PROCESS STANDARDIZATION, CHARACTERIZATION AND EXPERIMENTAL INVESTIGATION ON THE PERFORMANCE OF BIODIESEL FUELLED C.I.ENGINE

A thesis submitted in the fulfilment of the
requirements for the award of the degree of

Doctor of Philosophy

In

Mechanical Engineering

By

Satishchandra Shamrao Ragit
Reg. No. 90608504

Department of Mechanical Engineering
THAPAR UNIVERSITY, PATIALA-147004
PUNJAB
INDIA
May, 2011

CERTIFICATE

Certified that the thesis entitled, **"PROCESS STANDARDIZATION, CHARACTERISATION AND EXPERIMENTAL INVESTIGATION ON THE PERFORMANCE OF BIODIESEL FUELLED C.I. ENGINE"** which is being submitted by **MR. SATISHCHANDRA SHAMRAO RAGIT** to Thapar University, Patiala in fulfilment for the award of degree of Doctor of Philosophy in Mechanical Engineering is a record of bonafied research work carried out by him under our guidance and supervision. The matter presented in this thesis has not been submitted either partially or fully to any other University or Institution for the award of any other degree to the best of our knowledge.

डा. कृष्णेन्दु कुन्डु/Dr. Krishnendu Kundu
वैज्ञानिक एंव विभागाध्यक्ष/Scientist & Head
जैविक ईंधन विभाग/Deptt. of Bio-Fuel
मिराडो सैन्टर/MERADO CENTRE
सी.एस.आई.आर /CSIR Govt. of India
गिल रोड, लुधियाना /Gill Road, Ldh-141006.

Dr. S. K. Mohapatra
Senior Professor and Dean (Academic Affair)
Department of Mechanical Engineering
Thapar University, Patiala
PUNJAB

Dean, Academic Affairs,
Thapar University,
Patiala.

Dr. K. Kundu
Scientist-E1 and Head
Department of Biofuel
Mechanical Engineering Research and
Development Organization, Ludhiana
PUNJAB

ACKNOWLEDGEMENTS

An extensive research project requires guidance, help, assistance and cooperation of several people. I humbly wish to acknowledge and express my gratitude to all such people, without whom my research work may not have seen the light of the day. I would like to thank my supervisor Dr. S. K. Mohapatra for firstly, giving me this opportunity to be part of this project and more importantly giving me moral support throughout my current work. Whenever I needed him, he was always there to help me out, in spite of his busy schedule and he left no stones unturned to remove the obstacles in the path of this research work.

I deeply indebted to Dr. S. K. Mohapatra for his constant encouragement and valuable support. I would also like to thank Dr. K. Kundu for his continuing support and help throughout my time working on this project. His expertise, innovative ways of thinking, constant interest and follow up were the crucial factors in enabling this research work to take its final shape. My sincere thank to Cdr. V. R. Dahake, Scientist Inchage, MERADO for providing me laboratory facilities to carry out the research work. I would like to thank Shri Charan Dass for giving technical help in biodiesel preparation and determination of fuel properties. Furthermore, I would like to thank Shri Satwinder Singh and team of engine research laboratory for successful compression ignition engine testing of selected fuel.

I also wish to thank all the staff members (Teaching and Non – teaching) who helped me directly or indirectly to complete this work. I sincerely thank Dr. Abhijit Mukherjee, Director, Thapar University, Patiala for extending institutional facilities to me for this research work. Finally, I would like to thank my parents and sisters for their eternal support and understanding of my goals and aspirations. Without them, I would not have been able to complete much of what I have done and become who I am. They are the light that shines my way and the drive for ever persistent determination.

~~January~~ May, 2011

Thapar University, Patiala

Satishchandra S. Ragit

ABSTRACT

Biodiesel, an alternative fuel is derived from the fats of animals and plants. As energy demands increase and fossil fuels are limited, research is directed towards alternative renewable fuels. The main advantages of using this alternative fuel are its renewability, biodegradability and better quality of exhaust gases. It is technically competitive and environmentally friendly alternative to conventional petrodiesel fuel for use in CI engines. The use of biodiesel reduces the dependence on imported fossil fuels which continue to decrease in availability and affordability. Vegetable oils for biodiesel production vary considerably with location according to climate and feedstock availability. Generally the most abundant vegetable oil in a particular region is the most common feedstock. Nowadays, most of the commercial biodiesel comes from the transesterification of vegetable oil using a basic catalyst such as NaOH or KOH, because a basic catalyst faster than an acid catalyst. The fuel of bio-origin may be the biodiesel obtained from edible or non-edible vegetable oil through transesterification process. Most of the properties of biodiesel compare favourably with the characteristics required for the CI fuel. Due to the relatively high costs of edible oils, the cost of producing methyl or ethyl esters from edible oils is currently more expensive than hydrocarbon based diesel fuels. The cost of biodiesel can be reduced if we can consider non-edible oils instead of edible oils. Non-edible oils from plants hemp and neem are easily available in many parts of the world and are less expensive as compared to edible oils. Furthermore, the use of non-edible vegetable oils is of significance because of great need for edible oil as food and they are too expensive to be used as fuels. The experimental work presented in this thesis is mainly divided into three main parts. In the first part, transesterification process is used to prepare methyl esters from non-edible oils and testing of fuel properties of selected non-edible oils and their methyl esters. The present work discusses the feasibility of trasesterification of hemp and neem oil, from the point of view of the process technology and its use in diesel engines. The influence of process variables on product yield of the transesterification process has also been studied. A lot of research has already been carried out on karanja and jatropha oil but not on neem and hemp oil. Noting this, it was decided to carry out research on hemp and neem oil along with their methyl esters. This chapter focused on the source of oils, problems associated with the use of oils, production of biodiesel from non-edible oil, physical and chemical properties of oils and their methyl esters. The study of non-edible vegetable oil in with and without catalyst has not yet

been presented. Firstly, the optimum transesterification reaction conditions for non-edible oil with respective to different parameters were investigated. A study was conducted to standardize the esterification process parameters for the production of methyl ester of filtered neem oil and raw hemp oil. The transesterification reaction is affected by molar ratio of glycerides to alcohol, catalyst, reaction temperature, reaction time, preheating time, free fatty acid and water content of oils or fats. The effect of molar ratio 4:1, 6:1 and 8:1 on ester yield and its quality were investigated. The methanolysis of non-edible oils at 60℃ with 1-3% KOH were studied. The effect of process parameters such as molar ratio, catalyst concentration and reaction time was studied to standardize the esterification process for estimating the highest recovery of ester with lowest possible viscosity as well as to keep the process simple. In this thesis, an attempt has been made to review the work done on biodiesel production.

In the second part, evaluating the engine performance of given non-edible oil, methyl esters and its 20% blends and formulating the engine exhaust emission of given non-edible oil, methyl esters and its 20% blends. In this present research work, hemp biodiesel and biodiesel-diesel fuel blends as alternative fuels for diesel engines were studied. An experimental investigation has been carried out to evaluate the performance and emission characteristics of a diesel engine fuelled with hemp biodiesel and its blends (20%, 40%, 60%, 80% and 100%). The performance parameters analyzed include thermal efficiency, brake specific fuel consumption, brake specific energy consumption, and exhaust gas temperature whereas exhaust emissions include oxides of nitrogen, HC, smoke, CO_2, CO and oxygen level. The results of the experiment in each case were compared with baseline data of diesel fuel. Significant improvements have been observed in the performance parameters of the engine as well as exhaust emissions. The hemp biodiesel and hemp biodiesel-diesel fuel blends were tested in a single cylinder direct injection diesel engine. Engine performance and exhaust emission were measured at part and full load condition. This paper investigates the scope of utilizing non edible oils (hemp and neem oil) as an alternative diesel fuel. An experimental investigation has been carried out to evaluate the performance and emission characteristics of a compression ignition engine fuelled with hemp and neem oil and important fuel properties have been determined. It concluded that lower blends of hemp biodiesel (HME20) act as best alternative fuel among all tested fuel at full load condition. The objective of the present research was to explore technical feasibility of hemp and neem oil in direct injection CI engine without any substantial hardware modifications.

In the third part, analyzing the cost assessment of given methyl esters as compared to diesel fuel and comparing the tested biodiesel or methyl esters to other biodiesels such as Jatropha methyl ester, Pongamia methyl ester, Mahua methyl ester in relation with prominent fuel properties. The objective of the present study is to reveal the effect of different fuel and its blends on the performance and emission of C. I. engine and also shows the comparative study of different fuels with diesel. A study was undertaken to examine the yield of biodiesel of high quality, fuel characterization and C.I engine performance and emission characteristics. Performance and emission in existing engines, environmental considerations and economic aspects has been studied. The different fuel and its blends were then subjected to engine performance and emission tested and compared with diesel. The economics of HME and NME are more promising with integrated approach. The present work carried establishes the feasibility of biodiesel-fuelled CI engine utility system for agricultural and field applications. It experimentally demonstrates that a biodiesel fuelled compression ignition engine, apart from its implantation potential can contribute significantly to the twin problem of diesel oil scarcity and environmental pollution. Therefore various blends of HME, NME, HO and NO can be readily adopted as a substitute fuel to the existing compression ignition engine.

CONTENTS

Description **Page No.**

LIST OF FIGURES

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

LIST OF TABLES

NOMENCLATURE

BMEP	Brake Mean Effective Pressure
BTE	Brake Thermal Efficiency
EGT	Exhaust Gas Temperature
SFC	Specific Fuel Consumption
BSEC	Brake Specific Energy Consumption
NOX	Oxides of Nitrogen
UHC	Unburned Hydrocarbon
SO	Smoke Opacity
O_2	Oxygen Level
CO_2	Carbon Dioxide
CO	Carbon Monoxide
ASTM	American Society of Testing and Petroleum
EPA	Environmental Protection Agency
GC	Gas Chromatography
cSt	Centistokes
ISO	International standard organization
NDIR	Non Dispersive Infrared
NREL	National Renewable Energy Laboratory
OC	Organic Carbon
PAH	Polycyclic Aromatic Hydrocarbon
PM	Particulate Matter
HP	Horse Power
kW	Kilo Watt
SO_2	Sulphur dioxide
H_2SO_4	Sulphuric Acid
NaOH	Sodium Hydroxide
KOH	Potassium Hydroxide
SAE	Society of Automotive Engineers
TC	Total Carbon
THC	Total Hydrocarbon
VOC	Volatile Organic Compound
API	American Petroleum Institute
AFV	Alternative Fuelled Vehicle
TDC	Top Dead Centre
ATDC	After Top Dead Centre
BTDC	Bottom Top Dead Centre
CN	Cetane Number
SN	Saponification Number
IV	Iodine Value
IC	Internal Combustion
DI	Direct Injection
NA	Naturally Aspirated
CNG	Compressed Natural Gas
LPG	Liquid Petroleum Gas
cSt	centristroke
D	100 % Diesel
NME	Neem Methyl Ester
NO	Neem Oil

HME	Hemp Methyl Ester
HO	Hemp Oil
NME100	100% Neem Methyl Ester by Volume
NME20	20% Neem Methyl Ester by Volume, 80% Petroleum Diesel
HME100	100% Hemp Methyl Ester by Volume
HME20	20% Hemp Methyl Ester by Volume, 80% Petroleum Diesel
NO100	100% Neem Oil by Volume
NO20	20% Neem Oil by Volume, 80% Petroleum Diesel
HO100	100% Hemp Oil by Volume
HO20	20% Hemp Oil by Volume, 80% Petroleum Diesel
JME	Jatropha methyl ester
PME	Pongamia methyl ester
MME	Mahua methyl ester
UFME	Used frying methyl ester

Units

kPa	Kilopascal
MPa	Megapascal
BSU	Bosch Smoke Unit
HSU	Hartridge Smoke Unit
Vol	Volume
ppm	Parts per Million
MJ/kg	Megajoule per Kilogram
kJ/kg	Kilojoule per Kilogram
kJ/kW.hr	Kilojoule per Kilowatt hour
%	Percentage
^{O}C	Degree Celsius

CHAPTER 1

INTRODUCTION

Biodiesel can be produced from a wide variety of plant oils, both edible and non-edible biodiesel in most of the developed countries are being produced from sunflower, peanut, palm and several other feed stocks which are essentially edible in Indian context. Therefore, in the developing countries such as India, it is desirable to produce biodiesel from the non-edible oils which can be extensively grown in the waste lands of the country. Rising fuel costs and impending emission regulations have sharpened the automotive industry's focus on efficiency. Moreover the rapid depletion of fossil fuels due to widespread use has forced to search for some low emission and renewable fuel. In the search for alternative fuels, the favourable option was found to be renewable fuels like vegetable oils, alcohol etc. In present investigation, hemp oil, neem oil, hemp methyl ester and neem methyl ester have been taken for study due to environ-friendly nature. Furthermore the use of non-edible vegetable oils is of significance because of the great need for edible oil as food and they are too expensive to be used as fuels. Moreover, the commercial use of biodiesel is strongly dependent on the price of the feedstocks so lower cost feedstocks are needed. The high cost of biodiesel, which is mainly due to the high cost of oil feedstock, is the main obstacle to its broader commercialization. Environmental concern and depletion in petroleum resources have forced researchers to concentrate finding renewable alternatives to conventional diesel fuels. Due to the increase in price of petroleum and environmental concern about pollution coming from automobile emission, biodiesel is emerging as a developing area of high concern [13]. The world is confronted with the twin crises of fossil fuel depletion and environmental degradation. Alternative fuels, promise to harmonize sustainable development, energy conversion, management, efficiency and environmental preservation. Vegetable oil is a promising alternative to petroleum products [27].The economic feasibility of biodiesel depends on the price of crude petroleum and the cost of transporting diesel over long distances to remote areas. It is a fact that the cost of diesel will increase in future owing to increase in its demand and limited supply [33]. A great deal of research and development on internal combustion engines has taken place not only in the design area but also in finding an appropriate fuel. Many researchers have concluded that biodiesel holds promise as an alternative fuel for diesel engines, since its properties are very close to diesel fuel. The fuel properties of biodiesel such as cetane number, heat of combustion, gravity, and viscosity influence the combustion and so the engine performance and emission characteristics because it has different physical and chemical properties than petroleum-based diesel fuel. The objective of current research work is to investigate the usage of biodiesel and reduce the emissions of all regulate pollutants from diesel engines. A single cylinder, water cooled constant speed direct injection diesel engine was used for experiments. Exhaust gases are measured to estimate the emission various engine performance parameters such as thermal efficiency, brake specific fuel consumption etc were calculated [36]. Due to gradual depletion of world petroleum reserves and the impact of environmental pollution of increasing exhaust emissions, there is an urgent need for suitable alternative fuels for use in diesel engines. In view of this, vegetable oil is a promising alternative because it has several advantages. The problem of high viscosity of vegetable oils has been approached in several ways such as preheating the oils blending or dilution with other fuels, transesterification and thermal cracking / pyrolysis [41]. In recent years systematic efforts have been made by several researchers to use vegetable oils like sunflower, cottonseed, peanut, soybean, rapeseed, palm, olive, linseed, jatropha, coconut, pongamia, rubberseed, and jojoba etc. as alternate fuel for diesel. Many of the vegetable oils are edible in nature, continuous use of them cause shortage for food supply and proves far expensive to be used as fuel at present. So far a very few of non-edible vegetable oils have been tried on diesel engine leaving a lot of scope in this area. It is evident that vegetable oils offer acceptable engine performance and emissions for short-term operation while for long –term duration problems like filter clogging, carbon deposits on injector exterior, compression ring grooves, piston etc have been reported. The high viscosity of vegetable oils is responsible for these problems. Therefore, reduction in viscosity of vegetable oils is of the prime importance to make them suitable for diesel engines. Different methods are used to reduce the viscosity of non-edible oils. Testing of diesel engines with diesel and blending with preheating improves the performance and reduce the emissions compared with neat vegetable oil. It also reduces the filter clogging and ensures smooth flow of oil. From above stated factors it is evident that identification and testing of new non-edible vegetable oils on diesel engine is of great importance. In the present investigation, hemp oil and neem oil both are a non-edible vegetable oils selected for the test and its suitability as an alternate fuel is examined. The hemp oil, HO20, neem oil, NO20, HME, NME20, NME and NME20 have been tested to determine the engine performance. This is an accomplished by blending of hemp oil with diesel in 20:80% and 100:00 on gram basis. The performance and emission characteristics of neat hemp oil and its ester, neem oil and its ester have compared with the diesel results [43]. The diesel engine dominates the field of commercial transportation and agriculture machinery due to its ease of operation and higher fuel efficiency.

The consumption of diesel oil is several times higher than that of petrol. Due to the shortage of petroleum products and its increasing cost, efforts are on to develop alternative fuels especially for diesel oil for its partial replacement. It has been found that the vegetable oils are promising fuels because their properties are similar to that of diesel and are produced easily and renewably from the crops. Vegetable oils have comparable energy density, cetane number, heat of vaporization and stiochiometric air-fuel ratio with that of the diesel fuel [50]. Vegetable oils are non-toxic, renewable sources of energy, which do not contribute to the global CO_2 build up. In terms of the economic benefits, vegetable fuels could be used as an emergency energy source in the event of another petroleum fuel shortage [51]. As world's petroleum supplies are becoming constrained, attention has been directed to find out alternative source of fuels for engines. The non-renewable nature and limited resources of petroleum fuels have become a matter of great concern. After the 1973 oil embargo, it has become important to study the alternative sources of fuel for diesel engine because of the concern over the availability and the price of petroleum based fuels [53]. Due to shortage of petroleum diesel fuel and its increasing cost an alternative source of fuel for diesel is very much needed. Vegetable oil from crops such as soybean, peanut, sunflower, jatropha, mahua, neem, rape, coconut, karanja, cotton, mustard, linseed and castor have been tried in many parts of the world, which lack of petroleum reserves as fuels for CI engines. The long chain hydrocarbon structure, vegetable oils have good ignition characteristics, however they cause serious problems such as carbon deposits build up, poor durability, high density, high viscosity, lower calorific value, more molecular weight and poor combustion. These problems lead to poor thermal efficiency, while using vegetable oil in the diesel engine. These problems can be rectified by transesterification process [59]. In the present investigation, biodiesel is prepared from HO and NO oil. Biodiesel properties were determined and their engine performance and emission characteristics were studied on a four stroke single cylinder direct injection CI engine to check their feasibility as CI engine fuels along with finding economics of both biodiesel for market value.

1.1. Alternative Fuels

- **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 20-25 MPa 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.

- **Liquefied 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.

- **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.

- **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, sugarbeets etc using already improved and demonstrated technologies. 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. It is 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. restrictits 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.

1.1.1. 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 operate 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.

1.1.2. Biodiesel

Biodiesel is an alternative fuel formulated exclusively for diesel engines. It is made from vegetable oil or animal fats or it is the name for a variety of ester based fuels generally defined as the monoalkyl esters made from vegetable oils through simple transesterification process.

Use of biodiesel in CI engine

- It is recommended for use as a substitute for petroleum based diesel mainly because biodiesel is a renewable, domestic resource with an environmentally friendly emission profile and is readily biodegradable.
- Biodiesel is nontoxic, biodegradable. It reduces the emission of harmful pollutants from diesel engines (80% less CO2 emissions, 100% less sulphur) but emissions of nitrogen oxides are increased.
- Biodiesel has a high cetane number. The high cetane numbers of biodiesel contribute to easy cold starting and low idle noise.
- The use of biodiesel can extend the life of diesel engines because it is more lubricating and furthermore, power output are relatively unaffected by biodiesel.

1.1.2.1. Development of Biodiesel in India

Biodiesel is a relatively new product in India. In 1912, the use of vegetable oils for engine fuels may seem insignificant today. But such oil may in the course of time become as important as petroleum and the coal tar products of present time. Scientists discovered that the viscosity of vegetable oil could be reduced in a simple chemical process in 1970 and that it could work well as diesel fuel in modern engine. The fuel is called Biodiesel. It is alternative fuel that can be used in diesel engines and provides power similar to conventional diesel fuel. It reduces the countries dependence on foreign oil imports. As per its end use it is classified with petroleum products industry more particularly with diesel. This industry is known to everybody in world whether literate or illiterate. Contribution of this industry in economy of India or rather we can say world can be understood, simple in one sentence that any price change in products related to this industry affects almost all the commodities, services of every industry. Cost of petroleum products is directly proportional to the living cost of common man. Although biodiesel is new product but it is going to replace product of petroleum industry i.e. diesel in future. In India, however, continuing research work on renewable energy sources, including vegetable oils, is underway in various laboratories starting from the classic work of Prof. H.A. Javemann and his associates at the Indian Institute of Science from the early 1940's. Now national mission for biodiesel is proposed and in this regard planning commission has taken decision to blend 5% ethanol with petrol effective in eight major cities from 01.01.2003 as per phase I and has decided that this ratio gradually be increased to 10% and 20% over a period of time upto 2011-2012 in phase II. Daimler Chrysler India Ltd. has declared the commercial launch of biodiesel cars in five to ten years as a part of its biodiesel project. The National Oilseeds and Vegetable Oil Development (NOVOD) board has prepared Rs. 1,430 crore project for biodiesel production from Jatropha seeds and state governments are providing various incentives to promote integrated Jatropha oil extraction in their state e.g. Tamil Nadu. The southern railway adopted a three pronged strategy of large scale plantation of these trees, processing the oil into biodiesel and making use of it for its large fleet of road vehicles and locomotives. Awareness in India is only now giving shape to projects. In Andhra Pradesh four companies viz. Southern Online Biotechnology (SBT), Tree Oils Ltrs (Zaheerabad) Natural Bio Energy and the GMR group have seriously entered into this project. Others include Vrideshwar SSK Ltd. (Ahmednagar, Maharashtra) the Simbhioly Sugar Mills (Ghaziabad, Uttar Pradesh), Mewar Sugar Mills (Jaipur) SM Dyechem (Thane, Maharashtra) R.S. Petrochemicals (Punjab) and Progressive Petroleum (Mumbai) The Aditya Birla group proposed a project in Malaysia, which did not come off. All of them feel that government should offer incentives to offset risk of a Greenfield area.

1.1.2.2. Present Scenario in India

In India various oil companies and state governments are taking serious initiative for the development of biofuel in the country. They are following the guidelines given by the planning commission of India to the central government. In these initiatives the state governments are promoting biofuel industry by providing ***waste*** land to the private sector for the Jatropha plantation. They are also making industrial polices specifically for the biodiesel production and supply.

1.1.2.2.1. Transport Scenario in India

Total population of automobile vehicles registered in urban cities upto the year 2002 increases significantly (about 70% as compared to year 1995). The proportion of population of different category of automobile vehicles in major urban cities as shown in Table 1.1.

Table 1.1 : Proportion of Population of Different Category of Vehicle in Major Cities

Category of Vehicle	Proportion of Population (%)
2-Wheelers	72
Cars	18
Goods Carrier	4
Auto	3
Tractors	2
Buses	1

Although the population of two wheelers is the highest (70%), however, rate of increase of passenger cars in urban areas is also dramatically increasing during the last few years. Sale of diesel fuelled passenger cars is particularly increasing rapidly due to lower cost of diesel in India compared to gasoline. Therefore, the issue of utilization of biofuels in diesel vehicles is important in this country.

1.1.2.2.2. Refineries Scenario in India

There are eighteen refineries in the country established over a period of time. These refineries are gearing up for improving fuel quality to meet Euro II and Euro III standards (Directive 2003/17/EC of the European Parliament and of the council of 3 March 2003). As bulk of crude being imported has high sulphur, it would require substantial desulphurisation/hydrotreatment to achieve lower sulphur content in products. It is estimated that in the existing refineries in order to meet the auto fuel specifications the investment of around Rs. 18,000 crore are expected. Additional investment of around Rs. 12000 crore will be needed to achieve the recommended specifications for the year 2010. Total investment of Rs. 55,000 crore would be needed by oil and automobile industry to meet Euro IV specifications. Incremental production cost for diesel of Euro III equivalent fuel quality could vary between Rs 0.9-4.11 L^{-1}. The existing plants without major changes in infrastructure can be used for blending of biodiesel and ethanol with diesel.

1.1.2.3. Development of Biodiesel in Foreign Countries

According to survey of twenty six countries by the International Energy Agency (IEA), bio fuel is being produced within last six years in twenty one countries, mainly in European Union, East Europe and in U.S.A. with overall capacity around 13,00,000 tons. B20 (a blend of 20 percent by volume biodiesel with 80 percent by volume petroleum diesel) has demonstrated significant environmental benefits in US with a minimum increase in cost for fleet operations and other consumers. Biodiesel is registered as a fuel and fuel additive with the US Environmental Protection Agency and meets clean diesel standards established by the California Air Resources Board. Neat (100 percent) bio diesel has been designated as an alternative fuel by the Department of Energy and the Department of Transportation of US. Studies conducted with biodiesel on engines have shown substantial reduction in particulate matter (25 – 50%). However a marginal increase in NOx (1-6%) is also recorded; but it can be taken care of either by optimization of engine parts or by using De-NOx catalyst. HC and CO emissions are also reported to be lower. Non regulated emissions like PAH etc. were also found to be lower. In US biodiesel has been accepted as an alternative fuel and presently its production is about 100 million gallons. Each state has passed specific bills to promote the use of bio diesel by reduction of taxes. USA uses B20 and B100 bio diesel, France uses B5 as mandatory in all diesel fuel. It can also be used as an additive to reduce the overall sulphur content of blend and to compensate for lubricity loss due to sulphur removal from diesel fuel. While in European countries 5-15% blends have been adopted. Brazil is using upto 24% ethanol-gasoline blends [5].

1.1.2.4. Prospective Feedstock for Biodiesel Production in India and World

Oil can be extracted from a variety of plants and oil seeds. Under Indian condition only such plant sources can be considered for Biodiesel production and for blending with diesel which are not edible oil in appreciable quantity and which can be grown on large-scale on forests and wastelands. It is estimated that about 3 million hectares plantation is required to produce oil for 10% replacement of petrodiesel. 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. Other than this other minor oil seeds can be tried to supplement for the vast gap in production and consumption of petroleum oils. Thus in the present study the oils like Madhuca Indica (Mahua) oil, Salvadora linn(pilu) and Simrauba gluca are explored as diesel fuel extender or as a Biodiesel alternative[8]. Oils of tree borne oilseeds like Mahua are also edible and used in making of vanaspati and as confectionary and bakery fats after refining or modification. The non-edible oils, basically for industrial use are produced from linseed, castor and oilseeds of tree origin like Neem, Mahua, Kusum, Karanj, Sal etc [9]. Annual production and yield of some oil seed varieties are given the Table 1.2.

Table 1.2: Annual Production of Some Edible/Non-edible oil Seeds in India

Type	Production (MT)	Oil %
Neem	500	30
Karanja	200	27-39
Kusum	80	34
Pilu	50	33
Ratanjot	-	30-40
Mahua	490	35-40
Jajoba	-	50
Bhikal	-	37
Undi	04	50-73
Thumba	100	21

The present oil production capacity of the various oil extraction units depends mainly on the demand in the market. There are units that crush only 50 tones and there are some units that crush up to 900 tones/year. The capacity of production is need based. Therefore all these units have an expansion capacity to cater to the newer market where the oil can be used as biofuels or for making biodiesel after esterification.

1.1.2.5. Biodiesel as an Option for Energy Security

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 at 4.8%. The demand of diesel is projected to grow from 39.81 million metric tons in 2001-02 to 52.32 million metric tons in 2006-07 increasing at 5.6% per annum. Our crude oil production as per the tenth plan working group is estimated around 33-34 million metric tons per annum even though there will be increases in gas production from 86 million standard cubic meters per day (2002-04) to 103 million standard cubic meters per day in (2006-07)[2].

1.1.2.6. 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 1.3.

Table 1.3: Requirement of biodiesel fuel

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
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

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 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. In India no major producer of biodiesel is available. Because of this, it is possible that our production data will be primary data in India. Biodiesel is mainly produced from non-edible oils. This oil extracted from Jatropha, Karanja, and Neem etc. which is available in large quantity. Both State as well as Central government have taken steps for cultivation of these seeds for biodiesel production. Government is also going to provide subsidy for cultivation of these seeds.

1.1.2.7. Advantages of Biodiesel

Successful alternative fuels fulfil environmental and energy security needs without sacrificing operating performance. Operationally, biodiesel performs very similar to low sulphur diesel in terms of power, torque and fuel without major modification of engines or infrastructure. Biodiesel offers similar power to diesel fuel. One of the major advantages of biodiesel is the fact that it can be used in existing engines and fuel injection equipment with little impact to operating performance. Biodiesel has a higher cetane number than diesel fuel. In over 15 million miles of in-field demonstrations biodiesel showed similar fuel consumption, horsepower, torque and haulage rates as conventional diesel fuel. It provides significant lubricity improvement over petroleum diesel fuel. Lubricity results of biodiesel and petroleum diesel using industry test methods indicate that there is a marked improvement in lubricity when biodiesel is added to conventional diesel fuel. Even biodiesel level as low as 1 percent can provide up to a 65 percent increase in lubricity in distillate fuels. Using high percent blends fuel system components (primarily fuel hoses and fuel pump seals) that contain elastomers compounds incompatible with biodiesel. Manufacturers recommend that natural rubber not be allowed to come in contact with pure biodiesel. Biodiesel will lead to degradation of these materials over time, although effect will lessen with biodiesel blends.

1.1.2.8. Disadvantages of Biodiesel

Cold weather can cloud and even gel any diesel fuel, including biodiesel. Users of 20 percent biodiesel blend will experience an increase of the cold flow properties (cold filter plugging point, cloud point, pour point) of approximately 3 to 5 Fahrenheit. Precautions employed for petroleum diesel are needed for fueling with 20 percent blends. Same solutions work well with biodiesel blends, as do the use of cold flow improvement additives.

1.1.2.9. Selection of B20

It operates in conventional engines such petroleum diesel engine. It did not need modification for engine fuel system. Due to higher cetane number and better lubricant quality than diesel fuel, thereby, B20 is mostly used in C.I. engine fuel.

1.1.2.10. Environmental Benefits

For any manufacturing/production unit environmental considerations are of great importance. Basically there are three main phases during which environment get affected as per the following;

- Disturbance to existing set up of environment
- Emissions during manufacturing of product and its byproducts.
- Pollution caused by use of product manufactured/produced.

As the raw material is an agricultural product, for which we have to do the plantation on uncultivable shallows (An area of the sea, a lake, or a river where the water is not very deep) or semi fertile lands and these plants will become tree in 2-3 years which in turn balance the ecology. Regarding emissions during the manufacturing process, nothing has to burn, hence no fumes and no ash. Government has prescribed safety norms for that which are same as for petroleum products [5]. The number of feed stock for biodiesel is explored worldwide. The research on biodiesel is intensified during the last few decade using to the world energy demand and scarcity of petroleum fuels. United States alone has around 50 biodiesel plants. The feed stock used for different countries depends on the availability of oil seed for biodiesel production. Table 1.4 shows some of the feed stocks for biodiesel in few countries.

Table 1.4: Feedstock for biodiesel in some countries

Feedstock	**Countries**
Rape seed	Russia
Sunflower	Italy, Southern France
Soya bean	U.S.A.
Palm Oil	Malaysia
Linseed & Olive oil	Spain
Cotton Seed Oil	Greece
Jatropha Curcas Oil	Nicaragua
Beef Tallow	Ireland

Used frying Oil	Australia

1.2. Origin, Historical and Biological Aspects of Hemp Tree

The country of origin of the hemp plant is not positively known, but it is generally believed to have been the mountain districts in extreme north of India, where it is spread westward through Europe and southward through the peniscula of India. It has been used for thousands of years and it is thought that hemp was first cultivated plant in the world. It is the earliest known woven fabric and was first made into clothing around 8000-7000 BC. From 3000 BC to 100 BC, the Egyptian, Baby lonians, Persians and Hebrews cultivated hemp for a variety of purposes. The Romans from 500 BC to 500 AD, used hemp for clothing and rope in military campaigns In 1942, Columbus discovered America using ships powered with hemp oil and used hemp ropes. In 1970, the environmental and economic benefits of hemp became widely known as environmental and economic limits of tree became obvious. It grows on the banks of the lower, Ural and Volga, near the Caspian sea. It extends to Persia. The altai range, northern and western China. Nine hemp crops are cultivated in China. Hibiscus Cannabinus is a new crop in China which was introduced in the twentieth century. It has long history and cultivated in Bangladesh, Thailand, parts of Africa and to a small extent in southeast Europe. Today, principal farming areas are through China, India and in many other countries including Mackay and Australia etc. Probably native to Africa, East Indies, Asia, or Australia, now naturalized in Africa and Asia, generally cultivated in India, and introduced in India, Indochina, Taiwan, Indonesia, and North and South America. Its distribution is between 45 degree N and 30 degree S.

It is herbaceous annual plant that grows upto 1-5 metres. Fruit of hemp is not a true seed but an achene, which is not surrounded by a hard shell. The archenes are small and brown to grey and nuts are highly nutritious. It can grow in virtually any climate and soil conditions, and is excellent for reclaiming otherwise unusable land. It is extracted from the seed, is commonly used to produce paint, varnish and soap as well as for culinary purposes.

1) In fact, hemp has been estimated as having over 25,000 potential uses and its crop which has many environmental benefits.
2) It is annual in temperate zones and can grow up to 16’ (5m) tall.
3) It grows best in a well-drained, sandy loam where it requires at least 2.5” of rainfall during the growing season.

4) It is very nutritious.
5) Seed contains radium, thorium and rubidium and fatty oil like arachis oil.
6) It also contains 9.6% moisture, 6.4% ash, 20.4% fatty oil, 21.4% nitrogenous matter.
7) It is also have high essential fatty acids.

The authors of Pharmacographia say: - “It is found in Kashmir and in the Himalaya, growing 10 to 12 ft high and thriving vigorously at an elevation of 6000 to 10,000 ft. Table 1.5 shows scientific classification of hemp tree.

Table 1.5: Scientific classification of hemp tree

Kingdom	Plantae-plants
Subkingdom	Tracheobionta-Vascular plants
Superdivision	Spermatophyta-Seed plants
Division	Magnoliophyta-Flowering plants
Class	Magnoliopsida-Dicotyledons
Subclass	Dilleniidae
Order	Malvales
Family	Malvaceae-Mallow family
Genus	Hibiscus L.-rosemallow
Species	Hibiscus Cannbinus L.-brown Indian hemp

1.3. Origin, Historical and Biological Aspects of Neem Tree

It is thought to have originated in Assam in northeast India, and Myanmar, where it is common throughout the central dry zone. Later it became naturally distributed throughout most of the Indian subcontinent, particularly in drier areas. It is derived from the Persian Azad =Free, dirakht= Tree, i= of Indian origin which literally means, neem tree tree known as “Free tree of India.” According to an estimate, there are about 20 million neem trees in India and many parts of the neem tree have antimicrobial properties. A mature neem tree produces 30-50 kg fruit every year. It has a productive life span of 150-200 years.

It is cultivated all over India. It is grown in drier areas. It grows in all kinds of soil and is best suited for afforestation in hot and dry areas. It can grow into a big tree to a height of about 20 to 35m. it can grow even under semi arid and sub humid conditions up to 700 m above sea level.

