smelling etheric at room temperature and under normal pressure. Like LPG, DME is liquefied by applying a pressure of approx. 0.5 Mpa.

The greatest advantage of DME when used as an automobile fuel is that its high cetane number makes its applicable to a diesel engine, being an oxygen containing fuel, it prevents a diesel engine emitting soot and particulate matter to a greater extent than diesel fuel does.

Viscosity lower than that of diesel, low lubricity, reaction with some rubber components are some of the disadvantages of DME.

Table 1.3. : Comparison of Properties of Various Alternative Fuels [11]

Property	Compressed Natural Gas	Propane	Butane	Dimethyl Ether	Diesel
Chemical Structure	CH ₄	C ₃ H ₈	C ₄ H ₁₀	CH ₃ OCH ₃	
Mol. Weight (g/mol)	18.7	44.1	58.1	46.1	170
Density (kg/m ³)	465	500.5	578.8	667	831
Cetane Number	--	--	--	>55	40-55
Octane No. (RON)	120	112.1	91.8	--	--
Stoich. A/F Ratio	16.9	15.7	15.5	9	14.6
Boiling Point	-162/-88	-42	-0.5	-25	180/370
Vap. Pres. @ 293 kPa	--	830	210	530	--
L.C.V	49	46.4	45.7	28.8	42.7
S.I.Temp	650	470	365	235	250
Specific heat (kJ/kgK)	2.2	1.67	1.68	2.99	1.7
Latent Heat (kJ/kgK)	510	372	358	467	

1.7.5 BIODIESEL [d]

Biodiesel is a clean burning alternative fuel produced from a variety of renewable agricultural resources, such as soybeans and canola, animal fats, and recycled cooking oils. It can be burned in any standard, unmodified diesel engine either in pure form (BD100) or, depending on outside air temperatures, in a blend of any proportion with petroleum diesel. Biodiesel seamlessly integrates with current engine technology and fuelling infrastructure. In fact, it is the first clean fuel that does not require fleet operators to purchase new vehicles or construct new facilities.

Pure biodiesel is fully biodegradable, non-toxic to plants, animals and humans, and essentially free of sulphur and other aromatics.

1.7.5.1 Advantages of Biodiesel

Biodiesel has both environmental and performance benefits, plus a proven track record. Here is a summary of its many significant benefits.

Easy to use - Biodiesel can be used within current fuelling infrastructures and in all diesel vehicles with little or no engine modification.

Flexible - Biodiesel is easy to phase in and out, so flexibility in technology deployment can be maintained. Biodiesel can be used alone or mixed in any ratio with petroleum diesel fuel. For cold weather months, a blend of 20% biodiesel with 80% petroleum diesel (BD 20) is recommended.

Clean - Biodiesel cuts exhaust emissions, minimizing black smoke, odour, and greenhouse gas emissions, air toxins, and particulates, and does not contribute to sulphur dioxide emissions (acid rain). The lifecycle production and use of biodiesel produces approximately 80% less carbon dioxide emissions, and almost 100% less sulphur dioxide.

Better for engines - The use of biodiesel can extend the life of diesel engines because it is more lubricating than petroleum diesel fuel, while the higher Cetane index and flash point contribute to higher engine performance

Safe - Biodiesel is safer to handle and transport because it is as biodegradable as sugar, 10 times less toxic than table salt, and has a high flashpoint of about 300° F compared to 125° F for petroleum diesel fuel.

Proven - Biodiesel is the only alternative fuel in the U.S. to complete EPA Tier I Health Effects Testing under section 211(b) of the Clean Air Act, which provide the most thorough inventory of environmental and human health affecting attributes that current technology will allow. It has over 30 million successful U.S. road miles, and over 20 years of use in Europe.

Renewable - Biodiesel is made from natural, renewable resources such as used vegetable oils, animal fats, and domestically produced oilseed crops such as soy, canola and hemp. Thus increased use of biodiesel will also provide a major boost to the domestic agricultural economy.

1.7.5.2 A closer look at lower emissions

Biodiesel produces lower toxic emissions, is free of sulphur and aromatic compounds, and vastly improves a diesel engine's environmental performance. Compared to 100% petroleum diesel, biodiesel reduces emissions by the following percentages.

Table 1.4 [d]

Emission Type	B100	B20
Total unburned hydrocarbons	93%	30%
Carbon monoxide	50%	20%
Particulate matter	30%	22%
Sulphates	100%	20%
PAH	80%	13%
NPAH	90%	50%
Mutagenicity	85%	20%
Ozone potential of speciated HC	50%	10%

1.7.5.3 Further environmental benefits

- Biodiesel is less toxic than table salt and biodegrades faster than sugar.

- Pure biodiesel exhaust contains no benzene or formaldehyde and eliminates or drastically reduces other substances often classified as Toxic Air Contaminants.
- Biodiesel is the only alternative fuel to have passed the rigorous U.S. EPA Tier I and Tier II health effects testing, showing no increased risk to human health at any exposure level.
- The U.S. Department of Energy found that biodiesel reduces life-cycle carbon dioxide emissions (greenhouse gases) by nearly 80% as compared to petroleum diesel. Its production and use forms a closed carbon cycle.

1.7.5.4 A long-term, sustainable solution

- Biodiesel has a 3.2:1 energy ratio, the highest of any alternative or petroleum-based fuel.
- Biodiesel produces the highest number of BTU's of any alternative fuel.
- Because biodiesel is produced domestically, it both reduces dependence on imported petroleum and boosts the nation's agricultural industry.

1.7.6 HYDROGEN

Hydrogen is the most abundant element in the universe, but is rarely found in its uncombined form on the earth. Hydrogen gas is being explored for use in combustion engines and fuel cells electric vehicles. When combusted (oxidized) it creates only water vapour as a by-product. When burned in an internal combustion engine, however, combustion also produces small amounts of nitrogen dioxide and small amount of unburned HC and CO because of engine lubricants but the exhaust is free from CO₂. It is a gas at normal temperature and pressure, which presents greater transportation and storage hurdles. Storage systems being developed include compressed hydrogen, liquid hydrogen and chemical bonding between hydrogen and a storage material.

Very less emissions, high Octane rating, high energy content, large base source for production are some of the advantages of using hydrogen as fuel.

Infrastructure bottlenecks, Problems of fuel storage, Vehicle range and power loss, wider flammability limits, costly production, and limited field trial experience are some of the drawbacks of hydrogen fuel.

1.7.7 METHANOL

Methyl alcohol - wood alcohol - may be obtained organically by the distillation of hardwoods at high pressure and a temperature of around 350 °C - itself a high energy-consuming process. With a far higher cumulative toxicity rating than ethanol, the energy content is around 3.7 kWh per liter (about one third that of petrol), making it a less attractive alternative transport fuel. Trying to mix methanol with petrol brings problems - they are not entirely compatible, and the slightest amount of water absorbed by the fuel causes the alcohol to separate out in the bottom of the tank. Additives are commercially available, but this adds to the fuel cost.

1.7.8 ETHANOL

Ethanol is a clear, colourless liquid with a characteristic, agreeable odour. In dilute aqueous solution, it has a somewhat sweet flavor, but in more concentrated solutions it has a burning taste.

Ethanol has been made since ancient times by the fermentation of sugars. All beverage- ethanol and more than half of industrial ethanol is still made by this process. It can be made from raw materials such as sugarcane, sorghum, corn, barley, cassava, sugar beets etc using already improved and demonstrated technologies.

Ethanol as automotive fuel

Ethanol is used as an automotive fuel by itself and can be mixed with gasoline to form what has been called "gasohol" or can be mixed with diesel to form "diesohol" or "E-diesel". Because the ethanol molecule contains oxygen, it allows the engine to more completely combust the fuel, resulting in fewer emissions. Since ethanol is produced from plants that harness the power of the sun, ethanol is also considered a renewable fuel. The principal interest in ethanol as motor vehicle fuel lies in its use as blends with gasoline. Its very high octane rating makes it an effective knock suppressor like TEL with an additional advantage of being a fuel in itself with no hazardous component like lead in TEL, which causes lead pollution.

Its blends can permit higher compression operation of the engine without knock. Its higher latent heat of vaporization, uniform composition, stoichiometric air requirements, higher flash point etc. impart to its blends certain useful properties which

not only improve engine performance but also reduce engine emissions and make the blends safer as compared to gasoline.

Its lower calorific value, higher surface tension, greater solvent power etc. restrict its use as a complete motor vehicle fuel. It can be best utilized as a blend constituent with up to around 30% ethanol -gasoline blends useable in the present day automobiles without requiring any major engine modifications; and giving reduced levels of exhaust CO and HC emissions.

1.8 SELECTION OF AN ALTERNATIVE FUEL

Some of the requirements of fuel which must be put under consideration while selecting alternative fuel are as given below:

- It should be produced locally to cut transport cost and supply difficulty, to free foreign currency for other uses, and to reduce local under-employment.
- It should need only simple production plant to give low capital and cheap maintenance.
- It should require the minimum alteration to the engine to keep initial cost down and to enable a return to diesel use if the alternative supply fails.
- It should have minimum harmful effect on the engine to ensure reliability and to reduce the need for skilled maintenance.

Selection of suitable renewable source of energy in place of petroleum fuels depends upon social, political, ecological, economical and technical factors. Ever since the first energy crisis took place in 1973, various fuels have been tried to run IC engines. Exhaustive studies on the basis of performance, emission and combustion have established the feasibility of using a variety of alternative fuels to substitute the extinguishing fossils. The fuels such as CNG, LNG, Propane, Hydrogen, Alcohols, Biogas, Producer gas, DME and derivatives of vegetable oils are receiving more & more attention. But as far as India is concerned because of its vast agro-forestry base, fuels of bio-origin can be considered to be ideal alternative renewable fuels to run the internal combustion engines. The bio-origin fuels could be Biogas, Biomass, Producer gas and derivatives of Vegetable Oils, which can be modified to bring their properties comparable to fossil fuels. The bio-origin fuels can play a dual role in greenhouse gas mitigation related to the objectives of the Kyoto protocol and other climate change initiatives. It can

act as a source of sustainable energy to substitute fossil fuels and as a carbon store. Modern bio-energy options offer significant, cost-effective and perpetual opportunities toward meeting emission reduction targets while providing additional ancillary benefits arising from the wide occurrence of biomass materials. These include social benefits of employment in the growing, harvest and processing of biomass resources.

1.9 INTRODUCTION TO BIODIESEL

Biodiesel is biodegradable and non-toxic. 100% biodiesel is as biodegradable as sugar and less toxic than table salt. Biodiesel biodegrades up-to four times faster than petroleum diesel fuel with up-to 98% biodegradation in three weeks. Compared to crappy fossil fuel diesel, biodiesel has the following emissions characteristics [e]:

- 100% reduction of sulphur dioxide
- 40-60% reduction of soot emissions
- 10-50% reduction of carbon monoxide
- a reduction of all polycyclic aromatic hydrocarbons (PAHs) and specifically the reduction of the following carcinogenic PAHs:
 - phenanthren by 97%
 - benxofloroanthen by 56%
 - benz-a-pyrene by 71%
 - aldehydes and aromatic compounds by 13%
- 5-10% reduction of nitrous oxide depending on age and tuning of vehicle.

For every one ton of fossil fuel burnt, 3 tons of CO₂ is released into the atmosphere, biodiesel only releases the CO₂ that it has taken in while the plants it is made from were growing, and therefore there is no negative impact on the carbon cycle.

Thus, bio-diesel can supplement the supply of environment friendly fuels in our country in future. In conventional diesel a fuel, the reduction in sulfur content is compensated by adding additive for lubricity of fuel injection pump (FIP). Bio-diesel is reported to have superior lubricity. Flash point of bio-diesel is high (> 100 °C). Its blending with diesel fuel can be utilized to increase the flash point of diesel particularly in India where flash point is 35°C well below the world average of 55°C. This is

important from the safety point of view. The viscosity of biodiesel is higher (1.9 to 6.0 cSt) and is reported to result into gum formation on injector, cylinder liner etc. However, blends of up to 20% should not give any problem. While an engine can be designed for 100% bio-diesel use, the existing engines can use 20% biodiesel blend without any modification and reduction in torque output. In USA, 20% biodiesel blend is being used, while in European countries 5 -15% blends have been adopted. Bio-diesel can be blended in any ratio with petroleum diesel fuel. It can be stored just like the petroleum diesel fuel and hence does not require separate infrastructure. Bio-diesel has been accepted as clean alternative fuel worldwide.

CHAPTER 2

BIODIESEL: THE FUEL OF FUTURE

Bio-diesel is an eco-friendly, alternative diesel fuel prepared from domestic renewable resources i.e. vegetable oils and animal fats. These natural oils and fats are made up mainly of triglycerides. These triglycerides when reacted chemically with lower alcohols in presence of a catalyst result in fatty acid esters. These esters show striking similarity to petroleum derived diesel and are called "Bio-diesel" [p].

It is fatty acid ethyl or methyl ester made from virgin or used vegetable oils (both edible & non-edible) and animal fats. Oil can be extracted from a variety of plants and oilseeds. Under Indian condition only such plant sources can be considered for biodiesel production which are not edible oil in appreciable quantity and which can 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 in India are:

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

Of all the above prospective plant candidates as biodiesel yielding sources, *Jatropha curcas* stands at the top and sufficient information on this plant is already available. One hectare *Jatropha* plantation with 4400 plants per hectare under rain fed conditions can yield about 1500 literes of oil [n]. It is estimated that about 3 million hectares plantation is required to produce oil for 10% replacement of petrodiesel. The

residue oil cake after extraction of oil from *Jatropha* can be used as organic fertilizers. It is also estimated that one acre of *Jatropha* plantation could produce oil sufficient to meet the energy requirement of a family of 5 members and the oil cake left out when used as fertilizer could cater to one acre. The fact that *Jatropha* can be grown in any wastelands with less irrigation gives it a distinct advantage for consideration as the prime biodiesel feedstock in Indian conditions.

Biodiesel contains no petroleum but it can be blended with any quantity of diesel to create a biodiesel blend or can be used in its pure form. Just like petroleum diesel, biodiesel operates in compression ignition engine; which essentially require very little or no engine modifications because bio-diesel has properties similar to petroleum diesel fuels. It can be stored just like the petroleum diesel fuel and hence does not require separate infrastructure. The use of bio-diesel in conventional diesel engines results in substantial reduction of un-burnt hydrocarbons, carbon monoxide and particulate matters. Bio-diesel is considered clean fuel since it has almost no sulphur, no aromatics and has about 10 % built-in oxygen, which helps it to burn fully. Its higher cetane number improves the ignition quality even when blended in the petroleum diesel.

2.1 Biodiesel Initiatives in India

India has great potential for production of bio-fuels like bio-ethanol and biodiesel from non-edible oil seeds. From about 100 varieties of oil seeds, only 10-12 varieties have been tapped so far. The annual estimated potential is about 20 million tones per annum. Wild crops cultivated in the waist land also form a source of biodiesel production in India and according to the Economic Survey of Government of India, out of the cultivated land area, about 175 million hectares are classified as waste and degraded land [o]. Thus, given a demand-based market, India can easily tap its potential and produce biodiesel in a large scale. Table-2.1 depicts the annual production of non-edible oil seeds in India.

Table-2.1: Annual Production of Non-edible Oil Seeds in India [o]

Type	Production (MT)	Oil %
Neem	500	30
Karanja	200	27-39
Kusum	80	34
Pilu	50	33
Ratanjot	-	30-40
Jaoba	-	50
Bhikal	-	37
Wild Walnut	-	60-70
Undi	04	50-73
Thumba	100	21

Biodiesel has distinct advantage as an automotive fuel. Initial cost may be higher but *feedstock diversity and multi-feedstock production technologies* will play a critical role in reductions in production cost and making the fuel economically viable.

2.2 REQUIREMENT OF BIODIESEL:

The requirements of biodiesel have been worked out for blending ratios of 5, 10 and 20 percent. The table showing the demand of Biodiesel and the area required to be covered under plantation to meet the demand is given in Table 2.2

Table 2.2: Area Coverage Vs. Blending Requirements [11]

Year	Diesel Demand MMT	Bio-Diesel @ 5% MMT	*Area for 5% Mha	Bio-Diesel @ 10% MMT	*Area for 10% Mha	Bio-Diesel @20% MMT	*Area for 20% Mha
2001-02	39.81	1.99	1.67	3.98	3.34	7.96	6.68
2002-03	42.15	2.11	1.76	4.22	3.52	8.43	7.04
2003-04	44.51	2.23	1.87	4.45	3.74	8.90	7.48
2004-05	46.97	2.35	1.96	4.70	3.92	9.39	7.84
2005-06	49.56	2.48	2.07	4.96	4.14	9.91	8.28
2006-07	52.33	2.62	2.19	5.23	4.38	10.47	8.76
2011-12	66.90	3.35	2.79	6.69	5.58	13.38	11.19

- AREA CALCULATED ON THE BASIS OF PLANTATION DENSITY OF 2500 PER HECTARE, SEED PRODUCTION OF 1.5 KG PER TREE OR OF 3.75 MT OF SEED PER HECTARE CORRESPONDING TO 1.2 MT OF OIL PER HECTARE OF PLANTATION.

2.3 Analysis of Technologies With Reference to Indian Resources & Requirements

India has rich and abundant forest resources with a wide range of plants and oilseeds. The production of these oilseeds can be stepped up many folds if the government takes the decision to use them for producing diesel fuels. Economical feasibility of bio-diesel depends on the price of the crude petroleum and the cost of transporting diesel to long distances to remote markets in India. Further, the strict regulations on the aromatics and sulphur contents in diesel fuels will result in higher cost of production of conventional diesel fuels.

The production of ethyl esters from edible oils is currently much more expensive than hydrocarbon-based diesel fuels due to the relatively high costs of vegetable oils. The cost of bio-diesel can be reduced if we consider non-edible oils, and used frying oils instead of edible oils. Non-edible oils such as neem, mahua, karanja, babassu, Jatropha, etc. are easily available in many parts of the world including India, and are very cheap

compared to edible oils. The potential availability of some non-edible oils in India is given in Table 2.3.

Table 2.3 Non-edible oil sources of India [11]

Oil	Botanical	Potential (million tonnes)	Utilised (million tones)	Percent Utilisation
Rice bran	Oryza Sativa	474,000	101,000	21
Sal	<i>Shorea robusta</i>	720,000	23,000	3
Neem	<i>Melia azadirachta</i>	400,000	20,000	6
Karanja	<i>Pongamia glabra</i>	135,000	8,000	6

The processing of oilseeds for the production of edible vegetable oils generates by-product streams containing triglycerides, phospholipids and free fatty acids. In many cases these streams are of considerably lower value than the finished oil. Successful development of a scheme for ester synthesis from low-value lipids could address the economic barriers to a wider adoption of bio-diesel.

Fatty acid methyl ester could be produced from tall oil, a by-product in the manufacture of pulp by the Kraft process. Tall oil consists of free C₁₈ unsaturated fatty acids, resin acids and relatively small amounts of unsaponifiables. The fatty acid fraction of tall oil contains mainly oleic acid, linoleic acid and its isomers.

With the mushrooming of fast food centers and restaurants in India, it is expected that considerable amounts of used-frying oils will be discarded into the drains. These can be used for making bio-diesel, thus helping to reduce the cost of water treatment in the sewerage system and assisting in the recycling of resources.

Thermal and catalytic decomposition of vegetable oils to produce gasoline and diesel fuel has been studied by a number of scientists using various methods with the objective of finding a gasoline replacement, but the fuel obtained possessed an inferior octane number. At the present, a hydrocarbon fuel with a similar volatility and molecular weight as diesel fuel can be produced with an approximate volume yield of 50% from the decomposition of vegetable oils. The method that appears most promising is pre-hydrogenation followed by thermal or catalytic decomposition of vegetable oils.

Biodiesel can be used as a pure fuel or blend with petroleum diesel depending on the economics and emissions. The Indian Scenario is different from Europe and USA where refined vegetable oils, waste frying oils and tallow are used to produce bio-diesel. In India, non-edible oils are likely the preferred feedstock.

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

2.4 Potential bio-diesel crops: *Jatropha curcas* and *Pongamia Pinnata* ('Honge' or 'Karanja')

2.4.1 *Jatropha curcas*:

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

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

2.4.1.1 Indian Railways' Initiative towards biodiesel

Indian Railways' tied a treaty with IOC (Indian Oil Corporation) to plant and produce *Jatropha curcas* in 500 hectares of the Railway land which, in turn, can produce 800 tones of bio-diesel per annum. Under an agreement signed here between IOC and IR, Railways would offer 500 hectares of its land on lease to IOC in Gujarat and Rajasthan. Production of bio-diesel consists of doping diesel produced from crude with five per cent of *Jatropha Curcas*, commonly known as Rattan Jyoth in the north. Railways have already tested the bio-diesel fuel on a diesel locomotive hauling the premier Shatabdi Express between New Delhi and Amritsar and found it to be successful. Under the agreement, IOC will take up plantation, collection of seed, extraction, blending and testing by outsourcing some or all of the activities.

2.4.1.2 Advantages of Selection of *Jatropha curcas*:

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

- It can be grown in areas of low rainfall (200 mm per year) and in problematical soils. In high rainfall and irrigated areas too it can be grown with much higher yields. Therefore, it can be grown in most parts of the country.
- *Jatropha* is easy to establish, grows relatively quickly and is hardy.
- *Jatropha* lends itself to plantation with advantage on lands developed on watershed basis and on low fertility marginal, degraded, fallow, waste and other lands such as along the canals, roads railway tracks, on borders of farmers' fields as a boundary fence or live hedge in the arid/semi-arid areas and even on alkaline soils. As such it can be used to reclaim wastelands in the forests and outside.
- *Jatropha* seeds are easy to collect as they are ready to be plucked before the rainy season and as the plants are not very tall.
- *Jatropha* is not browsed by animals.
- Being rich in nitrogen, the seed cake is an excellent source of plant nutrients.
- Seed production ranges from about 0.4 tons per hectare per year to over 12 t /ha.
- The plant starts giving seed in a maximum period of two years after planting.
- Raising plants in nurseries, planting and maintaining them and collection of seed are labour intensive activities. Except for the cost of fertiliser and transportation

of the plants from the nursery, all the activities in the nurseries and in planting consist of labour. The cost of seed is entirely in the form of wage for labour.

- Various parts of the plant are of medicinal value, its bark contains tannin, the flowers attract bees and thus the plant has honey production potential.
- Like all trees, *Jatropha* removes carbon from the atmosphere, stores it in the woody tissues and assists in the build up of soil carbon. It is thus environment friendly.
- *Jatropha* can be established from seed, seedlings and vegetatively from cuttings. Use of branch cutting for propagation is easy and results in rapid growth;

It can meet a number of objectives such as meeting domestic needs of energy services including cooking and lighting; as an additional source of household income and employment through markets for fuel, fertilizer, animal feed medicine, and industrial raw material for soap, cosmetics, etc. in creating environmental benefits – protection of crops or pasture lands, or as a hedge for erosion control, or as a windbreak and a source of organic manure.

Thus it can be concluded that promotion of *Jatropha* plantation can generate tremendous job opportunities among the rural masses. Simultaneous production of indigenous biodiesel from its oil will resist the outflow of valuable foreign exchange caused by the import of crude petroleum [s]. It may lead to a revolutionary transformation of the current gloomy economic and energy scenario with an era of economic bloom and prosperity for all sections of society.

2.4.2 *Pongamia Pinnata* ('Honge' or 'Karanja'):

2.4.2.1 *Pongamia pinnata* - a nitrogen fixing tree for oilseed [u]:

Pongamia pinnata is one of the few nitrogen fixing trees to produce seeds containing 30-40% oil. It is often planted as an ornamental and shade tree. This species is commonly called pongam, karanga, or a derivation of these names.

Pongam (Legununosae, subfamily Papilionoideae) is a medium sized tree that generally attains a height of about 8 m and a trunk diameter of more than 50 cm. However, Troup (GOI 1983) reports trees attaining heights of 18 m. The trunk is

generally short with thick branches spreading into a dense hemispherical crown of dark green leaves. The bark is thin gray to grayish- brown, and yellow on the inside. The taproot is thick and long; lateral roots are numerous and well developed.

The alternate, compound pinnate leaves consist of 5 or 7 leaflets which are arranged in 2 or 3 pairs, and a single terminal leaflet. Leaflets are 5-10 cm long, 4-6 cm wide, and pointed at the tip. Flowers, borne on racemes, are pink, light purple, or white. Pods are elliptical, 3-6 cm long and 2-3 cm wide, thick walled, and usually contain a single seed. Seeds are 10-20 cm long, fig oblong, and light brown in color.

Ecology

Native to humid and subtropical environments, pongam thrives in areas having an annual rainfall ranging from 500 to 2500 mm. in its natural habitat, the maximum temperature ranges from 27 to 38°C and the minimum 1 to 16°C. Mature trees can withstand waterlogging and slight frost. This species grows to elevations of 1200 m, but in the Himalayan foothills is not found above 600 m.

Pongam can grow on most soil types ranging from stony to sandy to clayey, including Verticals. It does not do well on dry sands. It is highly tolerant of salinity. It is common along waterways or seashores, with its roots in fresh or salt water. Highest growth rates are observed on well-drained soils with assured moisture. Natural reproduction is profuse by seed and common by root suckers

Distribution

The natural distribution of pongam is along coasts and river banks in India and Burma. Native to the Asian subcontinent, this species has been introduced to humid tropical lowlands in the Philippines, Malaysia, Australia, the Seychelles, the United States (Little undated), and Indonesia.

2.4.2.2 Uses of Pongamia Pinnata ('Honge' or 'Karanja'):

Wood. With a calorific value of 4600 kcal per kg, pongam is commonly used as fuel wood. Its wood is beautifully grained and medium to coarse textured. However, it is not durable, is susceptible to insect attack, and tends to split when sawn. Thus the wood is not considered a quality timber.

Oil. A thick yellow-orange to brown oil is extracted from seeds. Yields of 25% of volume are possible using a mechanical expeller. However, village crushers average a yield of 20%. The oil has a bitter taste and a disagreeable aroma, thus it is not considered edible. In India, the oil is used as a fuel for cooking and lamps. The oil is also used as a lubricant, water-paint binder, pesticide, and in soap making and tanning industries.

Fodder and feed. Opinions vary on the usefulness of this species as a fodder. Troup reports that the leaves are eaten by cattle and readily consumed by goats. However, in many areas it is not commonly eaten by farm animals. Its fodder value is greatest in arid regions. The leaves contain 43% dry matter, 18% crude protein, 62% neutral detergent fiber, 40% acid detergent fiber, and *in vitro* dry matter digestibility of 50%. The presscake, remaining when oil is extracted from the seeds, is used as poultry feed.

Other uses. Incorporation of leaves and the presscake into soils improves fertility. Dried leaves are used as an insect repellent in stored grains. The presscake, when applied to the soil, has pesticidal value, particularly against nematodes.

Pongam is often planted in homesteads as a shade or ornamental tree and in avenue plantings along roadsides and canals. When planted as a shade or ornamental tree, branch pruning may be necessary to obtain a trunk of appropriate height. It is a preferred species for controlling soil erosion and binding sand dunes because of its dense network of lateral roots. Its root, bark, leaf, sap, and flower also have medicinal properties.

2.4.2.3 Silviculture

Pongam is easily established by direct seeding or by planting nursery-raised seedlings or stump cuttings of 1-2 cm root-collar diameter. Propagation by branch cuttings and root suckers is also possible. In peninsular India, the seeding season is April to June, and the seed yield per tree ranges from about 10 kg to more than 50 kg. There are 1500-1700 seeds per kg. Seeds, which require no treatment before sowing, remain viable for about a year when stored in air-tight containers.

Seed germinates within two weeks of sowing. Seedlings attain a height of 25-30 cm in their first growing season. Transplanting to the field should occur at the beginning of the next rainy season when seedlings are 60 cm in height. Seedlings have large root systems. Soil should be retained around the roots during transplanting. Seedling survival and growth benefit from annual weed control for the first three years after transplanting.

The spacing adopted in avenue plantings is about 8 m between plants. In block plantings, the spacing can range from 2 x 2 to 5 x 5 m. Pongam seedlings withstand shade very well and can be interplanted in existing tree stands. This species can be regenerated by coppice management. Information on management practices to maximize seed or biomass production is not available and should be investigated. Because it tolerates moderate levels of salinity, pongam is an ideal candidate for saline soil reclamation.

2.4.2.4 Advantages of Selection of Pongamia Tree [t] :

- The pongamia tree yields anywhere between nine to ninety kilos (20 to 200 pounds) of seeds per year. One kilo (2.2 pounds) of seeds produces one-quarter of a kilo of oil. The residual crushed seed, known as oil cake, is a good source of manure.
- One kilo of oil generates three units of electricity, and the economics of all this works out to much lower than the current price of diesel.
- The villages in Karnataka are already familiar with pongamia oil and seed. They use the oil for lighting lamps and the seed for soil fertiliser.
- In developing countries, there is no shortage of manpower for technical maintenance of the engines. Frequent cleaning of fuel injectors and filters are less

of a problem. In the case of pongamia oil, a simple filtering in rural areas is sufficient. In colder parts of India and other developing countries, the problem of freezing of waxes and gums in the oil could be solved by simple heating.

It may be possible to encourage the sustainable growth of the pongamia tree on India's over 90 million hectares (roughly 2 billion acres) of degraded lands. Since the tree is not grazed upon by cattle, rural areas could well be serviced in energy, economic and environmental benefits by the pongamia pinnata.

2.5. Statement of Problem:

Feedstock diversity and multi-feedstock production technologies will play a critical role in reductions in production cost and making the fuel economically viable. Therefore it is tried to make biodiesel with both popular feedstock Jatropha and Karanja and make blend of these two biodiesel in 50-50 ratios by volume. Then analysis of that biodiesel in different proportions with neat diesel. Aim of the present work was to examine the of blend of biodiesel of Jatropha and Karanja oil with diesel by evaluating the performance and exhaust emission characteristics.

Considering the above facts, the following are the statement of problem for the present study.

- To prepare biodiesel from Jatropha and Karanja oil
- To prepare blend of both biodiesel in 50-50 ratios by volume.
- To prepare of blend of biodiesel with diesel in different proportions.
- Physio-chemical characterization of various fuels
- Assessment of performance and emission characteristics of a unmodified diesel engine when fuelled with various blends of biodiesel with diesel.

2.6 Properties of Biodiesel:

A general understanding of the various properties of bio-diesel is essential to study their implications in engine use, storage, handling and safety.

2.6.1 Density/ Specific Gravity:

Bio-diesel is slightly heavier than conventional diesel fuel (specific gravity 0.88 compared to 0.84 for diesel fuel). This allows use of splash blending by adding bio-diesel on top of diesel fuel for making bio-diesel blends. Bio-diesel should always be blended at top of diesel fuel. If bio-diesel is first put at the bottom and then diesel fuel is added, it will not mix.

2.6.2 Cetane Number:

Cetane number of a diesel engine fuel is indicative of its ignition characteristics. Higher the cetane number better it is in its ignition properties. Cetane number affects a number of engine performance parameters like combustion, stability, driveability, white smoke, noise and emissions of CO and HC. Bio-diesel has higher cetane number than conventional diesel fuel. This results in higher combustion efficiency and smoother combustion.

2.6.3 Viscosity:

In addition of lubrication of fuel injection system components, Fuel viscosity controls the characteristics of the injection from the diesel injector (droplet size, spray characteristics etc.). The viscosity of methyl esters can go to very high levels and hence, it is important to control it within an acceptable level to avoid negative impact on fuel injection system performance. Therefore, the viscosity specifications proposed are same as that of the diesel fuel.

2.6.4 Distillation characteristics:

The distillation characteristics of bio-diesel are quite different from that of diesel fuel. Bio-diesel does not contain any highly volatile components, the fuel evaporates only at higher temperature. This is the reason that sometimes sump lubrication oil dilution observed in many tests. Boiling point of bio-diesel generally range between 330 to 357 deg. C. The limit of 360 deg. C is specified mainly to ensure that high boiling point components are not present in bio-diesel as adulterants/ contaminants.