Stem can grow to a girth of 2.5 m. The bark is rough and can be pale or grayish-black. Leaves alternately arranged with long, slender leaf stalks. Flowers look like in cluster during January to May and sometimes in September to October. They are whitish pink, star shaped and sweet smelling. Fruits are oval in shape and yellow brown when ripe with one seed inside. Neem oil and limonoids especially Azadirchta are two of the most important constituents of the neem seed. It usually fall to the ground and carried away with rain water. Table 1.6 shows scientific classification of neem tree, table 1.7 shows different names of neem tree in India and table 1.8 shows different names of neem tree in other countries.

Table 1.6: Scientific Classification of Neem Tree

Order	Rutales
Sub-order	Rutinae
Family	Meliaceae
Sub-family	Melioideae
Tribe	Melieae
Genus	Azadirachta
Species	Indica
Chemical Family	Tetranortiterpenoids
Chief intergradient	Azadirchtin
Botanical name	Azadirchta indica
Common name	Neem

Table 1.7: Different Names of Neem Tree in India

Marathi	Kadulimb, Kadunimb
Hindi	Neem
English	Margosa tree, Indian liac
Spanish	Margo
Punjabi	Nim or Neem
Farsi	Azad-darkhate hindi
Sanskrit	Arishtha or Nimb
Kannad	Bevu
Gujarati	Limdo, Timba

Bengali	Nimgach
Sindhi	Nimmi
Telgu	Vempu
Malayalam	Vepe

Table 1.8: Different Names of Neem Tree in Other Countries

Singapore	Kohumba
Indonesia	Mindi
Srilanka	Kohomba
Malaysia	Veppa
Kenia	Marubaini
Mali	Goge
Ghana	Governor
Naizeria	Dogoyaro
Swahili	Mooarobani
Germany	Neem-boom
Brahmi	Tamar
French	Azadirachra-the-end

1.4. Hemp Oil

Hemp oil that is non-refined varies from off yellow to dark green. It is especially useful for treating skin conditions. It contains approximately 19% LNA, 57% LA and around 1.7% GLA. It is a welcome edition to the Essential Therapeutics range. We are excited by its brilliant properties and sure that hemp seed oil will make a welcome edition to many aromatherapy treatments. Table 1.9 shows chemical composition of hemp oil and table 1.10 shows different names of hemp oil in different language.

Table 1.9: Chemical Composition of Hemp Oil

Oleic acid	45.3%
Linoleic acid	23.4%
Palmitic acid	14%
Stearic acid	6%

Table 1.10: Different Names of Hemp Oil in Different Languages

Sanskrit	Goni, Sana or Shanapu
Persic	Canna
Arabic	Kanneh or Kinnub
Greek	Kannabis
Latin	Cannabis
Italian	Canapa
French	Chanvre or Chanbre
Danish	Kamp or Kennep
Lettish and Lithuanian	Kannapes
Slavonic	Konopi
Erse	Canaib
Scaninarian	Hampr
Swedish	Hampa
German	Hanf
Anglo saxon	Haenep
English	Hemp
Spanish	Canamo
Russian	Konoplya
Hungarian	Kender
Chinese	Tall Ma

1.5. Neem Oil

It is derived from crushing the neem seed and by using large mechanical expellers. Azadirchtin is one of the main active compounds but along with there are other limonoid present in neem like nimbin, nimbidin. It is burnt in lamps throughout India. It acts as a good charcoal. It is unique, comprising, non-lipid associates commonly known as bitter and sulphur compounds that imparts odour to the oil. The Azadirachtin and oil content were found to be affected by seed quality and moisture content. It has low toxicity and its smell is a bit strong. It has dark yellow colour. It is identified by renewable grown agro-chemicals and nutrients which are biodegradable. It contains several thousands of chemicals which are terpenoids in nature. It contains bitter tetranortriterpenoids which are commercially available in India. It has medicinal use of high value. It is used for lubrication purposes. It is used for soap production. It contains1500 ppm minimum Azadirchtin content. Table 1.11 shows chemical composition of neem oil.

Table 1.11 : Chemical Composition of Neem Oil

Oleic acid	50%
Linoleic acid	13%
Palmitic acid	18%
Stearic acid	15%
Arachidic acid	2%

1.6. Vegetable Oil acts as a C .I. Engine Fuel

Vegetable oil can be produced from plant sources, which are viable to produce on a mass scale or in local rural areas on many land conditions. The various edible vegetable oils like sunflower, soybean, peanut, cotton seed etc have been tested successfully in the diesel engine. Research in this direction with edible oils yielded encouraging results. But as India still imports huge quantity of edible oils, therefore, the use of non-edible oils of minor oilseeds like Jatropha curcas, pongamia, hemp, neem, mahua (*Madhuca indica*) oil has been tested as a diesel fuel extender [3,4,7,8,13]. Diesel is produced from crude oil, biodiesel is produced from vegetable oils, and either edible or non edible oils can be used depending on their properties, using diesel derived from vegetable oils is not a new idea. When Rudolf Diesel invented the diesel engine he used peanut vegetable oil fuel in Paris as an alternative to diesel. Using straight vegetable oils as a fuel substitute an option but only with many modifications to be performed on the engine itself for continued satisfactory engine performance. In future more advanced engines may be designed to cope with these crude oils. However at the current time and for a transition period to a cleaner fuel system biodiesel is a viable option**.** To allow the use of vegetable oils as a fuel without modification of the engine, the fuel needs to be modified for compatibility with the engine. As the diesel engines are designed for diesel fuel any substitute needs to have similar properties for the engine to operate satisfactorily. Biodiesel is a viable opportunity that will not incur large costs for a new infrastructure as the storage and distribution will be the same as the diesel infrastructure.

1.6.1. Advantages and Disadvantages of Straight Vegetable Oil as C. I. Engine Fuel

The vegetable oil has found good application in diesel engine since its invention. Most of the oils are compatible with diesel fuel, hence blending of vegetable oil with diesel is one possible option and time consuming, and oil quality depending transesterification process can be eliminated [13]. Crude vegetable oil has a high viscosity compared to diesel, which can give rise to many problems. If the oil is too viscous, in cold conditions the oil may solidify to such an extent that it will not flow into the engine correctly, also resulting in the injector choking and ring sticking. Even if solidification is slight it will clog the fuel filter and nozzle, starving the engine of fuel. Viscous fuel will not disperse correctly in the cylinder once released from the nozzle and therefore will not mix with the compressed air, causing large quantities of unburnt HC emissions and low fuel efficiency. The high viscosity has been shown to cause problems if the engine is started in cold conditions. The inefficient mixing of oil with air contributes to incomplete combustion, leading to heavy smoke emission, and the high flash point attributes to lower volatility characteristics. These disadvantages, coupled with the reactivity of unsaturated vegetable oils, do not allow the engine to operate trouble free for longer period of time.

1.7. Biodiesel as a C.I. Fuel

When biodiesel as an alternative fuel is considered, one important factor is the reduction of greenhouse gases and pollutant emissions [1]. The greenhouse gases that are looked at the most are the NOx and COx emissions. NOx and COx are greenhouse gases that are theorized to be causing global warming. Even though the bio-diesel is burned, the NOx and COx amount given off when compared to gasoline and other alternative fuels is much lower. With the reduction of these two greenhouse gases, bio-diesel looks like a great alternative fuel for our environment.

Studies have already been done showing that NOx and COx are much lower when bio-diesel are burned when compared to gasoline in the American cars (1). Another study has shown that sometimes the NOx values may be larger when gasoline is burnt, but then went into more details about how reducing COx is more important than the NOx. The truth about whether or not both greenhouse gases are smaller when compared to gasoline still needs to be researched until a stable result may be found. Another important thing to consider while looking at bio-diesel as an alternative fuel is the cost of the fuel. The main concern that engineers argue is the cost of this new improved technology. Engineers argue that the capital costs for bio-diesel will not be worth the new technology. The cost of bio-diesel is much higher than the cost of ordinary diesel. Pure biodiesel (100%) sells for about \$1.50 to \$2.00 per gallon before taxes. Fuel taxes will add approximately \$0.50 per gallon. A mix of 20% bio-diesel and 80% diesel will cost about 15¢ to 20¢ more per gallon over the cost of 100% diesel. Researchers have already found great information about bio-diesel as an alternative fuel source. Although research has already been done, engineers still need to figure out what to do with the problems of bio-diesel. With continued research within the engineering field, engineers will find a way to make bio-diesel as an alternative fuel for gasoline.

1.8. Fuel Properties of Selected Fuels

Fuels: Fuels are substances which combine with air will yield heat. The chemical combination of fuel and oxygen in air produces products of combustion containing CO, CO_2, H_2O, SO_2 and N_2. Fuels exist in any of the three stages such as gaseous fuels, solid fuels, and liquid fuels.

Gaseous fuels: It can mix with and distribute homogeneously to various cylinders in a multi-cylinder engine. They are mostly used as natural gas, coke, oven gas, blast furnace gas, producer gas and liquefied petroleum gas.

Solid fuels: They are coal. The main obstacle is the excessive wear of the cylinder liners and piston rings. The sulphur content is greater in coal. This causes corrosive wear. Ash formation is another problem.

Liquid fuels: Most liquid fuels are derived from crude oil or petroleum which is existing at different parts of the world. The liquid fuels can be put into two main groups, liquid fuels which can vaporize easily and can be handled like gases, and liquids which have to be injected into the combustion chamber in the form of spray. Former group is used in SI engines while the latter group is used in CI engine. The most important liquid fuels used in engines are gasoline (petrol), fuel oil (diesel), gas oil and kerosene and alcohols.

General properties of fuel: The fuel characteristics include the physical and chemical properties of the fuel such as viscosity of fuel, pour and fire point of fuel, calorific value of fuel and ignition quality (cetane number).

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

1.8.1. Density/ Specific Gravity

Bio-diesel is slightly heavier than conventional diesel fuel (specific gravity 0.88compared 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.

1.8.2 Kinematic Viscosity

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.

1.8.3 Flash Point and Fire 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 biodiesel is around 160℃, 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.

1.8.4 Water Content or Moisture 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. It affects on quality of biodiesel. High content of above property disturbs standard specification of biodiesel. It causes blockage of fuel filter and fuel lines.

1.8.5 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**.**

1.8.6 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. Biodiesel generally has higher cloud point than diesel fuel.

1.8.7 Pour Point

Normally either pour point or CFPP are specified. French and Italian bio-diesel specifications specify pour point whereas others specify CFFP. Since CFFP 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 biodiesel.

1.8.8 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, drive ability, 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.

1.8.9. 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°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**.** It depends upon various factors on the one hand, it is influenced by type of feedstock used for fuel production and on its respective degree of refinement. High fuel acidity has been linked with corrosion and the formation of deposits within the engine.

1.8.10 FFA Content

If the oil has a high water or free fatty acid (FFA) content the reaction will be unsuccessful due to saponification (saponification is defined as the reaction of an ester with a metallic base and water) commonly known as making soap, and make separation of the glycerol difficult at the end of the reaction. The FFA content of the raw oil will determine the quantity of biodiesel as the final product. A very low content of FFA (<0.2) can give a full 100% yield. Unfortunately the FFA content of raw Jatropha oil can be up to 10. It is essential for viable production for the FFA to be no higher 2.5. The seeds should be stored at a temperature no less than 40°C and collected on a sunny dry day. The FFA quantity also depends on the seed quality, transport and storage.

1.8.11 Calorific Value

The total quantity of heat liberated by completely burning of one unit mass of fuel. The calorific value of a substance is the amount of energy released when the substance is burned completely to a final state and has released all of its energy.

1.8.12 Ash Content

It describes the amount of inorganic contaminants such as abrasive solids and catalyst residues and the concentration of soluble metal soaps contained in a fuel sample. These compounds are oxidized during the combustion process to form ash which is connected with engine deposits.

1.8.13 Carbon Residue Content

It is correlates with respective amounts of glycerides, free fatty acids, soaps and catalyst residue. The parameter serves as a measure of the tendency of a fuel sample to produce deposits on injector tips and inside the combustion chamber. It is also influenced by high concentration of polyunsaturated fatty acid methyl esters and polymers.

1.8.14 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

1.8.15 Iodine Value

It is important to measure the oxidation stability of oil. Type of parent oil is the major parameter affecting the iodine value of the esters. It negatively affects engine operation. It is correlated with viscosity and cetane number which both decreases with increasing degree of unsaturation. Fuel with high iodine numbers tend to polymerise and form deposits on injector nozzles, piston rings and piston ring grooves when they are heated.

1.8.16 Saponification Value

It is an indication of the amount of fatty acid saponifiable material in compounded oil. It gives information concerning the character of the fatty acid of the fat and in particular concerning the solubility of their soaps in water. The higher saponification numbers of a fat free from moisture and unsaponification matter, the more soluble the soap that can be made from it. The information is of special importance to soap makers. The saponification numbers are also used in setting product specifications for lubricants and additives.

1.8.17 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. Glycerin content can indicate the quality of biodiesel. A high content of free and total glycerin can lead to build up in fuel tanks, clogged fuel systems injector fouling and value deposits.

1.8.18. Copper Strip Corrosion

It is correlated to acid number.

1.9. Specification of Quality Standards of Biodiesel

Standards are of vital importance for the producers, suppliers and users of biofuels. 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. 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 monoalkylesters, dialkyl esters, residual vegetable oil, free glycerin, reactant alcohol, free fatty acids and the residual catalyst. In December 2001,

American Society of Testing and Materials (ASTM) issued a specification (D6751) for biodiesel (B100) which is presented in Table 12.

Table 13 shows proposal biodiesel specification for India and Table 14 summarizes standards for biodiesel in various coutries.

Table 1.12: ASTM Specification (D 6751) for B10

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

Property	ASTM Method	Limits	Units
Flash Point	D93.	130 min	Degrees C
Water & Sediment	D2709	0.050 max.	% Volume
Kinematic Viscosity	D445	1.9-6.0	mm^2/sec
Copper Strip 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

Table 1.13: Biodiesel Specification for India (Consideration of Fuel Properties)

Density/specific gravity	Water content
Kinematic Viscosity	Cloud point
Flashpoint	Ash
CFPP	Net calorific value
Pour point	Acid Number/Neutral No.
Cetane number	Ester content
Distillation characteristics	Methanol content
Conardson carbon Residue	Mono glycerides
Sulfur content	Di glycerides
Copper corrosion	Triglycerides
Total contamination	Iodine number
Phosphorous content	Poly Saturated ester(C 18:3 +)
Sulfated Ash	Free glycerol
Thermal stability	Total glycerol
Oxidation stability	Alkaline material(K Na)
Storage Stability	Lubricity

Table 1.14: Biodiesel Standards of Different Countries

Specifications	Units	Australia	France	Germany	Italy	Sweden	USA	Draft EU
Standards		ONC1191	-	DINE51606	UNI10635	SS155436	ASTMD6751	EN14214
Introduction Date		July 1997	Spt.1997	Spt.1997	April 1997	Nov.1996	Dec.2001	2001
Density @15ċ	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	$m\,m^2/s$	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		≥100	≥100	≥110	≥110	≥100	≥130	≥130
CFPP		0/-15	-	0-10/20	-	-5	-	0/-15
Pour Point		-	-10	-	0/-15	-	-	-
Ash Content	%mass	-	-	-	0.01	0.01	-	-
Cu Corrosion	3h/50ċ	-	-	1	-	-	NO.3	1
C. N.		≥49	≤≥49	≥49	-	≥48	≥47	≥49
Ester Content	%mass	-	≥96.5	-	≥98	≥98	-	≥96.5
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	-	-
Oxidation Stability	Hrs.							6 min.

1.10. Proposed Biodiesel Specification for India

Table1.15 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. 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 15 gives the proposed specifications for India.

Table 1.15: Summary of Proposed BIS Standard for Biodiesel

Standard/Specification	Units	Proposed BIS
Density@15°C	g/cm^3	0.87-090
Viscosity@40 °C	mm^2/s	3.5-5.0
Flashpoint o C ≥100	°C	≥100
Cu Corrosion (3h/50C), max		1
Cetane No ≥51	-	≥51
Acid No	mg koh/g	≤0.8
Ester Content	% mass	≥96.5

1.11. Scope of Work

In view of the large foreign exchange requirement for purchase of petroleum crude and the resulting unabated pollution, the government of India has set up a Committee on Development of Bio-fuel in 2002-03. The target of the mission is production of biodiesel sufficient to blend with high speed diesel to the extent of 20% by the year 2011-2012. Utilization of non-edible vegetable oils for production of biodiesel will prevent further wastage of already existing resources as well as plantation of oilseeds in wastelands, and use of environmentally friendly fuel will create cleaner environment. The work presented in this thesis with respect to study of two biodiesel from non-edible oil based on the availability of raw feedstock. As no work has been done on standardization of transeserification process parameter for hemp oil and neem oil. The present study focus on the standardization of transesterification process of hemp oil and neem oil. The goal of this work is to determine the usefulness of both biodiesel in a single cylinder diesel engine. So our aim of study is mainly to standardized fuel and conducts engine testing to evaluate performance and emission characteristics and also reveals cost assessment of obtained biodiesel.

1.12. Organization of Thesis

The division of dissertation divided into mainly seven parts. The experimental work based on biodiesel production, fuel characterization and diesel engine testing in detail, including the main components, instrumentation and data acquisition systems are presented in this thesis. The cost of tested biodiesel is also explored.

Chapter I

This chapter is related to alternative fuels and selection of alternative fuel for diesel engine. The development of research in biodiesel in India and foreign countries. It describes prospective feedstock for biodiesel production in India and world, biodiesel as an energy security, specification of quality standards of biodiesel, proposed biodiesel specification for India. It determines fuel properties, engine performance and emission analysis. It presents biodiesel demand, biodiesel requirement advantages, disadvantages and environmental benefits. It is experimentally measured that biodiesel, vegetable oil and non-edible oils (hemp and neem oil) act as a fuel which provides good results in compression ignition engine. The origin, historical and biological aspects of hemp and neem tree is also described in this chapter. The chemical compositions of hemp and neem oil are also described in this chapter. According to market value, cost assessments of selected biodiesels are to be evaluated.

Chapter II

It is related to literature review and problem formulation. Extensive literature on chemical structure of biodiesel and transesterification, fuel characterization, C. I. engine performance and emission and economic feasibility of tested fuel are reviewed. Later in this chapter objectives and problem formulation are described. An overview of research work in the field of biodiesel with relation to preparation method and fuel properties is presented in the chapter. The performance and exhaust emission characteristics of compression ignition engine are also described in this chapter. The past experimental results of methyl esters from different edible and non-edible oils are also discussed in this chapter which shows that these fuels can be successfully used in diesel engine.

Chapter III

This chapter deal with raw material used for conducting experiments such as purchasing of non-edible oils , chemicals, sample bottles, and diesel etc. The detailed study of standardization of fuel using different parameters, fuel properties is also described. It also studies engine performance and exhaust emission characteristics using C. I. engine. It provides a brief overview of chemical processes involved in producing biodiesel. It also covers the specific methods used to make the biodiesel samples. The entire engine performance and emission analysis are also shown from the completely instrumented single cylinder four stroke, water cooled diesel engine.

Chapter IV

It is related to test analysis and results of transesterification process, and fuel characterization. In addition, engine performance and exhaust emission profiles are also explained in this chapter. The cost analysis of the biodiesel and comparative study of different biodiesel are discussed in this chapter. The engine performance parameters viz., brake thermal efficiency, brake specific fuel consumption, brake specific energy consumption, exhaust gas temperature are also discussed in this chapter. The engine exhaust emission such as smoke opacity, unburned hydrocarbon, carbon-dioxide, carbon-monoxide, oxygen level and oxides of nitrogen etc are also described in this chapter. An economic evaluation of hemp and neem biodiesel are also described that will decide the final cost of biodiesel.

Chapter V

Conclusions regarding transesterification process, fuel characterization and C.I.engine testing along with economic evaluation of selected biodiesel are narrated in this chapter.

Chapter VI

It is related to future scope of work, recommendations and references.

CHAPTER 2

LITERATURE REVIEW AND PROBLEM FORMULATION

Feasibility studies on the use of different renewable liquid and gaseous fuels have been studied throughout the world. Attempts have been made in many developed countries of the world on the use of vegetable oils as diesel engine fuel. In most of the research work vegetable oil has been tried as pure, esterified or blended with diesel. Many researchers, engine manufacturers and users in different countries of the world have performed tests that demonstrated the potential and problems of this fuel source. However, there are several real problems that restrict the introduction of this source in to energy pool. This chapter reviews the feasibility of this fuel source and some of the results obtained from investigations on the use of vegetable oils and their esters as fuel in compression ignition engines. This chapter starts with basic approach for the process of transesterification and fuel characterization. It is followed by extensive literature survey on engine performance and emission. Later in this chapter literature on economic assessment is reviewed. The objective of this chapter is to review all the literature related to the subject extensively. Consequently, limitations of literature review are explored and problem is formulated.

2.1. Overview of Biodiesel Production

A brief overview of the production of biodiesels and the use of various components used is given here.

2.1.1. Feedstocks

Feedstocks for production of biodiesels are vegetable oils (soybean, canola, palm, and rapeseed), animal fats (beef, tallow, lard, poultry fat, fish oils) or recycled grease (mix of the above two). All of the above feedstocks contain triglycerides, free fatty acids (FFAs) and other contaminants. The proportions vary in level depending on the feedstock and these variables affect the chemical reactions needed to transform the primary raw materials (feedstock and alcohol) to create the biodiesels. Commercially available vegetable oils are made up of a small percentage of FFAs, but crude vegetable oil may contain more FFAs and phospholipids, which are removed in two processes: refining and degumming, respectively. The technology required depends on whether the vegetable oils are refined, degummed, or crude. Animal fats and recycled grease have high levels (up to 15% concentration) of FFAs. The FFA content affects the process and yield associated with the final product, and thus these feedstocks (greater that 1% concentration) must be pretreated before the reaction can begin. Other contaminants also affect the feedstock preparation necessary before it can be used in the reaction.

2.1.2. Alcohol

In order to form the biodiesel, a primary alcohol is coupled with the feedstock to form the esters. The most common alcohol is methanol but ethanol, isopropanol and butyl (derived from butane) can also be used. The key quality parameter associated with the process of transesterification is the water content. If the water content is high, it results in low yields, high levels of soap, and leftover FFAs/triglycerides. Therefore, it is important to use stronger alcohols, since the weaker ones are hygroscopic (absorb water from the air). Some alcohols also require higher operating temperatures, longer mixing times, and lower mixing speeds which result in higher operation costs and lower throughput. The decision of which alcohol to use with each process is determined by cost, amount needed, and ease of recycling. Quality requirements on fuel and water content in ethanol make methanol the most popular choice among alcohols. Conventionally, methanol is not renewable since it is normally generated from either natural gas or coal gas and steam however methanol can now be produced from renewable biomass materials (like wood, and black liquor from pulp and paper mills).

2.1.3. Catalyst

Catalysts are required to promote an increase in solubility which allows the reaction to occur at a faster rate. These include base, acid or enzyme catalysts. The most common catalysts are sodium hydroxide (NaOH) and potassium hydroxide (KOH). Most base catalyst systems use vegetable oil as the feedstock, but base catalysts are highly hygroscopic, so absorption of chemical water occurs when the catalyst is dissolved in the alcohol. This leads to poor quality biodiesel that may not meet the ASTM standard. Typically, base catalysts are used for vegetable oil processing plants because FFA and water content is low and the reaction is fast.

2.1.4. Glycerol

Glycerol is not a component in making biodiesel but it is the primary byproduct of the reaction. In trying to make biodiesel economically feasible in today‟s market, it is extremely important to consider glycerol profitability since it has many marketable applications. Glycerol in its pure form is a sweet-tasting, clear, colorless, odorless, viscous liquid. It is completely soluble in water and alcohol. Potential customers include pharmaceutical and cosmetic manufacturers, and many others. It can be used as a solvent, sweetener or in the manufacturing of dynamite, cosmetics, liquid soaps, candy, liquors, inks, and lubricants. Usually about 10% of the resulting mixture from the reaction can be recovered as glycerol.

2.1.5. Silica Gel

The characteristic of the silica gel is to absorb the moisture from the methyl ester. During the washing process the water is being sprayed in to Ester surface. Some percent of moisture will be present in the ester, it is very essential to remove the moisture as it will adversely affect the performance and life of the engine.

2.2. Transesterification Process of Vegetable Oils

2.2.1. Chemical Reaction

A catalyst is an element or compound that is used to speed up a chemical reaction without itself being changed in the process, this therefore means that the catalyst can be extracted in part and reused. For the reaction to take place the triglyceride and alcohol need to be in the presence of a catalyst (either KOH or NaOH).

Simple transesterification reaction is given by three consecutive and reversible equations. The first step is the conversion of triglyceride to form diglycerides, followed by the conversion of diglycerides to monoglycerides, and of monoglycerides to glycerol, yielding one methyl ester molecule per mole of glyceride at each step. R1,R2 and R3 are long chain hydrocarbons which may be the same or different. The step wise reactions are reversible and a little excess of alcohol is used to shift the equilibrium towards formation of esters. The figure 2.1 indicates the chemical reaction involved in the transesterification process.

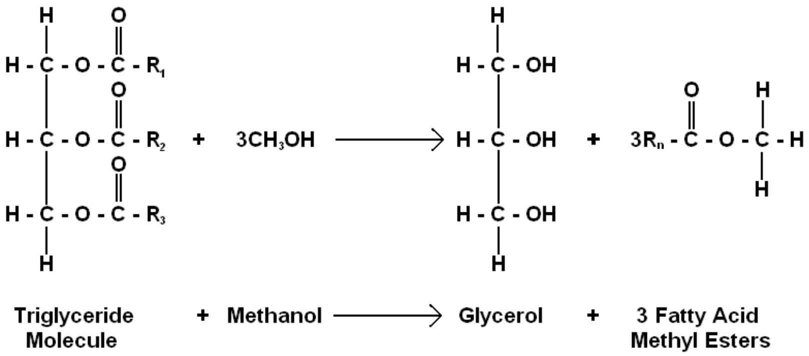


Fig. 2.1 Chemical reaction involved in the transesterification process

In presence of excess alcohol, the forward reaction is pseudo-first order and the reverse reaction is found to be second order. It is also found that the reaction is faster when catalysed by alkali. There are other parameters which affect the transesterification process like FFA %, moisture content, type of alcohol, temperature, stirring speed and duration of reaction etc.

2.2.2. Process of Biodiesel Production

Vegetable oils can be chemically reacted with an alcohol (methanol is the usual choice) to produce chemical compounds known as esters. Biodiesel is the name given to these esters when they are intended for use as fuel. Currently biodiesel is produced by a process called transesterification where the vegetable oil or animal fat is first filtered, then processed with alkali to remove free fatty acids. It is then mixed with an alcohol (usually methanol) and a catalyst (usually sodium or potassium hydroxide) along with application of heat. The oil's triglycerides react to form esters and glycerol, which are then separated from each other and purified. The methanol is charged in excess to assist in quick conversion and recovered for reuse. Primary aim of the process is to form alcohol ester and reduce the viscosity of the triglyceride. The Figure 2.2 indicates the stages of commercial process for biodiesel production.

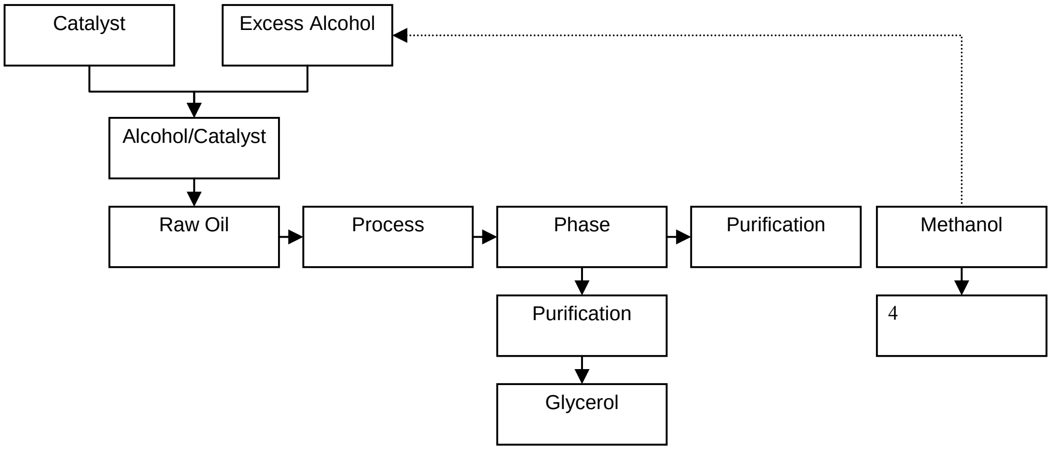


Fig. 2.2 Stages of biodiesel production

2.2.2.1. Single Stage Transesterification Process

In single stage process the requirement of FFA of oil in the range of 1-2% is a pr-requisite for a successful reaction and resulting high yield of 90-95% in terms of oil to ester conversion.

However the reaction of high FFA content oil is possible only to some extent, but a substantial reduction in yield in the range of 55-70% affects the biodiesel economics. The catalyst NaOH/KOH was employed for the transesterification process by varying both methanol and catalyst quantity. In single stage process the methanol oil ratio 0.195 to 0.3 w/w and alkali catalyst (NaOH) 0.9 to 1.% w/w is pre-mixed in a flask and added rapidly in to oil. The mixture is put into a glass reactor and stirred and heated for about 1-1.25 hrs at 65-70^{o}C. The rate of stirring in the start was more vigorous in the range of 650-700 rpm and it reduced to 450-500 rpm after the mixture temperature attained 70^{o}C. After the reaction is over within the specified time period the mixture is transferred in to a separating flask and kept overnight for settling. The upper layer is methyl ester (biodiesel) and lower dark layer is glycerol, bi-product of transesterification process. The ester layer is washed using hot water spraying over its surface, two to three times till neutralization, settled overnight and discarded the water residual catalyst bottom layer. Lastly ester layer is dried using silica gel by dropping the ester through the silica bed. Now the pure biodiesel is ready for using in diesel engine.

2.2.3. Standardization Process

Once biodiesel is being produced at estimated quantities, optimization needs to be carried out to reduce the quantity of alcohol and catalyst required to give a satisfactory yield. Firstly the quantity of catalyst should be fixed and the quantity of alcohol reduced or increases to a point where the transesterification is still converting a high yield. Then the catalyst proportion is adjusted with the fixed quantity of alcohol until the lowest possible amount can be used without over-affecting the conversion proportions. The alcohol content is again adjusted to establish the best yield. If an increase in alcohol increases the conversion but not to a justifiable amount in proportion to the amount of alcohol used this would be considered too much. Optimization is required to obtain the lowest possible cost in the transesterification stage of biodiesel, making it as economically viable as possible. Any excess methanol should be recycled as well as the catalyst. The following factors to be considered for standardization process are as below:

- Preheating time
- Preheating temperature
- Reaction time
- Reaction temperature
- Catalyst Concentration
- Molar ratio

2.3. Experimental Studies: Basic Approach

2.3.1. Transesterification Process

Karmee et al. [1] have conducted an experiment on crude pongamia oil and transesterified using KOH as catalyst and methanol to form biodiesel. The conversion was found to be 92% at 60^0 C with 1:10 molar ratio (oil: methanol) for KOH (1% by wt.) catalyzed transesterification. The fuel properties especially viscosity and flash point of the transesterified product compare well with accepted biodiesel standards such as ASTM and German biodiesel standards.

Bouaid et al. [2] have reported the process of biodiesel production for pilot plant using Brassica carinata oil as raw material with methanol and using KOH as catalyst. Methyl or ethyl esters are the products of transesterification of vegetable oils with alcohol (methanol / ethanol) using an alkaline catalyst. The factorial design of experiments procedure has been followed to optimize the variables that determine the yield of ester. According to this study, the maximum yield of ester (98%) can be obtained, working with an initial catalyst concentration (1.5%), an operating temperature of 25^0 C and with an alcohol /oil molar ratio of (6:1). The used methodology (Factorial design of experiments) allows to develop and to optimize this process, leading to obtain a simple technological model valid for the process scale up. The quality of biodiesel is in agreement with the European specification defined by EN 14214.

Meher et al. [3] have reported transesterification of karanja oil with methanol for the product of biodiesel. The reaction parameters such as catalyst concentration, alcohol/oil molar ratio, temperature and rate of mixing were optimized for production of karanja oil methyl ester (KOME). The yield of methyl esters from karanja oil under the optimal condition was 97-98%. Studies were carried out at molar ratio = 6:1, reaction temp = 65^0 C, rate of mixing = 360 rpm. Yield = above 85% in15 min. and Yield = 97-98% after 2 hrs. Molar ratio = 12:1, Reaction time = 1hr., Rate of mixing = 180 rpm and stirring at high rpm was a time efficient process.

Antolin et al. [4] have reported an experimental work on the transformation process of sunflower oil in order to obtain biodiesel by means of transesterification. Taguchi methodology was chosen for the optimization of the most important variables (temperature conditions, reactant proportion and methods of purification) with the purpose of obtaining a high quality biodiesel that fulfils the European pre-legislation with the maximum process yield. Fuel properties of sunflower methyl esters were characterized. These fuel properties like density, viscosity, flash point and sulphur content which also present good values of calorific power and cetane index.

Bhatti et al. [5] have assessed the acid and base catalyzed processes to produce biodiesel using waste chicken and mutton tallow. The effect of different process parameters such as reaction temperature, catalyst quantity, and reaction time on biodiesel yield was evaluated. Biodiesel produced from chicken and mutton fats using acid catalysis resulted in higher yield in composition to base catalysis. The fuel properties were determined. These properties are in the range of recommended standards.

Rashid et al. [6] have explored the utility of Moringa oleifera methyl esters as a potential source of biodiesel fuel. The important fuel properties of MOME were determined and are compared with other biodiesel fuels. Biodiesel was prepared from Moringa oleifera oil by alkali catalyzed transesterification with methanol after acid pretreatment. The methanolysis of Moringa oleifera oil was conducted by a standard procedure employing a 6:1 molar ratio of methanol to vegetable oil for 1 hr at 60^0 C. By using 1 wt % $NaOCH_3$ as catalyst, then Moringa oleifera oil appears to be an acceptable feedstock for biodiesel. Fuel properties have been studied. In this context, cetane number, oxidation stability and cloud point show good results as compared to diesel fuel.

Phan et al. [7] have conducted an experiment on transesterification process of waste cooking oil for a reaction temperature of up to 70°C**.** The molar ratio of methanol/WCO ranged from 5:1 to 12:1 in the presence of KOH catalyst concentration varying from 0.5 wt% of oil to 1.5 wt% of the WCO. The results showed that the highest yield of biodiesel (88-90%) was obtained at the ratio of methanol/WCO of 7:1-8:1 during 80-90 min at temperatures ranging 30-50^0 C in the presence of 0.75 wt% of KOH. The physical properties of biodiesel and its blends were characterized and they were within EN14214 standard.