2.6.5 Flash point:

Flash point of a fuel is defined as the temperature at which it will ignite when exposed to a flame or spark. The flashpoint of bio-diesel is higher than the petroleum based diesel fuel. Flashpoint of bio-diesel blends is dependent on the flashpoint of the base diesel fuel used, and increase with percentage of bio-diesel in the blend. Thus in storage, biodiesel and its blends are safer than conventional diesel. The flashpoint of bio-diesel is around 160 deg. C, but it can reduce drastically if the alcohol used in manufacture of bio-diesel is not removed properly. Residual alcohol in the bio-diesel reduces its flashpoint drastically and is harmful to fuel pump, seals, elastomers etc. It also reduces the combustion quality.

2.6.6 Cold Filter Plugging Point (CFPP):

At low operating temperature fuel may thicken and not flow properly affecting the performance of fuel lines, fuel pumps and injectors. Cold filter plugging point of biodiesel reflects its cold weather performance. . It defines the fuels limit of filterability. CFPP has better correlation than cloud point for bio-diesel as well as diesel fuel. Biodiesel thickens at low temperatures so need cold flow improver additives to have acceptable CFPP.

2.6.7 Pour Point:

Normally either pour point or CFPP are specified. French and Italian bio-diesel specifications specify pour point whereas others specify CFPP. Since CFPP reflects more accurately the cold weather operation of fuel, it is proposed not to specify pour point for bio-diesel. Pour point depressants commonly used for diesel fuel do not work for bio-diesel.

2.6.8 Cloud Point:

Cloud point is the temperature at which a cloud or haze of crystals appear in the fuel under test conditions and thus becomes important for low temperature operations. Bio-diesel generally has higher cloud point than diesel fuel.

2.6.9 Stability:

Bio-diesel age more quickly than fossil diesel fuel due to the chemical structure of fatty acids and methyl esters present in bio-diesel. Typically there are up to 14 types of fatty acid methyl esters in the bio-diesel. The individual proportion of presence of these esters in the fuel affects the final properties of bio-diesel. Saturated fatty acid methyl esters (C14: 0, C16: 0, C16: 0) increase cloud point, cetane number and improve stability whereas more polyunsaturates (C18: 2, C18: 3) reduce cloud point, cetane number and stability.

There are three types of stability criteria, which need to be studied:

2.6.9.1 Oxidation Stability:

Poor oxidation stability can cause fuel thickening, formation of gums and sediments, which, in turn, can cause filter clogging and injector fouling. Iodine number indicates the tendency of a fuel to be unstable as it measures the presence of C=C bonds that are prone to oxidation. Generally instability increase by a factor of 1 for every C=C bond on the fatty acid chain. Thus, C18: 3 are three times more unstable than C18: 0 fatty acids

2.6.9.1.1 Oxidation stability of biodiesel produced by several European manufacturers [x]

In the course of a round robin test for determination of the oxidation stability of FAME 22 biodiesel samples produced by 7 European manufacturers were analysed in the Rancimat. The samples contained no additives. Viscosity and acid number were found to be closely related to the oxidation stability.

2.6.9.1.2 Round robin test

A round robin test was carried out in 9 laboratories where the oxidation stability of FAME was determined using a test method similar to the Rancimat. The repeatability of the results was very high within one laboratory. The results of several labs differ with a standard deviation of 16% (at 110°C).

2.6.9.1.3 The Influence of Antioxidants on the Oxidation Stability of Biodiesel [v]

Oxidation stability of biodiesel is an important issue because FA derivatives are more sensitive to oxidative degradation than mineral fuel. Therefore, in the most recent

European Specifications for biodiesel, a minimum value of 6 h for the induction period at 110°C, measured with a Rancimat instrument [w], is specified. To guarantee this value at the filling station, the use of additional antioxidants will be necessary. The influence of different synthetic and natural antioxidants on the oxidation stability, using the specified test method is studied. Biodiesel produced from rapeseed oil, sunflower oil, used frying oil, and beef tallow, both undistilled and distilled, was investigated. The four synthetic antioxidants pyrogallol (PY), propylgallate (PG), TBHQ, and BHA produced the greatest enhancement of the induction period. The induction periods of methyl esters from rapeseed oil, used frying oil, and tallow could be improved significantly with PY, PG, and TBHQ, whereas BHT was not very effective. A good correlation was found between the improvement of the oxidation stability and the FA composition.

2.6.9.2 Thermal Stability: Current knowledge and database is still inadequate. More information is needed in this area.

2.6.9.3 Storage Stability: Very little data is available on the long-term storage stability of bio-diesel. Effect of presence of water, sediments, and additives on storage stability need to be investigated more. Based on the data available so far it is recommended that bio-diesel and its blends should not be stored in a storage tank or vehicle tank for more than 6 months. Depending upon the storage temperature and other conditions use of an appropriate antioxidants (e.g. Tenox 21, t-butylhydroquinone etc.) is suggested. The antioxidants must be properly mixed with the fuel for good effectiveness. To avoid growth of algae in fuel, water contamination need to be minimized and if necessary some biocide should be used.

2.6.10 Free and Total glycerol:

The degree of conversion completeness of the vegetable oil is indicated by the amount of free and total glycerol present in the bio-diesel. If the actual number is higher than the specified values, engine fouling, filter-clogging etc can occur. Manufacturing process controls are necessary to ensure low free and total glycerin. Free glycerol if present can build up at the bottom of the storage and vehicle fuel tanks.

2.6.11 Mono-, Di-, and Triglycerides:

Most of the bio-diesel standards, except Austrian and ASTM, specify a max. limit of 0.08 for Mono-glyceride. Draft EU standard calls for same limit. Di-and Triglycerides are also controlled in most of the standards. High levels of these glycerides can cause injector fouling, filter clogging etc.

2.6.12 Sulfur content:

Biodiesel generally contain less than 15ppm sulfur. ASTM D 5453 test is a suitable test for such low level of sulfur. ASTM D 2622 used for sulfur determination of diesel fuels gives falsely high results when used for biodiesel. More work need to done to assess suitability of ASTM D 2622 application to B20 biodiesel blend. The increase in oxygen content of the fuel affects precision of this test method.

2.6.13 Lubricity:

Wear due to excessive friction resulting in shortened life of diesel fuel pumps and injectors, has some times ascribed to lack of lubricity in the fuel. Numerous premature breakdown and in some cases, catastrophic failures, have occurred failures. All diesel fuel injection equipment (fuel pump and injector) of the diesel engine have reliance on diesel fuels for its lubrication, especially the Rotary (Distributor) and Common Rail type systems. The lubrication of the pump is not provided by viscosity alone but also by the lubricity property of the fuel. Even when the viscosity of the fuel is correct, several parts of the pump can wear out due to lack of lubricity. The lubricity of the fuel depends on the crude source, refining process to reduce sulfur content and the type of additives used.

BOCLE (Ball on Cylinder Lubricity Evaluator) and HFFR (High Frequency Reciprocating Rig) are commonly used for evaluating the lubricity of the fuel. BOCLE is normally used for finding the lubricity fuel without additive, as it does not properly characterize the lubricity of fuels with lubricity additives. HFFR method has been adopted by Fuel Injection Manufactures for lubricity evaluation of diesel fuels and they recommend a limit of 460 microns wear scar diameter (WSD). Lower the WSD better is the lubricity of fuel. In case of BOCLE method a higher value is better. Even with 2% biodiesel mixed in diesel fuel, the WSD values comes down to around 325 micron and is sufficient to meet the lubricity requirements of the fuel injection pump(460 micron max.). B100 performs still better, with a WSD of about 314 micron. With further

reduction of sulfur content is diesel for Euro II and Euro IV fuels, the lubricity loss due to sulfur removal can easily be compensated by the addition of appropriate amount of biodiesel in diesel fuel.

2% inclusion into any conventional diesel fuel is sufficient to address the lubricity problem. It also eliminates the inherent variability associated with use of other additives to make fuel fully lubricious. Second the biodiesel is a fuel component itself- any addition of it does cause any adverse consequences.

2.6.14 Sulfated Ash:

Sulfated ash is controlled to ensure that all the catalysts used in the transesterification process are removed. Presence of ash can cause filter plugging and or injector deposits. Soluble metallic soap, un-removed catalysts and other solids are possible sources of sulfated ash in the fuel.

2.6.15 Acid number/Neutralization number:

Acid number/Neutralization number is specified to ensure proper ageing properties of the fuel and/ or a good manufacturing process. Acid number reflects the presence of free fatty acids or acids used in manufacture of biodiesel. It also reflects the degradation of biodiesel due to thermal effects. For example, during the injection process several times more fuel returns from the injector than that injected into the combustion chamber of the engine. The temperature of this return fuel can, sometimes, be as high as 90 deg. C and thus accelerate the degradation of biodiesel. The resultant high acid number can cause damage to injector and also result in deposits in fuel system and affect life of pumps and filters. Sodium hydro peroxide and sulfuric acids are highly corrosive and can cause serious, many times permanent, injuries.

2.6.16 Water Content:

Biodiesel and its blends are susceptible to growing microbes when water is present in fuel. The solvency properties of the biodiesel can cause microbial slime to detach and clog fuel filters.

2.6.17 Phosphorous Content:

Phosphorous can come as impurity and can affect oxidation catalyst and cause injector fouling. As more and more OEMs are going to use catalytic converters in diesel engines, it is necessary to keep the level of phosphorous in fuel low. Usually biodiesel have less than 1ppm phosphorus. The specification of min. 10-ppm phosphorous content is intended to ensure compatibility with catalytic converters irrespective of the source of biodiesel.

2.6.18 Methanol/ethanol content:

High levels of free alcohol in biodiesel cause accelerated deterioration of natural rubber seals and gaskets. Damage to fuel pumps and injectors which have natural rubber diaphragms has been very common type of failure Methanol is membrane-permeable and can cause nerve damage. Therefore control of alcohol content is required.

2.6.19 Toxicity of Biodiesel

Impacts on human health represent a significant criteria as to the suitability of the fuel for commercial applications. Health effects can be measured in terms of fuel toxicity to the human body as well as health impacts due to exhaust emissions. Tests conducted by the Wil Research Laboratories investigated the acute oral toxicity of pure biodiesel fuel as well as B20 in a single dose study on rats, which concluded that biodiesel is not a toxic and there is no hazards anticipated from ingestion incidental to industrial exposure. The acute oral LD50 (lethal dose) is greater than 17.4-g/kg-body weight, which by comparison is far safer than even table salt. According to NIOSH (National Institute for Occupational Safety & Human Health), a 96-hr. lethal concentration of biodiesel for bluegills was greater than 1000 mg/l and this aquatic toxicity is deemed as insignificant. Other related effects of biodiesel are given below:

- Very mild human skin irritation. It is less than the irritation produced by 4% soap and water solution.
- It is biodegradable. It degrades at least 4 to 5 times faster than conventional diesel fuel.
- Biodiesel has a flash point of about 300 F well above conventional diesel fuel.
- Spills of biodiesel can decolorize any painted surface if left for long.

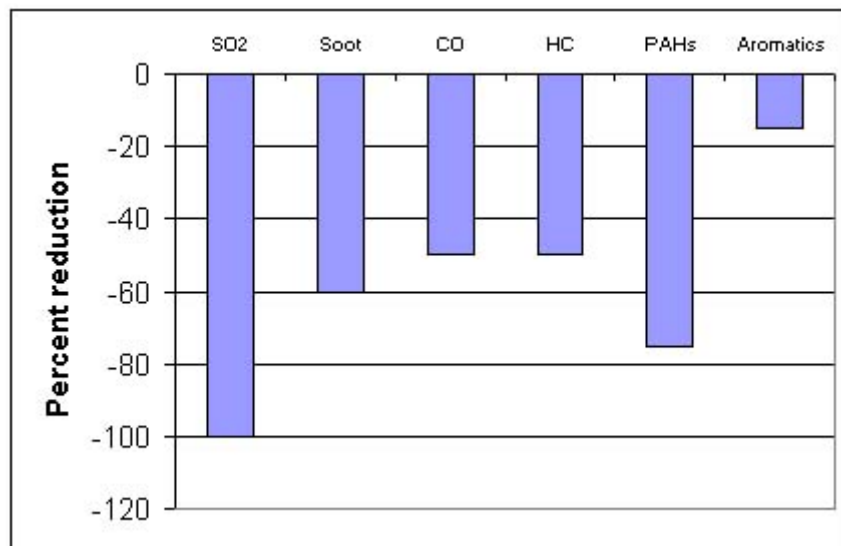
- There is no tendency for the mutagenicity of exhaust gas to increase for a vehicle running on biodiesel (20%RSME80% diesel).

2.8 Environmental Considerations [x]

Climate change is presently an important element of energy use and development. Biodiesel is considered "climate neutral" because all of the carbon dioxide released during consumption had been sequestered out of the atmosphere during crop growth. Combustion of one liter of diesel fuel results in the emission of about 2.6 kilograms of CO₂. Therefore, the use of biodiesel will directly displace this amount of CO₂ when used.

Combustion of biodiesel has been reported in a number of sources to have lower emissions compared with petroleum diesel. Lower emission of SO₂, soot, carbon monoxide (CO), hydrocarbons (HC), polyaromatic hydrocarbons (PAH), and aromatics are presented in the following Diagram. NO_x emissions from biodiesel are reported to range between plus or minus 10% as compared with petrodiesel depending on engine combustion characteristics.

Lower emissions of biodiesel compared with petrodiesel.



Production of Biodiesel involves growing the oil trees, pressing the seeds into oil and processing the oil into biodiesel by transesterification. The proposed project envisages use of *Jatropha Curcas* and *Pongamia Pinnata* Oils for production of Biodiesel.

2.8 Specifications and Quality Standards

Standards are of vital importance for the producers, suppliers and users of bio-fuels. Government Authorities need approval standards for the evaluation of safety, risks and environmental protection. Standards are necessary for the approval and warrantee commitment for vehicles operated with bio-fuels and are therefore, a pre-requisite for the market introduction and commercialization of bio-fuels. Creation of standards shall help expand the market for renewable sources of energy in India.

Conventionally Standards and codes for products have been developed, largely by examining the existing standards and codes in different countries and then writing standards for own country. With the formation of WTO, which seeks to eliminate discrimination of products based on national origin, and the realization that, in future, bio-fuels like ethanol and bio-diesel, can become internationally traded commodities like petroleum, it is essential that a worldwide view is taken while preparing a new national standard. But at the same time, the local imperatives (such as type of raw materials etc.) must be given due consideration.

In Europe bio-diesel is predominantly made from rapeseed oil and most information and data available are dealing with the rapeseed methyl ester (RME). Most of the experience in Austria, Italy, is also on RME. Germany has developed a standard for fatty acid methyl ester. Most of the Irish experience is on use of tallow fat for manufacture of bio-diesel. Very little experience is available on ethyl or propyl esters. No matter what the process or feedstock used, the bio-diesel produced must meet rigorous specifications to be used as a fuel in a compression ignition engine. It is not possible to recognize any blanket superiority of one feedstock over other since feedstock does not reliably predict a fuel's final properties.

Knowing that fuel adulteration is very rampant in India it is important that we ensure that chemical-grade fatty acid methyl esters used for purposes such as detergent

manufacture must not be allowed to use as engine fuel. A Worldwide survey of bio-diesel specification was done and an attempt was made to understand the rationale behind them before proposing a norm for India.

The key components, which determine the quality of biodiesel are monoalkyl esters, dialkyl esters, residual vegetable oil, free glycerin, reactant alcohol, free fatty acids and the residual catalyst. In December 2001, American Society of Testing & Materials (ASTM) issued a specification (D6751) for biodiesel (B100) which is presented in Table 2.4. Table 2.5 summarizes standards for biodiesel in various countries and Table 2.6 shows a comparison of selected properties of biodiesel and petrodiesel.

Table-2.4: ASTM Specification (D6751) for B100 [w]

Property	ASTM Method	Limits	Units
Flash Point	D93	130 min.	Degrees C
Water & Sediment	D2709	0.050 max.	% Volume
Kinematic Viscosity (40 C)	D445	1.9-6.0	mm ² /sec
Sulfated Ash	D874	0.020 max.	% mass
Sulphur	D5453	0.05 max.	% mass
CopperStrip Corrosion	D130	No.3 max.	
Cetane	D613	47 min.	
Cloud Point	D2500	Report	Degrees C
Carbon Residue (100% Sample)	D4530*	0.050 max.	% mass
Acid Number	D664	0.80 max.	Mg KOH/gm
Free Glycerin	D6584	0.020 max.	% mass
Total Glycerin	D6584	0.240 max.	% mass
Phosphorous Content	D4951	0.001 max.	% mass
Distillation Temperature (90% Recovered)	D1160	360 max.	Degrees C

*The carbon residue shall be run out on the 100% sample.

Table-2.5: Biodiesel Standards of Different Countries [w]

Specifications	Units	Australia	France	Germany	Italy	Sweden	USA	Draft EU
Standard/Specification		ONC1191	-	DINE51606	UNI10635	SS155436	ASTMD6751	EN14214
Introduction Date		Jly 1997	Spt1997	Spt1997	Apr1997	Nov1996	Dec2001	2001
Density @15c	g/cm ³	0.85-0.89	0.87-.89	.875-0.90	0.86-0.90	0.87-0.90	-	0.86-0.90
Viscosity@40c	Mm ² /s	3.5-5.0	3.5-5.0	3.5-5.0	3.5-5.0	3.5-5.0	1.9-6.0	3.5-5.0
Flash Point	°C	≥100	≥100	≥110	≥100	≥100	≥130	≥130
CFPP	°C	0/-15	-	0-10/-20	-	-5	-	0/-15
Pour Point	°C	-	-10	-	0/-15	-	-	-
Sulphur	%max	0.02	0.02	0.01	0.01	0.01	0.05	0.01
CCR 100%max		0.05	-	0.05	-	-	0.05	-
10%disti.residue	%max	-	0.3	-	0.5	-	-	0.3
SulphatedAshx	%max	0.02	-	0.03	-	-	0.02	0.01
(Oxid).Ash ,mx	%mass	-	-	-	0.01	0.01	-	-
Water max.	Mg/kg	-	200	300	700	300	≤0.05	500
TotalContaminants	Mg/kg	-	-	20	-	20	-	-
Cu Corrosion	3h/50c	-	-	1	-	-	NO.3	1
Cetane No.		≥49	≥49	≥49	-	≥48	≥47	≤49
Neutral No.		≤0.8	≤0.5	≤0.5	≤0.5	≤0.6	≤0.8	≤0.02
Methanol	%mass	≤0.20	≤0.01	≤0.3	≤0.02	≤0.02	-	≤0.02
Ester Content	%mass	-	≥96.5	-	≥98	≥98	-	≥96.5
Monoglyceride	%mass	-	≤0.8	≤0.8	≤0.8	≤0.8	-	≤0.8
Diglyceride	%mass	-	≤0.2	≤0.4	≤0.2	≤0.1	-	≤0.20
Triglyceride	%mass	-	≤0.2	≤0.4	≤0.1	≤0.1	-	≤0.03
Free Glycerol	%mass	≤0.02	≤0.02	≤0.02	≤0.05	≤0.02	≤0.02	0.25
Total Glycerol	%mass	0.24	0.25	0.25	-	-	0.24	≤115
Iodine No.		≤120	≤115	≤115	-	≤125	-	-
C18:3 & higher acids		≤15	-	-	-	-	-	10
Phosphorous	ppm	≤20	≤10	≤10	≤10	≤10	≤10	10
Alkaline Matter	(Na,K)	-	≤5	≤5	≤10	≤10	-	≤360
Distillation 95%	°C	-	≤360	-	-	-	≤360	*
IBP min.	°C	-	-	-	-	-	-	*
Bound Glycerin		-	-	-	-	-	-	Max 0.8
Oxidation Stability	Hrs.	-	-	-	-	-	-	6 min.
Sediment		-	-	-	-	-	-	≤0.05
Cloud Point		-	-	-	-	-	*	-

*Report

Table-2.6: Selected Fuel Properties for Petrodiesel & Biodiesel [w]

Fuel Property	Petrodiesel	Biodiesel
Fuel Standard	ASTM D975	ASTM PS121
Fuel Composition	C10-C21 HC	C12-C22 FAME
Lower Heating Value, Btu/gal	131,295	117,093
Kin. Viscosity, @40 C	1.3-4.1	1.9-6.0
Specific Gravity, kg/l @ 60 F	0.85	0.88
Density, lb/gal @ 15 C	7.079	7.328
Water, ppm by wt.	161	0.05% max.
Carbon, wt%	87	77
Hydrogen, wt%	13	12
Oxygen by dif. Wt%	0	11
Sulphur, wt%	0.05 max.	0.00-0.0024
Boiling Point, Degrees C	188-343	182-338
Flash Point, Degrees C	60-80	100-170
Cloud Point, Degrees C	-15 to 5	-3 to 12
Pour Point, Degrees C	-35 to -15	-15 to 10
Cetane Number	40-55	48-65
Stoichometric Air/Fuel Ratio	15	13.8
BOCLE Scuff, gm	3,600	>7,000
HFRR, microns	685	314

2.8.1 Proposed Bio-diesel Specifications for India

Table 2.7 below gives a comprehensive list of important fuel properties that have been considered for inclusion in the bio-diesel fuel specification. All these properties were considered, sometime or another, by different countries but not necessarily included in the final draft.

Table 2.7: Fuel Properties considered:

1	Density/specific gravity	17	Water content
2	Kinematic Viscosity	18	Cloud point
3	Flashpoint	19	(Oxi,) ash
4	CFPP	20	Net calorific value
5	Pour point	21	Acid Number/Neutral No.

6	Cetane number	22	Ester content
7	Distillation characteristics	23	Methanol content
8	Conardson carbon Residue	24	Mono -glycerides
9	Sulfur content	25	Di-glycerides
10	Copper corrosion	26	Triglycerides
11	Total contamination	27	Iodine number
12	Phosphorous content	28	Poly-Saturated ester(C 18:3 +)
13	Sulfated Ash	29	Free glycerol
14	Thermal stability	30	Total glycerol
15	Oxidation stability	31	Alkaline material(K, Na)
16	Storage Stability	32	Lubricity

Some of important properties specified are described below and reasons for the need to incorporate it in the fuel specification are mentioned in short. Since our feedstocks are going to be different from those used in developed countries, it was felt necessary to include all the relevant properties in the initial list for evaluation. An attempt should be made to reduce the final number of properties specified to the minimum possible. Of course, before the proposed specification for India are frozen, more deliberations would be necessary keeping in mind the local feedstock, manufacturing and quality control techniques used Table 2.9 gives the proposed specifications for India.

Table 2.9: Summary of Proposed BIS Standard for Biodiesel [11]

Standard/Specification		Proposed BIS
Density @15°C	g/cm ³	0.87-0.90
Viscosity@40 °C	mm ² /s	3.5-5.0
Flashpoint	° C	≥100
CFPP	° C	
Sulfur, max.,	% mass	0.035
CCR,100%disti.resid.max.. ,	% mass	0..05
Sulfated Ash, max,	% mass	0.02
(Oxid). Ash. Max,	% mass	?
Water .max	mg/Kg	500
Total Comtami., max.	mg/Kg	20
Cu Corrosion(3h/50C), max		1
Cetane No..		≥51
Acid No,	mg koh/g	≤0.8
Methanol,	% mass	≤0.02
Ester Content,	% mass	≥96.5
Monoglyceride, ?**	% mass	≤0.8
Diglyceride, ?	% mass	≤0.2
Triglyceride,?	% mass	≤0.2

Free Glycerol,	% mass	≤0.02
Total Glycerol,	% mass	≤0.25
Iodine No.		≤115
Phosphorus	ppm	≤10
Alkaline Matter(Na, K)		≤10
Distillation, T 95%	°C	≤360
Cloud point		*

* **measure and report**

** in the table means that this property needs further discussion.

Though the test methods used for petroleum products are available there is very little experience in the use of materials like karanja, jatrophaa, rice brawn oil etc. These test methods must be reviewed to ensure their applicability for biodiesel, the precision and the accuracy achievable.

FUEL CHARACTERIZATION

Engine Fuel passes through many stages. At each & every step proper analysis of the desired fuel are performed in order to ensure that the working properties of the fuel inside an engine should not interfere with its smooth operation. The blend of Jatropha biodiesel and Karanja biodiesel were prepared using high speed diesel in varying proportions from 10 % biodiesel to 100 % biodiesel as shown in the table 3.1. The various properties of fuel e.g., viscosity, density, calorific values, etc. was evaluated for the prepared blends, which are mentioned below.

Table 3.1: Composition of Eleven Fuel Samples Whose Performance Was Tested.

S.No.	Designation	Jatropha Biodiesel (%)	Karanja Biodiesel (%)	H. S. Diesel (%)	Blend of Jatropha and Karanja Biodiesel in equal ratio. (%)
1.	H.S.D.	-	-	100	-
2.	J.B.100	100	-	-	-
3.	K.B.100	-	100	-	-
4.	JKB100	-	-	-	100
5.	JKB90	-	-	10	90
6.	JKB80	-	-	20	80
7.	JKB70	-	-	30	70
8.	JKB60	-	-	40	60
9.	JKB50	-	-	50	50
10.	JKB40	-	-	60	40
11.	JKB30	-	-	70	30
12.	JKB20	-	-	80	20
13.	JKB10	-	-	90	10

Fuel characterization of the prepared samples was done with the same objective. The oil samples were subjected to several property tests in accordance with standard testing procedures. These tests included higher calorific value, specific gravity, kinematic viscosity at 40°C, and flash points.



3.1 KINEMATIC VISCOSITY OF FUEL

Viscosity is an important physical property of a diesel fuel. Improper viscosity leads to poor combustion, which results in loss of power and excessive exhaust smoke. Diesel fuels with extremely low viscosities may not provide sufficient lubrication for the closely fit pumps and injector plungers. They can promote abnormal wear and cause injector and injector pump leakage and dribbling leading to loss of power as fuel delivered by the injector is reduced. Diesel fuel with higher viscosity is also not desirable as too viscous fuel increases pumping losses in injector pump and injectors, which reduces injection pressure resulting in poor atomization and inefficient mixing with air ultimately affecting the combustion process.

Viscosity of oil is its resistance to flow. Viscosity of oil can be expressed in two ways Dynamic viscosity and kinematic viscosity. The definition of dynamic viscosity is given as the ratio between the applied shear stress and rate of shear of oil. Kinematic viscosity of the oil is its resistance of flow under gravity. Dynamic viscosity of oil can also be computed by multiplying kinematic viscosity by its density. Unit of dynamic viscosity is Poise and that of kinematic viscosity is Stokes. The kinematic viscosity of oil is generally expressed in centi-stokes.

3.1.1 kinematic viscosity measurement (ASTM D445)

Apparatus used: Redwood Viscometer:

The viscosity measurement was done by using a Redwood viscometer of capillary type by setting the temperature at 40°C. A fixed quantity of the test fuel is allowed to pass through the tube of known diameter. The time elapsed to pass this fixed quantity was measured with the help of stopwatch. Now by multiplying this time to the tube constant (a calibrated constant provided by the manufacturer) we get the viscosity. The viscosities of various blends are tabulated below.

Table 3.2: Kinematic Viscosity of various fuel sample at 40°C

S.No.	Fuel Sample	Tube Constant of Capillary Tube	Time taken by the Fuel to Flow Through the Capillary Tube. (Seconds)	Kinematic Viscosity (40°C) (cSt)
1.	H.S.D.	0.16224	27.88	4.5232
2.	J.B.100	0.16224	35.34	5.7335
3.	K.B.100	0.16224	39.36	6.3857
4.	JKB100	0.16224	37.24	6.0418
5.	JKB90	0.16224	35.54	5.7660
6.	JKB80	0.16224	35.06	5.6881
7.	JKB70	0.16224	34.02	5.5194
8.	JKB60	0.16224	32.01	5.1933
9.	JKB50	0.16224	31.18	5.0586
10.	JKB40	0.16224	30.05	4.8753
11.	JKB30	0.16224	29.64	4.8087
12.	JKB20	0.16224	28.97	4.7000
13.	JKB10	0.16224	28.03	4.5475



3.2 SPECIFIC GRAVITY

Specific gravity will provide more information about how the fuel will perform in a diesel engine than any other single test. Specific gravity is defined as the mass of unit volume of fluid (at some standard temperature) to that of the same volume of water at same temperature. Since petroleum fuels are sold on a volume basis, the specific gravity is important for determining the mass of purchased fuel. It is also important because a change in sp. gravity will also change the heating value/kg of fuel. To determine the sp. gravity of the various fuels, standard specific gravity bottle (25 ml capacity) was used.

Table 3.3: Specific gravity of the various fuel

S.No.	Fuel Sample	Weight of the empty bottle (gm)	Weight of the bottle with sample (gm)	Weight of the sample (gm)	Specific gravity of the sample (gm/cc³)
1.	H.S.D.	19.1466	38.6793	19.5327	0.781308
2.	J.B.100	19.1578	39.9659	20.8081	0.832324
3.	K.B.100	19.1076	40.2809	21.1733	0.846932
4.	JKB100	19.1568	40.1550	20.9982	0.839928
5.	JKB90	19.1485	40.0105	20.862	0.83448
6.	JKB80	19.1025	39.8522	20.7497	0.829988
7.	JKB70	19.1658	39.4846	20.3188	0.812752
8.	JKB60	19.1659	39.4386	20.2727	0.810908
9.	JKB50	19.1365	39.2636	20.1271	0.805084
10.	JKB40	19.1562	39.1966	20.0404	0.801616
11.	JKB30	19.1456	39.0642	19.9186	0.796744
12.	JKB20	19.1562	38.8065	19.6503	0.786012
13.	JKB10	19.1365	38.7575	19.621	0.78484

3.3 Measurement of Flash Point

Flash point of fuel is the minimum temperature at which it gives enough vapors to form a flammable mixture that ignite for a moment, when a tiny flame is brought near to it. It is desirable that the fuel should have high flash point, primarily from a fuel-handling standpoint. Too low a flash point will cause fuel to be a fire hazard, subject to flashing, and possible continued ignition and explosion.

3.3.1 Flash Point Measurement (ASTM D- 93)

Apparatus Used: Pensky-Marten's Closed Cup Apparatus

This apparatus essentially consists of, an oil cup about 5.0 cm. in diameter and 5.5 cm.deep. The level to which the oil is to be filled is marked inside the cup. The cup lid is provided with four openings of standard sizes. Through one of these passes a thermometer; while the second opening is used for introducing test flame. Through third opening passes stirrer carrying two blades; while the fourth is meant for admission of air.

Shutter is provided at the top of the cup. By moving the shutter, opening in the shutter opens and flame gets dipped into this opening, thereby bringing the flame over the surface of the vapours. Flame exposure device, a tiny flame, is connected to the shutter by a lever mechanism.



Procedure to measure flash point:

To determine the flash point of the fuel, thoroughly cleaned and dried oil cup was filled up to the mark. The lid was placed on the cup, thermometer was inserted and then oil cup was heated by heating the air bath by burner. The pilot flame was also ignited. Fuel was stirred well during the test. Heat was applied at

such a rate that the temperature as indicated by the thermometer increases 5°C to 6°C /minute. If the sample was expected to have a flash point of 110° C or below, the test flame was applied when the temperature of the sample was from 17°C to 28°C below the expected flash point and thereafter at a temperature reading, which was a multiple of 1°C. If the sample was expected to have a flash point above 110°C, the test flame was applied at each temperature that was a multiple of 2 °C, beginning at a temperature of 17°C to 28°C below the expected flash point. The temperature, at which a distinct flash (a combination of weak sound and light) appeared inside the cup, was recorded as the flash point of the sample fuel.