Tomasevic et al. [8] have conducted an experimental investigation on methyl esters obtained on the basis of heated refined sunflower oil and used frying oils. Transesterification reaction conditions that affect yield and purity of the esters including oil quality, molar ratio of methanol to vegetable oil, type and concentration of alkaline catalyst, temperature and reaction time were examined. The methanolysis of different oils at 25^0 C with 0.5%-1.5% potassium hydroxide or sodium hydroxide were studied. The effect of molar ratio 4.5:1, 6:1 and 9:1 on ester yield and its quality were investigated. By using 1% potassium hydroxide, temperature at 25^0 C, molar ratio 6:1 and 30 min, all investigated oils were sufficiently transesterified and could be used as fuel in diesel engines. Holser et al. [9] have reported methyl and ethyl esters of milkweed seed oil from transesterification process and determining fuel properties. The laboratory prepared milkweed biodiesel exhibited pour point and cloud point values that suggest improved cold weather performance. The kinematic viscosity, oxidative stability and lubricity values compared favorably to soybean esters.

Korus et al. [10] have performed the process for the production of the ethyl ester of winter rape (EEWR) for use as a biodiesel fuel. Rapeseed oil ethyl ester can be made successfully under the different conditions for transesterification such as room temperature, 0.5% sodium methoxide catalyst based on weight of rapeseed oil and 50% excess of the stoichimetric amount of required 200 proof alcohol, 1.0% potassium hydroxide catalyst and 100% excess of the stiochiometric amount of 200 proof alcohol, and extremely vigorous agitation with a little splashing until the reaction mixture becomes homogenous.

Srivastava et al. [11] have studied the triglycerides (vegetable oils/animal fats) as alternative fuels for diesel engines. To improve the fuel properties of triglycerides is the catalytic transesterification of triglycerides with alcohols to form mono-alkyl esters of long chain fatty acids, known as biodiesel which is quite similar to hydrocarbon based diesel fuels in its main characteristics and provides similar engine performance with attractive emission levels.

Ma et al. [12] have reported different factors affecting transesterification and molar ratio of glycerides to alcohol, catalysts, reaction temperature and reaction time and the contents of the free fatty acids and water in oils and fats. The commonly accepted molar ratio of alcohol to glycerides is 6:1. Base catalysts are more effective than acid catalyst and enzymes. The recommended amount of base used to use in between 0.1% and 1% w/w of oils and fats. The continuous transesterification process is one choice to lower the production cost.

Marchetti et al. [13] have studied different oils as raw material, different alcohol (methanol, ethanol, and butanol) as well as different catalysts, homogenous ones such as sodium hydroxide, potassium hydroxide, sulphuric acid and supercritical fluids and heterogeneous ones such as lipases. The alcohol-oil molar ratio that should be used varies from N= 1:1-6:1. However N = 6:1 is the most used ratio giving an important conversion for the alkali catalyst without using a great amount of alcohol.

Gerpen et al. [14] have described the processing and production of biodiesel. The emphasis will be on processing as it is conducted in the United States, where most biodiesel is produced by reacting soybean oil or used cooking oils with methanol.

Vicente et al. [15] have performed experimental investigation on different basis catalysts (sodium methoxide, potassium methoixde, sodium hydroxide and potassium hydroxide) for methanolysis of sunflower oil. The biodiesel purity was near 100 wt% for all catalysts. However, near 100wt%

biodiesel yields were only obtained with the methoxide catalysts. The biodiesel yields for the sodium and potassium hydroxide were lower, 85.9 and 91.67% respectively.

Lu et al. [16] have described two step process consisting of pre-esterification and transesterification process to produce biodiesel from crude Jatropha curcas L. oil. The effects of the methanol/oleic acid molar ratio, reaction time, temperature and catalyst amount on the conversion of the pre-esterification reaction were investigated. Temperature is found to influence the reaction rate. Higher yield was obtained at a higher temperature between 35 and 65^{o}C. The conversion increased with reaction time. The first 15 minutes is the fastest period of the reaction, in which a conversion of 90% is possible. The yield of biodiesel by transesterification was higher than 98% in 20 minutes of reaction time using 1.3% KOH as catalyst, and a molar ratio of methanol to oil of 6:1 at 64^{o}C.

Meher et al. [17] have studied the transesterification of Pongamia Pinnata oil by means of methanol and feasibility of methanolysis process by using KOH catalysts. The yield of biodiesel obtained was >97% by using oil/methanol molar ratio 12:1 KOH as catalyst at 65^{o}C and stirring at 360 rpm in 3 hr. It was observed that the best yield was obtained with a catalytic concentration of 1% of KOH. For higher value of catalyst concentration, the yields were lower. There are very few studies reported on production of biodiesel by utilizing non-edible oils, among which Karanja is one of the most potential species to produce biodiesel in India which could offer opportunities for generation of rural employment increasing income and improving environment.

Vivek et al. [18] have investigated the feasibility of Karanja oil for the production of biodiesel optimization of different parameters for high yield conversion. The optimum parameters for high conversions are: pressure one atmosphere, temperature 68-70^{o}C, reactant ratio 8-10 (Moles of MeOH: Moles of oil), reaction time 30-40 min, catalyst (KOH) 1.5% w/w.

Math et al. [19] have explained use of two stage transesterification method for conversion of restaurant waste oil into biodiesel and optimization of experimental conditions for biodiesel production. Maximum yield (85.50%) of biodiesel (methyl ester of restaurant waste oil) was obtained at optimum amount of methanol, catalyst NaOH concentration temperature and reaction time. It studies different amounts of methanol (20, 25, 30, 35, 40 and 45%), catalyst concentration (0.3, 0.5, 0.7, 1.0, and 1.5% NaOH), reaction temperature (30, 45, and 55℃) and different reaction times (60, 90, and 120 min) were selected for transesterification of restaurant waste oil in order to optimize experimental conditions for maximum biodiesel yield. Methyl ester yield (65.50-85.50%) in the laboratory scale biodiesel reactor was obtained maximum (85.50%) at the optimized process parameters such as methanol (35% by volume), NaOH (0.3g), reaction temperature (55 °C) and reaction time (90 min).

Alamu et al. [20] have explained biodiesel production through transesterification of Palm kernel oil (PKO) with ethanol using NaOH catalyst. The transesterification process carried out using 100g PKO, 20g, ethanol 1% NaOH (by weight of PKO at 60 °C) reaction temperature and 90 min reaction time yielded 95.8 g PKO biodiesel.

Ahmad et al. [21] have studied that peanut oil has low contents of saturated free fatty acid and is suitable source for biodiesel production. In order to achieve maximum yield of biodiesel transesterification of crude oil of this species was carried out at 60 °C at 1:6 molar ratio by using NaOH catalyst. An optimum conversion of Palm oil biodiesel (POB) from triglycerides (TD) was achieved by using 1:6 molar ratio (methanol to oil) at 60 °C).

Ullah et al. [22] have revealed that pretreatment of methoxide with molecular sieves can improve the yield of biodiesel and the biodiesel produced through base catalyzed transesterification of wild apricot kernel oil. Maximum yield (93%, w/w) of biodiesel was obtained when sodium methoxide prepared by dissolving sodium hydroxide pellets into methanol was treated with molecular sieve before transesterification. The 89% conversion of oil to biodiesel occurred when methoxide was not treated with molecular sieve under same conditions.

2.3.2. Transesesterification Process and Fuel Characterization

Lin et al. [23] have investigated the optimal reaction conditions of biodiesel production by RBO transesterification and proves the feasibility of RBO diesel to be used in current diesel engines and contributes to the development of this renewable energy source. The best combination of alkali-catalyzed esterification condition is: 6:1 methanol /oil molar ratio; 0.9 % w/w of KOH related to the quantity of starting oil; 60 °C reaction temperature and 60 min reaction time. The maximum conversion efficiency was 98.7% under these reaction conditions. The main fuel properties of RBO biodiesel agreed well within the parameters imposed according to the specifications of the ASTM D6751-02 and DIN V51606 standards for biodiesel.

Sinha et al. [24] have investigated the transesterification process for production of rice bran oil methyl ester. The various process variables like temperature, catalyst concentration, amount of methanol and reaction time were optimized with the objective of producing high quality rice bran oil biodiesel with maximum yield. The optimum conditions for transesterification of rice bran oil with methanol and NaOH as catalyst were found to be 55 °C reaction temperature, 1hour reaction time, 9:1 molar ratio of rice bran oil to methanol 0.75% catalyst (w/w). Rice bran oil methyl ester thus produced was characterized to find its suitability to be used as a fuel in engines. The properties of ROME are almost similar to other biodiesel except that ROME has a higher calorific value and cetane number. The viscosity of rice bran oil reduces substantially after transesterification and becomes comparable to that of diesel. The density, flash point and cloud and pour point s for ROME were higher than those of mineral diesel.

Eevera et al. [25] have tested both edible (coconut oil, palm oil, groundnut oil, and rice bran oil), and non-edible oils (pongamia, neem, and cottonseed oil) were used to optimize the biodiesel production process variables like catalyst concentration, amount of methanol required for reaction, reaction time and reaction temperature. The fuel properties like specific gravity, moisture content, refractive index, acid value, iodine number, saponification value and peroxide value were estimated. Based on CN and IV, the palm and coconut oil based methyl esters are not suitable to use as a biodiesel in cold weather conditions. In hot climate conditions, however, all the methyl esters produced in this experiment including coconut and palm oil based esters are suitable to use as a fuel.

Santos et al. [26] have studied triglyceride (TC) oil which is obtained from the kernels with good yield (49%), allowing the possibility of economical exploitation, and its fatty acid composition is comparable to that of some conventional oils. The crude oil was transesterified using conventional catalysts and methanol to form biodiesel. Based on the results obtained in this study regarding fuel properties of TC oil methyl esters. It is concluded that this material may be used as a separate fuel (B100) or as a mixture. Selected fuel properties of the biodiesel, obtained from methanolysis of TC oil, were determined in agreement with standard methods and presented in comparison to biodiesel produced from soybean oil and palm oil. They lie in the ASTM D 6751 and EN 14214 specification.

Radwan et al. [27] have investigated esterification method which is used to produce JME from raw jojoba oil. This method is optimized to produce the highest amount of fuel using a minimum amount of methyl alcohol. The chemical and physical properties were determined such as 0.25 JME and 0.10 JME. The 0.25 JME fuel gave highest cetane number with lower yield ratio and 0.1 JME fuel gave lowest cetane number with highest yield ratio.

Canoira et al [28] have summarized a process to convert the jojoba oil-wax to biodiesel by transesterification with methanol, catalyzed with sodium methoxide. The transesterification reaction has been carried out in an autoclave at 60 ^{o}C. With a molar ratio methanol/oil 7.5:1, and vigorous stirring (600 rpm) reaching a quantitative conversion of the oil after 4hr. A preliminary evaluation of some properties of JME as a diesel fuel (viscosity, density, cold filter plugging point and high C.V. is also reported.

Lang et al. [29] have synthesized canola methyl ester (CME), rapeseed methyl ester (RME), linseed methyl ester (LME) and sunflower methyl ester (SME) in a batch type reactor using both potassium hydroxide and sodium hydroxide as catalysts and maintaining molar ratio of 6:1. It has been reported that in a commonly used single stage process, a period of 1 hr is required to achieve 98% conversion of rapeseed oil to rapeseed methyl ester.

Lang et al. [30] have prepared biodiesel from peanut by transesterification of the crude oil with methanol (6:1) in the presence of NaOH (0.5%) as a catalyst at 60 ^oC. The maximum oil to ester conversion was 89%. The viscosity of biodiesel oil is nearer to that of petroleum diesel and the calorific value is about 6% less than that of diesel. Peanut seed oil have about 8.3% less heating value than that of diesel oil due to the oxygen content in their molecules. The important properties of peanut oil and its methyl ester such as density, kinematic viscosity, flash point, iodine number, neutralization number, pour point, cloud point, cetane number are found out and compared to that of ASTM and EN biodiesel standards. Comparison shows that the methyl ester has relatively closer fuel properties to diesel than that of raw peanut seed oil.

Saydut et al. [31] have investigated sesame seed oil as an alternative feedstock for the production of a biodiesel fuel. Biodiesel was prepared from sesame seed by transesterification of the crude oil with methanol in the presence of NaOH as catalyst. Properties of sesame seed oil and biodiesel produced by transesterification were within the limits of ASTM and EN standards. Sesame seed oil have about 7.5% less heating value than that of diesel oil due to the oxygen content in their molecules. Viscosity and density of methyl esters of sesame seed oil are found to be very close to that of diesel. The calorific value of biodiesel is found to be slightly lower than that of diesel.

Mohamad et al. [32] have investigated the aspects of catalyst concentration, catalyst type and excess alcohol and their effect on conversion efficiency. The intention was to optimize the yield in terms of these fundamental process variables. Highest catalyst concentration produced biodiesel with lower specific gravity in a much shorter time than lower concentrations when excess alcohol is in the range of 100%.

Allen et al. [33] have presented a method, which has been verified experimentally and predicted the viscosities of biodiesel fuels from the knowledge of the fatty acid composition. The viscosity of biodiesel fuels reduce considerably with increase in unsaturation.

Ramadhas et al. [34] have reviewed the production and characterization of vegetable oil as well as the experimental work carried out in various countries in this field. This paper gives a comprehensive review of the methods used for producing biodiesel, experimental investigation on different oils, characterization, merits, demerits and challenges faced by biodiesel are described.

Demirbas et al. [35] have reviewed the production and characterization of biodiesel as well as the experimental work carried out by many researchers in this field. There are more than 350 oil bearing crops identified, among which only sunflower, safflower, soybean, cottonseed, rapeseed and peanut oils are considered as potential alternative fuels for diesel engines. The most important variables affecting the methyl ester yield during the transesterification reaction are molar ratio of alcohol to vegetable oil and reaction temperature. The commonly accepted molar ratios of alcohol to glycerides are 6:1-30:1.

2.3.3. Transesesterification Process, Fuel Characterization, Engine Performance and Exhaust Emission Analysis

Kalbande et al. [36] have studied biodiesel production from non-edible oils by using biodiesel processor and evaluated fuel properties of biodiesel such as kinematic viscosity and specific gravity. These are to be within limit of BIS standard. The important factor that affects the transeserification reaction is the amount of methanol and sodium or potassium hydroxide, reaction temperature and reaction time. A molar ratio of 6:1 is normally used in industrial processes to obtain methyl ester yields higher than 98% by weight, because lower molar ratio required more reaction time.

Bora et al. [37] have analyzed performance and emission characteristics of single cylinder diesel engine using Karabi seed biodiesel and its blends with diesel. BSFC increased and BTE decreased with increase in proportion of biodiesel in blends. Smoke level, unburned hydrocarbons and carbon monoxide in exhaust emissions reduced, whereas NOx increased with increase in percentage of Karabi biodiesel in blends.

Stalin et al. [38] have prepared Karanja biodiesel by alkali catalyzed transesterification process. Performance of IC engine using Karanja biodiesel blending with diesel and with various blending ratios has been evaluated. Brake power, brake specific fuel consumption and brake thermal efficiency are calculated. As the load increases, brake thermal efficiency increases upto 70% load and then decreases for all the fuel samples tested. The low brake thermal efficiency for B60, B80 and B100 may be due to the lower HHV and the increase in fuel consumption.

Kandasamy et al. [39] have discussed the performance characteristics of a single cylinder diesel engine using rice bran and pungam oil blended with diesel fuel. Experiments are carried out for the various blends i.e. B20, B40, B60, B80 and the results were compared with the neat diesel. They have reported that preheating ensures the enhancement of combustion efficiency and the overall performance of the engine. The temperature is varied from 27^{o}C to 80 ^{o}C. Continuous heating is required in order to reduce the viscosity of the blended oil so that the engine performance will improve. Performance of the engine is found to be good for the B40 blend. However, the overall performance of the engine is found to be good when the oil and diesel blend is supplied to the cylinder after preheating.

Balusamy et al. [40] have investigated methyl ester of Thevetia peruviana seed oil (TPSO) and blended with diesel fuel, has been tested in naturally aspirated single cylinder diesel engine at rated speed of 1500 rpm. Brake thermal efficiency increases with increasing brake power for all fuels. At maximum load, BSFC of B20 (3.4%) and B100 (10.3%) are higher than that of diesel due to higher density and viscosity of the fuel blends. Mechanical efficiency increases with increasing brake power for all fuels. The performance and emission parameters like brake thermal efficiency, brake specific fuel consumption, CO, HC, NOx, CO_2, O_2, smoke and exhaust gas temperature are measured, analyzed, and compared with that of diesel. Engine performance with TPSO has been found comparable to that of diesel and CO, HC emissions are less but NOx and smoke are slightly higher than that of diesel.

Yamin et al. [41] have attempted a comparative study on the use of new as well as waste oil as source for biodiesel fuel for C.I. engine. The engine performance and emission characteristics are studied and compared with pure diesel fuel. It can be observed that there is loss in the fuel calorific value of about 13.43% for waste oil biodiesel and 7.24% for unused oil biodiesel. Further, the density of the fuel was found to increase by about 4.75% w.r.t. pure reference fuel. Regarding performance, biodiesel showed improvement in the torque, power and thermal efficiency and reduction in the specific fuel consumption. This was achieved both as full and low load. Regarding the emission characteristics of the normal diesel caused a higher burning gas temperature in the engine cylinder and consequently lowered the CO emissions compared to biodiesel.

Boppana et al. [42] have investigated Mahua oil ethyl ester which was prepared by transesterifiction using sulphuric acid as catalyst and tested in a 4-stroke direct injection natural aspirated diesel engine. Tests were carried out at constant speed of 1500 rev/min at different brake mean effective pressures. The comparison of MOEE with diesel in terms of engine performance and emission shows better results. The MOEE is found to burn more efficiently than diesel. The emission of carbon monoxide, hydrocarbon, oxides of nitrogen and smoke were decreased by 58%, 63%, 12% and 70% respectively.

Vedaraman et al. [43] have discussed about Mahua oil which is transesterified with methanol using sodium hydroxide as catalyst to obtain mahua oil methyl ester. This biodiesel is tested in a single cylinder, four stroke, direct injection, constant speed, compression ignition diesel engine to evaluate the performance and emissions. In this present study Mahua oil was transeseterified using 6:1 molar ratio of methanol to oil to obtain methyl ester of low viscosity (5.2cSt) and good conversion (92%. MOME possess lower calorific value around 12% compared to diesel. The cetane number is slightly higher by (10%) which is favorable for combustion. Flash and fire points are high which is higher than diesel, which create problem in low temperature regions. The performance of diesel engine with biodiesel does not vary much. The specific fuel consumption is higher (20%) than that of diesel and thermal efficiency is lower (13%) than that of diesel. Exhaust pollutant emission are reduced compared to diesel. Carbon monoxide, hydrocarbon, smoke number, oxides of nitrogen were reduced by 30%, 35%, 11%, 4%, respectively, as compared to diesel.

Altiparmak et al. [44] have experimentally measured that tall oil methyl ester-diesel fuel blends as alternative fuels for diesel engines. The blends of tall oil methyl ester –diesel fuel were tested in a direct injection diesel engine at full load condition. Fuel blends of TOME on the engine performance and exhaust emission were studied. It was observed that the engine torque and power output with tall oil methyl ester-diesel fuel blends increased up to 6.1% and 5.9% respectively. It was also seen that CO emissions decreased to 38.9% and NOx emissions increased up to 30% with the new fuel blends. The smoke opacity did not vary significantly.

Rao et al. [45] have carried out transesterification process of used cooking oil using an alkaline catalyst. The combustion, performance and emission characteristics of used cooking oil methyl and its blends with diesel oil are analyzed in a direct injection C. I. engine and compared with the baseline diesel fuel. Performance and emission results have shown that the SFC increases with increase in percentage of UCME in the blend due to the lower C.V. of UCME. The brake thermal efficiency decreases with increase in percentage of UCME in the fuel Increase in oxygen content in the UCME-diesel blends as compared to diesel results in better combustion chamber temperature. This leads to increase in NOx. UCME recorded higher values of NOx compared to diesel at rated load. Emissions of CO and HC decrease with increase in percentage of USME in the blend. It is also observed that there is a significant reduction in smoke intensity especially at higher loads even with 20% UCME.

2.3.4. Transesesterification Process, Fuel Characterization, Engine Performance, Exhaust Emission Analysis and Economic Analysis of Biodiesel

Gumus et al. [46] have presented that the cost analysis of hazelnut oil methyl ester production. In this paper hazelnut kernel oil of Turkish origin was evaluated as alternative fuel in a diesel engine. Hazelnut kernel oil was transesterified with methanol using potassium hydroxide as catalyst to obtain hazelnut kernel oil methyl ester and comprehensive experimental investigation was carried out to examine performance and emission of a direct injection diesel engine running with hazelnut kernel oil methyl ester and its blends with diesel fuel. Results showed that hazelnut kernel oil methyl ester and its blends with diesel fuel are generally comparable to diesel fuel. It is also expected that the price of hazelnut kernel oil methyl ester will be lower than the price of conventional diesel fuel in the near future due to the linear increase in the price of conventional diesel fuel. The cost analysis of hazelnut oil methyl ester undertaken in this study includes only costs of hazelnut kernel oil, methanol, catalyst, and sulfuric acid. Costs of some factors such as operating, electricity and water were neglected. Glycerol which yields a biodiesel production was not considered in the cost analysis.

Sharma et al. [47] have examined that the various factors contributing to the cost of biodiesel include raw material, other reactants, nature of purification, its storage, etc. However, the major factor which contributes the cost of biodiesel production is the feedstock, which is about 80% of the total operating cost. The cost of biodiesel depends on raw material (vegetable oil, methanol and catalyst), electricity and labour work**.** In Indian context, the government has fixed the price of biodiesel delivered at refinery field, In order to encourage biodiesel application in refinery field, An Indian government has provided subsidies to reduce the price of biodiesel. This paper describes the latest development of biodiesel of various edible and non-edible oil. They evaluated the performance and emission characteristics. In addition, the cost analysis of different biodiesel in different countries are also found out.

2.3.5. Transesesterification Process, Fuel Characterization and Economic Analysis of Biodiesel

Barnwal et al. [48] have reviewed the possibilities of using neat vegetable oils and biodiesel, the processes available, fuel characteristics, performance analysis and economic analysis of biodiesel production. The economic feasibility study shows that the biodiesel obtained from non-edible oils is cheaper than that from edible oils.

2.3.6. Fuel Characterization, Engine Performance, Exhaust Emission Analysis and Economic Analysis of Biodiesel

Agarwal et al. [49] have studied the economic analysis of biodiesel and it is found that use of vegetable oil and its derivative as diesel fuel substitutes has almost similar cost as that of mineral diesel. It investigates the performance and emission characteristics of linseed oil, mahua oil, rice bran oil and linseed oil methyl ester in a stationary single cylinder, four stroke diesel engine and compared it with mineral diesel. The performance and emission parameter for different fuel blends were found to be very close to diesel. Smoke density and BSFC were slightly higher for vegetable oil blends compared to diesel. However, BSEC for all oil blends was found to be lower than diesel. Vegetable oil blends showed performance characteristics close to diesel. Economic analysis was also conducted to find out the cost for different vegetable oils, biodiesel and mineral diesel. It shows that cost per unit energy produced is almost for all fuels.

2.3.7. Economic Analysis of Biodiesel

Dorado et al. [50] have evaluated the economic aspects involved in the production of a low cost transesterification process to produce biodiesel from waste olive and Ethiopian mustard oil. Final cost of both biodiesels, including seed cost, oil extraction, processing, and distribution were compared with the cost of mineral diesel fuel. It has identified that the price of the feedstock is one of the most significant factors. Also, glycerol is found to be a valuable by product that could reduce the final manufacturing costs of the process up to 6.5% depending on the raw feedstock used. Biodiesel can only compete with diesel fuel prices.

2.3.8. Fuel Characterization, Engine Performance and Exhaust Emission Analysis

Verma et al. [51] have studied that the esters of four plant oils, viz., linseed, jatropha, sunflower and rice bran. It was observed that methyl esters exhibited lower values of viscosity, flash point and density as compared to their un-etherified plant oils in all cases. However, no significant variation was noticed in the gross heat values of these oils.

Albuquerque et al. [52] have evaluated that the properties of biodiesel oils obtained from different biomass sources (castor, soybean, cotton, and canola) and their blends (20%, 40%, 60%, 80% and 100%). It has been observed that the biodiesel obtained from castor oil presents problems for specific gravity and viscosity specification within the European limits. Blends of castor biodiesel oil with the other biodiesel oils can improve these properties in order to comply with the European specification.

Erdogan et al. [53] have examined that the feasibility and the effect of corn oil used as fuel on the performance of a small diesel engine (naturally aspirated air cooled and with continuous rating of 5.5kW at 3400 rpm was selected as the test engine). To evaluate the performance of a blend of 50% corn oil and diesel fuel and neat corn oil as fuel at room temperature and compared with diesel fuel. To evaluate the performance of neat corn oil at high temperature (50^0 C and 90^0 C) and to compare the results with diesel fuel. The engine performance of these fuels was comparable to diesel fuel.

Pramanik et al. [54] have investigated to reduce the viscosity of Jatropha curcas oil close to that of conventional fuel to make it suitable for use in a C.I. engine and evaluated the performance of the engine with the modified oils. The viscosity of the blends containing 70% and 60% vegetable oil came close to that of diesel in the temperature ranges of 70-75^0 C and 60-65^0 C respectively. The corresponding temperatures were found to be 55-69 and 45^0 C for 50 and 40% blends, whereas only at 35-40^0 C did the viscosity of 30:70 J/D blend became close to the specification range. Acceptable brake thermal efficiencies and SFCS were achieved with the blends containing up to 50% jatropha oil.

Ramadhas et al. [55] have analyzed the suitability of rubber seed oil as an alternative for the diesel fuel in C.I. engine. Significant reduction in viscosity of rubber seed oil is achieved by simply diluting with diesel in varying proportions. Engine performance and emission tests were conducted with rubber seed oil-diesel blends in a C.I. engine. From the experimental results obtained, rubber seed oil is found to be a promising alternative fuel and does not need any major modification in the structure of the engine.

Hebbal et al. [56] have experimentally carried out the suitability of Deccan hemp oil as an alternative fuel in a single cylinder DI diesel engine. The properties such as density, viscosity, flash point and fire point of deccan hemp oil is higher and calorific value is 0.92 times that of diesel. The blend containing 75% of diesel has viscosity 7.658cSt, which is very close to viscosity of diesel at 30^0 C and does not require any heating prior to injection into combustion chamber.

Blends containing 50%, 25%, and 0% diesel require preheating up to 70^0 C, 80^0 C and 95^0 C respectively. Performance and emission characteristics of 50% blend are better than the other blends. The viscosity of Deccan hemp oil is reduced first by blending with diesel on volume basis, then analyzed and compared with diesel. Further blends are heated and effect of viscosity on temperature was studied. The performance and emission characteristics of blends were evaluated at variable loads and at constant rated speed of 1500rpm and results were compared with diesel. The thermal efficiency, brake specific fuel consumption and brake specific energy consumption are well comparable with diesel and emissions are a little higher for 23% and 50% blends. 25% of blend of Deccan hemp oil without heating and up to 50% blend with preheating can be substituted for diesel engine without any engine modification.

2.3.9. Engine Performance and Exhaust Emission Analysis

Altun et al. [57] have studied that the sesame oil and diesel fuel mixture as a fuel in a direct injection diesel engine and determined engine performance and exhaust emissions characteristics. The sesame oil is blended with diesel fuel at 50% ratio on volume basis in order to reduce the high viscosity of sesame oil. The experimental results show that the engine power and torque of the mixture of sesame oil-diesel fuel are close to the values obtained from diesel fuel and the amounts of exhaust emissions are lower than those of diesel fuel.

Purushothaman et al. [58] have evaluated the performance, emission and combustion characteristics of a single cylinder, constant speed, direct injection diesel engine using orange oil as an alternative fuel. The results are compared with the standard diesel fuel operation. The results indicated that the brake thermal efficiency was higher compared to diesel. CO and HC emissions were lower and oxides of nitrogen were higher compared to diesel operation. The smoke emissions are reduced marginally for orange oil than the diesel fuel.

Balasubbramanian et al. [59] have investigated a high linolenic linseed oil methyl ester in a constant speed, DI diesel engine with varied fuel injection pressures (200 bar, 220 bar and 240 bar). The main objective of this study is to investigate the effect of injection pressures on performance, emissions and combustion characteristics of engine. At 240 bar, thermal efficiency is similar to diesel and a reduction in CO, UHC and smoke emissions with an increase in the oxides of nitrogen was noticed compared to diesel.

Banapurmath et al. [60] have experimental investigations carried out on a single cylinder, four stroke, direct injection, CI engine operated with methyl esters of Honge oil, Jatropha oil and

Sesame oil. Engine performance in terms of higher brake thermal efficiency and lower emissions (HC, CO and NOx) with sesame oil methyl ester operation was observed compared to methyl esters of Honge and Jatropha oil operation.

Sureshkumar et al. [61] have examined that the results of performance and emission in an unmodified diesel engine fueled with Pongamia pinnata methyl ester and its blends with diesel. The experiments are conducted in a diesel engine coupled with an exhaust gas analyzer to study the performance characteristics and the extent to which the PPME could replace petrodiesel. It is used to analyze the usability of PPME as a unmodified CI engine. It was found that blends of PPME and diesel could be successfully used with acceptable performance and better emission than pure diesel up to a certain extent.

Baiju et al. [62] have investigated the scope of utilizing BD developed from both through the methyl as well as ethyl alcohol route (methyl and ethyl ester) from karanja oil as an alternative diesel fuel. In the present work, methyl and ethyl esters of karanja oil were prepared by transesterification using both methanol and ethanol. The physical and chemical properties of ethyl esters were comparable with that of methyl esters. Performance and exhaust emission characteristics of the engine were determined using petrodiesel as the baseline fuel and several blends of diesel and BD as test fuels.

Ramdhas et al. [63] have concluded that the rubber seed oil, a non-edible type vegetable oil is chosen as a potential alternative for producing biodiesel and use as fuel in C. I. engines. The important properties of biodiesel produced from rubber seed oil are quite close to that of diesel. Hence the methyl esters of rubber seed oil can be a prospective fuel or performance improving additive in C.I. engines. The various blends of biodiesl-diesel are used as fuel in C. I. engines and its performance emission characteristics are analyzed. The lower concentration of biodiesl blends found to improve the thermal efficiency. Higher the concentration of biodiesel blend higher is the reduction of smoke density in exhaust gas.

Herchel et al. [64] have described that the effect of pure coconut oil and coconut oil-diesel fuel blends on the performance and emissions of a direct injection diesel engine. A 412cc single cylinder direct injection diesel was used. Increasing the amount of coconut oil in the fuel blend decreases the BMEP, and increases the BSFC. This is attributed to the lower heating value of the coconut oil. Coconut oil engine operation resulted in better emissions, lower smoke and lower NOx emissions compared with standard diesel fuel.

Keskin et al. [65] have showed that the cotton oil biodiesel-diesel fuel blends in a single cylinder direct injection diesel engine. Power output and toque of engine with blends of cotton soapstock biodiesel and diesel fuel decreased by 6.2% and 5.8% respectively. Specific fuel consumption value with fuel blend increased by 10.5%, depending on the amount of biodiesel and engine speeds. The lowest percent heat losses to exhaust were obtained with blend of B20. However, percent heat loss from exhaust of B40 and B60 are similar with values of diesel fuel.

Nabi et al. [66] have studied the combustion and exhaust emissions with neat diesel fuel and diesel-biodiesel blends. The study consists of two phases, In the first phase of this study, preparing of biodiesel was done and in the next phase, combustion and exhaust emissions were investigated with typical diesel fuel and the blends of diesel and esterified oil. Methyl ester of non-edible neem oil was prepared with lye catalyst and methanol. The smoke and CO were reduced while NOx emission was increased with diesel-NOME blends when compared with diesel fuel.

Pugazhvadivu et al. [67] have experimentally presented that the waste frying oil a non-edible vegetable oil was used as an alternative fuel for diesel engine. The high viscosity of the waste frying oil was reduced by preheating. The properties of waste frying oil such as viscosity, density, calorific value and flash point were determined. The effect of temperature on the viscosity of waste frying oil was evaluated. It was determined that the waste frying oil requires heating temperatures of 135^0 C to bring down its viscosity to that of diesel at 30^0 C. The performance and exhaust emissions of a single cylinder diesel engine was evaluated using diesel, waste frying oil (without preheating) and waste frying oil preheated to two different inlet temperatures (75^0 C and 135^0 C).

Sahoo et al. [68] have investigated the biodiesel development from polanga seed oil through transesterification process and were tested for their use as a substitute fuel of diesel in a single cylinder diesel engine. HSD (high speed diesel) and polanga oil methyl ester, fuel blends (20, 40, 60, 80 and 100%) were used for conducting short-term engine performance tests at varying loads (0, 20, 40, 60, 80 and 100%). Tests were carried out over entire range of engine operation at varying conditions of speed and load. The BSFC and BTE were calculated from the recorded data. The engine performance parameters such as fuel consumption, thermal efficiency, exhaust gas temperature and exhaust emissions (CO, CO_2, NOx and O_2) were recorded. From emission point of view the neat POME was found to be the best fuel as it showed lesser exhaust emission as compared to HSD.

Wang et al. [69] have experimentally evaluated that the performance and gaseous emission characteristics of a diesel engine when fuelled with vegetable oil and its blends of 25%, 50% and 75% of vegetable oil with ordinary diesel fuel separately having constant speed 1500rpm. The experimental results show that the basic engine performance power output and fuel consumption are comparable to diesel when fueled with vegetable oil and its blends. The emission of nitrogen oxides from vegetable oil and its blends are lower than that of pure diesel fuel. The CO emissions from the vegetable oil and its blends are lower than that of the diesel fuel at the engine full load and HC emissions of vegetable oil and its blends are lower than that of diesel fuel.

Singh et al. [70] have investigated the emission characteristics of methyl ester of rice bran oil and their blends with diesel. The emission characteristics of methyl ester of refined rice bran oil-diesel blend mixed in proportion of 10:90, 20:80, 30:70, 50:50 and 10:0 (V/V) were studied. The emission of CO, UHC, nitric oxide and nitrogen dioxide by different fuels at various load on 3.73 kW CI engine were compared with respect to diesel. The emission of CO from the engine was found to be lower on all the blends of methyl ester of rice bran oil-diesel compared to diesel at rated load. The emission of UHC from engine at higher loads was found to be more and fuel blend as compared to diesel.

Shaheed et al. [71] have studied that the possible use of coconut oil based fuels that can be produced in the Maldives and can be used as a substitute for diesel fuel. The combustion data of coconut oil, coconut oil methyl esters and diesel fuel were compared using a naturally aspirated single cylinder four stroke diesel engine. Fuel conversion efficiency for COME fuel was better than COIL. The high viscosity of the coconut oil together with its long molecular chain could be the cause of inadequate combustion, leading to increased CO, HC and smoke.

Sundervapandian et al. [72] have evaluated the performance characteristics, combustion parameters and emissions of vegetable oil esters like Jatropha, Mahua and Neem oil esters. The predicted results of these fuels are compared with experimental result of diesel fuel. The brake thermal efficiency is reduced about 3% for jatropha, 4% for mahua and 5% for neem oil ester. The brake specific fuel consumption is increased about 8% for jatropha oil ester whereas for mahua and neem oil ester is increased about 11% to 13%. The brake power is reduced about 7% for jatropha, 9% for mahua and 12% for neem oil ester. The carbon monoxide is reduced about 19% for jatropha whereas foe mahua and neem oil ester it is reduced about 16%. The concentration of hydrogen is decreased about 18% for jatropha oil ester 16% for mahua oil ester and 15% for neem oil ester. The formation of nitric oxides is decreased about 1.8% for jatropha oil ester, 2.5% for mahua oil ester and 3% for neem oil ester. The smoke level is decreased about 12% for jatropha oil ester 11% for mahua oil ester and 10% for neem oil ester.