Table 3.4: Flash point of the various fuel

S.No.	Fuel Sample	Flash Point (°C)
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1.	H.S.D.	67
2.	J.B.100	162
3.	K.B.100	172
4.	JKB100	166
5.	JKB90	154
6.	JKB80	143
7.	JKB70	131
8.	JKB60	118
9.	JKB50	109
10.	JKB40	97
11.	JKB30	85
12.	JKB20	78
13.	JKB10	72

3.4 Calorific Value of the Fuel Sample

One of the important characteristics of a good fuel is high calorific value as the amount of heat liberated and temperature attained thereby depends upon the calorific value of the fuel. Calorific value of a fuel is *“the total amount of heat liberated, when a unit mass (or volume) of the fuel is burnt completely.”*

Usually, all fuels contain some hydrogen and when the calorific value of the hydrogen fuel is determined experimentally, the hydrogen is converted in to steam. If products of combustion are condensed to room temperature (15°C) the latent heat of condensation of steam also gets in the measured value of heat, which is then called higher or gross calorific value of the fuel. Hence, gross or higher calorific value (HCV) is *the total amount of heat produced, when unit mass /volume of the fuel have been burnt completely and the products of combustion have been cooled to room temperature.*

In actual use of any fuel, the water vapour and moisture etc are not condensed and escape as such along with hot combustion gases hence; a lesser amount of heat is available. Therefore, net or *lower calorific value (LCV)* is *“the net heat produced, when unit mass/ volume of the fuel is burnt completely and the products are permitted to escape.”* The standard procedure used for measuring calorific value of fuel in India is given by IS: 1448 part I, 1960 that gives details of equipments to be used and procedure

for conducting the experiments. Most commonly, Bomb Calorimeter is used to find out calorific value of solid and liquid fuels.

3.4.1 Measurement of Calorific Value

Apparatus Used: Bomb Calorimeter

It consists of a strong cylindrical stainless steel bomb in which the combustion of the fuel is made to take place. The bomb has a lid, which can be screwed to the body of the bomb to make a perfect gas tight seal. The lid is provided with two stainless steel electrodes and an oxygen inlet valve. To one of the electrodes, a small ring is attached. In this ring, a nickel or stainless steel crucible can be supported. The bomb is placed in a copper calorimeter containing water and is surrounded by an air jacket to prevent heat losses due to radiation. The calorimeter is provided with an electrically operated stirrer and a thermometer.

To determine the calorific value of the fuel, a known mass of the given fuel was taken in clean crucible. The crucible was then supported over the ring. A fine magnesium wire, touching the fuel sample, was stretched across the electrode. A cotton thread was made to attach with the magnesium wire and touches the fuel sample. The bomb lid was tightly screwed and bomb was filled with oxygen to about 20 -25 atmospheric pressure. The bomb was then lowered into copper calorimeter, containing a known mass of water. Electrical circuit was completed by connecting the electrodes to a 6-volt battery and stirring of the water was also started. Due to burning of the sample, heat is liberated. Uniform stirring of water was continued and maximum temperature attained recorded. It may be noted that before determining the calorific value of the unknown fuel the water equivalent of the calorimeter was determined by burning known quantity of Benzoic acid (CV, 26460 KJ /Kg). The capacity of the bomb calorimeter was 1.6031 liters. The water equivalent of the calorimeter is measured by the following equation.

$$C.V * x = (W + w) * \Delta t * C_p \text{ ----- (1)}$$

Where

C.V - The calorific value of the fuel burnt in KJ/Kg.

x - The quantity of the fuel burnt.

W - The water contained in the calorimeter.

w - The water equivalent of the bomb calorimeter.

Δt - The temperature of the water.

C_p - Specific heat of water



Table 3.5: Observation and calculated values of the Calorific Value of various Fuels

S.No.	Fuel Sample	Weight of the Empty Crucible (gm)	Weight of the Crucible with fuel (gm)	Weight of the fuel (gm)	Change in water temp. (°C)	Calorific Value KJ/Kg	Water equivalent of calorimeter
1	Benzoic Acid	10.2986	12.3816	2.083	6.1	26460 (Known)	0.5571
2.	H.S.D.	10.2982	11.0125	0.7143	3.3	42122.2	
3.	J.B.100	10.2986	11.5639	1.2653	5.5	39774.8	
4.	K.B.100	10.2982	11.3734	1.0752	4.2	35882.8	
5.	JKB100	10.2996	11.9357	1.6361	6.4	35446.6	
6.	JKB90	10.2986	11.862	1.5634	6.2	36073.4	
7.	JKB80	10.2962	12.6218	2.3256	9.4	36801.7	
8.	JKB70	10.2958	12.03	1.7342	7.1	37358.3	
9.	JKB60	10.2986	11.3334	1.0348	4.3	38105.8	
10.	JKB50	10.2958	12.4192	2.1234	9	38703.4	
11.	JKB40	10.2936	11.9815	1.6879	7.3	39396.7	
12.	JKB30	10.2956	11.5313	1.2357	5.4	40203.6	
13.	JKB20	10.2982	12.1947	1.8965	8.5	40689.1	
14.	JKB10	10.2978	12.0636	1.7658	8	41460.6	

EXPERIMENTAL SETUP, OBSERVATION AND EVALUATION OF PERFORMANCE CHARACTERISTICS

The objectives of the present work was to evaluate the feasibility of using biodiesel made from the seeds of Jatropha and Karanja trees in different proportions with fossil diesel by evaluating the performance and exhaust emission characteristics of a diesel engine. It was also aimed to find out the optimal concentration of biodiesel blend, based on the performance characteristics and also to observe whether there was any specific combustion related problem of biodiesel fuel with unmodified C.I engine. The various stages of experimentation were planned out as follows.

1. To prepare the biodiesel from Jatropha & Karanja oil and prepare blend of Jatropha & Karanja derived biodiesel in 50-50% proportions to assess its suitability as a fuel in a diesel engine.
2. To evaluate the relevant performance parameters such as power developed, fuel consumption rate, brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC), thermal efficiency, and brake mean effective pressure (BMEP) for various test fuels at different load conditions.
3. To measure smoke density experimentally for different blends and comparison with pure diesel operation.
4. To analyze the experimental data from biodiesel and diesel fuelled CI engine and comparative evaluation of performance and emission characteristics.

To achieve the above-mentioned goals, biodiesel made from Jatropha and Karanja is mixed in equal ratios by volume, then several blends of that biodiesel with diesel in different concentrations (10%, 20%, 30%...100%) were prepared and subjected to emission and performance tests on the unmodified diesel engine running at 1500 rpm. The testing was done in Center of Advanced Studies & research in Automotive Engineering, Mechanical Engineering Department, Delhi College of Engineering, Delhi. Engine performance and exhaust emission data were recorded and relevant parameters

like BMEP, BSFC, BSEC and thermal efficiency etc were calculated. Based on these parameters, various curves were drawn and compared to base line diesel curve in order to assess the performance of the engine with different biodiesel blends.

4.1 MEASUREMENT OF VARIOUS PARAMETERS:

4.1.1 Measurement of fuel flow:

Accurate measurement of fuel consumption is very important in engine testing work and simplest method of measurement is to use a glass burette of known volume with suitable marking on it. Time taken by the engine to consume the known volume of fuel is measured by a stopwatch. Volume divided by the time gives the volumetric fuel flow rate.

The above-mentioned method was also used in present work. A fuel tank of about 5 lts capacity with burette capacity of 100cc was mounted on stand at sufficiently high position with required piping, joints and valves. It was connected to fuel pump via fuel filter.

4.1.2 Measurement of Power:

As it is also shown in the figure that engine had a provision of being loaded mechanically on brake drum dynamometer The load was applied on the engine by putting weight on the pan and from spring balance reading of resisting force can be noted down. Water flow arrangement was there to cool the drum so that correct reading can be obtained.

4.1.3 Measurement of Smoke:

THE SMOKE OF THE ENGINE EXHAUST IS A VISIBLE INDICATOR OF THE COMBUSTION PROCESS IN THE ENGINE. SMOKE IS ALSO DUE TO INCOMPLETE COMBUSTION. SMOKE IN THE DIESEL ENGINE, IN GENERAL, CAN BE DIVIDED INTO TWO CATEGORIES VIZ., BLUE WHITE SMOKE AND BLACK SMOKE. THE BLUE- WHITE SMOKE FROM THE ENGINE IS CAUSED BY LIQUID DROPLETS OF FUEL OIL OR LUBRICATING OIL WHILE IT STARTS FROM THE COLD. ON THE OTHER HAND IN BLACK SMOKE

CARBON PARTICLES ARE SUSPENDED IN THE EXHAUST GAS. IT LARGELY DEPENDS UPON THE AIR FUEL RATIO AND INCREASES RAPIDLY AS THE LOAD IS INCREASED AND AVAILABLE AIR IS DEPLETED.

IN PRESENT WORK, SMOKE DENSITY WAS MEASURED BY THE AVL-437 SMOKE METER, MANUFACTURED BY M/S AVL INDIA PVT.



4.2 ENGINE SYSTEM

THE ENGINE SELECTED FOR EMISSION AND PERFORMANCE TESTING BEST REPRESENTS THE ENGINE SYSTEM MOST COMMON AMONG THE RURAL SECTION & IS WIDELY USED IN AGRICULTURAL SECTOR OF INDIA. IT IS A SINGLE CYLINDER, FOUR STROKE, DIRECT INJECTION, AND WATER-COOLED NATURAL ASPIRATED VERTICAL DIESEL ENGINE. KIRLOSKAR INDIA LIMITED HAS MANUFACTURED THE ENGINE, & IT DEVELOPS 5.2 KW POWER OUTPUT AT THE RATED SPEED OF 1500 RPM.



Table 4.1: Engine Specifications

No. of Cylinders	1
No. of strokes	4
Fuel	H.S. diesel
Rated power	5.2 KW @ 1500 rpm
Cylinder diameter	87.5 mm
Stroke length	110 mm
Compression Ratio	17.5 : 1
Orifice diameter	20 mm
Inlet Valve Opens	4.5° Before TDC
Inlet Valve Closes	35.5° After BDC
Fuel Injection	23° Before TDC
Exhaust Valve opens	35.5° Before BDC

Exhaust Valve Closes	4.5° After TDC
Drum Brake diameter	347 mm
Pan weight	1.5 kg

4.3 ENGINE EXPERIMENTATION PROCEDURE:

Starting of the engine:

The engine was started at no load by pressing the inlet with decompression valve lever and it was released suddenly when the engine was hand cranked at sufficient speed.

Preliminary run:

Feed controlled was adjusted to obtain the engine rated speed and it was allowed to run for about 30 minutes till the steady state conditions reached. To assess the present condition of the engine, a constant speed test with diesel as a fuel was carried out and base line data were generated. Test results with all other fuels were compared with base line data to evaluate the performance of the engine.

Measurements:

With the help of fuel measuring device and stopwatch, the time elapsed for consumption of 20cc of fuel was measured. RPM, power output (in terms of weight applied and spring scale reading) and smoke density were also measured.

Loading:

The engine was loaded gradually keeping the rated speed within variation of permissible range and the observations of various parameter were recorded. Short-term performance test were carried out on the engine with various blend of biodiesel and diesel.

4.4 FORMULAE USED FOR CALCULATION OF VARIOUS ENGINE PERFORMANCE PARAMETERS

4.4.1 Mass Flow Rate of the Fuel:

By knowing the volume flow rate (for the 20 ml.) of the fuel and multiplying it by the density of the fuel we get the mass flow rate of the fuel.

$$\text{Mass flow rate (m)} = \text{volume flow rate (v)} \times \text{density } (\rho) \times 3600$$

Where m – mass flow rate in kg/hr
 v - volume flow rate in m³/sec
 ρ - density in kg/m³

4.4.2 Power:

Power output of the engine can be calculated by the brake drum dynamometer. By knowing the torque on the shaft of the engine we get the power output of the engine by the following relationship [12]:

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

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

4.4.3 Brake Specific Fuel Consumption:

Brake specific fuel is the fuel consumed by the engine per unit of power produced.

$$\text{BSFC (kg/kW-hr)} = \frac{\text{fuel consumed per unit time (kg/hr)}}{\text{Power (kW)}}$$

4.4.4 Brake Specific Energy Consumption:

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

$$\text{BSEC (kJ/kW-hr)} = \text{BSFC (kg/kW-hr)} \times \text{Calorific Value (kJ/kg)}$$

4.4.5 Brake Thermal Efficiency:

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

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

4.4.6 Brake Mean Effective Pressure:

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

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

$$L A n K$$

Where, B.P = Brake Power (kW)

L = Length of Stroke (m),

A = Cross Sectional Area of the cylinder

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

N = Engine Speed (RPM)

K = No of Cylinders.

4.5 OBSERVATION TABLES

FUEL: H.S.D.

Calorific Value: 42122.213 KJ/Kg

Specific Gravity: 0.7813 gm/cc³

OBSERVED VALUES:

S.N o	Speed (rpm)	Fuel Consumption (ml)	Manometer Reading (cm)	Effective Load (kg)	Smoke meter Reading (%)	Time (sec.)
1	1564	20	2.5	.65	10.8	97.02
2	1557	20	2.5	1.9	18.6	92.18
3	1557	20	2.5	3.55	29.5	87.9
4	1555	20	2.5	4.75	38	79.29

5	1550	20	2.5	6.25	49.3	70.25
6	1536	20	2.5	8.90	62.5	62.10

CALCULATED VALUES:

S.No	Effective Load (kg)	Power (kw)	Fuel Consumption (kg/hr)	Bmep (bar)	BSFC (Kg/kw-hr)	BSEC (kJ/kw-hr)	Brake Thermal Efficiency (%)
1	0.65	0.1812	0.5798	0.2102	3.1998	134782.65	2.671
2	1.9	0.5273	0.6103	0.6144	1.1574	48752.249	7.3842
3	3.55	0.9852	0.64	1.1479	0.6496	27362.589	13.156
4	4.75	1.3165	0.7095	1.5359	0.5389	22699.660	15.858
5	6.25	1.7267	0.8008	2.021	0.4638	19536.282	18.428
6	8.90	2.4366	0.9059	2.8779	0.3718	15661.038	22.988

FUEL: JB 100

Calorific Value: 39774.79 KJ/Kg

Specific Gravity: 0.8323 gm/cc³

OBSERVED VALUES:

S.N	Speed (rpm)	Fuel Consumption (ml)	Manometer Reading (cm)	Effective Load (kg)	Smoke meter Reading (%)	Time (sec.)
1	1571	20	2.5	.75	6.8	97.26
2	1559	20	2.5	1.75	10.3	89.7
3	1552	20	2.5	3	18.7	79.7
4	1550	20	2.5	4.75	23.5	72.37
5	1548	20	2.5	6.5	27.5	65.28

6	1540	20	2.5	9.75	31.8	58.36
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CALCULATED VALUES:

S.No	Effective Load (kg)	Power (kw)	Fuel Consumption (kg/hr)	Bmep (bar)	BSFC (Kg/kw-hr)	BSEC (kJ/kw-hr)	Brake Thermal Efficiency (%)
1	.75	0.21	0.6162	0.2425	2.9343	116711.16	3.0846
2	1.75	0.4863	0.6681	0.5659	1.3738	54642.606	6.5881
3	3	0.8299	0.7519	0.9701	0.906	36035.96	9.9899
4	4.75	1.3123	0.8281	1.536	0.631	25097.892	14.343
5	6.5	1.7935	0.918	2.1019	0.5118	20356.737	17.683
6	9.75	2.6763	1.0269	3.1528	0.3837	15261.587	23.589

FUEL: KB 100

Calorific Value: 35882.79 KJ/Kg

Specific Gravity: 0.8469 gm/cc³

OBSERVED VALUES

S.N	Speed (rpm)	Fuel Consumption (ml)	Manometer Reading (cm)	Effective Load (kg)	Smoke meter Reading (%)	Time (sec.)
1	1570	20	2.5	.75	7.3	100.25
2	1564	20	2.5	1.50	11.5	92.65
3	1555	20	2.5	3	19.6	82.35
4	1550	20	2.5	4.75	22.5	72.89

5	1546	20	2.5	6.6	25.6	67.25
6	1541	20	2.5	9.50	30.5	60.38

CALCULATED VALUES:

S.No	Effective Load (kg)	Power (kw)	Fuel Consumption (kg/hr)	Bmep (bar)	BSFC (Kg/kw-hr)	BSEC (kJ/kw-hr)	Brake Thermal Efficiency (%)
1	.75	0.2099	0.6083	0.2425	2.898	103988.32	3.4619
2	1.50	0.4182	0.6582	0.4851	1.5739	56475.924	6.3744
3	3	0.8315	0.7405	0.9701	0.8906	31957.213	11.266
4	4.75	1.3123	0.8366	1.536	0.6375	22875.279	15.737
5	6.6	1.8187	0.9068	2.1342	0.4986	17891.159	20.122
6	9.50	2.6093	1.0099	3.0719	0.387	13886.640	25.922

FUEL: JKB 100

Calorific Value: 35446.62 KJ/Kg

Specific Gravity: 0.8399 gm/cc³

OBSERVED VALUES:

S.N	Speed (rpm)	Fuel Consumption (ml)	Manometer Reading (cm)	Effective Load (kg)	Smoke meter Reading (%)	Time (sec.)
o						

1	1571	20	2.5	0.75	7.2	91
2	1564	20	2.5	2	15.5	82.9
3	1556	20	2.5	3.25	25.6	77.64
4	1548	20	2.5	4.75	33.6	68.5
5	1540	20	2.5	6	40.1	65.56
6	1540	20	2.5	9	48	57.04

CALCULATED VALUES:

S.No	Effective Load (kg)	Power (kw)	Fuel Consumption (kg/hr)	Bmep (bar)	BSFC (Kg/kw-hr)	BSEC (kJ/kw-hr)	Brake Thermal Efficiency (%)
1	0.75	0.21	0.6646	0.2425	3.1648	112181.452	3.2091
2	2	0.5575	0.7295	0.6467	1.3085	46381.8978	7.7615
3	3.25	0.9014	0.7789	1.051	0.8641	30629.4214	11.753
4	4.75	1.3106	0.8828	1.536	0.6736	23876.8409	15.078
5	6	1.6469	0.9224	1.9401	0.5601	19853.65	18.133
6	9	2.4704	1.0602	2.9102	0.4292	15213.6878	23.665

FUEL: JKB 90

Calorific Value: 36073.36 KJ/Kg

Specific Gravity: 0.8345 gm/cc³**OBSERVED VALUES:**

S.N o	Speed (rpm)	Fuel Consumption (ml)	Manometer Reading (cm)	Effective Load (kg)	Smoke meter Reading (%)	Time (sec.)
1	1563	20	2.5	.7	10	104.63
2	1555	20	2.5	2	13.9	95.68
3	1559	20	2.5	3.7	21.5	84.5
4	1544	20	2.5	5.4	25.5	72.35
5	1541	20	2.5	6.75	34.6	66.62
6	1522	20	2.5	9.8	54.2	64.87

CALCULATED VALUES:

S.No	Effective Load (kg)	Power (kw)	Fuel Consumption (kg/hr)	Bmep (bar)	BSFC (Kg/kw- hr)	BSEC (kJ/kw-hr)	Brake Thermal Efficiency (%)
1	.7	0.195	0.5742	0.2263	2.9446	106221.62	3.3891
2	2	0.5543	0.628	0.6467	1.133	40871.119	8.8085
3	3.7	1.0281	0.711	1.1964	0.6916	24948.337	14.431
4	5.4	1.4861	0.8304	1.7462	0.5588	20157.795	17.86
5	6.75	1.854	0.9019	2.1827	0.4865	17549.690	20.515
6	9.8	2.6586	0.9262	3.169	0.3484	12567.959	26.586

FUEL: JKB 80

Calorific Value: 36801.74 KJ/Kg

Specific Gravity: 0.8299 gm/cc³**OBSERVED VALUES:**

S.N o	Speed (rpm)	Fuel Consumption (ml)	Manometer Reading (cm)	Effective Load (kg)	Smoke meter Reading (%)	Time (sec.)
1	1570	20	2.5	0.7	8.8	111.4
2	1558	20	2.5	1.9	15	105.68
3	1554	20	2.5	3.4	21.3	90.76
4	1547	20	2.5	5.5	29.4	75.26
5	1545	20	2.5	6.6	32.5	71.83
6	1527	20	2.5	9.75	41.1	61.56

CALCULATED VALUE:

S.No	Effective Load (kg)	Power (kw)	Fuel Consumption (kg/hr)	Bmep (bar)	BSFC (Kg/kw- hr)	BSEC (kJ/kw-hr)	Brake Thermal Efficiency (%)
1	0.7	0.1959	0.5364	0.2264	2.7381	98772.473	3.5726
2	1.9	0.5276	0.5655	0.6144	1.0718	38663.429	9.1265
3	3.4	0.9417	0.6584	1.0994	0.6992	25222.495	13.991
4	5.5	1.5166	0.794	1.7785	0.5235	18884.405	18.685

5	6.6	1.8175	0.8319	2.1342	0.4577	16510.778	21.372
6	9.75	2.6537	0.9707	3.1528	0.3658	13195.636	26.742

FUEL: JKB 70

Calorific Value: 37358.23 KJ/Kg

Specific Gravity: 0.8127 gm/cc³

OBSERVED VALUES:

S.N o	Speed (rpm)	Fuel Consumption (ml)	Manometer Reading (cm)	Effective Load (kg)	Smoke meter Reading (%)	Time (sec.)
1	1568	20	2.5	0.65	3.6	99.44
2	1564	20	2.5	2.75	12	89.7
3	1560	20	2.5	3.40	14.7	82.64
4	1552	20	2.5	5.25	22	67.28
5	1556	20	2.5	6.75	22.8	65.22
6	1530	20	2.5	9.5	27.4	58.07

CALCULATED VALUES:

S.No	Effective Load (kg)	Power (kw)	Fuel Consumption (kg/hr)	Bmep (bar)	BSFC (Kg/kw- hr)	BSEC (kJ/kw-hr)	Brake Thermal Efficiency (%)
1	0.65	0.1817	0.5885	0.2102	3.2389	120999.57	2.9753
2	2.75	0.7666	0.6524	0.8892	0.851	31791.853	11.323
3	3.40	0.9454	0.7081	1.0994	0.749	27981.314	12.866
4	5.25	1.4523	0.8698	1.6976	0.5989	22373.843	16.09
5	6.75	1.8721	0.8972	2.1827	0.4792	17902.063	20.107

6	9.5	2.5907	1.0077	3.0719	0.389	14532.351	24.774
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FUEL: JKB 60

Calorific Value: 38105.76 KJ/Kg

Specific Gravity: 0.8109 gm/cc³**OBSERVED VALUES:**

S.N o	Speed (rpm)	Fuel Consumption (ml)	Manometer Reading (cm)	Effective Load (kg)	Smoke meter Reading (%)	Time (sec.)
1	1573	20	2.5	.75	13.2	99.71
2	1563	20	2.5	2	16.5	94.15
3	1561	20	2.5	3.5	22.5	90.26
4	1553	20	2.5	5	33.1	77.32
5	1549	20	2.5	6.3	39.7	69.74
6	1534	20	2.5	9.25	46.7	53.8

CALCULATED VALUES:

S.No	Effective Load (kg)	Power (kw)	Fuel Consumption (kg/hr)	Bmep (bar)	BSFC (Kg/kw- hr)	BSEC (kJ/kw-hr)	Brake Thermal Efficiency (%)
1	.75	0.2103	0.5856	0.2425	2.7846	123420.74	3.3927
2	2	0.5572	0.6201	0.6467	1.1129	32428.001	8.4891
3	3.5	0.9738	0.6469	1.1317	0.6643	28541.214	14.221
4	5	1.384	0.7551	1.6168	0.5456	22821.539	17.316
5	6.3	1.7394	0.8372	2.0372	0.4813	18260.280	19.628
6	9.25	2.5291	1.0852	2.991	0.4291	14823.140	22.018

FUEL: JKB 50

Calorific Value: 38703.42 KJ/Kg

Specific Gravity: 0.8051 gm/cc³

OBSERVED VALUES:

S.No	Speed (rpm)	Fuel Consumption (ml)	Manometer Reading (cm)	Effective Load (kg)	Smoke meter Reading (%)	Time (sec.)
1	1563	20	2.5	0.7	17.2	94.04
2	1559	20	2.5	2	19.4	87.44
3	1559	20	2.5	3.5	20.3	85.76
4	1548	20	2.5	5	22	73.73
5	1532	20	2.5	6.5	32.9	71.3
6	1546	20	2.5	9.25	45	60.82

CALCULATED VALUES:

S.No	Effective Load (kg)	Power (kw)	Fuel Consumption (kg/hr)	Bmep (bar)	BSFC (Kg/kw-hr)	BSEC (kJ/kw-hr)	Brake Thermal Efficiency (%)
1	0.7	0.195	0.6164	0.2263	3.161	122341.51	2.9426
2	2	0.5558	0.6629	0.6468	1.1927	46161.569	7.7987
3	3.5	0.9726	0.6759	1.1318	0.6949	26895.006	13.385
4	5	1.3796	0.7862	1.6168	0.5699	22057.079	16.322
5	6.5	1.7749	0.813	2.1018	0.4581	17730.036	20.307
6	9.25	2.5489	0.9531	2.9911	0.3739	14471.208	24.875

FUEL: JKB 40

Calorific Value: 39396.699 KJ/Kg

Specific Gravity: 0.8016 gm/cc³**OBSERVED VALUES:**

S.N o	Speed (rpm)	Fuel Consumption (ml)	Manometer Reading (cm)	Effective Load (kg)	Smoke meter Reading (%)	Time (sec.)
1	1572	20	2.5	0.7	18	101.62
2	1559	20	2.5	2	23	76.36
3	1555	20	2.5	3.7	23.6	88.18
4	1549	20	2.5	5.4	25.9	78.08
5	1545	20	2.5	6.6	27	73.65
6	1532	20	2.5	9.75	39	61.6

CALCULATED VALUES:

S.No	Effective Load (kg)	Power (kw)	Fuel Consumption (kg/hr)	Bmep (bar)	BSFC (Kg/kw- hr)	BSEC (kJ/kw-hr)	Brake Thermal Efficiency (%)
1	0.7	0.1961	0.5679	0.2263	2.896	114092.83	3.1554
2	2	0.5558	0.7558	0.6468	1.3598	53571.630	6.7198
3	3.7	1.0255	0.6545	1.1964	0.6382	25142.973	14.318
4	5.4	1.4909	0.7392	1.7461	0.4958	19532.883	18.43
5	6.6	1.8175	0.7837	2.1342	0.4312	16987.856	21.192
6	9.75	2.6624	0.937	3.1528	0.3519	13863.698	25.964

FUEL: JKB 30

Calorific Value: 40203.569 KJ/Kg

Specific Gravity: 0.7967 gm/cc³**OBSERVED VALUES:**

S.N o	Speed (rpm)	Fuel Consumption (ml)	Manometer Reading (cm)	Effective Load (kg)	Smoke meter Reading (%)	Time (sec.)
1	1569	20	2.5	0.7	16.7	100.85
2	1560	20	2.5	2	21.7	89.44
3	1558	20	2.5	3.5	19.5	88.06
4	1545	20	2.5	5	23.4	76.15
5	1546	20	2.5	6.5	32.3	71.88
6	1535	20	2.5	9.5	42.3	63.82

CALCULATED VALUES:

S.No	Effective Load (kg)	Power (kw)	Fuel Consumption (kg/hr)	Bmep (bar)	BSFC (Kg/kw- hr)	BSEC (kJ/kw-hr)	Brake Thermal Efficiency (%)
1	0.7	0.1958	0.5688	0.2264	2.905	116791.36	3.0824
2	2	0.5561	0.6414	0.6467	1.1534	46370.796	7.7636
3	3.5	0.9719	0.6514	1.1317	0.6702	26944.431	13.36
4	5	1.3769	0.7533	1.6168	0.5471	21995.372	16.367
5	6.5	1.7911	0.7981	2.1018	0.4456	17914.710	20.096
6	9.5	2.5992	0.8989	3.0719	0.3458	13902.394	25.892

FUEL: JKB 20

Calorific Value: 40689.09 KJ/Kg

Specific Gravity: 0.7860 gm/cc³**OBSERVED VALUES:**

S.N o	Speed (rpm)	Fuel Consumption (ml)	Manometer Reading (cm)	Effective Load (kg)	Smoke meter Reading (%)	Time (sec.)
1	1566	20	2.5	0.75	7.4	118.05
2	1562	20	2.5	2	13	92.89
3	1553	20	2.5	3.5	16	89.9
4	1553	20	2.5	5.2	18.9	80.18
5	1549	20	2.5	6.3	23.3	70.65
6	1524	20	2.5	9.6	34	58.13

CALCULATED VALUES:

S.No	Effective Load (kg)	Power (kw)	Fuel Consumption (kg/hr)	Bmep (bar)	BSFC (Kg/kw- hr)	BSEC (kJ/kw-hr)	Brake Thermal Efficiency (%)
1	0.75	0.2093	0.4794	0.2425	2.2905	93198.376	3.8627
2	2	0.5568	0.6092	0.6467	1.0941	44517.940	8.0866
3	3.5	0.9688	0.6295	1.1317	0.6498	26439.775	15.236
4	5.2	1.4394	0.7058	1.6815	0.4903	19949.864	18.565
5	6.3	1.7394	0.801	2.0372	0.4605	18737.329	21.235
6	9.6	2.6077	0.9736	3.1042	0.3734	15193.308	29.365

FUEL: JKB 10

Calorific Value: 41460.636 KJ/Kg

Specific Gravity: 0.7848 gm/cc³**OBSERVED VALUES:**

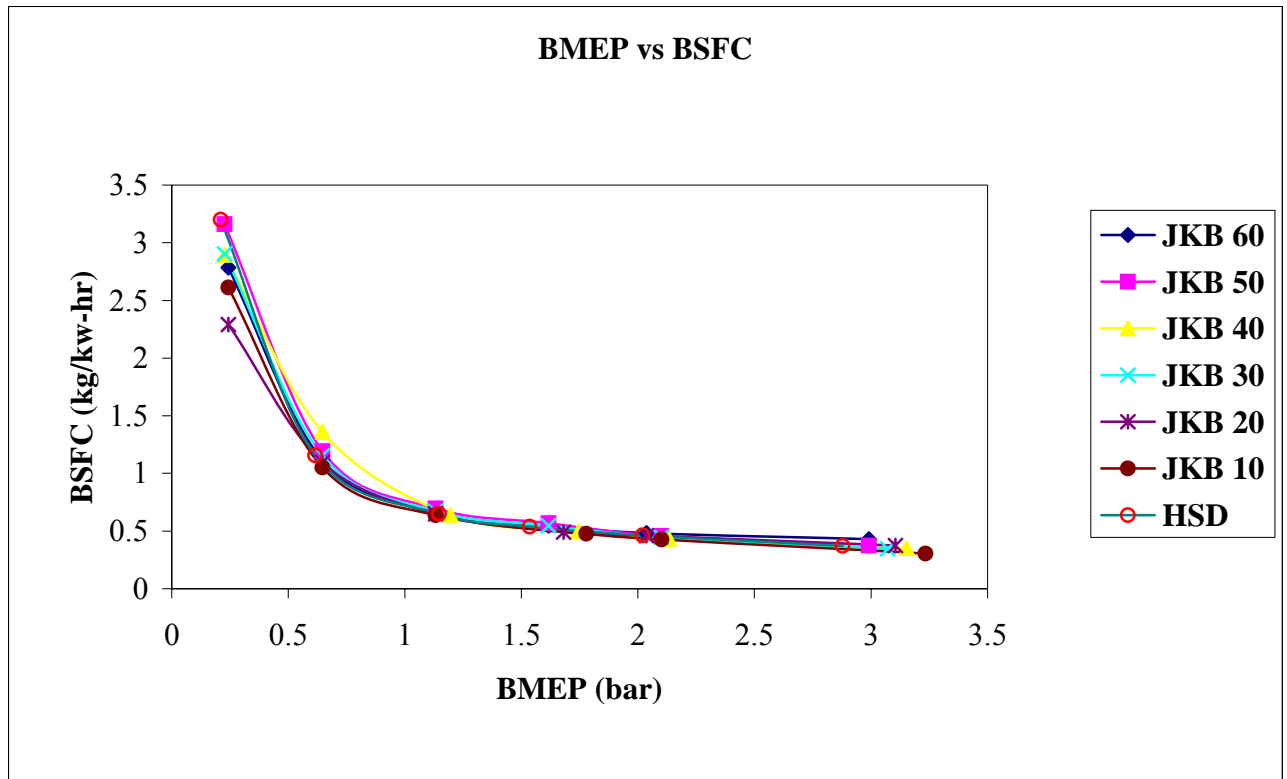
S.N o	Speed (rpm)	Fuel Consumption (ml)	Manometer Reading (cm)	Effective Load (kg)	Smoke meter Reading (%)	Time (sec.)
1	1562	20	2.5	0.75	8	103.58
2	1555	20	2.5	2	14	96.98
3	1556	20	2.5	3.5	18	91.3
4	1545	20	2.5	5.5	25	78.36
5	1543	20	2.5	6.5	26	74.06
6	1521	20	2.5	10	36	68.25