Bari et al. [73] have quantified the effects of fuel inlet temperature on the injection system. To find a suitable temperature to heat CPO lower its viscosity for use in diesel engines. To compare the performance, combustion characteristics and emission of CPO with those of diesel. This study focused on finding out the effects of preheating of fuel on the injection system utilizing a modified method of friction test, which involves injecting fuel outside the combustion chamber during motoring. Results show that preheating of CPO lowered CPO's viscosity and provided smooth fuel flow, but did not affect the injection system, even heating up to 100^0C.

Gopalkrishnan et al. [74] have reported that the performance of some vegetable oils and methyl esters of some vegetable oils. The vegetable oils tested were karanji oil (Pongamia glabra), rice bran oil and palm oil on a single cylinder diesel engine. In the second phase tests were conducted with methyl esters of karanji oil, soybean oil, sunflower oil, rapeseed oil and neem oil. The results of the tests are discussed with reference to the thermal efficiency, combustion parameters like delay period, combustion duration and peak pressure and smoke emission.

Altin et al. [75] have studied that the effects of vegetable oil fuels and their methyl esters (raw sunflower oil, raw cottonseed oil, raw soybean oil and their methyl esters, refined corn oil, distilled opium poppy oil and refined rapeseed oil) on a direct injected, four stroke, single cylinder diesel engine performance and exhaust emissions. The performance and exhaust emissions of a diesel using 100% refined vegetable oil and their methyl esters. Because of its high viscosity vegetable oils were heated before the fuel pump and before the injectors to minimize its resistance to flow. The higher specific fuel consumption values in the case of vegetable oils are due to their lower energy content. NO_2 emissions with vegetable oil fuels were lower than those with diesel fuel.

Agarwal et al. [76] have reviewed that the production, characterization and current status of vegetable oil and biodiesel as well as the experimental research work carried out in various countries. This paper touches greenhouse gas emissions, fuel versatility, infrastructure, availability, economics, engine performance and emissions effect on wear and lubricating oil etc. This review focuses on performance and emission of biodiesel in C.I. engines, combustion analysis, wear performance on long term engine usage and economic feasibility. Economic feasibility of biodiesel depends on the price of the crude petroleum and the cost of transporting diesel long distances to remote markets. The cost of biodiesel can be reduced if we consider non-edible oils and used frying oils instead of edible oils. Non-edible oils such as mahua, karanja, babassu, jatropha, and neem etc. are easily available in many parts of the world and are cheaper compared to edible oils. Twelve economic feasibilities have been studied. A 20% blend of biodiesel with mineral diesel improved the cetane number of diesel. The C.C. of biodiesel was found to be slightly lower than mineral diesel.

Nabi et al. [77] have studied different parameters for the optimization of cottonseed biodiesel production in the first phase of this study, while in the next phase of the study performance test of a diesel engine with neat diesel fuel and cottonseed biodiesel mixtures. The transesterification results showed that with the variation of catalyst, methanol or ethanol, variation of biodiesel production was realized. A maximum of 77% biodiesel was produced with 20% methanol in the presence of 0.5% sodium hydroxide. Biodiesel mixtures showed less CO, PMs, smoke emissions than those of neat diesel fuel. NOx emission with biodiesel mixtures showed higher values when compared with neat diesel fuel. Compared to the neat diesel fuel, 10% biodiesel mixtures reduced PM, smoke emissions by 24% and 14% respectively. Biodiesel mixtures (30%) reduced CO emissions by 24%, while 10% increase in the NOx emission was experienced with the same blend.

Karabektas et al. [78] have investigated performance parameters and exhaust emissions of a diesel engine fuelled with diesel fuel and a biodiesel, namely cottonseed oil methyl ester, subjected to preheating at different temperatures in order to lower its viscosity. The cottonseed oil methyl ester was produced by means of transesterification process using cottonseed oil, which can be described as biomass based, and renewable energy source and also determined fuel properties of cottonseed oil methyl ester. A higher brake thermal efficiency was determined with the preheated COME mainly due to its lower heating value and improved combustion compared to diesel fuel. Particularly, COME90 and COME 120 yielded with a high improvement in the brake thermal efficiency. The use of preheated COME usually yielded a significant decrease in CO emissions, while NOx emissions were increased due to higher combustion temperatures caused by preheating and oxygen content of COME. The COME90 is found to be the moderate fuel among other preheated COMEs with reference to diesel fuel.

Qi et al. [79] have characterized the effect of biodiesel produced from soybean crude oil on the combustion characteristics, performance and exhaust emissions of a diesel engine. The properties, performance, emissions and combustion characteristics of the engine fueled with biodiesel and diesel were compared. The power output for biodiesel is almost the same as that for diesel under speed characteristics at full load. The BSFC for biodiesel is higher than that for diesel. The higher fuel consumption reflects its lower heating value. Both fuels give nearly identical BSEC. The emission of carbon monoxide, hydrocarbon, nitrogen oxides and smoke are averagely decreased by 27, 27, 5, and 52% respectively under speed characteristic at full load.

Nwafor et al. [80] have evaluated the potential of rapeseed methyl ester as a liquid fuel for diesel engines in relation to meeting emission requirements. The emissions of hydrocarbon were significantly reduced compared to test results on baseline diesel fuel. There was no marked difference in the emissions of carbon monoxide though a little higher carbon dioxide emissions were recorded when running on RME and blends. The fuel consumption of RME is a little higher than diesel fuel operation. The trends showed an increased in fuel consumption proportional to the amount of RME added in the blend. The exhaust temperatures for both diesel fuel and RME were similar.

Usta et al. [81] have examined the effects of tobacco seed oil methyl ester addition to diesel No.2 on the performance and emissions of a four cycle, four cylinder turbocharged indirect injection diesel engine at both full and partial loads. The addition of TOSOME decreased CO emission due to the fact that TOSOME contains about 11.4% oxygen by weight, and this oxygen helps to oxidize the combustion products in the cylinder. The NOx emission slightly increased due to higher combustion temperature and the presence of fuel oxygen with blend at full load. However, the increasing amount of NOx emission slowed down with decreasing load.

Usta et al. [82] have performed detailed experimental study on the performance and exhaust emissions of a turbocharged indirect injection diesel engine fuelled with tobacco seed oil methyl ester at full and partial loads. The result showed that the addition of tobacco seed oil methyl ester to the diesel fuel reduced CO and SO_2 emissions while causing slightly higher NOx emissions. Meanwhile, it was found that the power and the efficiency increased slightly with the addition of tobacco seed oil methyl ester.

Murugan et al. [83] have studied the performance, emission and combustion characteristics of a single cylinder air cooled DI diesel engine fueled with low and high concentration distilled tyre pyrolysis oil-diesel fuel (DTPO-DF) blends and compared with DF operation. It observed that the engine is able to run up to 90% DTPO and 10% DF (DTPO90). The brake thermal efficiency increase with increase in percentage of DTPO blends but lesser than DF. About 1-2% drop in the thermal efficiency is noticed for DTPO20 and DTPO90 operations compared to DF. NOx is lowered by about 22% and 18% in DTPO20 and DTPO90 respectively than that of DF operation.

HC emission is higher by about 7% and 11% for DTPO20 and DTPO90, respectively at full load than that of DF operation. Smoke is higher for compared to DF.

Kandukalpatti et al. [84] have conducted rice bran oil methyl ester (RBOME) in Kirloskar four stroke, single cylinder, water cooled, direct injection IC engine at 1500 rpm. RBOME showed 15% increase in SFC, 25% in BTE, less EGT, 12% FC, more indicated thermal efficiency and mechanical efficiency, 60% reduction in HC, more than 75% reduction in CO, minimum of 10% reduction in NOx. The combustion of RBOME and its blends are found to be lesser pollutants than compared to diesel.

Kumar et al. [85] have tested rice bran biodiesel in single cylinder, direct injection diesel engine to evaluate performance and emission results and compared with diesel fuel. The power developed from the engine with biodiesel as a fuel was 4% lower as compared to diesel, because of lower heating value of biodiesel. BSFC and BSEC were also higher due to same reason. BTE was higher in diesel as compared to biodiesel. Smoke opacity was lesser of biodiesel than diesel making it more environmental friendly fuel.

Hazar et al. [86] have clarified the effect of preheating of raw rapeseed oil-diesel (RRO) fuel blends on the engine performance and emission characteristics of CI engine. The highest value of decreased BSFC was observed with the use of RRO50 blend. The exhaust gas temperature for RRO50 is fairly higher when compared with RRO20 and diesel fuel. The NOx emission lowers when RRO blends are used. The CO emission decreased for all tested fuels with preheating due to the improvement in spray characteristics and better air-fuel mixing. Smoke density for all test fuels decrease with preheating. It can be concluded that preheating test fuel slightly affects engine performance while it significantly reduces exhaust emissions when operating with vegetable oil.

Agarwal et al. [87] have conducted using various blends of Jatropha oil with mineral diesel in single cylinder, four stroke, water cooled, direct injection diesel engine at different loads and constant speed (1500 rpm) to study performance and emission characteristics. BSFC and exhaust gas temperatures for unheated Jatropha oil was found to be higher compared to diesel and heated jatropha oil compared to heated jatropha oil and diesel. The emissions such as CO_2, CO, HC, and smoke opacity were higher for jatropha oil compared to that of diesel. These emissions were found to be close to diesel for preheated jatropha oil. For blends, BSFC and EGT were found higher compared to diesel. Thermal efficiency was also found to be close to diesel for jatropha oil blends. Emission parameters such as smoke opacity, CO_2, CO, and HC were found to have increased with increasing proportion of jatropha oil in the blends compared to diesel.

Agarwal et al. [88] have analyzed the performance and emission characteristics of a CI engine fuelled with Karanja oil and its blends (10%, 20%, 50% and 75%). These parameters were evaluated in a single cylinder CI engine used in agriculture sector of developing countries. Performance and emission characteristics of karanja oil and its blends were found to be comparable to that of mineral diesel. Thermal efficiency of the engine with preheated oil blends is nearly 30% and for lower blends (unheated) such as K10, K20 and K50, it was 24-27%. The BSFC and BSEC of the engine with preheated lower blends showed an improved trend. The unheated oil blends up to K50 also showed an improved trend compared to mineral diesel. The smoke density from exhaust gas of preheated lower blends as well as unheated lower blends was almost similar to that of diesel fuel. The HC emissions from unheated and preheated lower blends (K10 and K20) are lower than that of mineral diesel. The emissions of NO from all blends with and without preheating are lower than mineral diesel at all load conditions.

Oner et al. [89] have investigated the performance and emission characteristics of tallow methyl ester (B100) and its blends (5%, 20%, and 50% by volume) with petroleum diesel fuel (B5, B20, and B50) in a stationary single cylinder, four-stroke, direct injection and air-cooling diesel engine. It was observed that the addition of biodiesel to the diesel fuel decreases the thermal efficiency of engine and increase the specific fuel consumption. This is due to the lower heating value of biodiesel compared to diesel fuel. The exhaust emissions from biodiesel and its blends, at the range of tests, are lower than that of pure diesel fuel. The lowest CO, NOx emissions and the highest exhaust temperature were obtained for B20 among all other fuels.

Godiganur et al. [90] have performed the performance and emission characteristics of methyl ester of mahua oil and its blend in 6BTA 5.9 G2-1 Cummins, 158 HP rated power, turbocharged, DI, water cooled diesel engine at constant speed 1500 rpm under variable load conditions. The result indicates that with the increase of biodiesel in the blends, the CO, HC reduces significantly and fuel consumption and NOx emission of biodiesel increases slightly compared with diesel. Brake specific energy consumption decreases and thermal efficiency of engine slightly increases when operating on 20% biodiesel than that of operating diesel.

Devan et al. [91] have studied various methyl ester of paradise oil-eucalyptus blends in single cylinder, four-stroke DI diesel engine to study the performance and emission characteristics. The results show a 49% reduction in smoke, 34.5% reduction in HC emissions and a 37% reduction in CO emissions for the Me50-Eu50 blend with a 2.7% increase in NOx emission at full load. There was a 2.4% increase in BTE for the Me50-Eu50 blend at full load.

Ramesh et al. [92] have tested the performance and emission characteristics of 5.2kW diesel engine with jatropha biodiesel and its blends. In the case of jatropha biodiesel alone, the fuel consumption was about 14 percent higher than that of diesel. The percent increase in specific fuel consumption ranged from 3 to 14 for B20 to B100 fuels. The brake thermal efficiency for biodiesel and its blends was found to be slightly higher than that of diesel fuel at tested load conditions and there was no difference between the biodiesel and its blended fuel efficiencies. For jatropha biodiesel and its blended fuels, the exhaust gas temperature increased with increase in load and amount of biodiesel. The carbon monoxide reduction by biodiesel was 16, 14 and 14 percent respectively at 2, 2.5 and 3.5 kW load conditions. The carbon dioxide emission from the biodiesel-fuelled engine was slightly higher than diesel fuel as compared with diesel. The NOx emission from biodiesel was increased by 15, 18 and 19 percent higher than that of the diesel fuel at 2, 2.5 and 3.5 KW load conditions respectively.

Ghai et al. [93] have performed on 4-stroke, single cylinder, DI diesel engine using sunflower methyl ester (SFME) and its various blends (SFME25 and SFME 30) to analyzed performance and emission characteristics. It is reported that 1.5 to 4% increase in brake thermal efficiency with SFME blends. The brake power values were comparable to those obtained from pure diesel. With biodiesel blends, significant reduction in emissions of hydrocarbons as well as smoke was noticed. The NOx emissions with SFME blends were observed to be somewhat higher as compared to diesel.

Suryawanshi et al. [94] have investigated on 4-stroke, single cylinder, water cooled diesel engine having a compression ratio of 17.5:1 and developing 5.2 kW at a speed of 1500 rpm using palm oil methyl ester to evaluate performance and emission characteristics. The brake thermal efficiency is higher as compared to diesel at part and full load. The brake specific energy consumption is lower as compared to diesel at all loads. Exhaust gas temperature is higher with blends of biodiesel as diesel. There is a significant reduction in smoke emission and unburned hydrocarbon for all blends of biodiesel at part and full loads. Smoke and HC emission was further reduced with an increase in blending of POME. The increase in NOx emission is 12% for POME100 as compared to diesel at full load. This is mainly due to the higher burning rate of biodiesel and its blends, which leads to higher peak temperature and increased oxygen concentration with POME fuels.

Sudhir et al. [95] have conducted on single cylinder, four stroke, naturally aspirated, open chamber (direct injection), water cooled, 5.2 kW output computerized diesel engine using methyl esters of waste cooking oil and to investigate the emissions and performance characteristics. It is observed that the thermal performance of the WCO-biodiesel is marginally less by 1-1.85% compared to base line diesel operation.

Sharma et al. [96] have performed the performance and emission characteristics of neem-diesel blend (B20) on constant speed (1500 rpm) kirloskar engine, vertical single cylinder, four stroke, high speed , water cooled CI engine having compression ratio 16.5:1 and studied various aspects of engine performance and emission using neem-diesel blend (B20) through extensive experimentation at different injection pressure. The brake thermal efficiency at higher loads was observed to be slightly low (upto 2%) as compared to that with pure diesel. This effect was more at higher injection pressure, brake specific fuel consumption was slightly higher as compared with pure diesel and tend to increase of injection pressure through the load range. It was observed that for neem-diesel blend (B-20) optimum injection pressure was 1.57 kN/cm^2, as highest brake thermal efficiency and lowest brake specific fuel consumption was observed over the entire load range. No significant change in the volumetric efficiency was observed. The CO emission at all injection pressures with both neem-diesel blend and pure diesel tends to initially decrease with increase in load and further increases sharply near full load. The HC emission was significantly reduced with neem-diesel blend as compared to that of pure diesel.

Rao et al. [97] have explored technical feasibility of Jatropha oil in direct injection compression ignition engine without any substantial hardware modifications. In this paper, performance and emission of single cylinder water-cooled diesel engine using methyl ester of jatropha oil. Three blends were obtained by mixing diesel and esterified jatropha in the following proportions by volume: 75% Diesel +25% Esterified Jatropha, 50% Diesel +50% Esterified Jatropha and 25% Diesel +75 % Esterified Jatropha. Performance parameters like brake thermal efficiency, specific fuel consumption, brake power were determined and exhaust emissions like CO_2, CO, NOx and smoke have been evaluated. Saravanan et al [98] have investigated the feasibility of high FFA CRBO (Crude rice bran oil) as a CI engine fuel in blended form and also to analyze the effect of FFA on the performance and emission characteristics of the engine. The brake thermal efficiency for diesel is marginally higher when compared with CRBO blends at all loads. It is observed that the unburned hydrocarbon emission of CRBO blends is significantly lower than that of diesel and CRBO blends exhibit a marginally higher CO emission than that of diesel at all loads. It observed that unburned hydrocarbon emission increases as the FFA content of the blend increases and the CO emission increases with decrease in FFA content of the blend. The NOx emission of CRBO blends is lower at lighter loads and marginally higher at higher loads and it decreases with increase in FFA content of the blend. It is found that the difference in CO_2 emission between CRBO blends and diesel is marginal at all operating conditions. At higher loads a significantly higher CO_2 emission is observed for CRBO blends when compared with diesel.

Gumus et al [99] have examined the performance and emissions of a direct injection diesel engine running on hazelnut kernel oil methyl ester and its blends with diesel fuel. The performance and emission parameters of prepared neat HOME (B100) and its diesel fuel blends (B5, B20, and B50) were studied and compared to No.2 diesel fuel. HOME and its diesel fuel blends were experimentally studied in a direct injection single cylinder, four stroke engine, in terms of performance and emissions characteristics. The lower HOME content blends (B5, B20) improved BTE of the diesel engine and slightly reduced BSFC. The maximum BTE increased from 29.96% with diesel to 30.80 % with B20. Furthermore, B5 and B20 improved exhaust emissions.

Banapurmath et al. [100] have conducted four-stroke, direct injection and water cooled CI engine of Marotti oil methyl ester (MOME) and its various blends (MAR10, MAR15, and MAR20) using an injection timing of 23 before top dead centre (BTDC) and an injection timing of 205 bar at various power outputs and at a constant rated speed of 1500 rpm and evaluating performance and emission characteristics of tested fuels to check their feasibility as CI engine fuels. The brake thermal efficiency with MAR20 blend operation was closer to diesel operation followed by the MAR10 blend. The maximum brake thermal efficiency with MOME operation was 28.38% at 80% power output whereas it was 31.25% with diesel-only operation. However, the thermal efficiency with MAR20 at 80% power output was 29.9% which is close to diesel operation and this was followed in efficiency by MAR10 blend operation. It was observed that the EGT increased with an increase in brake power for all the injected fuels tested. The maximum temperature of exhaust gas at 80% power output was 434℃ with the MAR20 and 450℃ with MOME.

Venkateswara Rao et al. [101] have investigated to examine performance and emissions of different blends (B10, B20, and B40) of PME, JME, and NME in comparison to diesel. A slight drop in efficiency was found with methyl esters when compared with diesel. This drop in thermal efficiency must be attributed to the poor combustion characteristics of methyl esters due to high viscosity. It was observed that the brake thermal efficiency of B10 and B20 are very close to diesel. The pongamia methyl ester had better brake thermal efficiency than compared with the methyl esters of jatropha and neem. So B20 can be suggested as best blend for biodiesel preparation with pongamia oil. Smoke, HC, and CO emissions at different loads were found to be higher for diesel compared to B10, B20, and B40 blends. Consequently, it was found that the PME gives better performance compared to JME and NME.

2.4. Limitations from literature

Literature survey showed that the process parameter involved in transesterification is still very limited. In particular, existing transesterification process is not efficient to serve as a primary approach to the standardization and recovery of methyl esters based on raw feedstocks. To be particular many transesterification processes based on jatropha and pongamia oil, but no work has been done by transesterification of hemp and neem oil.

Even if some transesterification process has been discussed in literature for optimization of methyl esters, but the approach is entirely different from basic process of transesterification from non-edible oils. Availability of cheapest non-edible oils is expected to result in greatly increased recovery of methyl esters. A few published works on laboratory production and testing of available methyl esters have revealed promising results through series of ASTM standards fuel tests. In India, the high cost of edible oils prevents their use in biodiesel preparation but non-edible oils are affordable for biodiesel production. India has more than 100 million ha of waste lands which can be utilized for the production of hemp and neem. Non-edible oil should be used for biodiesel preparation as edible oil is in heavy demand for cooking purposes. Low cost of raw feedstocks reduces the cost associated with biodiesel. Based on literature survey the following points are quantified

- Although transesterification process has been identified as production technique for biodiesel, only limited experiences exist from different non-edible oils. Mostly the experiences from small batch wise biodiesel production method were reported.
- Availability of non-edible oils are used for optimization of many transesterification processes. However limited data are available.
- Biodiesel is mainly used as alternative fuel. Even though cost of alternative fuel is more, but due to emission norms, it is not much used in mobile vehicles in Punjab state.
- Fuel properties of non-edible oil and its methyl esters have been discussed for smooth running of engine but none such experience mentioned for stationary vehicles as well as heavy loaded vehicles. Even though it was done for experimental units.
- The engine performance and emission analysis have been discussed for environmental benefits. No such experience has been mentioned in literature in which selected oils and its methyl esters is explained.

- The study done previously focused on mainly five parameters for standardization of tranesterification process, such paper is found which is considering seven parameters for transesterification process.
- Previous studies are not much focused on selected non-edible oils and its methyl esters.

2.5. Problem Formulation

The use of biodiesel in conventional diesel engines results substantial reduction of un-burnt hydrocarbons, carbon monoxide and particulate matters. Under Indian conditions an emphasis is being laid by the government to explore the possibility of using non edible oils as biodiesel. With a view to avoid twin crises arising out of the fuel starvation and environmental degradation, the potential of biodiesel is being adopted as an alternative fuel for CI engines. Due to gradual depletion of world petroleum reserves and the impact of environmental pollution of increasing exhaust emissions, there is an urgent need for suitable alternative fuels for the use in diesel engines. There has been plenty of research done so far on biodiesel production method and diesel engine performance and emission characteristics. Research in the area of biodiesel has shifted towards making it more economically feasible by lowering production costs and increasing the energetic yields from various feedstocks. Feedstock diversity and multi-feedstock production technologies will play a critical role in reduction in production cost and making the fuel economically viable.

A very limited study on non-edible oil and biodiesel is done in past but due to unavailability of raw feedstocks. In this work, seven process variables used for standardization of transesterification process, various fuel properties of non-edible oils and its biodiesel tested in diesel engine to evaluate performance and emission characteristics. Finding of this work clearly indicate that no research work has been done elsewhere.

2.6. Objectives of Research

On the basis of the trend of energy consumption and subsequent effect on environment due to combustion, the following points have been carefully analyzed in evolving the objective of the present investigation.

The rapid depletion and ever rising cost of liquid petroleum fuel have necessitated the urgency of identifying renewable clean-burning alternative fuels for use in existing CI engines.

1. The growing concern of environmental degradation due to combustion of fossil fuels.

2. The CI engines can ensure the use of biodiesel in existing diesel engines with good efficiency.

The present study was also aimed at to prepare biodiesel using vegetable oil by formulating its properties and bringing them closer to the conventional diesel fuel.

This survey has been carried out with following aims and objectives:

i) ***To optimize transesterification to produce biodiesel using different process variables***
ii) ***To prepare biodiesel from hemp and neem oil***
iii) ***To determine fuel properties of selected non-edible oils and its biodiesels***
iv) ***To evaluate compression ignition engine testing of selected fuel.***
v) ***To evaluate economic assessment of both biodiesels***
vi) ***To compare hemp and neem methyl ester with reference diesel fuel as well as different biodiesel w.r.t.to some fuel properties***

CHAPTER 3
MATERIALS AND METHODS

This chapter describes briefly the methodology used for standardization of methyl transesterification process parameters for hemp oil, neem oil, hemp methyl ester and neem methyl ester. It studies characteristic fuel properties and experimental procedure adopted to evaluate performance of a 5.2 kW, diesel engine on the blends. The experiments were conducted in the Internal Combustion Engine Laboratory, Department of Mechanical Engineering, Thapar University, Patiala. The parameters studied and methodologies of analytical interpretations are discussed in this chapter.

3.1. Materials

The hemp oil used in this present study was supplied by Agrawal oil mill, Udaipur (Rajasthan). The commercial diesel fuel was purchased from petrol pump which is nearer to Gurunanak Engineering College, Ludhiana (Punjab). All chemicals (Methanol,KOH Catalyst, and Silica gel) were procured during experimentation from THAMES chemicals, near choura bazar, Ludhiana (Punjab) All chemicals are brought locally and other reagents were analytical grade and large number of sample bottles were purchased from Choice beauty corner (gift items shop) to put different biodiesel sample during experimentation from Ludhiana (Punjab). Water bath shaker is used for transesterification of raw hemp oil. The fuel properties have been determined by using equipments such as hydrometer, Redwood viscometer, closed cup flash and fire apparatus, cloud and pour point apparatus and bomb calorimeter. The filtered neem oil used in this present study was supplied from Mechanical Engineering Research and Development Organization (MERADO), Gill Road, Ludhiana.

3.2. Standardization of Transesterification Process

3.2.1 Single stage process

1. A known quantity of oil (previously filtered up to 53 micron thickness sieve) was taken.
2. The above filtered oil i.e., triglyceride molecule of above oil (or) complex fatty acid in a biodiesel reactor vessel was taken.
3. Neutralizing the free fatty acids using sodium or potassium methoxide (known quantity of methanol) is used because of its low cost and its physical and chemical advantages (polar and shortest chain alcohol) with known amount of alkali NaOH of KOH as a catalyst

4. Creating an alcohol ester under desired temperature with suitable speed. Stir for agitating the mixture.
5. Within a process period of 1 hr, biodiesel is formed along with the glycerine with clear phase separation.

The methyl transesterifications of hemp and neem oil were carried out as per the steps described in Fig. 3.1 and Fig. 3.2.

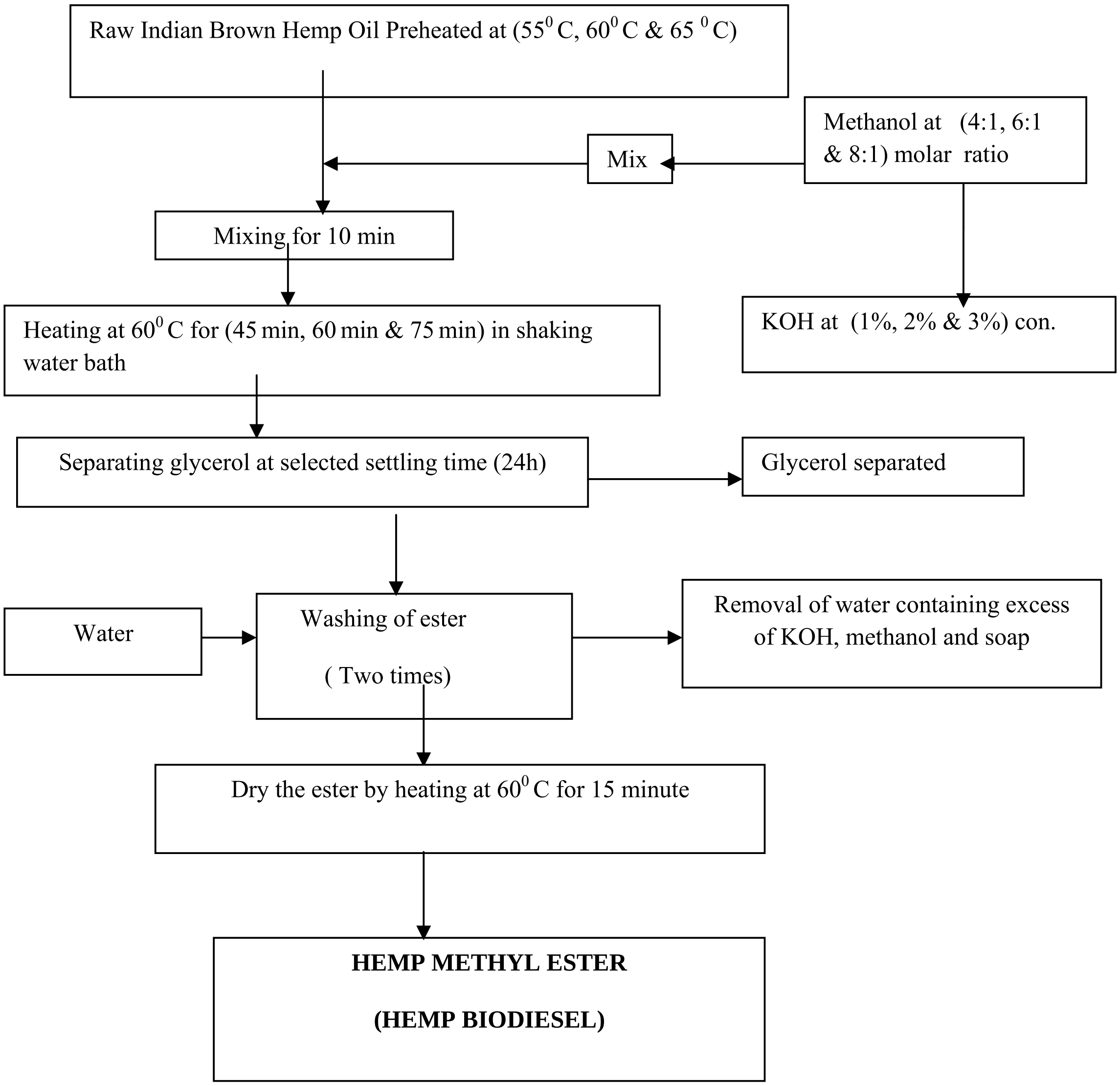


Fig. 3.1 Schematic diagram of simple procedure developed for the production of hemp methyl ester

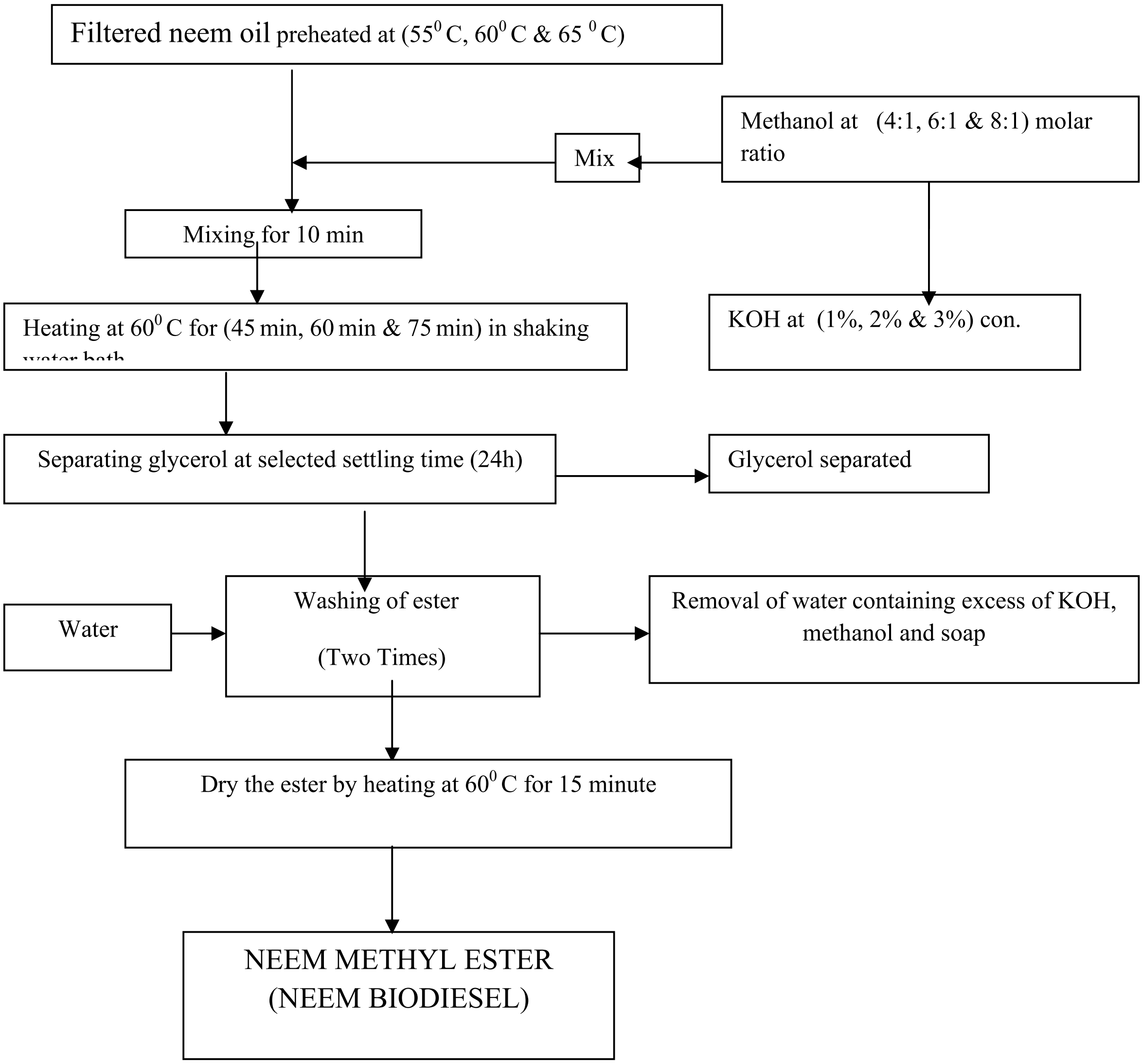


Fig. 3.2 Schematic diagram of simple procedure developed for the production of Neem methyl ester

3.3. Determination of Methanol Quantity for Transesterification Process of Hemp Oil

Molecular weight of hemp oil = 314.45 gm/mol

Molecular weight of methanol (CH_3OH) = 12+3+16+1= 32 gm/ mol

For calculating the quantity required for 1000gm (1kg) of oil

$$X /32 = 1000/ 314.45$$

X = 101.176 gm methanol required for one kg of oil

X = 10.2 gm methanol required for 100 gm of oil

Hence,
Methanol quantity required at 4:1 ratio for the transesterification process
$10.2 \times 4 = 40.18$ gm approximately 40.2 gm of methanol.
Methanol quantity required at 6:1 ratio for the transesterification process
$10.2 \times 6 = 61.2$ approximately 61.2 gm of methanol
Methanol quantity required at 8:1 ratio for the transesterification process
$10.2 \times 8 = 81.6$ gm approximately 81.6 gm of methanol

The molecular weight of hemp oil is 314.45 gms/mole. The number of moles in 100 gm of hemp oil is 10.2. The 4 mole of oil required 40.2 gm of methanol, 6 mole of oil required 61.2 gm of methanol and 8 mole of oil required 81.6 gm of methanol for transesterification process. The molecular weight of methanol is 32. Calculations reveal that every litre of hemp oil requires 101.176 gms of methanol for transesterification process ($10.2 \times 32 = 326.4$ gms), hence 326.4 gms of methanol was considered. Weight of catalyst (KOH) required for transesterification process is 1%, 2% and 3% of oil. The purity of methanol was 99.5% and purity of KOH was 98% which was used for transesterification process.

3.4 Calculation for Quantity of Methanol for Transesterification Process of Neem Oil

Molecular weight of neem oil = 720 gm/mol

Molecular weight of methanol (CH_3OH) = 12+3+16+1= 32 gm/ mol
For calculating the quantity required for 1000gm (1kg) of oil
$X / 32 = 1000 / 720$
X = 44.44 gm methanol required for one kg of oil
X = 4.44 gm methanol required for 100 gm of oil
Hence,
Methanol quantity required at 4:1 ratio for the transesterification process
$4.44 \times 4 = 17.8$ gm approximately 18 gm of methanol.
Methanol quantity required at 6:1 ratio for the transesterification process
$4.44 \times 6 = 26.7$ approximately 27 gm of methanol
Methanol quantity required at 8:1 ratio for the transesterification process
$4.44 \times 8 = 35.6$ gm approximately for 36 gm of methanol

The molecular weight of neem oil is 720 gms/mole. The number of moles in 100 gm of hemp oil is 4.44. The 4 mole of oil required 18 gm of methanol, 6 mole of oil required 27 gm of methanol and 8 mole of oil required 36 gm of methanol for transesterification process. The molecular weight of methanol is 32.Calculations reveal that every litre of hemp oil requires 101.176 gms of methanol for transesterification process ($4.44\times 32 = 142.08$ gms), hence 142.08 gms of methanol was considered. Weight of catalyst (KOH) required for transesterification process is 1%, 2% and 3% of oil. The purity of methanol was 99.5% and purity of KOH was 98% which was used for transesterification process.

3.5. Standardization of methyl transesterification process parameters

Transesterification process is defined as the chemically reacting triglycerides such as one of the vegetable oil with an alcohol in presence of an alkaline or acidic catalyst to produce glycerol and fatty acids ester. In this process the ester is produced when vegetable oil combines with a simple alcohol in presence of a catalyst. The fatty acids of vegetable oil exchange places with the (OH) groups of the alcohol producing glycerol and methyl, ethyl or butyl fatty acids ester depending on the type of alcohol used. The three distinct stages in the preparation of an ester are namely:

- Heating oil at a desired temperature.
- Stirring and heating of alcohol-oil mixture with an alkaline or acidic catalyst.
- Separation of glycerol and washing of ester with water.

The following parameters affect the level of ester recovery:

- Molar ratio of vegetable oil- alcohol mixture
- Preheating time
- Preheating temperature
- Reaction time
- Reaction temperature
- Type of catalyst
- Concentration of catalyst

The effect of process parameters shown in Table 3.1 were studied to standardize the transesterification process for estimating recovery of ester as well as recovering ester of lowest possible viscosity. In order to standardize the process parameters, three levels of catalyst (KOH) concentration (1%, 2%, and 3%) and three levels of reaction temperature (60^0C, 75^0C and 90^0C) was set. The transesterification was done at 6:1 molar ratio and then allowed to settle for 24 h in order to obtain maximum recovery of ester with lowest possible kinematic viscosity as reported by past researchers. Total 64 ester samples were prepared to study the effect of the three levels of catalyst concentration and reaction temperature on ester recovery and subsequent measure of their kinematic viscosity. Each sample was replicated twice, thus, making total 128 experiments. The water bath shaker used for transesterification which is shown in plate 3.1.

Plate 3.1 Water bath shaker for transesterification

Table 3.1 Process parameters selected for standardization of transesterification process (Hemp and neem oil)

Optimizing Parameter	**Level Selected**
Preheating Temperature, (^{0}C)	55^{0}C,60^{0}C and 65 ^{0}C
Molar Ratio	4:1, 6:1 and 8:1
Catalyst Concentration, (%)	1%, 2% and 3%
Reaction Time (Minutes)	45min, 60min and 75min
Reaction Temperature (^{0}C)	60^{0}C
Settling Time	24 hrs
Washing Time	24 hrs

3.6. Determination of Fuel Properties

The equipments were used to determine the fuel properties which are shown in table 9 and fuel properties of hemp and neem methyl ester were determined and summarized in Table 10 together with the relevant specifications from the biodiesel standards ASTM D6751 and EN 14214. Most of these parameters comply with the limits prescribed in the ASTM D6751 and EN 14214. The characteristic fuel properties of hemp oil, neem oil, hemp methyl ester, neem methyl ester, diesel and esters-diesel blends in the proportions of 20:80, and 100:0 on volume basis were determined in accordance with standards of Bureau of Indian Standards, New Delhi and the Institute of Petroleum, London.

The fuel properties of non-edible as follows:-
Density, viscosity, FFA content, acid value, moisture content, flash and fire point, pour and cloud point, calorific value or heating value, cetane number, saponification number.
The fuel properties of biodiesel fuel as follows:-
Density, viscosity, FFA content, acid value, moisture content, flash and fire point, pour and cloud point, calorific value or heating value, total glycerin, free glycerin ,copper strip corrosion, Iodine value, Cetane number , Saponification number, Ash content, Carbon content, Fuel stability.

Table 3.2: Different apparatus and standards used for fuel characterization

Name of fuel property	Methods/Standards
Relative density	Hydrometer, IS: 1448 [P: 32]: 1992.
Kinematic viscosity	Redwood Viscometer, IS : 1448 [P : 25] 1976
Flash point and fire point	Closed cup flash and fire point apparatus, IS: 1448 [P: 32]: 1992
Cloud point and pour point	Cloud and Pour point apparatus, IS: 1448 [P: 10]: 1970
Calorific value (MJ/Kg)	Bomb Calorimeter, IS: 1448 [P: 6]: 1984
FFA content (%)	Titration with 0.1N NaOH
Acid value (%)	Titration with 0.1 N KOH
Ash content (%)	Electric Muffle Furnace, ASTM D482-IP 4of IIP
Carbon residue content (%)	Carbon Residue Apparatus, ASTM D189-IP 13 of IIP

Table 3.2:-Different apparatus and standards used for fuel characterization (Continue)

Name of fuel property	Methods/Standards
Cetane number	Aniline Point Apparatus IS: 1448 (P:3)-1984
Copper strip corrosion test	Copper Strip Corrosion Apparatus, IS:1448[P:15]-1976
Glycerine content	Gas Chromatography, ASTM method D-6584
Fuel Stability (Seconds)	Storage Time method / oxidation method
Moisture Content (%)	Hot air oven with digital temperature controller
Iodine value	Titration with standard 0.1N Na_2SO_3
Saponification number	Titration with 0.5N HCL

3.6.1. Relative density and API gravity

The relative density of the selected fuels at 15^0C was determined as per **IS: 1448 [P: 32]: 1992**. The empty pyknometers of 50 ml capacity (Plate 3.2) were weighed on an Adair Dutt make, MJ 500 series electronic balance of range 0 - 500g, having readability of 0.001 g. The pyknometers were then filled with fuel samples and weighed. The samples were maintained at 15^0C by keeping them in a Saveer Biotech make walk-in temperature control chamber. A mercury thermometer of 0 – 100^0C range was also used to measure the temperature of fuels kept inside the temperature control chamber. The weights of the empty pyknometers were subtracted from the weights of the filled ones to get the weight of the fuel samples. Three replicates were taken for each sample and their mean was calculated. This value when divided by the volume of the fuel sample gave the density (ρ_F) of the fuel sample at 15^0C. The density of distilled water (ρ_w) at 15^0C was also determined. Equation 3.1 was used to calculate the relative density.

Relative density = Density of the fuel at 15°C/ Density of the water at 15°C

The API (American Petroleum Institute) gravity, which is an indicator of heat content and lightness of a fuel, was also calculated. The higher the API gravity, the lighter is the fuel. The following relationship was used to determine the API gravity of diesel, jatropha oil and their blends with diesel.

API Gravity = 141.5/Relative density at 15℃ -131.5

Plate 3.2 Pyknometers used for measurement of relative density

3.6.2 Kinematic viscosity

Viscosity can be defined as the resistance to flow of liquid due the internal friction between the liquid and surface. It plays an important role in the performance of an engine fuel system operating through a wide range of temperature. Kinematic viscosity affects the injection system. Low viscosity can result in an excessive wear in injection pumps and power loss due to pump leakage whereas high viscosity may result in excessive pump resistance, filter blockage, high pressure and coarse atomization and fuel delivery rates.

A Redwood Viscometer No.1 of WISWO make as shown in Plate 3.3 was used for measurement of kinematic viscosity of selected fuel samples. The instrument measures the time of gravity flow in seconds of a fixed volume of the fluid (50ml) through specified orifice made in an agate piece as per **IS : 1448 [P : 25] 1976**. The apparatus could be used for flow time between 30 to 2000 seconds. The fuel was filled in a cup fitted with agate jet at the bottom up to a specified level indicated in the cup. The cup was surrounded by water jacket having an immersion heater. The water was heated to 38^0C by regulating the rate of heating using a voltage regulator of the instrument. A silver plated metallic ball was used to open and close the agate jet. A standard 50 ml volumetric glass was kept below the agate jet to collect a falling fuel sample. Each test was replicated thrice. Kinematic viscosity in centistokes was then calculated from time units by using the relationships given by **Guthrie (1960)**.

$$\nu_k = 0.26\ t\ -\ \frac{179}{t}$$

When 34 < t < 100 and

$$\nu_k = 0.24\ t - \frac{50}{t}$$

When t > 100 where,

ν_k = Kinematic viscosity in centistokes, cSt

t = Time for flow of 50 ml sample, s

Plate 3.3 Redwood viscometer used for measurement of kinematic viscosity

3.6.3 Calorific Value or Gross heat of combustion

The heat of combustion or calorific value of a fuel is an important measure since it is the heat produced by the fuel within the engine that enables the engine to do the useful work. The gross heat of combustion of fuel samples was determined as per **IS: 1448 [P: 6]: 1984** with the help of a Widson Scientific Works make Isothermal Bomb Calorimeter (Plate 3.9). A fuel sample of 1 ml was burnt in the bomb of calorimeter in the presence of pure oxygen. The sample was ignited electrically. As the heat was produced, the rise in temperature was measured. The water equivalent (effective heat capacity of the calorimeter) was also determined using pure and dry benzoic acid as test fuel. Each sample was replicated three times.

The gross heat of combustion of the fuel samples was calculated using the equation given below:

$$H_c = \frac{W_C \times \Delta T}{M_S}$$

where,

H_c = Heat of combustion of the fuel sample, Cal / g

W_c = Water equivalent of the calorimeter, Cal / ^{0}C

ΔT = Rise in temperature, ^{0}C

M_s = Mass of sample burnt, g

Plate 3.4 Isothermal bomb calorimeter used for measurement of calorific value

3.6.4 Cloud and pour points

The Cloud and Pour point is the measure which indicates that the fuel is sufficiently fluid to be pumped or transferred. Hence it holds significance to engines operating in cold climate. The cloud point is defined as the temperature at which a cloud or haze of wax crystal appears at the bottom of a test jar when chilled under prescribed conditions. The pour point is defined as the temperature at which the fuel ceases to flow. Both properties may indicate the tendency towards filter plugging and flow problems in the fuel line.

The cloud and pour point of fuel samples were determined as per **IS: 1448 [P: 10]: 1970** using the cloud and pour point apparatus as shown in Plate 3.5. The apparatus mainly consists of 12 cm high glass tubes of 3 cm diameter. These tubes are enclosed in an air jacket, which is filled with a freezing mixture of crushed ice and sodium chloride crystals. The glass tube containing fuel sample is taken out from the jacket at every 1^0C interval as the temperature falls, and is inspected for cloud formation. The point at which a haze was first seen at the bottom of the sample was taken as the cloud point.

The apparatus and the procedure for the pour point was same as for cloud point only the sample was pre-heated to 48^0C and then cooled to 35^0C in air before it was filled in the glass tube. Thereafter, the cooled samples were placed in the apparatus and withdrawn from the cooling bath at 1^0C interval for checking its flow ability. The pour point was taken to be the temperature 1^0C above the temperature at which no motion of fuel was observed for five seconds on tilting the tube to a horizontal position. Three replications were made for each fuel type.

Plate 3.5 Cloud and pour point apparatus

3.6.5 Flash and fire point

Flash point measures the tendency of the sample to form a flammability mixture with air under controlled laboratory conditions. This is the property that must be considered in assessing the overall flammability and hazard of material. Flash point can indicate the possible presence of highly volatile and flammable material in relatively non volatile material. It is defined as the lowest temperature at which the fuel gives off sufficient vapours and ignites for a moment. The fire point is an extension of flash point in a way that it reflects the condition at which vapour burns continuously for five seconds. The fire point is always higher than flash point by 5 to 8^0C.

The flash and fire point of the fuel samples was determined as per **IS: 1448 [P: 32]: 1992**. A Pensky Martin Flash Point (closed) apparatus as shown in Plate 3.6 was used for measuring the flash and fire point of the fuel samples. The sample was filled in the test cup up to the specified level and heated by heating the air bath with the help of a heater. The fuel sample was stirred at a slow constant rate. The sample was heated in such a way that rate of temperature rise was approximately 5^0C per min. The temperature was measured with the help of a thermometer of -10 to 400^0C range. At every 1^0C temperature rise, flame was introduced for a moment with the help of a shutter. The temperature at which a flash appeared in the form of sound and light was recorded as flash point. The fire point was recorded as the temperature at which fuel vapour catches fire and stays for minimum of five seconds.

Plate 3.6 Pensky marten apparatus used for measurement of flash and fire point

3.6.6 Ash content

Ash in a fuel can result from oil, water soluble material compounds or extraneous solids, such as dirt and rust. The ash content of diesel, hemp and neem oil were measured as per the standard **ASTM D482-IP 4** of Institute of Petroleum, USA. An electric muffle furnace of Wiswo make was used in the experiment as shown in Plate 3.7. In order to measure the ash content, sample was taken in a silica dish. The dish was first weighed empty and then with the fuel sample. The sample weight was obtained from the difference between the initial and final weight of the dish. The sample was then placed in the muffle furnace and heated at 775 ± 25^0C for two hours. Each sample was replicated three times. The ash content was obtained using the equation given below

$$A_s = \frac{Wa}{Ws} \times 100$$

where,

A_s = Ash content, percent
W_a = Weight of ash, g
W_s = Weight of sample, g

Plate 3.7 Muffle furnaces used for measurement of ash content

3.6.7 Carbon residue

Carbon residue was determined for different fuels by using a carbon residue apparatus. The measurement was made in accordance with the **ASTM D189–IP 13** of Institute of Petroleum, London. This procedure determines the amount of carbon residue left after evaporation and pyrolysis of an oil. It is intended to provide some indication of relative coke forming properties. In this method, 10 g weight to the nearest 5 mg of each fuel sample was weighed free of moisture and other suspended matter into an iron crucible of the apparatus (Plate 3.8). The crucible was then placed in the centre of skidmore crucible of the apparatus and the sand was leveled in the large sheet iron crucible and then the skidmore crucible was set on it in the exact centre of the iron crucible. Thereafter, the covers were applied to both skidmore and iron crucible loosening the latter fitting to allow free exit to the vapours as it formed. The fuel sample was then heated with a high strong flame from gas burner for 20 min. When the smoke appeared on the chimney, immediately the burner was moved or tilled so that the gas flame plays on the sides of the crucible for the purpose of igniting the vapours. After that the ignited vapour was burnt uniformly with the flame above the chimney for another period of time. When the vapour ceased to burn and no further smoke was observed, the burner was adjusted and the heat was held as at the beginning to make the bottom and the lower part of the sheet iron crucible, a cherry red for about 15 min. Thereafter, the burner was removed and allowed to cool until no smoke appeared. The cover of skidmore was then removed with a tong and it was cooled and weighed. The percentage of carbon residue on the original sample was then calculated using the equation as given below:

$$C_r = \frac{W_c}{W_s} \times 100$$

where,

C_r = Carbon residue, %
W_c = Weight of carbon residue, g
W_s = Weight of the sample, g

Plate 3.8 Carbon residue content measurement apparatus

3.6.8 Acid value

Free fatty acids present in a vegetable oil may be corrosive to some engine parts. At elevated temperatures, free fatty acids may react with many metals producing fatty acid metal salts thus increasing wear. Acid value is, therefore, an important characteristic to be measured. The acid value or number defined as the mg KOH required to neutralize the free fatty acid present in one gram of sample. However, the free fatty acid content is expressed as oleic acid equivalents. The total acid value of different fuel samples was measured as per method describe by **Cox and Pearson, 1962**. The procedure described below was followed in order to determine total acidity of various fuels selected for the study:

- Dissolve 1 to 10 g of oil in 50 ml of the neutral solvent (neutral solvent is the mixture of 25 ml ether, 25 ml alcohol and 1 ml of 1% phenolphthalein solution and neutralize with N/10 alkali) in a 250 ml conical flask.
- Add a few drops of phenolphthalein.
- Titrate the contents against 0.1N KOH.
- Shake constantly until a pink colour which persists for 15 seconds is obtained.

During the course of study, each sample was replicated three times. The total acidity of a fuel sample was then calculated using equation given below:

$$A_v = \frac{56.1\,N \times T_v}{W_s}$$

where,

A_v = Acid value, mg of KOH/g
T_v = Titrate value, ml
N = Normality of the potassium hydroxide solution
W_s = Weight of sample, g

3.6.9 Fuel stability

The characteristic of vegetable oil changes with time due to the changes in chemical structure of fatty acids present in it. Generally, there are up to 14 types of fatty acids present in a vegetable oil. Some of these fatty acids improve the stability whereas some reduce it. Saturated fatty acid (C 14:0, C 16:0) increase cloud point, cetane number and improve stability whereas more polyunsaturated (C 18:2, C18:3) reduce cloud point, cetane number and stability. Oxidation and polymerization of fat present in vegetable oils increase the viscosity with time. The unsaturated fatty acids have unstable double bonds and when these fatty acids come in contact with atmospheric oxygen they are converted to peroxide. Cross-linking at this stage may occur and oil irreversibly polymerizes into a plastic like solid and hence the viscosity of vegetable oil increases. Generally, instability increases by a factor one for every double bond on fatty acid chain. Thus, C 18:3 are three times more unstable than C 18:0 fatty acids. Since kinematic viscosity of oil greatly influences the engine performance, therefore, it were measured for hemp and neem oil with diesel in every 30 days interval during a period of two months. The change in kinematic viscosity was recorded to assess oxidative stability of oil as well as its ester blends with diesel.

3.6.10 Free Fatty Acid Content (FFA Content)

As FFA can cause saponification instead of biodiesel production it is important to know the FFA content within an oil batch and whether it is necessary to take steps to reduce the content for success in the transesterification process. FFA content can be acquired from the use of a titration. The method for FFA estimation is described below:

1. Take 50ml of Neutralise spirit in a conical flask with the addition of the indicator phenolphthalein
2. 10ml of base oil is added to the conical flask
3. Heat contents until first bubbling occurs (approx 70°C)
4. Phenolphthalein will indicate end of reaction as a red/pink colour when NaOH is used as titrate (0.1N)
5. When quantities are know the FFA content can be calculated.

$$\text{Weight of sample} = \text{Volume} \times \text{density}$$

$$(28.2 \times V \times N)/\ (\text{weight of sample})$$

Where V = volume of NaOH consumed in the titration

And N = Normality of NaOH

3.6.11 Moisture Content

Water tends to settle in fats which have softened and melted. Hence, mix the samples thoroughly to distribute the water uniformly. Soften solid fats with gentle heat but do not melt. Mix thoroughly with a mixer.

Weight accurately 5 g of the sample into a tarred dish which had been previously dried and cooled in a desiccator. Dry in an oven at 105^0 C, remove from the oven, cool in a desiccator and weigh. Repeat the procedure until the loss in weight does no exceed 0.05% per 30 min drying period.

$$\%\ \text{Moisture and volatile matter} = \frac{\text{Loss in weight}}{\text{Wt of sample}} \times 100$$

3.6.12 Aniline Point/Diesel Index

As it is well known that there is a time lag (delay period) between the injection of diesel fuel into hot compressed air and its ignition. If the delay period is unduly large, there will be an accumulation of too much fuel in the cylinder, which will eventually burn with an undue rapidity. A rapid rise in the cylinder pressure will follow and cause a "diesel knock". The delay period is inherently connected with the type of hydrocarbon. The preferred hydrocarbons in the order of decreasing ignition quality (increasing delay period) are paraffins, olefins, naphthalene, iso-paraffins, and aromatics. This order is the reverse of the order of gasoline anti-knock quality. The ignition quality of fuel in a standard engine is measured by matching against the blends of two reference fuels and expressed in terms of cetane number. N-paraffin (n-hexadecane or cetane, $C_{16}H_{34}$) is given 100 CN and an aromatic (α-methyl naphthalene) is given 0 CN. If the given fuel matches with a 40/60 blend of cetane and α-methyl naphthalene, it is assigned a CN 40. In practice, secondary reference fuels are used in the test, because the primary references are costly and not easily available.

High-speed engines, above 1500 rpm, need high CN fuel of 45-50. Low-speed engines are not so demanding since there is more time available for combustion. A CN of 25-30 may suffice their requirements. Diesel fuels are largely composed of distillates. Cracked fractions are rich in iso-paraffins and aromatics and hence the amount of cracked fractions in good diesel should be low.

In the experimentation, the cetane number of the diesel oil was determined by the method suggested by Sarkar and Gunthur. This method for approximate judgment of CN for a fuel is by measuring diesel index. Numerically diesel index is usually three units higher than CN. The cetane number determined using this method is supposed to be fairly accurate. It has been found to be a reliable parameter and helps in the evaluation of the ignition quality of the diesel fuel.

Diesel index is evaluated by converting aniline point into an empirical diesel index with the help of the following formula.

$$\text{Diesei index} = \frac{\text{Aniline point } (^0\text{F}) \text{ x Degree API}}{100}$$

Aniline point is defined as the temperature at which a liquid just becomes completely miscible with an equal volume of aniline. Aromatics are easily miscible with aniline and have a low aniline point. On the other hand, paraffin's have high aniline point. This test is therefore an indication of the type of hydrocarbon present in a petroleum product. A high aniline point is an indication of high suitability as a diesel fuel. Aniline point can be evaluated using ASTM standard: (D-611) or Indian Standard code IS: 1448(P: 3)-1984.

Aniline point apparatus is shown in Plate 3.9. The fuel mixture was constantly heated. At a certain temperature, the bulb dipped in the mixture of fluids became visible as the two fluids became totally miscible. The liquids were then cooled and the temperature at which the bulb became visible was noted. After repeating the process of heating and cooling, the range of the two temperatures narrowed and got merged. This temperature was aniline point temperature. API gravity was fond out in the following way as suggested by the American Petroleum Institute.

$$\text{API} = \frac{141.5}{\text{Sp.gr.}(15.5^0/15^0\text{C}} - 131.5$$

Plate 3.9 Aniline point apparatus

3.6.13 Copper strip Corrosion Test

1] Normally the corrosion test is operated at 50°C and 100°C constant temperatures. Please start the copper strip corrosion test bath at desired working temperature. The temperature will attain approximate 15 to 20 minutes time after start. The copper strip corrosion apparatus shown in Plate 3.10.

2] Prepare the copper strip for performing test, wash it properly with solvent and prepare surface of strip by rubbing with silicon carbide grit paper.

3] Finally polish it clamping with vice. When strip is clean, immerge it in prepared sample.

4] Keep strip in to sample-tube with 30ml of sample, stopper with a vented cock and slide the sample tube in test in test bomb and screw the lid tight.

5] After 2Hr+ and – 5 min in the bath, withdrawn the bomb and immerse for a few minutes in tap water. Open the bomb, withdrawn test tube and examine the strip.

6] Compare the copper strip with corrosion standards or comparison chart. For more details please also consult working instructions provided by 1P and ISI institutions, which is also enclosed with this.

Report:- Report the corrosiveness in accordance with one of the four numbered classifications listed in table 3.3 and state the test temperature and the duration of the test.

Table 3.3 Copper strip classifications

Classification	Designation	Description
Freshly polished strip		
1	Slight Tarnish	Light orange, almost the same as a freshly polished strip
2	Moderate Tarnish	Claret Red Multicoloured with lavender blure or silver or bath, overlaid on claret red. Silvery Brassy or gold.
3	Dark Tarnish	Magenta overcast on brassy strip Multicoloured with red and green showing but no grey.
4	Corrosion	Transparent black, dark grey or brown with peacock green barely showing. Graphite or lusterless black glossy or jet black.

Standard Procedure

This method covers the diction of the corrosiveness to copper of aviation gasoline, farm tractor fuel, solvent, kerosene diesel fuel, fuel oil, lubricating oil and certain other petroleum products.

A polished copper strip is immersed in a given quantity of sample and heated at a temperature and for a time characteristics of the material being tested. At the end of this period the copper strip is removed, washed and compared with the copper strip corrosion standards.

The apparatus consists the following items

1] Copper strip corrosion test bomb

2] Polish copper strip

3] Constant temperature water bath to hold test bombs.

4] Glass test tube

5] Polishing vice

Plate 3.10 Copper strip corrosion apparatus

3.6.14 Iodine Value

The iodine value is a measure of the degree of unsaturation of an oil or fat. It is constant for particular oil for fat. It is a useful parameter in studying oxidative rancidity of oils since higher the unsaturation the greater the possibility of the oils to go rancid.

Principle

The oils contain both saturated and unsaturated fatty acids. Halogens add across the double bonds of unsaturated fatty acids to form addition compounds. Iodine monochloride (ICl) is allowed to react with the fat in the dark. Iodine gets incorporated into the fatty acid chain wherever the double bonds exist. The amount of iodine consumed is then determined by titrating the iodine released (after adding KI) with standard thiouslphate and comparing with a blank in which the fat is omitted. Hence the measure of iodine absorbed by an oil or fat gives the degree of unsaturation.

The iodine value or number is defined as the number of grams of iodine absorbed by 100g of the oil/fat.

Reagents

1] Hanus iodine solution: Dissolve 6.8g of iodine in 500 ml of glacial acetic acid and heat to dissolve. Cool and add 1.5 ml of bromine.

2] 15% KI solution: Prepare in water.

3] Standard 0.1N sodium thiosulphate solution: Dissolve 6.2g of Na2S2O3.5H2O in 250 ml of water. Standardize against standard K2Cr2O7 solution and dilute to get exactly 0.1N Na2S2O3 solution.

4] 1% Starch indicator: To 1g of starch add 10 ml of water and pour the suspension into 90 ml of boiling water. Boil for 1-2 minute and cool.

5] Chloroform

Method

1] Weigh out 0.2-0.3g of oil or fat into 500 ml conical flask.

2] Add 20 ml of chloroform and dissolve the oil completely.

3] Add 25 ml of Hanus iodine solution, mix well, stopper the flask and keep in dark for 30 minutes.

4] Add 20 ml of KI solution and mix well.

5] Titrate against standard 0.1N Na2S2O3 solution using starch as an indicator with vigorous shaking to extract the iodine from the chloroform layer.

6] Conduct blank similarly in the absence of oil.

Calculation

Iodine number of oil or fat = A×N× 0.1269× 100/ Weight of oil (g) g I2/ 100g oil or fat

A = ml of $Na_2S_2O_3$ (Blank-Test)
N = Normality of $Na_2S_2O_3$ solution

Note: 1 ml of 0.1N $Na_2S_2O_3$ = 0.1269g of iodine.

3.6.15 Saponification Number

Saponification is the process by which the fatty acids in the glycerides of the oil /fat are hydrolysed by an alkali. The resultant salts of fatty acids are called soaps.

When the oil or fat (triglyceride) is heated with KOH (or alkali) it is saponified (hydrolysed) and release fatty acids and glycerol. Each molecule of the number of milligram of KOH required to saponify the fatty acids resulting from the complete hydrolysis of 1g of fat or oil. This value gives an indication of the nature of fatty acids in the fat since the longer the carbon chain the less acid is liberated per gram of fat hydrolysed. Thus, this value is useful for a comparative study of the fatty acid chain length in oils.

Principle

A known quantity of oil is refluxed with an excess amount of alcoholic KOH. After saponification, remaining KOH is estimated by titrating it against a standard acid.

Reagents

1] 0.5N Alcoholic KOH solution: Dissolve 28g of KOH in one litre of 90% alcohol.

2] Standard 0.5N HCL: Prepare approximately 0.6N HCL solution by diluting 54 ml of concentrated HCL to 1 litre with water. Standardise this solution against standard 0.5N sodium carbonate solution and dilute to get exactly 0.5N HCL.

3] 1% Phenolphthalein solution in alcohol.

Method

1] Accurately weigh out 1-2g of oil into a 250 ml conical flask, add 25 ml of alcoholic KOH and dissolve the oil completely.

2] Connect air condenser to the flask and boil for about 30 minutes on a boiling water bath.

3] Cool to room temperature, add 2-3 drops of Phenolphthalein indicator and mix.

4] Titrate against standard 0.5N HCL until the pink colour disappears.

5] Treat the blank similarly in the absence of oil.

Calculation

Saponification value of an oil (mgKOH) = (Blank-Titrate)× 28.06/ Weight of oil (g)

Notes

1] 1 ml of 0.5N HCL = 28.06 mg KOH

2] If the sample is not liquid, melt it and filter through filter paper to remove any impurities and the last traces of moisture.

3] Alcohol should not get dried up during saponification. Effective cooling of alcohol vapour is essential.

4] Clarity and homogeneity of the test solution are indicators of complete saponification.

3.6.16 Glycerine Content

Determination of free and total glycerine content

Reagents

- n-Heptane
- Pyridine
- Derivatization reagent: n-methyl-n-trimethylsilytriflu-oroacetamide(MSTFA) (Pierce Chemical)
- Glycerin
- Monoglyceride standards: monopalmitin, monoolein, monolinolein, monolinolenin and monostearin
- Diglyceride standard: diolein
- Triglyceride standard: triolein
- Internal standard components: butanetriol, tricaprin

Internal standard solution

Prepare a combined solution of 1-mg/mL butanetriol and 8-mg/mL tricaprin in n-heptane

Sample Preparation

Standards are prepared in pyridine. Standards and samples are treated in an identical manner. Into 2.0-mL disposable autosampler vials, weigh approximately 100 mg of sample or standard, record actual weight.

- Add ISTD
- Add 100 µL MSTFA
- Allow to stand 20 min at room temperature
- Add 1.5-mL heptanes, cap vial and shake.

Analysis

Inject 1-µ derivatized sample into column injector. Collect chromatogram for processing.

Calculations

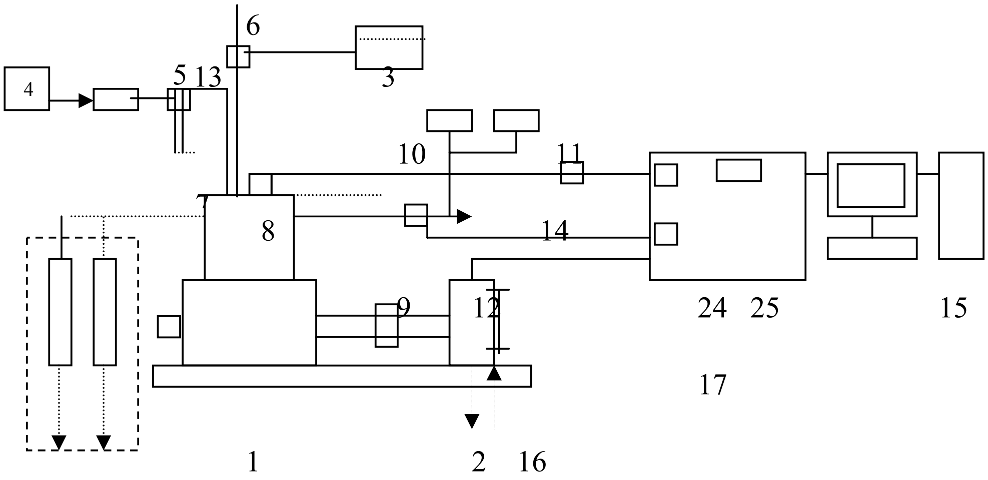
Total diglycerides are calculated as summed time groups including all peaks eluting with diolein±0.35 min. Total triglycerides are calculated as a summed time group including all peaks eluting with triolein±1 min. Free glycerin is calculated by the area of the glycerin peak. The gas chromatography apparatus as shown in Plate 3.11.

Plate 3.11 Gas Chromatography apparatus

3.7. Evaluation of Performance and Exhaust Emission Parameters

3.7.1. Experimental setup

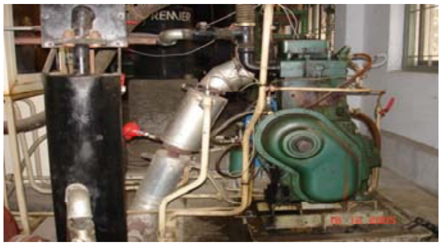
The computerized CI engine set-up along with the high-speed data acquisition system, eddy current dynamometer, piezo-electric transducer and 'Engine soft' software was supplied by Apex Innovations Pvt Ltd., Sangli, India. The set-up (Figure 5.1) consists of a constant speed (1500 RPM) 661cc, single cylinder, 4-stroke, Kirloskar make (model – TV1), DI Diesel Engine (Plate - 34) connected to eddy-current type dynamometer. The engine can be started by hand cranking with the help of decompression lever. The eddy current dynamometer (Plate-35) was used to apply load to the system. Load on the engine was changed by controlling the current given to the electromagnets. The calibrated Digital PT100 type temperature sensors were used for temperature measurement. The control panel (Plate-36) has indicators for water temperature (inlet and outlet) for engine and the calorimeter, exhaust gas temperature to and from the calorimeter, rotameter for measurement of water flow to the engine and calorimeter, loading switch and the engine speed indicator. the set-up enables the study of the engine for P-θ diagram, indicated power, brake power, thermal efficiency, volumetric efficiency, fuel consumption, air-fuel ratio, heat balance etc. A fuel tank was fabricated with appropriate valves for fuel supply. Fuel consumption was measured through graduated fuel metering tube controlled through the METERING / REGULAR option of the fuel metering cock. Air box with U tube manometer measures air-flow rate. The software package used was complete in all aspects for the above-referred calculations. Readings were taken under stabilized condition of the engine.