CALCULATED VALUES:

S.No	Effective Load (kg)	Power (kw)	Fuel Consumption (kg/hr)	Bmep (bar)	BSFC (Kg/kw- hr)	BSEC (kJ/kw-hr)	Brake Thermal Efficiency (%)
1	0.75	0.2088	0.5456	0.2425	2.613	108336.64	3.3229
2	2	0.5543	0.5827	0.6467	1.0512	43583.420	8.2597
3	3.5	0.9707	0.6189	1.1318	0.6376	26435.301	13.619
4	5.5	1.5146	0.7211	1.7785	0.4761	19739.408	18.238
5	6.5	1.7877	0.763	2.1019	0.4268	17695.399	20.344
6	10	2.711	0.828	3.2336	0.3054	12662.078	28.429

4.6 GRAPHS AND THEIR INTERPRETATION

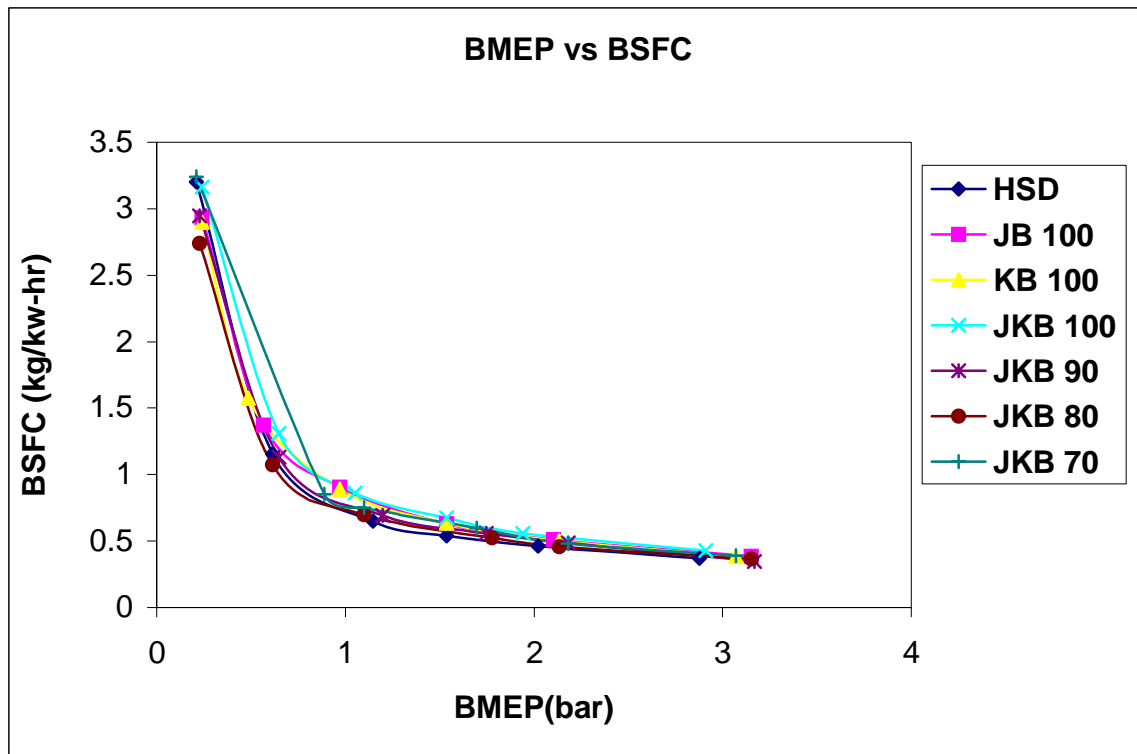
Graph No.1



Graph Interpretation:

The above graph suggests that at low engine loads i.e. at low BMEP, Diesel with 20 % biodiesel blend (JKB 20) has the least BSFC, followed by JKB10. This is because of better combustion of fuel which may be probably of oxygen content & high cetane rating of biodiesel. The sample JKB 50, JKB 30, and JKB 40 have significantly similar BSFC as compared to Neat Diesel (HSD). The difference however narrows as the load progresses towards maximum, but the trend continues to be unchanged. As the load increases, the BSFC starts decreasing for all the fuels, which implies that at higher loads compression ignition engines run more efficiently than at part loads. At the full load condition the fuel sample JKB 10 has the least value of BSFC.

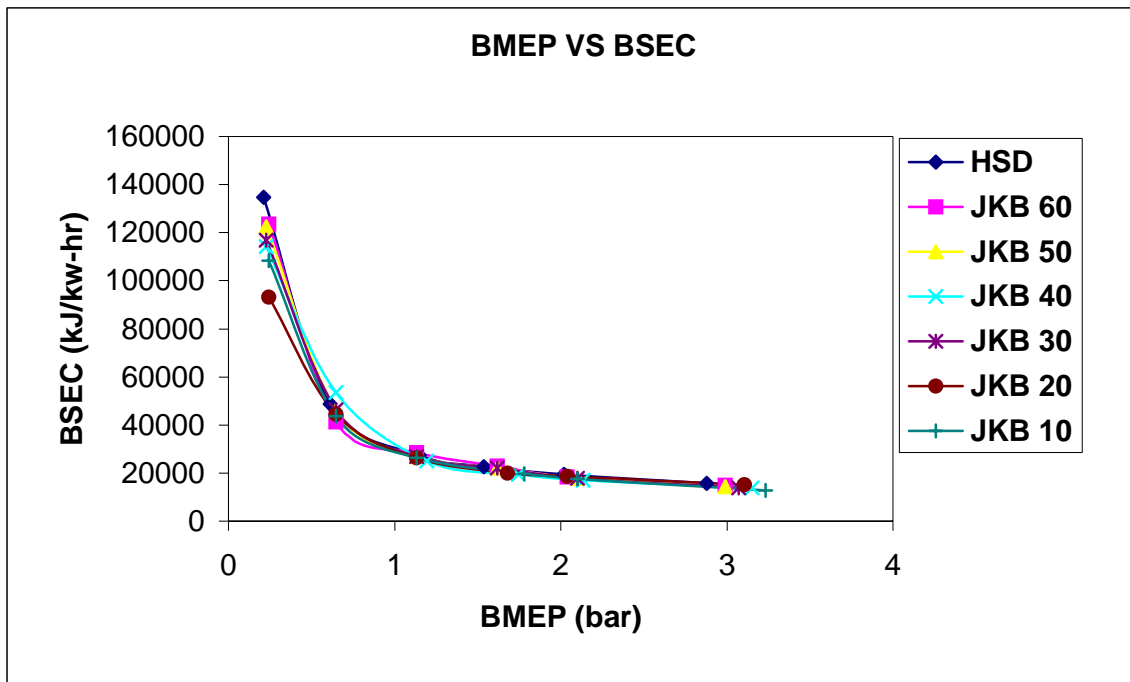
Graph No.2



Graph Interpretation:

The above graph suggests that at low engine loads i.e. at low BMEP, the sample JKB 80 has the least BSFC and JKB 70 and JKB 100 have significantly similar BSFC as compared to Neat Diesel (HSD). However at low loads it is seen that JB100 and KB100 depicts the same behavior. Even as the value of load increases same nature is there. At higher loads the BSFC of Diesel is comparable to these blends. JKB70, JKB90 and JB100 has the least value of BSFC at highest value of BMEP. The BSFC starts decreasing for all the fuels, which implies that at higher loads compression ignition engines run more efficiently than at part loads.

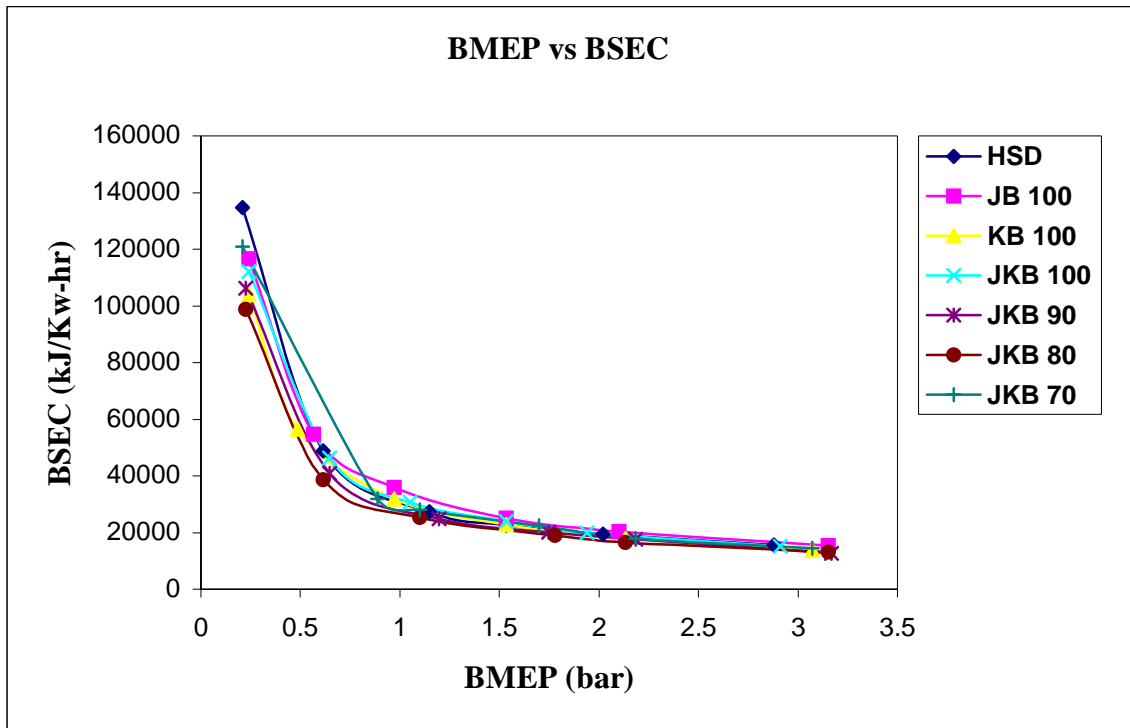
Graph No. 3



Graph Interpretation:

BSFC is not a very reliable parameter to compare the two fuels as the calorific values and specific gravity of the blends follow different trends. Hence, brake specific energy consumption is more reliable parameter for comparison. The graph presents the variation of BSEC w.r.t BMEP for various blends & neat diesel. *Brake Specific Energy Consumption* is a function of BSEC & Calorific Value. As it can be observed from the graph JKB 20 has the lowest BSEC closely followed by JKB 30 & JKB 40 and at high loads JKB 10, JKB 20, JKB 30, JKB 40, JKB 50 and JKB 60 all have their BSEC lower than neat diesel. The difference becomes narrower at high loads. At lower load minimum BSEC of JKB 20 is due to better combustion of fuel, higher cetane no. of fuel.

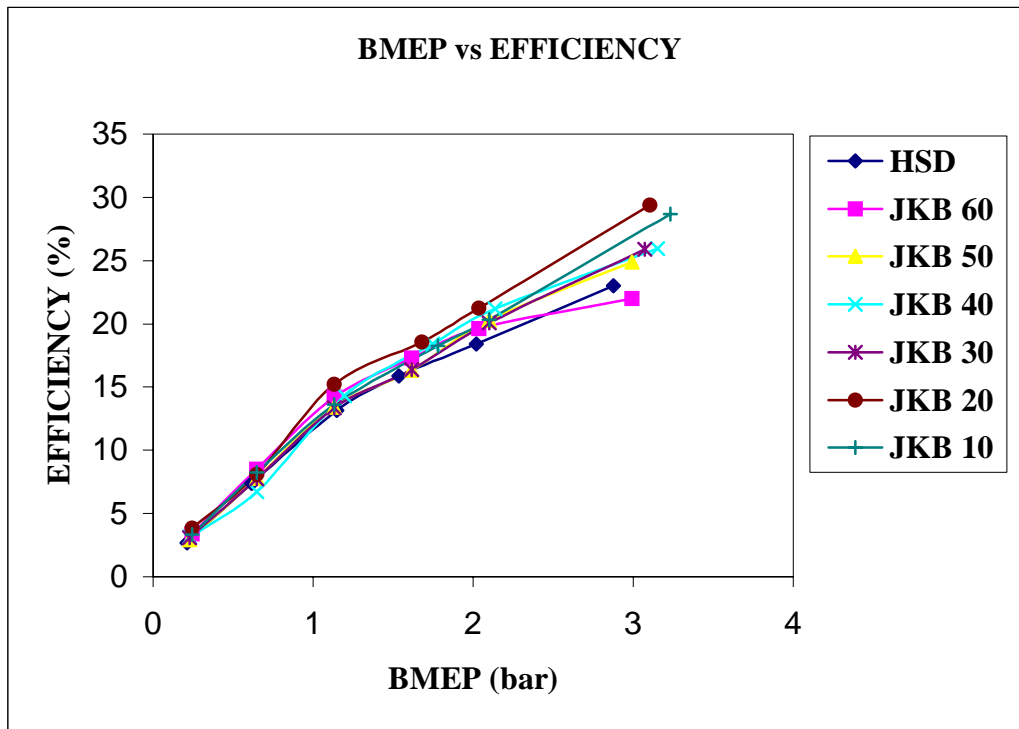
Graph No. 4



Graph Interpretation:

From the above graph, it is evident that, at low loads, diesel has the maximum BSEC in comparison to all other biodiesel blends. Minimum brake specific energy consumption is shown by JKB 80 fuel sample. As the load increases BSEC of all the blends decreases, but the pattern remains the same and at full load there is very little difference between the value of BSEC for all biodiesel blends. Overall it can be analyzed that JKB 20 has the minimum BSEC.