18 Fig.3.3 Line sketch of computerized experimental set up with accessories

1. Engine
2. Dynamometer
3. Fuel Tank
4. Air Surge Tank
5. Orifice Plate
6. Burette (Diesel)
7. Manometer
8. Pressure Transducer
9. Exhaust Gas Sampling Chamber
10. Smoke Meter
11. Emission Analyzers
12. To Exhaust
13. 3 – Way Valve
14. Amplifier
15. Data Acquisition System with Computer
16. TDC Encoder
17. Stop Watch
18. Rotameter
19. Inlet Water Temperature to Engine
20. Outlet Water Temperature from Engine
21. Outlet Water Temperature from Calorimeter
22. Exhaust Gas Temperature from Engine
23. Exhaust Gas Temperature from Calorimeter
24. Loading Switch
25. Speed Indicator

ENGINE



10

ENGINE-DYNAMOMETER SIDE VIEW

11

FUEL TANK

Plate 3.12 Different CI Engine Parts

3.7.2 Engine test procedure

A four stroke, single cylinder water cooled diesel engine is employed for the present study. The detail specification of the engine used are given in table 2 and experimental set up as shown in figure 1.AVL 437 Smoke meter is employed to measure the smoke opacity of exhaust gas emitted from the diesel engine.AVL DiGas 4000 Five gas analyzer was used to measure the concentration of gaseous emissions such as Oxides of nitrogen, unburned hydrocarbon, smoke opacity, carbon monoxide, carbon dioxide and oxygen level. The performance and emission tests are carried out on the C.I. engine using various blends of biodiesel and diesel as fuels. The tests are conducted at the constant speed of 1500rpm at various BMEP. The experimental data generated are documented and presented here using appropriate graphs. These tests are aimed at optimizing the concentration of ester to be used in the biodiesel-diesel mixture for 1 hr engine test operation. In each experiment, engine parameters related to thermal performance of engine such as brake thermal efficiency, brake specific fuel consumption, brake specific energy consumption, exhaust gas temperature and applied BMEP are measured. In addition to that, the engine emission parameters such as Oxides of nitrogen, unburned hydrocarbon, smoke opacity, carbon monoxide, carbon dioxide and oxygen level.

3.7.2.1 Engine

The photograph of diesel engine with pressure transducer for sensing cylinder gas pressure and thermocouple for sensing exhaust gas temperature as shown in Plate 3.12. This engine is widely used in agriculture sector. The engine has open type combustion chamber in an aluminium alloy piston in combination with long stem nozzle. Fuel is supplied to the fuel pump by gravity feed, through the fuel tank and paper element filter. Lubrication is done by forced feed to main and large end bearings and camshaft bush. Other working parts are splash lubricated. By-pass filter is used for cleaning the lubricating oil. The engine can be started by hand cranking using decomposition lever.

3.7.2.2 Eddy Current Dynamometer

The photograph of eddy current dynamometer with diesel engine is depicted in Plate 3.12.

It consists of a stator on which are fitted a number of electromagnets and a rotor disc made of copper and coupled to the output shaft of the engine. When a rotor rotates eddy current are produced in the stator due to magnetic flux set up by the passage of the field current in the electromagnets. These eddy current are dissipated in producing heat hence this dynamometer requires cooling arrangement. The torque is measured with the help of moment arm. The load is controlled by regulating the current in the electromagnets. The SAJ make AG 20 eddy current dynamometer was used for present investigation. Dynamometer load measurement was from a strain gauge load cell. This SAJ dynamometer unit comprises a rotor mounted on a shaft running in bearing which rotates within a casing supported in ball bearing trunnions which form part of bed plate of the machine. Two field coils connected in series are secured in the casing. When these coils are supplied with direct current a magnetic field is created in the casing across the air gap at the either side of rotor. When the rotor turns in the magnetic field, eddy currents are induced created a breaking effect between rotor and casing. The rotational torque exerted on the casing is measured by the strain gauge load cell incorporated in the restraining linkage between the casing and dynamometer bed plate.

3.7.2.3. Control Panel

The photograph of control panel of computerised diesel engine set up is depicted in Plate 3.13

The control panel was equipped with rotameter, inlet water temperature indicator from engine, outlet water temperature indicator from engine, outlet water temperature indicator from calorimeter, loading switch and speed indicator.

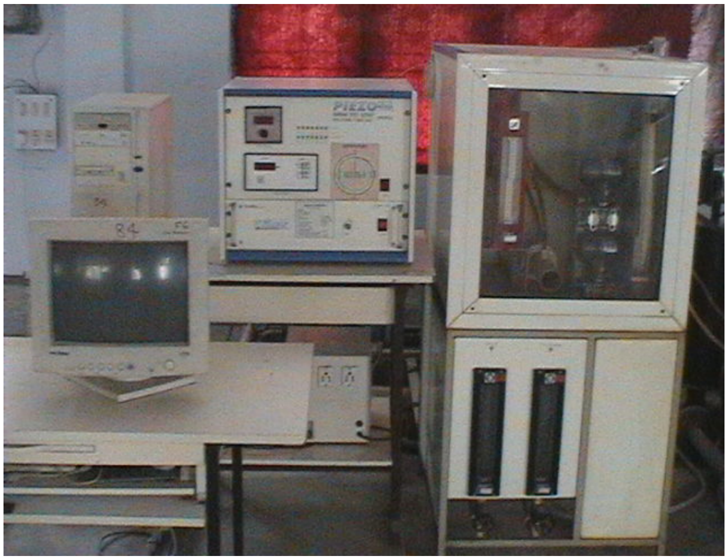


Plate 3.13 Control Panel of Computerised Compression Ignition Engine

3.7.3. Software

The software is specially designed by M/S Apex Innovations Pvt. Ltd. Sangli, for the engineering students to demonstrate working of I.C. Engine and study the effect of various parameters in the performance of engine. Software is fully configurable. Before installing the software, it has to be ensured that the existing computer matches the requirements mentioned in the manual. These minimum requirements are as below.

1) P-II or equivalent processor, 2) 2 GB HDD, 3) 64 MB RAM, 4) CD ROM, 5) Colour monitor, mouse, keyboard, printer etc., 6) Free slot on mother-board for ADC/DCA card installation, 7) 'Windows 98' operating system.

3.7.3.1. Installation requirements for the Machine

For the installation of the set-up suitable area (3800L × 5000 D × 2000 H) including movement space is identified and simple PCC foundations are made as per the machine requirement. Electrical supply (230 V, single phase, 5A, Max load 1kW, two plugs) for the machine and computer (through stabilizer) is arranged. Water supply (1000LPH capacity) with ½ Inch line and drain line with 1″ connection is established. A back-pressure valve is installed in the exhaust line to control the pressure as per the requirement of smoke meter. The length of the exhaust pipe is extended up to the nearest wall so that the exhaust gases are discharged outside the laboratory in the atmosphere. Additionally an exhaust fan is used to keep laboratory free from exhaust gases.

Precautions

1. Before starting the engine, check all nuts and bolt for are proper tightening and ensure proper oil level in the engine.
2. During the experimentation, power failure may stop the cooling water circulation pump. This will stop the cooling water for the engine, dynamometer and piezo sensor. In such a case the engine should be stopped immediately. Never leave the engine unattended from this point of view.
3. Use clean water, Any suspended matter may clog piping and rotameter float.
4. Pressure crank angle and other sensors are delicate instruments and should be handled carefully.

3.7.3.2. Experimentation Methodology

First the experimentation is performed with diesel (for getting the base line data of the engine) and then hemp and neem methyl ester and also its 20% blends. The performance of the engine is evaluated in terms of brake thermal efficiency, brake specific energy consumption, exhaust gas temperature, and emission of the engine is analyzed in relation with smoke, HC, CO, CO2 , O2 and NOx, It also found out economic viability.

3.7.3.3. Experimentation Procedure

1. Check for all electrical connections and proper earthing for the equipments.
2. Ensure water in the main water supply tank.
3. Ensure selected fuel about 2 litre in quantity in the fuel supply tank and fuel knob on regular position.
4. Start water pump. Set cooling water flow for engine at 300 LPH and calorimeter flow at 80 LPH. Maintain this flow rate throughout the experiment. Ensure that adequate water flow rate for dynamometer cooling and piezo sensor cooling.
5. Start electric-supply to the computer through the stabilizer and open the engine software.
6. Start two power switches provided on the set-up and set channel selector to ‘ 7’ (load) position. Set the load to minimum position using the rotary knob.
7. Start electric power supply to the smoke meter and 5-gas analyzer.
8. Start the engine by rotating the handle and operating the decompression lever. Let the engine run on the minimum load and smoke meter and gas analyzer to get warmed up simultaneously.
9. Change fuel properties (calorific value and specific gravity) in the software in the ‘configure’ option as per the fuel selected for test.
10. Choose run option in the software. Run the engine for fifteen minutes so that engine gets stabilized. Ensure that smoke meter and gas analyzer have reached their default display and then turn the fuel supply switch to metering position. Choose log option of the software. After 1 minute the display changes to input mode then enter the values of water flows in cooling jacket and calorimeter and then the file name (applicable only for the first reading) in the software. The first reading for the engine gets logged for the no load condition. Turn the fuel knob back to regular position.
11. Open the handle of the exhaust connection for inserting the gas sample probe of the 5-gas analyzer. Insert the probe. Choose NOx mode of the instrument from the display. After the reading is stabilized get the print out by choosing the print option. Note the fuel name and load value on the print out for future reference.

12. Open valve of the smoke meter connection. Adjust the back-pressure to 75 mm of Hg. By closing the back-pressure valve and take the reading for smoke when the value has stabilized. Note the fuel reference and load value on the print out for future reference.
13. Change the load to 1 bar BMEP gradually by rotating the loading knob and observing in the monitor for load value. Allow the engine to run for 10 minutes for stabilization at new load. After stabilization again turn the fuel knob to metering position and choose the log option from software. After one minute after the fuel logging is over, feed the cooling water and calorimeter flow rates and turn back the fuel knob to regular position. Take the reading of 5-gas analyzer and smoke meter as mentioned above.
14. Repeat the procedure for loads of 2, 3, 4, 5, 6, 6.5 bar BMEP.
15. Reduce the load to minimum position (no load condition) gradually ensuring that the RPM's are not shooting beyond 1550 RPM and allow the engine to stabilize.
16. Save the files with appropriate names.
17. Put off the engine and computer.
18. Allow the water pumps to be on for 15 minutes so that engine gets cooled down and then put off the pumps.

3.8. Measurement of Parameter regarding engine performance and exhaust emission

The computerised CI engine set up along with a high-speed digital data acquisition system was supplied by Apex Innovations Pvt. Ltd., Sangli, India. An eddy current dynamometer, a piezoelectric transducer and digital PT-100 type temperature sensor was calibrated and used in the setup by Apex Innovations. Following parameters were measured from the experimental CI engine setup.

1. Brake power
2. Fuel consumption
3. Air consumption
4. Exhaust gas temperature
5. Cooling water temperature (inlet and outlet)
6. Speed of the engine
7. Exhaust gas analysis (Smoke, NOx, CO_2, UBHC, CO and O_2)

3.8.1. Measurements of Performances

Brake power is one of the most important parameter in the engine experiment. The SAJ make AG 20 eddy current dynamometer was used for present investigation. The fuel consumption of an engine is measured by determining the time required for consumption of given volume of fuel using a glass burette. The mass of fuel was calculated by multiplying volumetric fuel consumption to its density. An air box with orifice meter and manometer was used for accurate volumetric measurement of air consumption and finally mass flow rate was determined. Digital PT-100 type temperature sensor was used for temperature measurement.

3.8.1.1. Brake mean effective pressure

The BMEP is an important concept for improving different fuels. It is the average pressure the engine can exert on the piston through one complete operating cycle. It is the average pressure of the gas inside the engine cylinder based on neat power. BMEP is important because it is independent of the RPM and the size of the engine. Thus, all of the following plots in this chapter will be plotted against BMEP.

3.8.1.2. Brake specific fuel consumption

It defined as the fuel flow rate per unit power output. It is a measure the efficiency of the engine in using the fuel supplied to produce work. It is desirable to obtain a lower value of BSFC meaning that the engine used less fuel to produce the same amount of work. This is one of the most important parameters to compare when testing various fuels.

3.9.1.3. Brake thermal efficiency

It is the ratio of the thermal power available in the fuel to the power the engine delivers to the crankshaft. This greatly depends on the manner in which the energy is converted since the efficiency is normalized with fuel heating value

3.9.1.4. Exhaust gas temperature

Exhaust gases of an I.C. engine contain significant enthalpy and may contain unburned combustion products (Hydrocarbon). When the air fuel ratio is high, the amount of incomplete combustion products is likely to be low, there is an insufficient amount of oxygen to complete combustion. The exhaust temperature is related to the determination of system efficiency.

3.8.2. Measurements of Emissions

3.8.2.1. Smoke Meter

There are different methods of measuring smoke density like comparison method of assessment of soot intensity compares the colour of the deposits on the filter with standard gray charts (Ringleman Charts). In a continuous filtration type method (Van Brand smoke meter) measurement of smoke density is achieved by continuously passing exhaust gas through a moving strip of filter and collecting particles on the filter. The exhaust sample is continuously passed at a constant rate through the filter. The intensity of stain is measured by the amount of light which passes through the filter and is the indication of the smoke density of the exhaust. More popularly light extinction type (Hartridge type) smoke meter is used to measure the smoke density. In this method the reduction in intensity of light beam when it passes through the smoke is used to obtain the value of smoke density and hence opacity. In the present work AVL 437-smoke meter manufactured and marketed by M/S AVL India Pvt.Ltd, Gurgaon, and tested and approved by ARAI Pune is used for measuring the smoke density. It measures the opacity of the polluted air, in particular diesel exhaust gases in a measurement chamber of defined measurement length. Opacity is the extinction of light between the light source and receiver. The smoke level or smoke density is defined as the ratio of electric output from photocell when sample is passed through the column to the electric output when clean air is passed through it. The sample of gas is fed into a chamber with non-reflective inner surfaces. The effective length of light absorption track is determined by taking into consideration possible influences of devices used to protect the light source and photocell. The effective length is 0.430±0.005 m. Light scatter on the photocell from reflections or diffused light inside the chamber is reduced to a minimum by the use of matt black light traps. The light source is an incandescent bulb with colour temperature between 2800 K to 3250 K. The receiver is a photocell with spectral sensitivity tuned to the sensitivity curve of the human eye. The entire circuit including the display is designed so that the current delivered from the photocell is a liner function of the intensity of the received light within the operating temperature range. The absorption coefficient is calculated in accordance with ECE-R24 ISO 3173. The response time of the electrical circuit, specified as the time within which the indicator reaches 90% of the full scale when a completely opaque plate is placed in front of the photocell, is between 0.9 and 1.1 seconds. The exhaust gas pressure in the measurement chamber does not deviate from the surrounding pressure by more than 75 mm water (750 Pa). The opacity measurement equipment possesses a suitable pressure sensor for measuring the pressure in the chamber. The temperature of the gas to be measured is maintained between 70 to 130 deg at each point in the measurement chamber. An appropriate temperature sensor connected to a regulator ensures that temperature in the measurement chamber is maintained at 100 ± 5 deg. The equipment has a microprocessor-controlled program sequence to check the measurement process and to store values of pressure, temperature, opacity and absorption. The portable remote unit permits results to be printed out to provide clear documentation of the vehicle/engine under test.

Smoke is only loosely related to total particulate since opacity is greater for dark smoke than for white smoke and in fact, smoke opacity may be completely uncorrelated with mass emissions of PM. In most instances, smoke opacity is used as an indicator of engine malfunction in an inspection and maintenance program. The AVL make 437 smoke meter was used to measure the smoke opacity of CI engine exhaust gas in a measurement chamber. The smoke opacity is the extinction of light between light source and receiver. A light beam is projected across a flowing stream of exhaust gases, a certain portion of light is absorbed or scattered by the suspended soot particle in the exhaust. The remaining portion of the light falls on a photocell, generating a photoelectric current, which is a measure of smoke density in Hartridge unit. The AVL smoke meter used for smoke opacity as shown in Plate 3.14.

Plate 3.14 AVL smoke meter used for smoke opacity

3.8.2.2. Five-Gas Analyzer

AVL make 5-Gas analyzer is used to measure emissions of CO, HC, CO_2, O_2 and NO. It measures CO, HC and CO_2 using infrared measurement and O_2 and NO using electrochemical measurement technique.

1. Do not allow the tester to draw exhaust gas for unnecessarily long time. Insert the probe into the exhaust pipe only when measurements are being do.
2. Before switching off the instrument, unit should be purged with clean ambient air with fan running for few minutes.
3. Instruments must be switched on once your every month to charge the lead acid battery.

4. Pre-filter, particulate filter and condensate filter must be replaced as per the schedule given in the manual.
5. Empty and clean the condensate trap (on the back-side) when it is half full.
6. Perform leak check operation once a day preferably at the beginning of the reading for that day.
7. Insert the probe at least 30 cm into the exhaust pipe.

The AVL DiGas 4000 five gas analyzer was used to measure NOx, CO_2, UBHC, CO and O_2 of CI engine exhaust gas in a measurement chamber. An infrared exhaust gas analyzer was used for the measurement of HC/CO/ CO_2 in the exhaust. For measuring NOx/ O_2, an electrochemical analyzer was utilised. The AVL Diagas 4000 gas analyzer used for exhaust gases as shown in Plate 3.15.

Plate 3.15 AVL Digas 4000 Five gas analyser used for NOx, CO_2, UBHC, CO and O_2

CHAPTER 4

RESULTS AND DISCUSSION

Worldwide, biodiesel is largely produced by methyl transesterification of edible and non edible oils. The concept of methyl transesterification is gaining attention as ethanol is derived from renewable biomass sources. The studies were, therefore, conducted on standardizing methyl transesterification process parameters for raw hemp oil and filtered neem oil, characteristic fuel properties of diesel, raw hemp oil, filtered neem oil, methyl esters of hemp and neem oil and their 20% blends with diesel. The fuel consumption test and rating test of a 5.2 kW, constant speed CI engine was also conducted to evaluate the performance of the engine on diesel and methyl esters of hemp and neem oil with diesel.

The recovery of ester as well as its kinematic viscosity is affected by the transesterification process parameters such as catalyst concentration, reaction temperature and reaction time, preheating temperature, molar ratio used. The above parameters were standardized to obtain methyl ester of hemp and neem oil with lowest possible kinematic viscosity and highest level of recovery. The fuel properties such as kinematic viscosity, relative density, gross heat of combustion, cloud and pour point, flash and fire point, ash content, carbon content and total acidity of diesel, raw hemp oil, filtered neem oil, and methyl ester of hemp and neem oil as well as their 20% blends with diesel were compared.

A 5.2 kW, stationary, constant speed, single cylinder,4-stroke diesel engine having a standard injection timing of 23° BTDC was tested on diesel and selected hemp and neem oil, hemp and neem methyl ester, 20% blends of hemp and neem oil, 20% blends of their methyl esters. The brake thermal efficiency, fuel consumption, brake specific fuel consumption, exhaust gas temperature and emission of smoke opacity, carbon monoxide, carbon dioxide, oxygen level, and oxides of nitrogen were measured. The results of parameters measured and their analytical interpretation with discussion are presented in this chapter.

4.1 Standardization of Transesterification Process Parameters regarding hemp methyl ester

Transesterification of vegetable oils is done to significantly reduce its viscosity by separating glycerol content from it. The separation of glycerol is influenced by the parameters such as molar ratio, preheating time, preheating temperature, catalyst type, catalyst concentration, reaction time, reaction and temperature, etc. The recovery of ester and reduction in kinematic viscosity of a vegetable oil due to separation of glycerol largely depend on selecting the appropriate process parameters as mentioned below. Table 4.1, 4.2, and 4.3 revealed ester recovery and its kinematic viscosity regarding HME with different preheating temperature (55℃, 60℃ & 65℃).

Table 4.1 Ester recovery and its respective kinematic viscosity regarding hemp methyl ester (Preheating temperature = 55℃)

Preheating Temperature ^{0}C	Reaction Temperature ^{0}C	Reaction Time Min	Catalyst Con. %	Methanol Quantity gm	Molar Ratio	Settling Time hr	Ester Recovery %	Kinematc Viscosity cSt
55	60	75	3	82	8:1	24	Ester not formed	-
55	60	75	2	82	8:1	24	74.82	2.19
55	60	75	1	82	8:1	24	Ester not formed	-
55	60	60	3	82	8:1	24	84.76	2.76
55	60	60	2	82	8:1	24	Ester not formed	-
55	60	60	1	82	8:1	24	Ester not formed	-
55	60	45	3	82	8:1	24	Ester not formed	-
55	60	45	2	82	8:1	24	83.67	6.55
55	60	45	1	82	8:1	24	87.49	5.22
55	60	75	3	61	6:1	24	76.75	1.64
55	60	75	2	61	6:1	24	86.56	1.52
55	60	75	1	61	6:1	24	82.93	2.14
55	60	60	3	61	6:1	24	78.89	2.9
55	60	60	2	61	6:1	24	70.15	2.73
55	60	60	1	61	6:1	24	90.77	5.17
55	60	45	3	61	6:1	24	79.10	2.35
55	60	45	2	61	6:1	24	90.63	1.13
55	60	45	1	61	6:1	24	93.32	4.25
55	60	75	3	41	4:1	24	85.11	1.61
55	60	75	2	41	4:1	24	93.38	3.22
55	60	75	1	41	4:1	24	93.16	1.87
55	60	60	3	41	4:1	24	77.91	5.02
55	60	60	2	41	4:1	24	92.32	2.93

55	60	60	1	41	4:1	24	82.47	2.17
55	60	45	3	41	4:1	24	87.12	1.76
55	60	45	2	41	4:1	24	93.89	2.38
55	60	45	1	41	4:1	24	89.26	2.15

Table 4.2 Ester recovery and its respective kinematic viscosity regarding hemp methyl ester (Preheating temperature = 60℃)

Preheating Temperature ^{0}C	Reaction Temperature ^{0}C	Reaction Time Min	Catalyst Con. %	Methanol Quantity gm	Molar Ratio	Settling Time hr	Ester Recovery %	Kinematc Viscosity cSt
60	60	75	3	82	8:1	24	Low yield	Not detected
60	60	75	2	82	8:1	24	63.67	5.64
60	60	75	1	82	8:1	24	Ester not formed	-
60	60	60	3	82	8:1	24	77.63	6.72
60	60	60	2	82	8:1	24	Ester not formed	-
60	60	60	1	82	8:1	24	Ester not formed	-
60	60	45	3	82	8:1	24	Low yield	Not detected
60	60	45	2	82	8:1	24	Low yield	Not detected
60	60	45	1	82	8:1	24	84.99	10.87
60	60	75	3	61	6:1	24	Low yield	Not detected
60	60	75	2	61	6:1	24	Ester not formed	-
60	60	75	1	61	6:1	24	82.72	14.75
60	60	60	3	61	6:1	24	Ester not formed	-
60	60	60	2	61	6:1	24	Low yield	Not detected
60	60	60	1	61	6:1	24	76.84	9.72
60	60	45	3	61	6:1	24	Ester not formed	-
60	60	45	2	61	6:1	24	75.50	5.77
60	60	45	1	61	6:1	24	88.68	10.34
60	60	75	3	41	4:1	24	77.68	14.39
60	60	75	2	41	4:1	24	62.99	13.88
60	60	75	1	41	4:1	24	85.64	14.22
60	60	60	3	41	4:1	24	80.78	14.98

60	60	60	2	41	4:1	24	Ester not formed	-
60	60	60	1	41	4:1	24	83.57	15.98
60	60	45	3	41	4:1	24	73.69	15.22
60	60	45	2	41	4:1	24	85.66	15.68
60	60	45	1	41	4:1	24	83.90	15.03

Table 4.3 Ester recovery and its respective kinematic viscosity regarding hemp methyl ester (Preheating temperature = 65℃)

Preheating Temperature ^{0}C	Reaction Temperature ^{0}C	Reaction Time Min	Catalyst Con. %	Methanol Quantity gm	Molar Ratio	Settling Time hr	Ester Recovery %	Kinematc Viscosity cSt
65	60	75	3	82	8:1	24	Low yield	Not detected
65	60	75	2	82	8:1	24	69.68	7.39
65	60	75	1	82	8:1	24	85.81	5.30
65	60	60	3	82	8:1	24	Low yield	Not detected
65	60	60	2	82	8:1	24	72.62	6.99
65	60	60	1	82	8:1	24	-	-
65	60	45	3	82	8:1	24	71.81	17.69
65	60	45	2	82	8:1	24	Low yield	Not detected
65	60	45	1	82	8:1	24	87.48	7.88
65	60	75	3	61	6:1	24	-	-
65	60	75	2	61	6:1	24	87.86	5.92
65	60	75	1	61	6:1	24	86.09	4.15
65	60	60	3	61	6:1	24	-	-
65	60	60	2	61	6:1	24	85.67	4.58
65	60	60	1	61	6:1	24	75.98	5.04
65	60	45	3	61	6:1	24	-	-
65	60	45	2	61	6:1	24	78.79	6.22
65	60	45	1	61	6:1	24	85.80	5.82
65	60	75	3	41	4:1	24	79.49	5.76
65	60	75	2	41	4:1	24	89.80	5.29
65	60	75	1	41	4:1	24	87.75	5.77
65	60	60	3	41	4:1	24	77.60	5.47

65	60	60	2	41	4:1	24	88.48	5.38
65	60	60	1	41	4:1	24	78.72	6.76
65	60	45	3	41	4:1	24	71.69	7.21
65	60	45	2	41	4:1	24	87.96	6.91
65	60	45	1	41	4:1	24	87.36	7.55

4.2. Alkaline transesterification of hemp oil

In single stage process the methanol oil ratio 0.408 to 0.816 w/w and alkali catalyst (KOH) 0.01 to 0.03. % w/w is pre-mixed in a flask and added rapidly in to oil. The mixture is put into water bath shaker and stirred and heated for about 0.75-1.15 hrs at 60^{o}C. The rate of stirring in the start was more vigorous in the range of 650-700 rpm and it reduced to 450-500 rpm after the mixture temperature attained 60^{o}C. After the reaction is over within the specified time period the mixture is poured in to a separating flask and kept overnight for settling. The upper layer is methyl ester (biodiesel) and lower dark layer is glycerol, bi-product of transesterification process as shown in Fig. 4.1. The ester layer is washed using hot water spraying over its surface, two to three times till neutralization, settled overnight and discard the water residual catalyst bottom layer as shown in Fig. 4.2. Lastly ester layer is dried using silica gel (fig. 4.3) by dropping the ester through the silica bed. Now the pure biodiesel is ready for using in diesel engine. The complete phase separation shown by fig 4.4.The result obtained during the trials are tabulated and analyzed here. The result obtained indicated that oil methanol ratio of 0.37w/w and 0.01 %w/w alkali catalyst produced yield of 90.625% ester whereas oil methanol ratio of 0.287w/w and 0.014 %w/w alkali catalyst produced yield of 93.886% ester.

Fig. 4.1

Fig. 4.2

Fig. 4.3

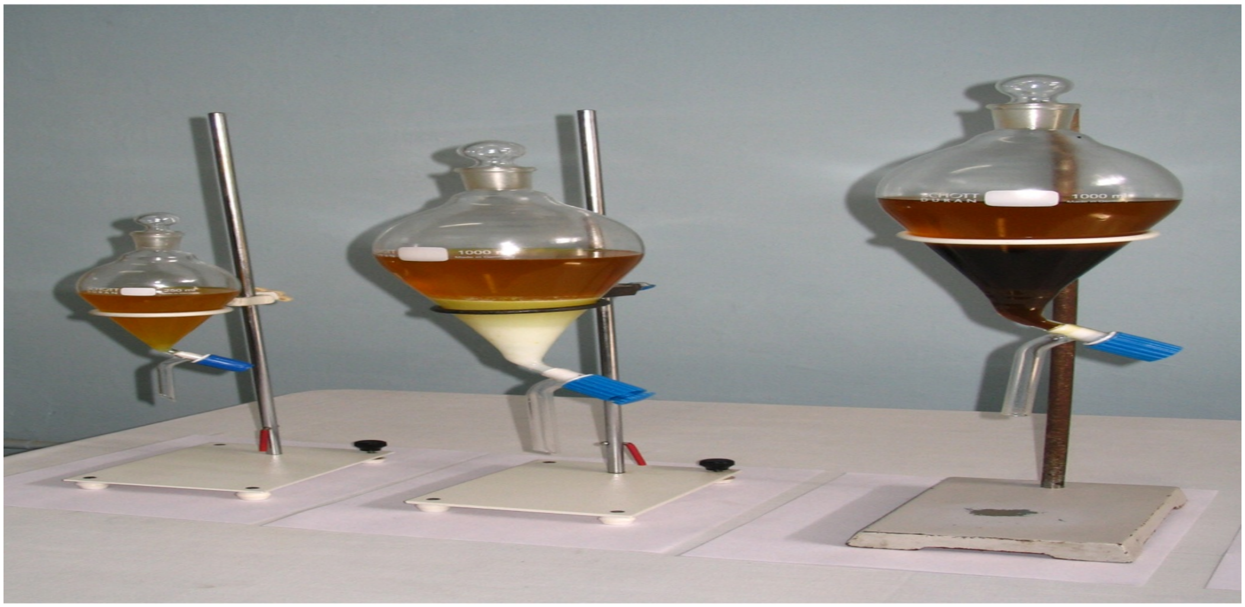


Fig. 4.4 Complete phase separation of hemp methyl ester

Fig.4.1 Separation of hemp methyl ester from glycerol

Fig. 4.2 Hemp methyl ester after water wash

Fig.4.3 Hemp methyl ester after silica gel

Fig. 4.4 Complete phase separation of hemp methyl ester

4.2.1. Effect of ester recovery

Table 4.4 shows the percent methyl ester recovered by esterification process carried out at different quantity of methanol used, catalyst concentration and reaction temperature. It is evident from the table that the recovery of hemp methyl esters observed at different process parameters varied between 62.99 to 93.89 percent. It is, therefore, seen that highest recovery of 93.89 of methyl ester was obtained at 4:1 molar ratio when raw hemp oil was reacted with 0.37w/w at 60^0 C for 45 minute in presence of 2 percent KOH and then allowed to settle for 24 hr. After the reaction is over within the specified time period the mixture is poured in to a separating flask and kept overnight for settling. The upper layer is methyl ester (biodiesel) and lower dark layer is glycerol, The ester layer is washed using hot water spraying over its surface, two to three times till neutralization, settled overnight and discard the water residual catalyst bottom layer Lastly ester layer is dried using silica gel by dropping the ester through the silica bed. Now the pure biodiesel is ready for using in diesel engine. Out of 81 experiments, 14 experiments shows unsuccessful in nature and 9 experiments have seen in low yield with high glycerol content and remaining experiments reveals that successful in nature. While increasing the molar ratio along with reaction temperature and catalyst concentration, it observed that ester doesn't give good result. The maximum recovery of esters have observed at different preheating temperature (55℃, 60℃ & 65℃) i.e. 93.89%,88.68% and 89.80% respectively.

Table 4.4 :-Optimized process parameters for maximum yield of ester regarding hemp methyl ester

Preheating Temperature (^{0}C)	Reaction Temperature (^{0}C)	Reaction Time (Min.)	Catalyst Concentration (%)	Molar Ratio	Max. Ester Yield (%)	Kinematic viscosity (cSt)
55	60	45	2	4:1	93.89	2.38
60	60	45	1	6:1	88.68	10.34
65	60	75	2	4:1	89.80	5.29

4.2.2. Effect of kinematic viscosity

Table 4.5 showed the kinematic viscosity of hemp methyl esters obtained by esterification of raw hemp oil at the selected process conditions. It is evident that the methyl esters obtained from esterification of raw hemp oil at different process conditions ranged between 1.125 to 17.69 cSt.

The lowest viscosity of esters have observed at different preheating temperature (55℃, 60℃ and 65℃) i.e. 1.13Cst, 5.64Cst and 4.15 cSt. It is, therefore, seen that lowest viscosity of 1.13 cSt .of hem p methyl ester was obtained at 6:1 molar ratio when the raw hemp oil reacted with methanol at 60^0 C reaction temperature for 45 minute in presence of 2 percent KOH and then allowed to settle for 24 h.

Table 4.5 :-Optimized process parameters for lowest viscosity of ester regarding hemp methyl ester

Preheating Temperature (^{0}C)	Reaction Temperature (^{0}C)	Reaction Time (Min.)	Catalyst Concentration (%)	Molar Ratio	Ester Recovery (%)	Lowest viscosity (cSt)
55	60	45	2	6:1	90.63	1.13
60	60	75	2	8:1	63.67	5.64
65	60	75	1	6:1	86.09	4.15

4.2.3. Effect of preheating temperature

The preheating of vegetable oil is used to resolve the fuel filter clogging problem and also improve engine performance. The high molecular weight and the chemical structure of vegetable oils contribute to their high viscosity. The high viscosity of vegetable oils deteriorates the atomization, evaporation and air fuel mixture formation characteristics leading to improper combustion and higher smoke emission. The preheating of hemp oil is help to lower viscosity of hemp oil and provided smooth fuel flow. In the present work, experiments have been done using preheating temperature (55^0C, 60^0C and 65^0C) to reduce viscosity and easy to support transesterification process to produce hemp methyl ester from raw hemp oil. If preheating temperature are increased, there will be slight reduction in the conversion. This is because high temperature enhances transesterification and saponification reactions.

4.2.4. Effect of molar ratio

One of the most important parameters affecting the yield of ester is the molar ratio of alcohol to vegetable oil. Molar ratio is the ratio of number of moles of alcohol to number of moles of triglycerides in the oil. Theoretically, transesterification reaction requires three moles of alcohol for each mole of oil. However, in practice, the molar ratio should be higher than that of stiochiometric ratio in order to drive the reaction towards completion. In present research, methanol was used. The effect of methanol in the presence of 4:1, 6:1 and 8:1 (molar ratio) was investigated, keeping other process parameters fixed. The reaction temperature was kept constant at 60℃. The reaction was performed with different concentration of KOH. The result as shown in table 4.1,4.2, & 4.3 It was found that the ester recovery decreases with increases in molar ratio (6:1 and 8:1) and for low values of molar ratio (4:1), the ester recovery gain in higher quantity. The maximum conversion efficiency is achieved very close to the molar ratio of 4:1.

4.2.5. Effect of catalyst concentration

The effect of KOH concentration was studied in the range of 0.01-0.03% (weight of KOH/weight of oil).The reaction temperature was kept constant at 60^{o}c.The results for different molar ratios of methanol to oil are shown in table 4.1, 4.2 & 4.3. It was found that the ester recovery increases as the amount of catalyst decreased from 3-1%.Ester recovery decreases drastically as KOH concentration increases above 2% whereas ester recovery increase as KOH concentration reduces to almost 1%. This lesser recovery at high KOH concentration may possibly be due to high soap formation. It also shows that the lowest molar ratio of alcohol to oil, lesser amount of KOH can be used. As far as viscosity is concerned, 2% KOH shows better results than 1% and 3% KOH. The viscosity of brown hemp methyl ester is found to be within the ASTM limits. The excess KOH reduces the recovery and also leads to undesirable extra processing cost because it is necessary to remove it from the reaction products at the end.

4.2.6. Effect of reaction time

Several investigators found that the reaction starts very fast and almost 80% of the conversion takes place in first 5 min, and after 1 hr, almost 93-98% conversion of the triglycerides into ester takes place. In the present work, the effect of reaction time from 45 min to 75 min on the reaction recovery is evaluated. Table 4.1, 4.2, & 4.3 observed that the reaction time was increased beyond 1hr, the ester yield decreased slightly. In order to achieve perfect contact between the reagents and the oil during transesterification, they must be stirred well at constant rate. The results obtained from the present experiments with hemp oil, reveal that, about 45 min of reaction is sufficient for the completion of the esterification. The variation in ester recovery was sensitive to reaction temperature of brown hemp oil. Excess methanol in the ester decreases the flash point of the ester. The excess methanol can be removed by washing. The HME with different preheating temperature (55^0C, 60^0C and 65^0C) as shown in Plate 4.1. The sample of HO, HME and its 20% blends as shown in Plate 4.2 and Plate 4.3 shows HME used for C.I. engine testing.

Preheating temperature = 65℃ Preheating temperature = 60℃

Preheating temperature = 55℃

Plate 4.1 Hemp methyl ester with different preheating temperature

Plate 4.2 Hemp oil, hemp methyl ester and its 20% blends

Plate 4.3 Hemp methyl ester used for C.I. engine testing

4.3 Standardization of transesterification process parameters regarding neem methyl ester

Transesterification of vegetable oils is done to significantly reduce its viscosity by separating glycerol content from it. The glycerol present in oil is separated when the oil is reacted with methyl, ethyl or butyl alcohol using either alkaline or acidic catalyst. The separation of glycerol is influenced by the parameters such as molar ratio, preheating time, preheating temperature, catalyst type, catalyst concentration, reaction time, reaction and temperature, etc. The recovery of ester and reduction in kinematic viscosity of a vegetable oil due to separation of glycerol largely depend on selecting the appropriate process parameters as mentioned below. The table 4.6, 4.7, and 4.8 reveals ester recovery and its respective kinematic viscosity regarding NME with different preheating temperature (55^0C, 60^0C and 65^0C).

Table 4.6 Ester recovery and its respective kinematic viscosity regarding neem methyl ester (Preheating temperature = 55℃)

Preheating Temperature ^{0}C	Reaction Temperature ^{0}C	Reaction Time Min	Catalyst Con. %	Methanol Quantity gm	Molar Ratio	Settling Time hr	Ester Recovery %	Kinematc Viscosity cSt
55	60	45	1	36	4:1	24	84.01	21.52
55	60	45	2	36	4:1	24	69.55	13.34
55	60	45	3	36	4:1	24	Low Yield	Not detected
55	60	60	1	36	4:1	24	87.17	23.57
55	60	60	2	36	4:1	24	60.95	11.7
55	60	60	3	36	4:1	24	Low Yield	Not detected
55	60	75	1	36	4:1	24	83.99	21.9
55	60	75	2	36	4:1	24	52.95	15.72
55	60	75	3	36	4:1	24	41.53	11.21
55	60	45	1	27	6:1	24	77.03	29.68
55	60	45	2	27	6:1	24	78.44	20.09
55	60	45	3	27	6:1	24	Low Yield	Not detected
55	60	60	1	27	6:1	24	80.41	28.45
55	60	60	2	27	6:1	24	83.36	2.674
55	60	60	3	27	6:1	24	51.59	16.67
55	60	75	1	27	6:1	24	84.37	20.08
55	60	75	2	27	6:1	24	61.34	7.96
55	60	75	3	27	6:1	24	59.74	21.71
55	60	45	1	18	8:1	24	82.16	25.93
55	60	45	2	18	8:1	24	79.58	20.64
55	60	45	3	18	8:1	24	Low Yield	Not detected
55	60	60	1	18	8:1	24	81.56	22.9
55	60	60	2	18	8:1	24	74.38	18.04
55	60	60	3	18	8:1	24	61.38	12.44

55	60	75	1	18	8:1	24	80.65	31.9
55	60	75	2	18	8:1	24	Low Yield	Not detected
55	60	75	3	18	8:1	24	67.69	13.97

Table 4.7 Ester recovery and its respective kinematic viscosity regarding neem methyl ester (Preheating temperature = 60℃)

Preheating Temperature ^{0}C	Reaction Temperature ^{0}C	Reaction Time Min	Catalyst Con. %	Methanol Quantity gm	Molar Ratio	Settling Time hr	Ester Recovery %	Kinematc Viscosity cSt
60	60	45	1	36	4:1	24	Low Yield	Not detected
60	60	45	2	36	4:1	24	74.66	13.73
60	60	45	3	36	4:1	24	50.43	10.84
60	60	60	1	36	4:1	24	84.71	20.5
60	60	60	2	36	4:1	24	66.47	8.4
60	60	60	3	36	4:1	24	Low Yield	Not detected
60	60	75	1	36	4:1	24	Low Yield	Not detected
60	60	75	2	36	4:1	24	Low Yield	Not detected
60	60	75	3	36	4:1	24	Low Yield	Not detected
60	60	45	1	27	6:1	24	71.28	25.86
60	60	45	2	27	6:1	24	Low Yield	Not detected
60	60	45	3	27	6:1	24	Low Yield	Not detected
60	60	60	1	27	6:1	24	80.14	8.78
60	60	60	2	27	6:1	24	63.21	8.65
60	60	60	3	27	6:1	24	62.24	22.3
60	60	75	1	27	6:1	24	Low Yield	Not detected
60	60	75	2	27	6:1	24	75.54	21.5
60	60	75	3	27	6:1	24	60.36	18.04
60	60	45	1	18	8:1	24	72.22	25.73
60	60	45	2	18	8:1	24	74.95	19.84
60	60	45	3	18	8:1	24	58.09	21.27
60	60	60	1	18	8:1	24	87.69	3.06
60	60	60	2	18	8:1	24	75.68	20.92
60	60	60	3	18	8:1	24	82.87	18.01

60	60	75	1	18	8:1	24	69.83	23.9
60	60	75	2	18	8:1	24	76.81	21.42
60	60	75	3	18	8:1	24	61.52	13.29

Table 4.8 Ester recovery and its respective kinematic viscosity regarding neem methyl ester (Preheating temperature = 65℃)

Preheating Temperature ^{0}C	Reaction Temperature ^{0}C	Reaction Time Min	Catalyst Con. %	Methanol Quantity gm	Molar Ratio	Settling Time hr	Ester Recovery %	Kinematc Viscosity cSt
65	60	45	1	36	4:1	24	68.2	22.05
65	60	45	2	36	4:1	24	62.49	14.73
65	60	45	3	36	4:1	24	Low Yield	Not detected
65	60	60	1	36	4:1	24	77.20	24.67
65	60	60	2	36	4:1	24	62.02	8.49
65	60	60	3	36	4:1	24	56.36	9.87
65	60	75	1	36	4:1	24	82.61	28.87
65	60	75	2	36	4:1	24	64.44	8.66
65	60	75	3	36	4:1	24	58.53	12.20
65	60	45	1	27	6:1	24	Low Yield	Not detected
65	60	45	2	27	6:1	24	65.71	20.37
65	60	45	3	27	6:1	24	Low Yield	Not detected
65	60	60	1	27	6:1	24	Low Yield	Not detected
65	60	60	2	27	6:1	24	51.65	26.42
65	60	60	3	27	6:1	24	Low Yield	Not detected
65	60	75	1	27	6:1	24	69.14	24.01
65	60	75	2	27	6:1	24	54.9	20.55
65	60	75	3	27	6:1	24	50.17	12.11
65	60	45	1	18	8:1	24	75.82	25.64
65	60	45	2	18	8:1	24	Low Yield	Not detected
65	60	45	3	18	8:1	24	Low Yield	Not detected
65	60	60	1	18	8:1	24	74.63	22.91
65	60	60	2	18	8:1	24	Low Yield	Not detected
65	60	60	3	18	8:1	24	Low Yield	Not detected
65	60	75	1	18	8:1	24	79.45	29.66
65	60	75	2	18	8:1	24	Low Yield	Not detected
65	60	75	3	18	8:1	24	50.30	11.64

4.4. Alkaline transesterification of neem oil

In single stage process the methanol oil ratio 0.178 to 0.356 w/w and alkali catalyst (KOH) 0.01 to 0.03. % w/w is pre-mixed in a flask and added rapidly in to oil. The mixture is put into water bath shaker and stirred and heated for about 0.75-1.15 hrs at 60°C. The rate of stirring in the start was more vigorous in the range of 650-700 rpm and it reduced to 450-500 rpm after the mixture temperature attained 60°C. After the reaction is over within the specified time period the mixture is poured in to a separating flask and kept overnight for settling. The upper layer is methyl ester (biodiesel) and lower dark layer is glycerol, bi-product of transesterification process as shown in Fig. 4.5. The ester layer is washed using hot water spraying over its surface, two to three times till neutralization, settled overnight and discard the water residual catalyst bottom layer as shown in Fig. 4.6. Lastly ester layer is dried using silica gel (Fig. 4.7) by dropping the ester through the silica bed. Now the pure biodiesel is ready for using in diesel engine. The complete phase separation shown in Fig.4.8. The result obtained during the trials are tabulated and analyzed here. The result obtained indicated that oil methanol ratio of 0.21w/w and 0.016 %w/w alkali catalyst produced yield of 83.360 % ester whereas oil methanol ratio of 0.257w/w and 0.0075 %w/w alkali catalyst produced yield of 87.694 % ester.

Fig 4.5

Fig4.6

Fig 4.7

Figure 4.5 Separation of neem methyl ester from glycerol

Figure 4.6 Neem methyl ester after water wash

Figure 4.7 Neem methyl ester after silica gel

Figure 4.8 Complete phase separation of neem methyl ester

Fig. 4.8 Complete phase separation of neem methyl ester

4.4.1. Effect of ester recovery

Table 4.9 showed the percent methyl ester recovered by esterification process carried out at different molar ratio used, catalyst concentration and reaction temperature. It is evident from the table that the recovery of hemp methyl esters observed at different process parameters varied between 41.53 to 87.69 percent. It is, therefore, seen that highest recovery of 87.69% of methyl ester was obtained at 8:1 molar ratio when raw neem oil was reacted with 0.37 w/w at 60^0 C for 60 minute in presence of 1 percent KOH and then allowed to settle for 24 h. The recovery of high quality glycerol as a ester byproduct is primary options to be considered to lower the cost of ester. On one hand, we decreasing the molar ratio, it shows low yield On the other hand, we increasing the molar ratio, it improves conversion efficiency of methyl ester. Out of 81 experiments, only 21 experiments gives low yield with high glycerol content. All experiments reported as a successful in nature, however 25% an experiment shows low conversion efficiency of methyl ester. The maximum esters recoveries have observed at different preheating temperature (55℃, 60℃ and 65℃) i.e. 87.17%, 87.69% and 82.61%.

Table 4.9 Optimized Process Parameters for Maximum ester recovery regarding neem methyl ester

Preheating Temperature (^{0}C)	Reaction Temperature (^{0}C)	Reaction Time (Min.)	Catalyst Con. (%)	Molar Ratio	Max. Ester Recovery (%)	Kinematic viscosity (cSt)
55	60	60	1	4:1	87.17	23.57
60	60	60	1	8:1	87.69	3.06
65	60	75	1	4:1	82.61	28.87

4.4.2. Effect of kinematic viscosity

Table 4.10 showed the kinematic viscosity of methyl esters obtained by esterification of raw neem oil at the selected process conditions. It is evident from the table that the methyl esters obtained from esterification of raw neem oil at different process conditions ranged between 2.7 to 29.66 cSt. It is, therefore, seen that lowest viscosity of 2.7 cSt. of neem methyl ester was obtained at 6:1 molar ratio when the raw hemp oil reacted with methanol at 60^0 C reaction temperature for 60 minute in presence of 2 percent KOH and then allowed to settle for 24 hr. The lowest viscosities of esters have observed at different preheating temperature (55℃, 60℃ and 65℃) i.e. 2.674 cSt, 3.06 cSt and 8.49 cSt. It reported as the viscosity at 25 ^{0} C is 8.8 centipoise at the same time viscosity of diesel is 6.8 centipoise [1].

Table 4.10 Optimized Process Parameters for Lowest viscosity of ester regarding neem methyl ester

Preheating Temperature (^{0}C)	Reaction Temperature (^{0}C)	Reaction Time (Min.)	Catalyst Con. (%)	Molar Ratio	Lowest viscosity (cSt)	Ester Recovery (%)
55	60	60	2	6:1	2.674	83.36
60	60	60	1	8:1	3.06	87.69
65	60	60	2	4:1	8.49	62.02

4.4.3. Effect of preheating temperature

The preheating of vegetable oil is used to resolve the fuel filter clogging problem and also improve engine performance. The high molecular weight and the chemical structure of vegetable oils contribute to their high viscosity. The high viscosity of vegetable oils deteriorates the atomization, evaporation and air fuel mixture formation characteristics leading to improper combustion and higher smoke emission. The preheating of neem oil is help to lower viscosity of neem oil and provided smooth fuel flow. In the present work, experiments have been done using preheating temperature (55^0C, 60^0C and 65^0C) to reduce viscosity and easy to support transesterification process to produce neem methyl ester from filtered neem oil. If preheating temperature is increased, there will be slight reduction in the conversion. This is because high temperature enhances transesterification and saponification reactions. But molar ratio having (8:1), preheating temperature improves the ester recovery.

4.4.4. Effect of molar ratio

One of the most important parameters affecting the yield of ester is the molar ratio of alcohol to vegetable oil. Molar ratio is the ratio of number of moles of alcohol to number of moles of triglycerides in the oil. Theoretically, transesterification reaction requires three moles of alcohol for each mole of oil. However, in practice, the molar ratio should be higher than that of stiochiometric ratio in order to drive the reaction towards completion. In present research, methanol was used. The effect of methanol in the presence of 4:1, 6:1 and 8:1 (molar ratio) was investigated, keeping other process parameters fixed. The reaction temperature was kept constant at 60℃. The reaction was performed with different concentration of KOH. It was found that the ester recovery increases with increases in molar ratio (6:1 and 8:1) and for low values of molar ratio (4:1), the reduction in ester recovery takes place. The maximum conversion efficiency is achieved very close to the molar ratio of 8:1. The molar ratio of 6:1 reported as best that is useful for engine performance by considering viscosity.

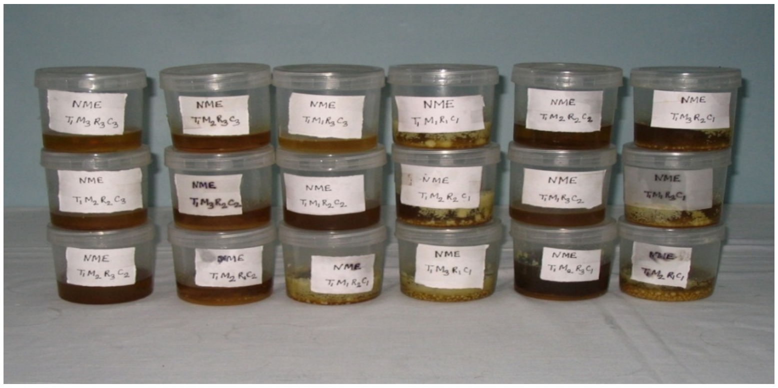
4.4.5. Effect of catalyst concentration

The effect of KOH concentration was studied in the range of 0.01-0.03% (weight of KOH/weight of oil).The reaction temperature was kept constant at 60℃. The results for different molar ratios of methanol to oil are shown in table 4.6, 4.7 & 4.8. It was found that the ester recovery increases as the amount of catalyst decreased from 3-1%. Ester recovery decreases drastically as KOH concentration increases above 1% whereas ester recovery increase as KOH concentration reduces to almost 1%. This lesser recovery at high KOH concentration may possibly be due to high soap formation. It also shows that the lowest molar ratio of alcohol to oil, lesser amount of KOH can be used. As per as viscosity is concern, 2% KOH shows better results than 1% and 3% KOH. The viscosity of neem methyl ester is found to be within the ASTM limits. The excess

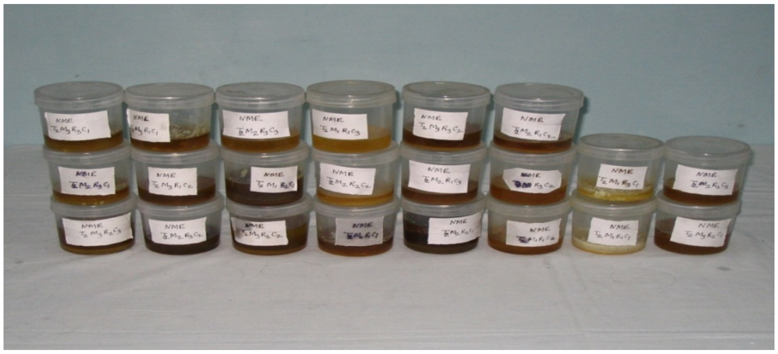
KOH reduces the recovery and also leads to undesirable extra processing cost because it is necessary to remove it from the reaction products at the end.

4.4.6. Effect of reaction time

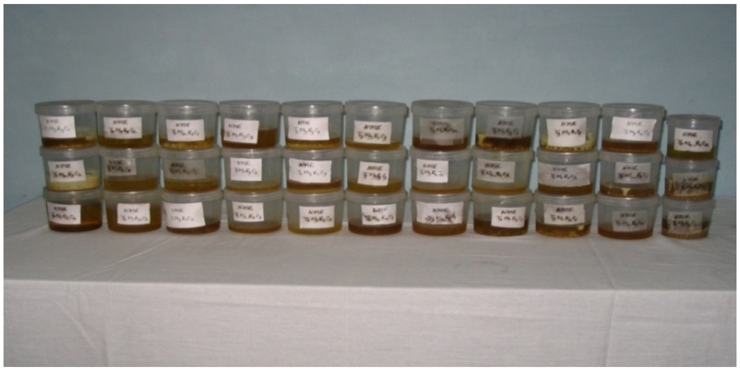
Several investigators found that the reaction starts very fast and almost 80% of the conversion takes place in first 5 min, and after 1 hr, almost 93-98% conversion of the triglycerides into ester takes place. In the present work, the effect of reaction time from 45 min to 75 min on the reaction recovery is evaluated. It is observed from table 4.6, 4.7 and 4.8 that the reaction time was increased beyond 1hr, the ester yield decreased slightly. In order to achieve perfect contact between the reagents and the oil during transesterification, they must be stirred well at constant rate. The results obtained from the present experiments with neem oil, reveal that, about 60 min of reaction is sufficient for the completion of the esterification. The variation in ester recovery was sensitive to reaction temperature of neem oil.



Preheating temperature = 65℃



Preheating temperature = 60℃



Preheating temperature = 55℃

Plate 4.4 Neem methyl ester with different preheating temperature

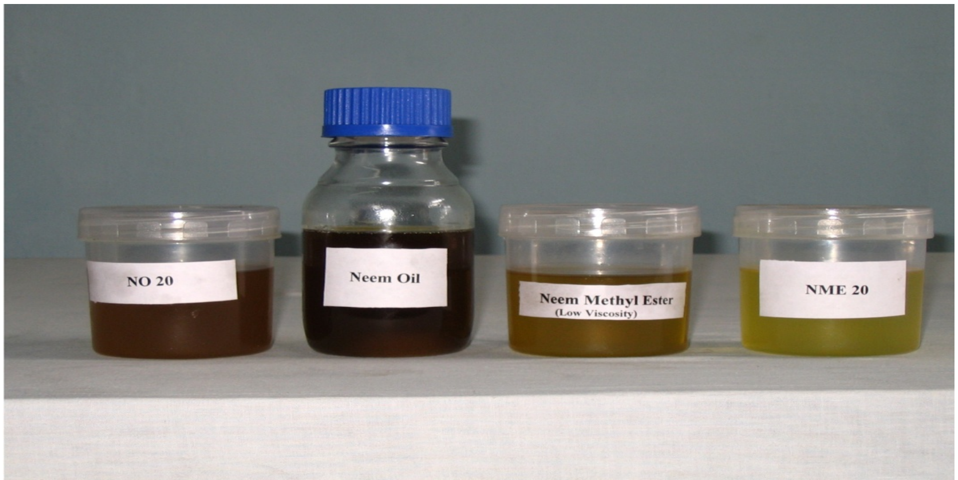


Plate 4.5 Neem oil, Neem methyl ester and its 20% blends

Plate 4.6 Neem methyl ester used for C.I. engine testing

4.5. Fuel Characterization

4.5.1. Characterization of Hemp oil and Neem oil

4.5.1.1. Relative density

The relative densities of hemp oil and hemp methyl ester were observed 6.99 and 3.37 percent higher than that of diesel respectively. The experimental results indicated that the relative density of hemp methyl ester is slightly increased to that of diesel.

4.5.1.2. Kinematic viscosity

The kinematic viscosity of diesel, hemp oil and hemp methyl ester were found as 2.6, 42.72, and 1.13 centistokes at 40^0C hemp methyl ester had the kinematic viscosity 56.54 percent less than that of diesel. The results indicated that the hemp oil was observed the kinematic viscosity percent more than that of diesel.

4.5.1.3. Flash and fire point

The hemp methyl ester was found to have lower flash and fire point than those of diesel. The flash and fire point of hemp oil was found to be higher than those of diesel.

4.5.1.4. Cloud and Pour Point

The results thus indicate that pour point of hemp methyl ester is higher than that of diesel whereas cloud point of hemp methyl ester is lower than that of diesel. The result also shows that the cloud and pour point of hemp oil is lower than those of diesel.

4.5.1.5. Calorific value

The calorific value of diesel, hemp oil and hemp methyl ester and were found as 43, 43.52, and 42.92 MJ/Kg respectively. The calorific value of hemp oil is increased by 1.21% than that of diesel respectively whereas the calorific value of hemp methyl ester is decreased by 0.19% than that of diesel.

4.5.1.6. Free Fatty Acid Content

The FFA content of hemp oil and neem oil were found as 0.175% and 0.403% respectively.

4.5.1.7. Moisture Content

The moisture content of diesel was observed as 0.02%. The moisture content of neem oil and hemp oil were higher than that of diesel fuel.

4.5.1.8. Cetane Number

The cetane number of diesel, hemp oil and neem oil were found as 55, 56 and 57.83 respectively.

4.5.1.9. Saponification Number

The saponification numbers of hemp and neem oil were observed 193 and 196 respectively.

4.5.1.10. Acid Value

Acid values of hemp and neem oil were found to be increased with diesel. The fuel properties of hemp and neem oil as shown in Table 4.11.

Table 4.11 Fuel properties of hemp and neem oil compared to diesel

Properties	**Units**	**HO**	**NO**	**Diesel**	**ASTM D6751**	**EN 14214**
Density (15℃)	Kg/m3	883	920	830	-	860-900
Viscosity (40℃)	cSt	42.72	35.83	3.7	1.9-6.0	3.5-5.0
Flash point℃		125	100	60	>130	>101
Fire point℃		135	109	65	-	Min 120
Cloud point ℃		2	19	-12	10	-1
Pour point℃		-10	10	-16	-15	-
Calorific value	MJ/Kg	43.52	44.65	43	-	-
Acid value	mg KOH/g	0.35	0.81	0.22	<0.8	<0.5
Free Fatty Acid	%	0.175	0.403	-	-	-
Moisture content	w/w%	0.22	0.24	-	<0.03	-
Cetane number		56	57.83	-	48-60	Min. 51
Saponification number		193	196	-	-	-

4.5.2. Characterization of Hemp and Neem Methyl Ester

4.5.2.1. Relative Density

The relative densities of neem oil and neem methyl ester were observed 10.84 and 4.58 percent higher than that of diesel respectively. The experimental results indicated that the relative density of neem methyl ester was slightly increased to that of diesel.

4.5.2.2. Kinematic Viscosity

The kinematic viscosity of diesel, neem oil, and neem methyl ester were found as 3.7, 35.83 and 2.7 cSt. at 40^0C. The results indicated that the neem methyl ester had the kinematic viscosity 3.846 percent more than that of diesel The results indicated that neem oil was observed the kinematic viscosity more than that of diesel.

4.5.2.3. Flash and Fire Point

The neem methyl ester was found to have higher flash and fire pint than those of diesel. The flash and fire point of neem oil was found to be higher than those of diesel.

4.5.2.4. Cloud and Pour Point

The result also reveals that the cloud and pour point of neem oil and neem methyl ester are lower than those of diesel.

4.5.2.5. Calorific Value

The calorific value of diesel, neem oil, and neem methyl ester were found as 43, 44.65 and 39.81 MJ/Kg respectively. The calorific value of neem oil is increased by 3.84% than that of diesel whereas the calorific value of neem methyl ester is decreased by 7.42% than that of diesel. The result shows that the calorific value of neem oil is slightly lower than diesel fuel.

4.5.2.6. Free Fatty Acid Content

The FFA content of hemp methyl ester and neem methyl ester were found as 0.05% and 0.07% respectively.

4.5.2.7. Acid Value

The acid value of hemp methyl ester and neem methyl ester were found to be reduced with diesel. Ester values were found to be less than the maximum limit prescribed by the Bureau of Indian Standards.

4.5.2.8. Moisture Content

The moisture content of diesel was observed as 0.02%. The moisture content of neem oil and hemp oil were higher than that of diesel fuel. The moisture content of diesel was observed as 0.02%. The moisture content of hemp and neem methyl ester were reduced as compared to diesel fuel. The moisture content of hemp methyl ester was obtained 0.025% whereas moisture content of neem methyl ester was obtained 0.03%.

4.5.2.9. Cetane Number

The cetane number of diesel, neem methyl ester and hemp methyl ester were found as 55, 51 and 52 respectively.

4.5.2.10. Copper Strip Corrosion Content

The copper strip corrosion at 3 hr 50 ^{0}C for diesel, hemp methyl ester and neem methyl ester were found as 1a, 3a and 3a respectively.

4.5.2.11. Iodine Value

The iodine values of hemp methyl ester and neem methyl ester were found as 95 and 74 respectively.

4.5.2.12. Saponification Number

The saponification numbers of hemp methyl ester and neem methyl ester were found as 190 and 192 respectively.

4.5.2.13. Ash Content

It is clear from the results that hemp oil and neem oil increased the ash content to great extent with diesel respectively.

4.5.2.14. Carbon Residue Content

The esters of hemp and neem oil were found to have carbon residue content lower than that of diesel which is better for engine performance and it also prevents carbon deposition inside the combustion chamber.

4.5.2.15. Fuel Stability

The hemp methyl ester was 1.13 cSt which is increased to 1.56 cSt on 30th day and 1.93 on 6 cSt 0th day whereas neem methyl ester was 2.67 cSt which is 3.53 on cSt 30th day and 3.91 on cSt 60th day. The kinematic viscosity of hemp methyl ester and neem methyl ester were increased by 70.8 % and 46.44 % in a period of 60th day. Hemp oil, neem oil, hemp methyl ester and neem methyl ester were found to be stable in terms of oxidative stability even after two month and their kinematic viscosity remained within the prescribed limit for the diesel as stated by the Bureau of Indian Standards.

4.5.2.16. Free and Total Glycerin

The free glycerin of hemp methyl ester and neem methyl ester were found as 0.00 and 0.00 respectively whereas total glycerin of hemp methyl ester and neem methyl ester were found as 0.020 and 0.025 respectively. The fuel properties of hemp and neem methyl ester as shown in Table 4.12.

Table 4.12 Fuel properties of hemp and neem methyl ester compared to diesel

Properties	**Units**	**HME**	**NME**	**Diesel**	**ASTM D6751**	**EN 14214**
Density (15deg)	Kg/m3	858	868	830	-	860-900
Viscosity (40 deg)	cSt	1.13	2.7	3.7	1.9-6.0	3.5-5.0
Flash point	℃	47	76	60	>130	>101
Fire point	℃	55	81	65	-	Min 120
Cloud point	℃	-4	9	-12	10	-1
Pour point	℃	-17	2	-16	-15	-
Calorific value	MJ/kg	42.92	39.81	43	-	-
Acid value	mg KOH/g	0.1	0.14	0.22	<0.8	<0.5
Copper corrosion content	3h, 50deg	1	1	1	Max. 1	Max. 3
Moisture content	w/w%	0.025	0.03	-	<0.03	-
Cetane number		52	51	-	48-60	Min. 51
Ester content	**%**	93.89	87.70	-	-	-

4.6. Engine Performance and Exhaust Emission Analysis

4.6.1. Performance Characteristics

4.6.1.1. Brake Thermal Efficiency

The variation of brake thermal efficiency with respect to brake mean effective pressure for different fuels considered for the present analysis is presented in figure 4.9. For neem methyl ester and its 20% blends, the maximum brake thermal efficiency obtained while using NME100, and NME20 are 16.53% and 12.8% respectively at part load. Brake thermal efficiency of NO is 63.11% higher than that of diesel at part load whereas it reduces 11.2% with diesel fuel at full load. In case of full load, NME show decreasing trend with diesel fuel. Brake thermal efficiency of diesel is 15.37% and 36.89% at part load and full load respectively. For neem oil and its 20% blends, the brake thermal efficiency of NO is 63.11% higher than that of diesel at part load whereas it reduces 11.2% with diesel fuel at full load. Brake thermal efficiency of NO20 is 4.36% higher than that of diesel at part load whereas it reduces 16.37% with diesel fuel at full load.

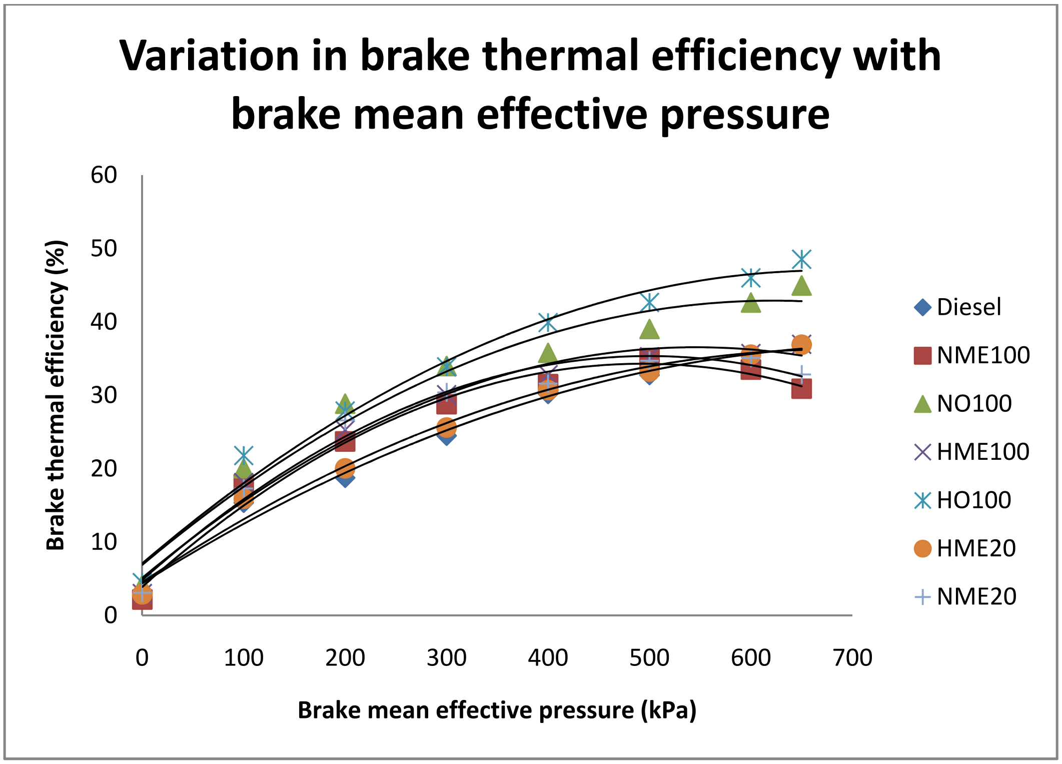


Fig. 4.9 Variation of brake thermal efficiency with respect to brake mean effective pressure

For hemp methyl ester and its 20% blends, the brake mean effective pressure of a diesel engine directly relates to the brake power. Brake thermal efficiency of HME was observed 17.83% higher than that of diesel at part load condition but slightly increases at full load condition. Brake thermal efficiency of HME20 was observed 3.58% higher than that of diesel at part load condition but slightly increases at full load condition. It increased due to the reduction in heat loss and increase in power developed with increase in load. The results indicate that a significant improvement in thermal efficiency could be realized by preheating HME. Higher brake thermal efficiency favours better and complete combustion and lesser amount of unburned hydrocarbon in engine exhaust thus improving smoke opacity values.

For hemp oil and its 20% blends, the brake thermal efficiency of HO is 41.83% higher than that of diesel at part load as well as it increases 31.61% with diesel fuel at full load. Brake thermal efficiency of HO20 is 8.28% higher than that of diesel at part load as well it increases 6.32% with diesel fuel at full load. By considering above points, finally, HME, HME20 and HO show increase in trend with diesel fuel at all loads. In case of NME, NME20 and NO, it increases at part load and decreases at full load.

4.6.1.2. Brake Specific Fuel Consumption

The variation of brake specific fuel consumption with brake mean effective pressure for different fuel is presented in fig. 4.10. For neem methyl ester and 20% blends, the brake specific fuel consumption is found to decrease with increase in brake mean effective pressure. This is due to the higher percentage increase in brake power with brake mean effective pressure as compared to the increase in fuel consumption. At part load, brake specific fuel consumption of NME100 was obtained 8.25% lower than that of diesel whereas brake specific fuel consumption of NME100 was observed 27.75% higher than that of diesel at full load. Finally, we conclude that it decreases at part load on one hand, it shows increasing trend at full load. It may noted that the calorific value of neem methyl ester is decreased by 7.42% than that of diesel. With increase in biodiesel percentage in the blends, the calorific value of fuel decreases. Hence, the specific fuel consumption of higher percentage of biodiesel in blends increase as compared to that of diesel. The specific fuel consumption of neem oil methyl ester is higher than that of diesel for full load. This is caused due to the combined effect of higher viscosity and lower calorific value of the filtered neem oil.

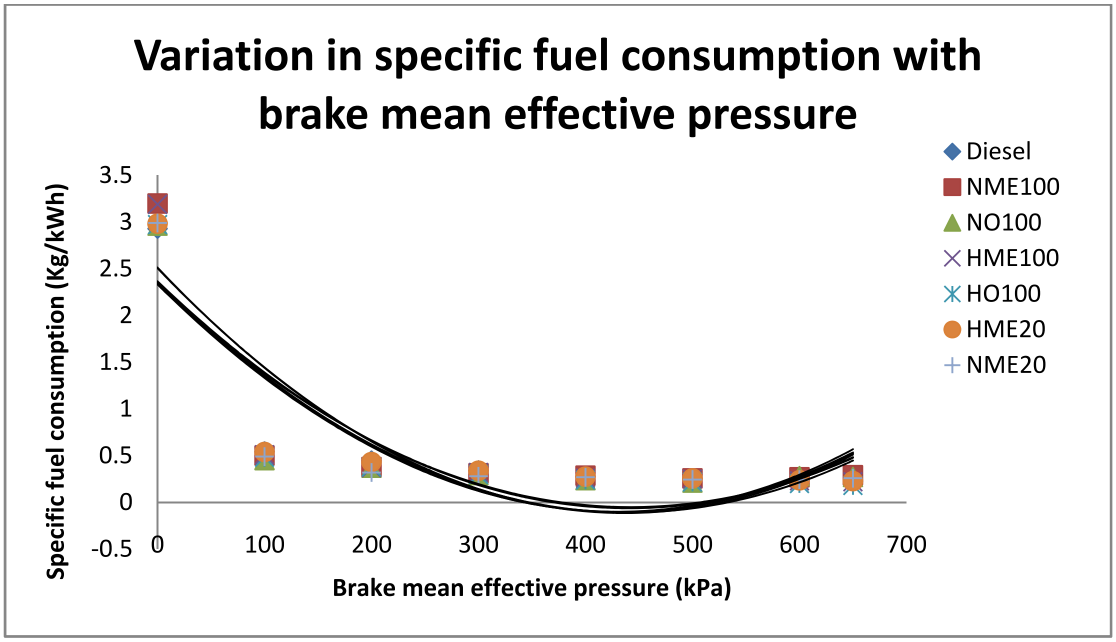


Fig. 4.10 Variation of brake specific fuel consumption with respect to brake mean effective pressure

For neem methyl ester and 20% blends, the brake specific fuel consumption is found to decrease with increase in brake mean effective pressure. This is due to the higher percentage increase in brake power with brake mean effective pressure as compared to the increase in fuel consumption. At part load, brake specific fuel consumption of NME100 was obtained 8.25% lower than that of diesel whereas brake specific fuel consumption of NME100 was observed 27.75% higher than that of diesel at full load. Finally, we conclude that it decreases at part load on one hand, it shows increasing trend at full load. It may noted that the calorific value of neem methyl ester is decreased by 7.42% than that of diesel. With increase in biodiesel percentage in the blends, the calorific value of fuel decreases. Hence, the specific fuel consumption of higher percentage of biodiesel in blends increase as compared to that of diesel. The specific fuel consumption of neem oil methyl ester is higher than that of diesel for full load. This is caused due to the combined effect of higher viscosity and lower calorific value of the filtered neem oil.