Graph No. 5

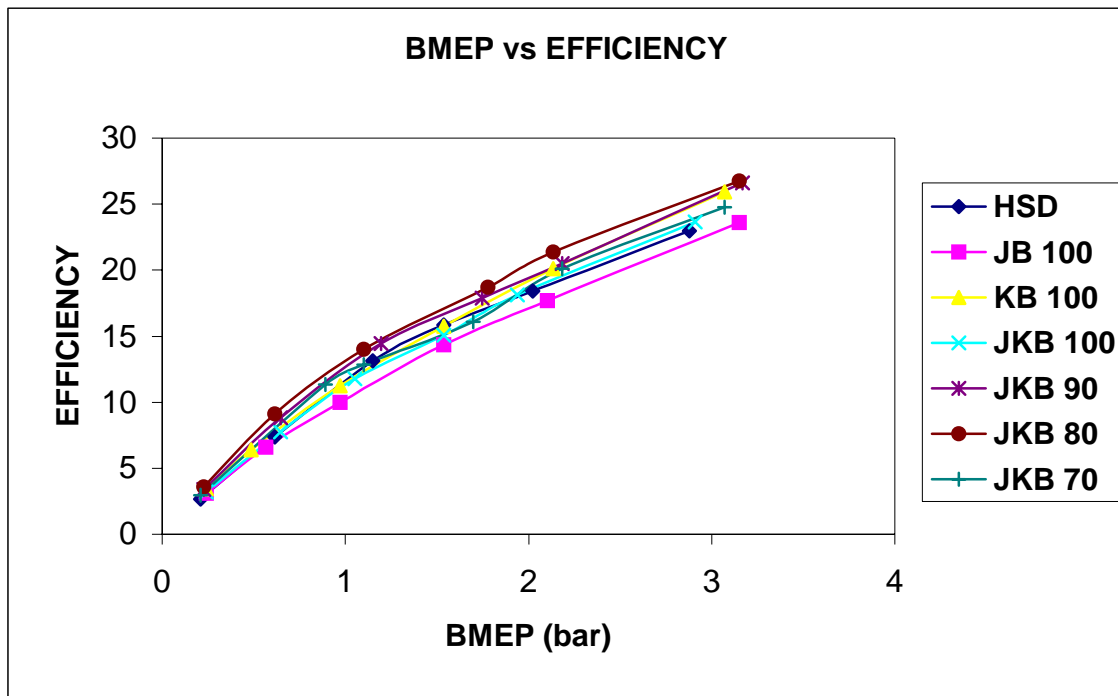


Graph Interpretation:

The variations in the values of *Thermal Efficiency w.r.t BMEP* are shown in the above graph. Among the all blends of Biodiesel, JKB 20 has the highest value of thermal Efficiency for a given BMEP. The lead diversifies as the *Brake Mean Effective Pressure* increases. High Thermal Efficiency can be interpreted as the cause of complete combustion, hence meager requirement of fuel for the same power output. The reduction in the mass flow rate of various blends due to *better Combustion* is counter acted by the reduction in the *Calorific Values* of the

same. Hence, a drastic difference is not observed in the values of thermal efficiencies. After, JKB20 the next higher thermal efficiency is of JKB 10, JKB 30 and JKB 40.

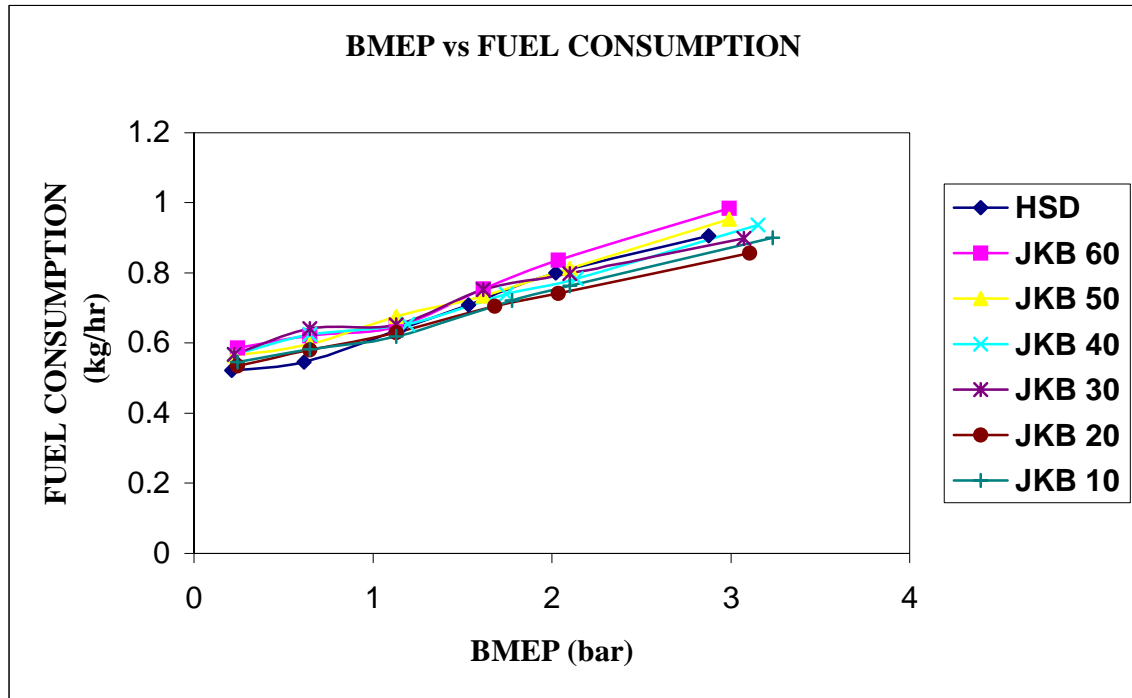
Graph No. 6



Graph Interpretation:

As it can be seen from the graph, thermal efficiency of engine increases as the concentration of biodiesel in diesel increases. It can be observed from the graph that at low load there is small increase in thermal efficiency as soon the load is further increased, there is sudden rise in thermal efficiency till certain point, as the load is increased further thermal efficiency decreases. It can be seen that JKB 80, has the highest thermal efficiency as compared to neat diesel. It is also seen that diesel has least value of thermal efficiency in comparison to all other biodiesel blends.

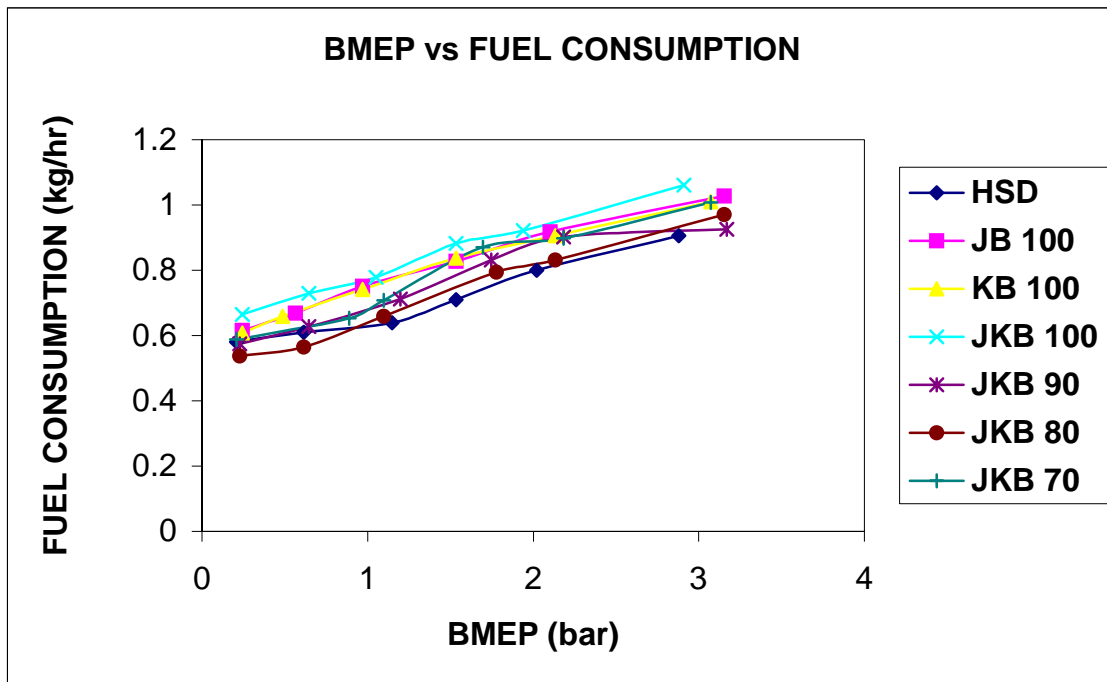
Graph No. 7



Graph Interpretation

The above presents the variations of Fuel Consumption vs Brake Mean Effective Pressure for various Biodiesel blends. The graph suggests that the fuel consumption at low load is similar to neat Diesel. But as load increases fuel consumption of all the blends goes on increasing. These lower values of fuel consumptions can be attributed to the better combustion due to the desired oxygen availability. While the diesel has the higher calorific value but it is the wastage of the fuel due to improper burning that results in higher fuel consumption rates. At low loads JKB 20 has the least value of fuel consumption. At higher value of loads JKB 20 has the least value of fuel consumption and JKB 60 has the maximum value of it.

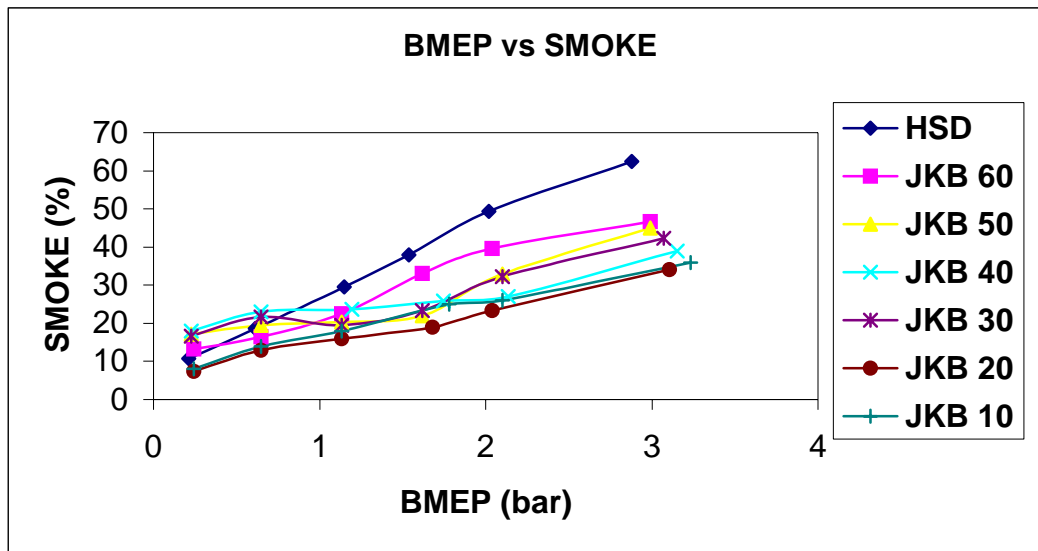
Graph No. 8



Graph Interpretation:

The trends obtained are for the variation of Fuel Consumption of higher percentage Biodiesel Blends vs BMEP. Neat diesel has a lower fuel consumption rate as compared all types of biodiesel blends. This can be attributed to the higher calorific value of the neat diesel. As the percentage of Biodiesel increases in the blends, the calorific value of the fuel goes down. The net decrease in the calorific value demand the enhanced fuel flow rate in the engine manifold. JKB 100 has the highest value of fuel consumption for all loads.

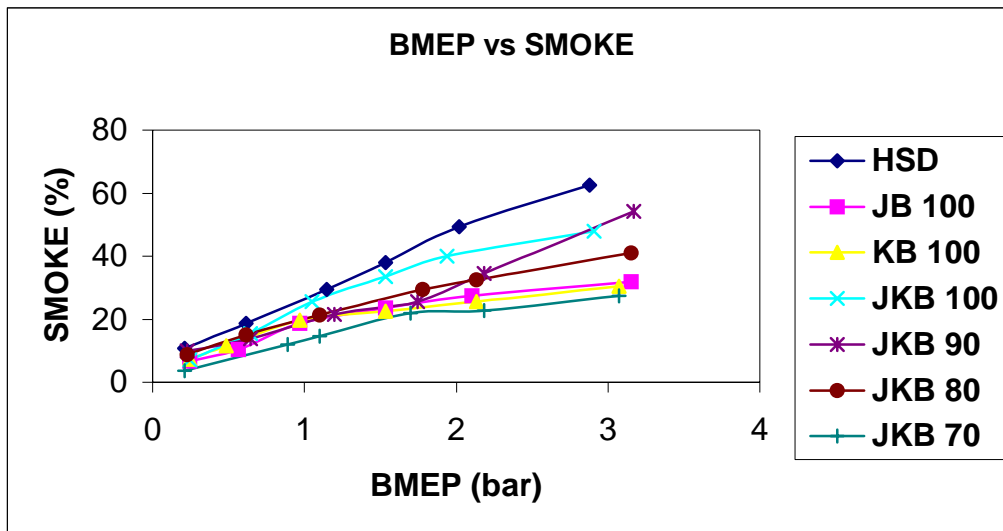
Graph No. 9



Graph Interpretation:

It can be observed that the smoke density has reduced with the use of biodiesel in compression ignition engine in comparison to the diesel, it can be seen that at low load, the smoke density is some what lower for all blends as the load on the engine increases the smoke density increases. It may be noted that smoke density is maximum for HSD and minimum for JKB 20 at throughout the engine operation. It emphasizes the fact that at 20 % biodiesel blend complete combustion will be there.

Graph No. 10



Graph Interpretation:

The graph shows variation of BMEP vs SMOKE DENSITY. It is clear from the graph that HSD has maximum value of smoke density almost at all loads. JKB 70 & KB 100 has almost the least values of smoke density among all high % biodiesel samples. Overall it seen that JKB 20 has the least value of smoke density

CONCLUSION, RECOMMENDATIONS AND FUTURE SCOPE OF WORK

5.1 CONCLUSION

Blends of biodiesel made from Jatropha and Karanja oil with diesel have the potential to substitute the conventional diesel fuel, provided the waste barren land available in India is used to its full potential. It is very obvious that economics of the product is controlled by the availability of the raw materials. So, the plantation of the trees and their usage should be properly managed to explore the benefits from this neglected plant. The important conclusions are as follows:-

- The fuel characterization tests have highlighted the striking similarity of various physical & chemical properties of blends of biodiesel derived from Jatropha and Karanja & Diesel, when compared to diesel.
- The presence of oxygen in the molecular structure of Biodiesel intensifies the complete combustion phenomenon.
- The calorific value of the blends decreases as the percentage of biodiesel is increased, which affects the performance of high percentage blends.
- The specific gravity of low percentage blends is higher than diesel resulting in the enhanced volumetric efficiency, hence compensating for the lower calorific value of the fuel.
- The flash point of all the blends is more than the conventional diesel, making them easily transportable fuels.
- The viscosity of blends is more than that of diesel, and it increases towards JB 100, KB 100 & JKB100. The high viscosity coupled with the low calorific value of KB100 makes it unsuitable to be used independently as fuel. But there is not much significant difference between the viscosities of Diesel & JKB 10, & JKB 20.

- Engine testing experiments have revealed that JKB 20, JKB 10, & JKB 30 have higher thermal efficiencies than the fossil diesel. The specific fuel consumption for the low percentage blend is significantly low, hence lesser fuel consumption, favouring the economics.
- The smoke emissions of fuel sample JKB 20, JKB 10 & JKB 40 are considerably less due to complete combustion of the fuel. The results confirm the potential of these blends have in reducing the overburdening imports of diesel fuel.

All these results confirm the potential of these blends in reducing the overburdening imports of diesel fuel.

5.2 RECOMMENDATIONS AND FUTURE SCOPE OF WORK

Biodiesel has distinct advantage as an automotive fuel. Initial cost may be higher but feedstock diversity and multi-feedstock production technologies will play a critical role in reductions in production cost and making the fuel economically viable. The following points may be considered before introducing the fuel in India:

- Biodiesel may be introduced as a diesel fuel extender or blends (JKB 10, JKB 20) and not as a sole diesel engine fuel (JKB 100).
- The process and production stage for biodiesel may become very decentralized and uncontrolled down the line. It may be produced by various local units in small scale using different feedstocks, different technologies and different practice of housekeeping thereby increasing the chance of getting tampered and adulterated. Therefore, proper planning, streamlining, quality control logistics and institutional arrangements need to be worked out before introduction of the fuel.
- Government may consider providing support to the activities related to collection of seeds, production of oil from non-edible sources, production of bio-fuels and its utilization for cleaner environment.
- Legal framework should be there to enforce regulations on bio-fuels.

- The blends prepared for this project work were utilized within short time span. Thus, long term stability of blends was not studied. So there is scope for study of long term stability of blends.
- Long-term performance and endurance test evaluate the durability of the engine with prolonged operation on these blends.
- There is also scope for research on compatibility of elastomers and metals in engines using these fuel blends to avoid the unforeseen problems in sealing gasket, O-rings and other metal components in the engine system due to corrosive effect of ethanol methanol on these components.
- Pilot projects and R&D work on biodiesel needs to be encouraged and supported to establish techno-economic viability of large-scale production.
- Specifications for biodiesel should be established along with test methods and should be independent of any specific feedstock.
- Energy education on biodiesel programme and storing information and database for wider information dissemination among the public at large should be taken up at a larger scale.

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