For neem oil and its 20% blends, the brake specific fuel consumption is found to decrease with increase in brake mean effective pressure. This is due to the higher percentage increase in brake power with brake mean effective pressure as compared to the increase in fuel consumption. At part load, brake specific fuel consumption of NO20 was obtained 9.54% lower than that of diesel whereas brake specific fuel consumption of NO20 was observed 18.94% higher than that of diesel at full load. Finally, we conclude that it decreases at part load on one hand, it shows increasing trend at full load. The specific fuel consumption of neem oil is higher than that of diesel for full load. This is caused due to high viscosity of the filtered neem oil.

For hemp methyl ester and its 20% blends, the brake specific fuel consumption of HME was found 6.42% lower than that of diesel at part load condition and 3.08% lower than that of diesel at full load condition. Brake specific fuel consumption of HME20 was found 1.28% lower than that of diesel at part load condition and 0.44% lower than that of diesel at full load condition. Due to the combined effect of low heating value and high density of hemp methyl ester.

For hemp oil and its 20% blends, the variation of specific fuel consumption with brake mean effective pressure for different fuel is presented in figure 3. for all fuel tested, brake specific fuel consumption is found to decrease with increase in brake mean effective pressure. This is due to the higher percentage increase in brake power with brake mean effective pressure as compared to the increase in fuel consumption. At part load, brake specific fuel consumption of HO20 was obtained 2.38% lower than that of diesel as well as brake specific fuel consumption of HO20 was observed 4.41% lower than that of diesel at full load. At part load, brake specific fuel consumption of HO was obtained 11.74% lower than that of diesel as well as brake specific fuel consumption of HO was observed 20.7% lower than that of diesel at full load. By considering above points, finally, HME, HME20 and HO show decrease in trend with diesel fuel at all loads. In case of NME, NME20 and NO show decrease in trend with diesel fuel at part load and increase in trend with diesel fuel at full load**.**

4.6.1.3. Brake Specific Energy Consumption

The variation of brake specific energy consumption with respect to brake mean effective pressure for different fuels considered for the present analysis present in fig. 4.11.

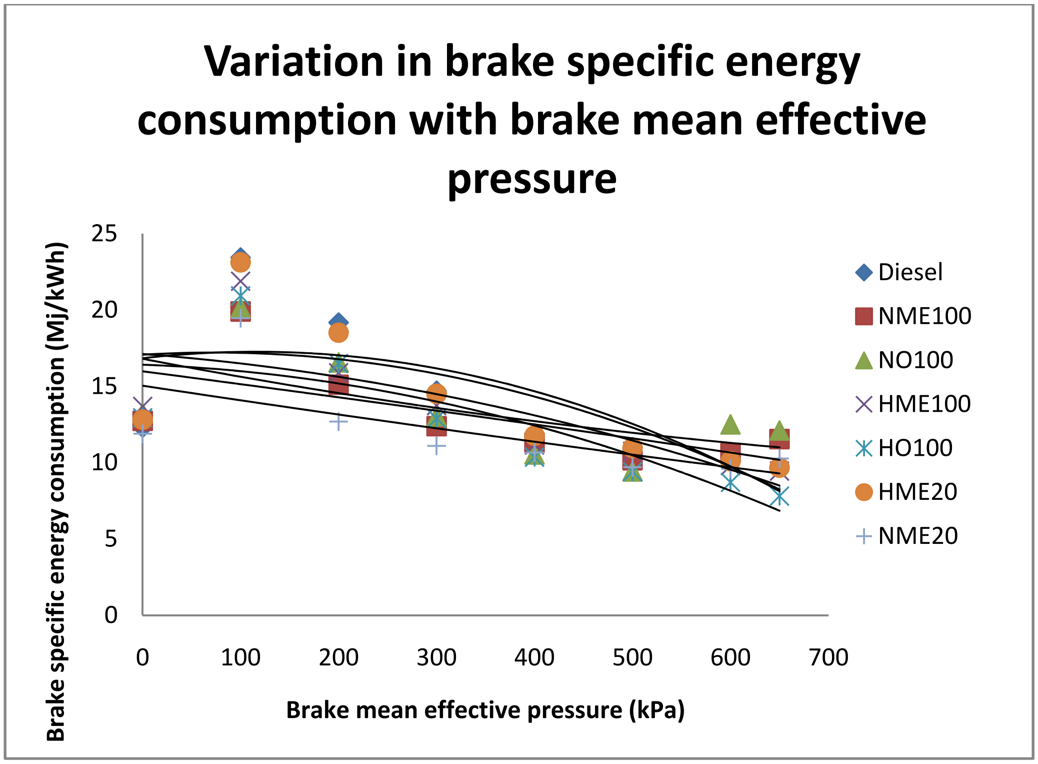


Fig. 4.11 Variation of brake specific energy consumption with respect to brake mean effective pressure

For neem methyl ester and its 20% blends, the brake specific energy consumption of NO is increased by 23.96% at full load whereas it decreases by 14.07% at part load. The brake specific energy consumption at part load is decreased at all loads when tested with NME100 and its blend. But it revealed that brake specific energy consumption of NME100 and its blend show increasing in trend at full load. The brake specific energy consumption of NME100 was observed 15.06% lower than that of diesel at part load whereas 18.27% higher than that of diesel at full load. it is slightly increased due to lower calorific value. The differences in brake specific energy consumption may be a reflection of higher density.

For neem oil and its 20% blends, the brake specific energy consumption of NO is increased by 23.96% at full load whereas it decreases by 14.07% at part load. The brake specific energy consumption at part load is decreased at all loads when tested with NO and its blend. But it revealed that brake specific energy consumption of NO and its blend show increasing in trend at full load. The brake specific energy consumption of NO20 was observed 6.07% lower than that of diesel at part load whereas 23.5% higher than that of diesel at full load. it is slightly increased due to lower calorific value. For hemp methyl ester and its 20% blends, the brake specific energy consumption of HME was found 6.59% lower than that of diesel at part load condition and 3.26% lower than that of diesel at full load condition. Brake specific energy consumption of HME20 was found 1.32% lower than that of diesel at part load condition and 0.65% lower than that of diesel at full load condition. For hemp oil and its 20% blends, the brake specific energy consumption of HO was decreased by 19.75% at full load as well as it was decreased by 10.67% at part load. The brake specific energy consumption at all load conditions were decreased at all loads when tested with HO and its blend. The brake specific energy consumption of HO20 was observed 2.14% lower than that of diesel at part load as well as 3.95% lower than that of diesel at full load. By considering above points, finally, HME, HME20 and HO show decrease in trend with diesel fuel at all loads. In case of NME, NME20 and NO show decrease in trend with diesel fuel at part load and increase in trend with diesel fuel at full load**.**

4.6.1.4. Exhaust Gas Temperature

The variation of brake thermal efficiency with respect to brake mean effective pressure for different fuels is shown in fig. 4.12. For neem methyl ester and its 20% blends, the biodiesel also contains some amount of oxygen molecules in the ester form. It is also taking part in combustion. When biodiesel concentration is increased, the exhaust gas temperature increases by small value. Using 100% filtered neem oil, higher exhaust gas temperature is attained at full load, which is indicating more energy loss in this case. The exhaust gas temperature increases with increase in brake mean effective pressure at full load only.NME100 and its blend have show decreasing in nature at part load. The exhaust gas temperature of NME100 was obtained 6.83% lower than that of diesel at part load and it increases at full load by 14.44% than that of diesel. It shows increasing in trend at full load. For neem oil and is 20% blends, the biodiesel also contains some amount of oxygen molecules in the ester form. It is also taking part in combustion. Using 100% filtered neem oil, higher exhaust gas temperature is attained at full load, which is indicating more energy loss in this case. The exhaust gas temperature increases with increase in brake mean effective pressure at full load only. NO show decreasing in nature at part load. The exhaust gas temperature of NO20 was obtained 1.59% lower than that of diesel at part load and it increases at full load by 11.92% than that of diesel. It shows increasing in trend at full load.

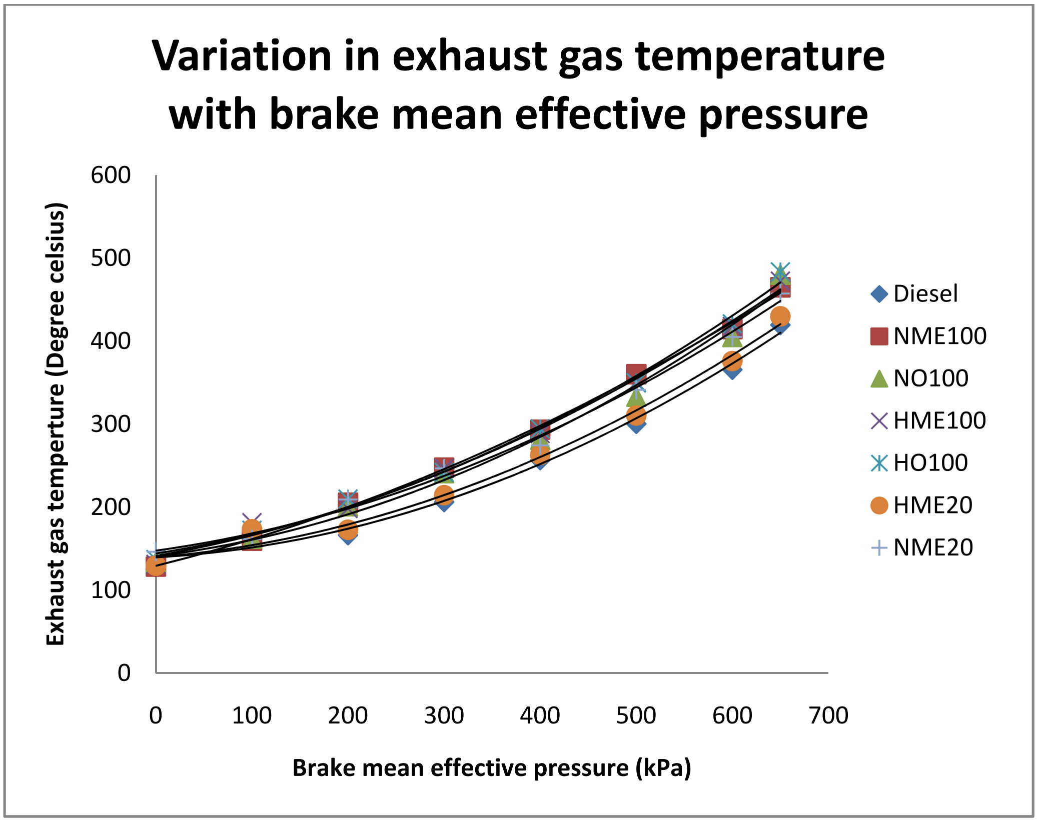


Fig. 4.12 Variation of exhaust gas temperature with respect to brake mean effective pressure

For hemp methyl ester and its 20% blends, the hemp methyl ester shows 5.74% higher than that of diesel fuel at part load condition whereas it shows 12.78% higher than that of diesel fuel at full load condition. HME20 shows 1.15% higher than that of diesel fuel at part load condition whereas it shows 2.48% higher than that of diesel fuel at full load condition. It is observed that exhaust gas temperature is increases with load because more fuel is burnt at higher loads to meet the power requirements. This may be due to the oxygen content of the fuel which improves combustion and thus may increase the exhaust gas temperature. Higher exhaust gas temperature may be because of better combustion of hemp methyl ester.

For hemp oil and its 20% blends, the variation of brake thermal efficiency with respect to brake mean effective pressure for different fuels as shown in figure 5. Using 100% raw hemp oil, higher exhaust gas temperature is attained at all load conditions, which is indicating more energy loss in this case. The exhaust gas temperature increases with increase in brake mean effective pressure at full load only. The exhaust gas temperature of HO20 was obtained 0.07% higher than that of diesel at part load as well as it increases at full load by 3.06% than that of diesel. The overall results revealed that it slightly increases at part load and it largely increases at full load for all tested fuels. It shows increasing in trend at full load. By considering above points, finally, HME, HME20 and HO increases than that of diesel fuel at all loads. NME and NME20 show decreases with diesel fuel at part load and increases at full load. In case of NO, it decreases at part load but increases at full load.

4.6.2. Exhaust Emission characteristics

4.6.2.1. Oxides of Nitrogen

The variation of oxides of nitrogen with respect to brake mean effective pressure for different fuels as shown in fig. 4.13.

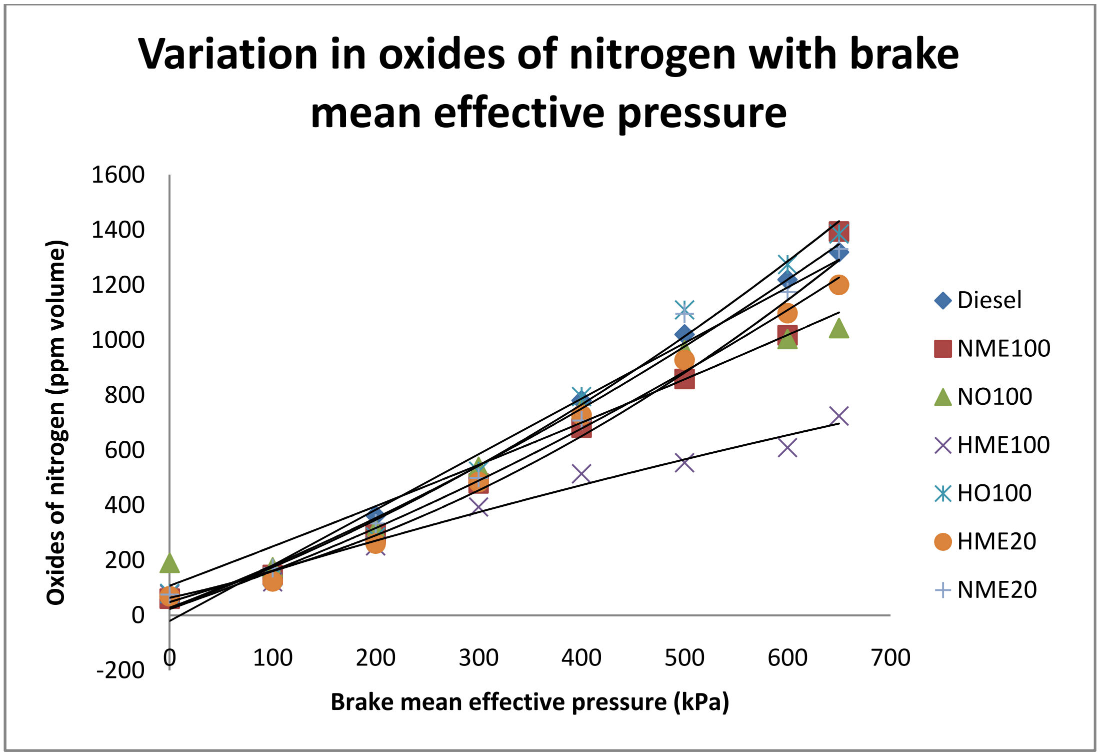


Fig. 4.13 Variation of oxides of nitrogen with respect to brake mean effective pressure

For neem methyl ester and its 20% blends, it can be seen that NO_X emission was a direct function of engine power output. This trend is due to NO_X formation which is a temperature dependent phenomenon. NO_X emission of NME100 and its blend show decreasing in trend with diesel fuel at all load condition and it also decrease at full load for NO but it increases at part load. NME100 lowers by 3.22% and 6.06% at part and full load condition respectively. NO increases by 41.13% than that of diesel fuel at part load but decreases by 20.91% than that of diesel fuel at full load. It increased due to increase in fuel inlet temperature. It increases because It is associated with the oxygen content of the given ester since the oxygen present in the fuel may provide additional oxygen for NO_X formation. It could be possibility of higher combustion temperature arising from improved combustion. It has to be noted that a larger part of the combustion is completed before TDC for ester and it blends compared to diesel due to their lower ignition delay. However NO_X can be controlled by adopting EGR and by employing suitable catalytic converters. Reduced oxygen and flame temperature leads to lower NO_X formation.

For neem oil and its 20% blends, the variation of oxides of nitrogen with respect to brake mean effective pressure for different fuels as shown in figure 9. It can be seen that NO_X emission was a direct function of engine power output. This trend was occurred as NO_X formation is a temperature dependent phenomenon. NO_X emission decreases at full load for NO100 but it increases at part load. NO20 increases by 10.48% at part and lowered by 15.07% at full load condition. NO increases by 41.13% than that of diesel fuel at part load but decreases by 20.91% than that of diesel fuel at full load.

For hemp methyl ester and its 20% blends, the oxides of nitrogen of HME is 1.61% less than that of diesel at part load condition and 45.07% lower than that of diesel fuel at full load condition. Oxides of nitrogen of HME20 is 0.32% less than that of diesel at part load condition and 9.01% lower than that of diesel fuel at full load condition. It shows effective result at full load condition. Reduced oxygen and flame temperature leads to lower NOx formation.

For hemp oil and its 20% blends, the variation of oxides of nitrogen with respect to brake mean effective pressure for different fuels as shown in figure 9. It can be seen that NO_X emission is a direct function of engine power output. This trend is due to NO_X formation which is a temperature dependent phenomenon. NO_X emission increases 12.9% at part load and 5% at full load for HO and HO20 increase by 2.58% and 1% at part and full load respectively.

Consequently, it is found that HO and its blends show increasing trend at all load condition. It increases due to increase in fuel inlet temperature. By considering above points, finally, HME and HME20 show decrease trend with diesel fuel at all loads whereas HO shows increase trend at all loads. NME reveals decrease in trend with diesel fuel at part load whereas NME20 reveals increase in trend with diesel fuel, But NME and NME20 decrease at full load. In case of NO, it increases at part load and decreases at full load.

4.6.2.2. Smoke Opacity

The variation of smoke opacity with respect to brake mean effective pressure for different fuels as shown in fig. 4.14.

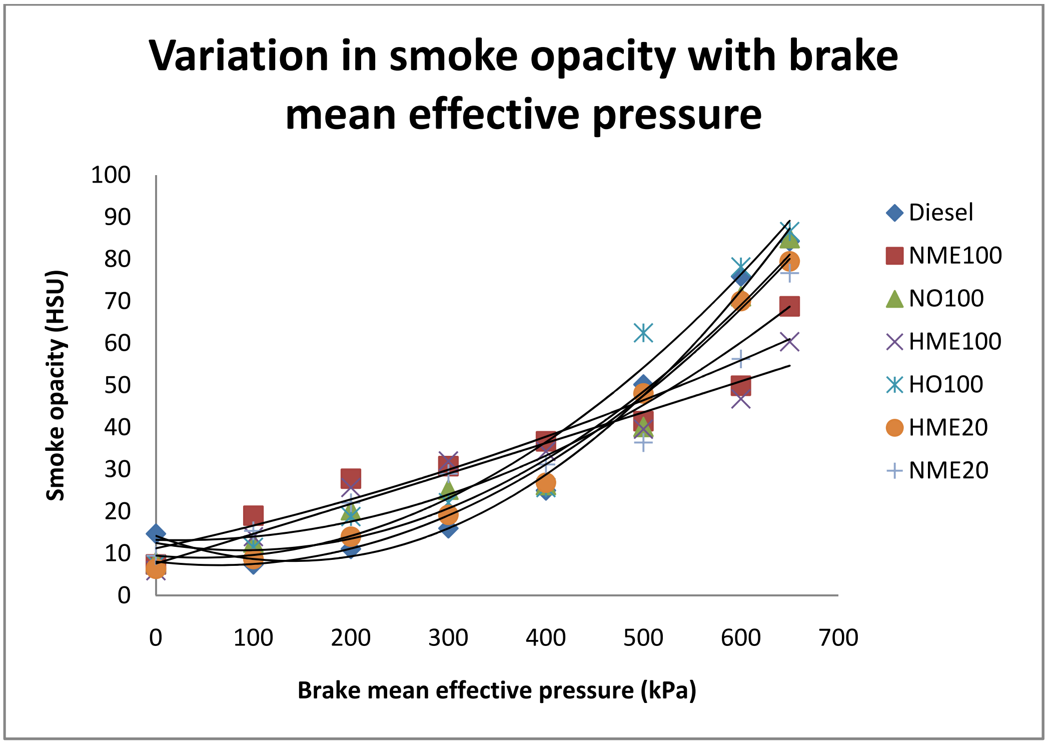


Fig. 4.14 Variation of oxides of nitrogen with respect to brake mean effective pressure

For neem methyl ester and its 20% blends, it increases with high percentage at part load and it decreases at full load condition. It lowers by 18.39% than that of diesel fuel. In case of NO, it again increases by 70.27% than that of diesel fuel at part load and slightly increases at full load condition. It increases due to the higher viscosity and poor volatility of neem oil and its ester compared to diesel and it is mainly due to emission of heavier molecules of hydrocarbon and particulates. It is reduced due to reduction in viscosity and subsequent improvement in spray and fuel-air mixing. Smoke is formed due to incomplete combustion. As smoke is low then better combustion of tested fuel takes place.

For neem oil and its 20% blends, the variation of smoke opacity with respect to brake mean effective pressure for different fuels as shown in figure 11.NO20 revealed that it increases with high percentage at part load and it decreases at full load condition. It lowers by 13.76% than that of diesel fuel. In case of NO, it again increases by 70.27% than that of diesel fuel at part load and slightly increases at full load condition. It increases due to the higher viscosity and poor volatility of neem oil and its ester compared to diesel and it is mainly due to emission of heavier molecules of hydrocarbon and particulates. It is reduced due to reduction in viscosity and subsequent improvement in spray and fuel-air mixing. Smoke is formed due to incomplete combustion. As smoke is low then better combustion of tested fuel takes place.

For hemp methyl ester and its 20% blends, it increases at part load condition. However, it reduces at full load condition. HME increases by 89.18% than that of diesel fuel at part load condition whereas it lowers by 28.35% than that of diesel fuel at full load condition. HME20 increases by 17.83% than that of diesel fuel at part load condition whereas it lowers by 5.67% than that of diesel fuel at full load condition. As smoke is low then better combustion of ester /oil takes place. It decreased due to preheating. This may be due to the reduction in viscosity and subsequent improvement in spray, fuel-air mixing and combustion characteristics by preheating. It increased due to the higher viscosity and poor volatility of given oil/ester compared to diesel and it is mainly due to emission of heavier molecules of hydrocarbon and particulates.

For hemp oil and its 20% blends, HO20 revealed that it increases by 11.08% at part load and it also increases by 0.54% at full load condition. In case of HO, it again increases by 55.41% than that of diesel fuel at part load and slightly increases (2.73%) at full load condition. It increased due to the higher viscosity and poor volatility of neem oil and its ester compared to diesel and it is mainly due to emission of heavier molecules of hydrocarbon and particulates. It is reduced due to reduction in viscosity and subsequent improvement in spray and fuel-air mixing. Smoke is formed due to incomplete combustion. As smoke is low then better combustion of tested fuel takes place. By considering above points, finally, HME and HME20 show increase with diesel fuel at part load and decrease at full load. In case of HO, it increases at all loads.NME and NME20 show increase in trend with diesel fuel at part load and decreases at full load. In case of NO, it increases at all loads.

4.6.2.3. Unburned Hydrocarbon

The variation of unburned hydrocarbon with respect to brake mean effective pressure for different fuels as shown in fig. 4.15. For neem methyl ester and its 20% blends, it shows decreasing in trend at all load conditions. It lowers by 5.26% and 2.59% with diesel fuel at part and full load respectively. NO decreases by 15.79% at part load and slightly increased at full load condition. High percentage of oxygen content and cetane number leads to low hydrocarbon. For neem oil and its 20% blends, NO20 lowers by 35.08% and 3.89% with diesel fuel at part and full load respectively. NO40 shows that 40.35% reduction in unburned hydrocarbon at part load condition but it increases by 7.79% at full load condition. NO decreases by 15.79% at part load and slightly increases at full load condition.

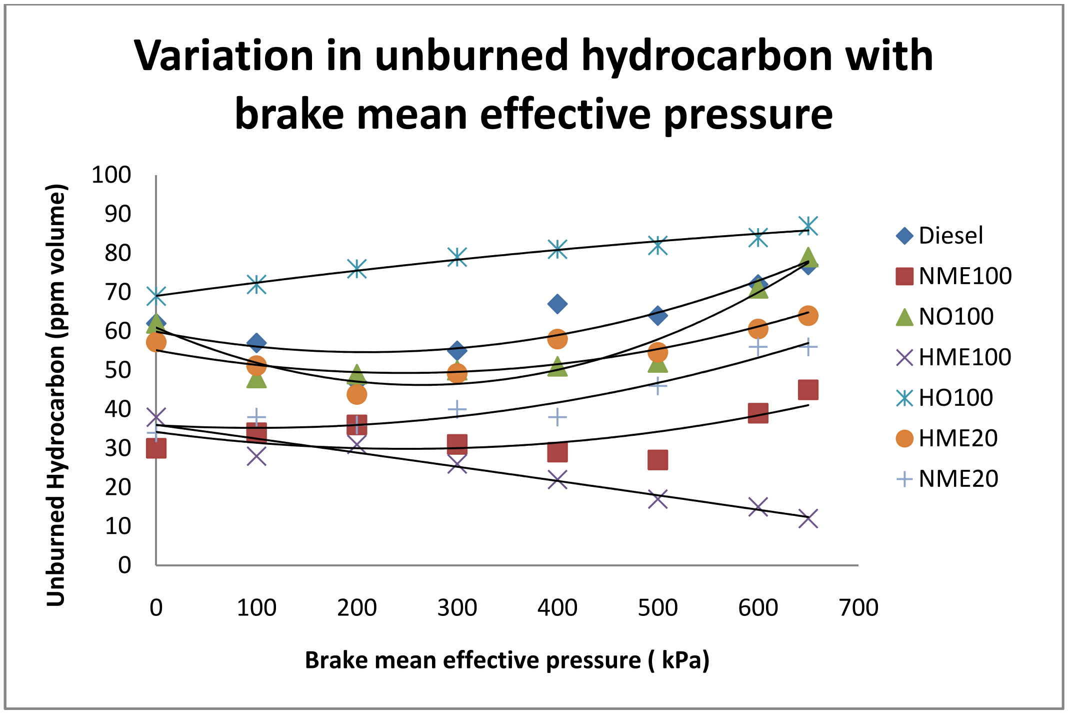


Fig. 4.15 Variation of unburned hydrocarbon with respect to brake mean effective pressure

For hemp methyl ester and its 20% blends, it shows decreasing trend with diesel fuel at all load condition. HME decreases 50.87% than that of diesel at part load condition whereas it again reduces 84.42% than that of diesel fuel at full load condition. HME20 decreases 10.17% than that of diesel at part load condition whereas it again reduces 16.88% than that of diesel fuel at full load condition.

For hemp oil and its 20% blends, HO20 increase by 5.26% and 2.59% with diesel fuel at part and full load respectively as well as HO shows that 26.32% increase in unburned hydrocarbon at part load condition and it also increases by 12.98% at full load condition. Ultimately, it was observed that HO and its blends reveals increase in nature at all load conditions. High percentage of oxygen content and cetane number leads to low HC. By considering above points, finally, HME and HME20 decreases with diesel fuel at all loads whereas HO increases with diesel fuel at all loads. NME and NME20 show decreasing trend at all loads whereas NO decreases at part load and increases at full load.

4.6.2.4. Carbon Monoxide

The variation of carbon monoxide with respect to brake mean effective pressure for different fuels as shown in fig. 4.16.

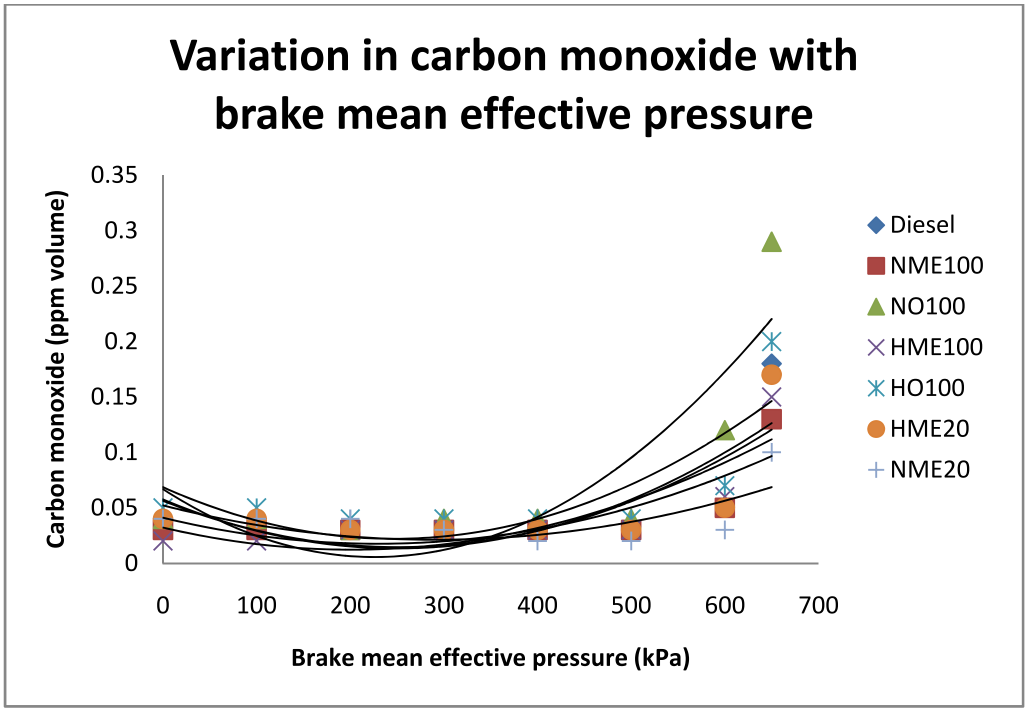


Fig. 4.16 Variation of carbon monoxide with respect to brake mean effective pressure

For neem methyl ester and its 20% blends, 100% filtered neem oil and various blends of biodiesel operation at the rated engine speed of 1500rpm at various brake mean effective pressures. The fuels are producing low amount of carbon monoxide at part load condition and are giving more emissions at full load conditions. The carbon monoxide emissions are found to be increasing with increasing brake mean effective pressure. i.e. full load. In case of 100% filtered neem oil, it increases at all loads. This is due to high viscosity and poor atomization tendency of filtered neem oil leads to poor combustion and higher carbon monoxide emission. The carbon monoxide emissions increase as the fuel-air ratio becomes greater than the stoichiometric value. Carbon monoxide concentration in the exhaust emission is negligibly small when a homogenous mixture is burned at stoichiometric air-fuel ratio mixture or on the lean side stoichiometric. It is interesting to note that, the engine emits more carbon monoxide using diesel as compared to that of biodiesel blends under all loading conditions. With increasing biodiesel percentage, carbon monoxide emission decreases. Biodiesel itself has about 11% oxygen content in it. This helps for the complete combustion. Hence, carbon monoxide emission decreases with increasing biodiesel percentage in the fuel.

For neem oil and its 20% blends, the 100% filtered neem oil and various blends of neem oil operated at the rated engine speed of 1500 rpm at various brake mean effective pressures. The carbon monoxide emissions are found to be increasing with increasing brake mean effective pressure. i.e. full load. In case of 100% filtered neem oil, it increases at all loads. This is due to high viscosity and poor atomization tendency of filtered neem oil leads to poor combustion and higher carbon monoxide emission. The carbon monoxide emissions increase as the fuel-air ratio becomes greater than the stoichiometric value. Carbon monoxide concentration in the exhaust emission is negligibly small when a homogenous mixture is burned at stoichiometric air-fuel ratio mixture or on the lean side stoichiometric. It is interesting to note that, the engine emits more carbon monoxide using diesel as compared to that of neem oil blends under all loading conditions.

For hemp methyl ester and its 20% blends, HME and its blends decrease slightly at all load condition. It can be observed that HME fuel properties are comparable with diesel fuel. The main difference in ester-based fuel contains small amount of oxygen and that acts as a combustion promoter inside the cylinder. This results in better combustion for HME than diesel fuel. Hence CO, which is present in the exhaust gas due to incomplete combustion, is slightly lower in comparison to diesel. It is decreased due to lack of oxygen since ester is an oxygenated fuel. it leads to better combustion of fuel resulting in the decrease in carbon monoxide. Reduction in carbon monoxide emission is a strong advantage in favour of ester. It depends on the physical and chemical properties of the fuel. It is decrease due to better air fuel mixing.

For hemp oil and its 20% blends, the 100% raw hemp oil and various blends of neem oil operated at the rated engine speed of 1500rpm at various brake mean effective pressures. The carbon monoxide emissions are found to be increasing with increasing brake mean effective pressure. i.e. full load. In case of 100% raw hemp oil, it slightly increases at all loads. This is due to high viscosity and poor atomization tendency of raw hemp oil leads to poor combustion and higher carbon monoxide emission. The carbon monoxide emissions increase as the fuel-air ratio becomes greater than the stoichiometric value. The carbon monoxide concentration in the exhaust emission is negligibly small when a homogenous mixture is burned at stoichiometric air-fuel ratio mixture or on the lean side stoichiometric. It is interesting to note that, the engine emits more carbon monoxide using diesel as compared to that of hemp oil blends under all loading conditions. By considering above points, finally, HME and HME20 show slightly lower than diesel fuel at all loads whereas HO show slightly higher than diesel fuel at all loads. In case of NME and NME20, it decreases at all loads whereas NO increase at all loads.

4.6.2.5. Carbon Dioxide

The variation of carbon dioxide with respect to brake mean effective pressure for different fuels as shown in fig. 4.17. For neem methyl ester and its 20% blends, carbon dioxide emission increase with increase in brake mean effective pressure, as expected. At full load, NME100 and its blend show lower emission is to be found in comparison with diesel. At full load, Neem oil gives a lower percentage CO2 emission which is due to the incomplete combustion. At part load neem oil gives higher percentage of CO_2 emissions as compared to diesel which is due to complete combustion whereas at part load NME100 shows increasing in trend as compared to diesel. The combustion of fossil fuels produces CO_2 which are getting accumulated in the atmosphere and leads to many environmental problems.

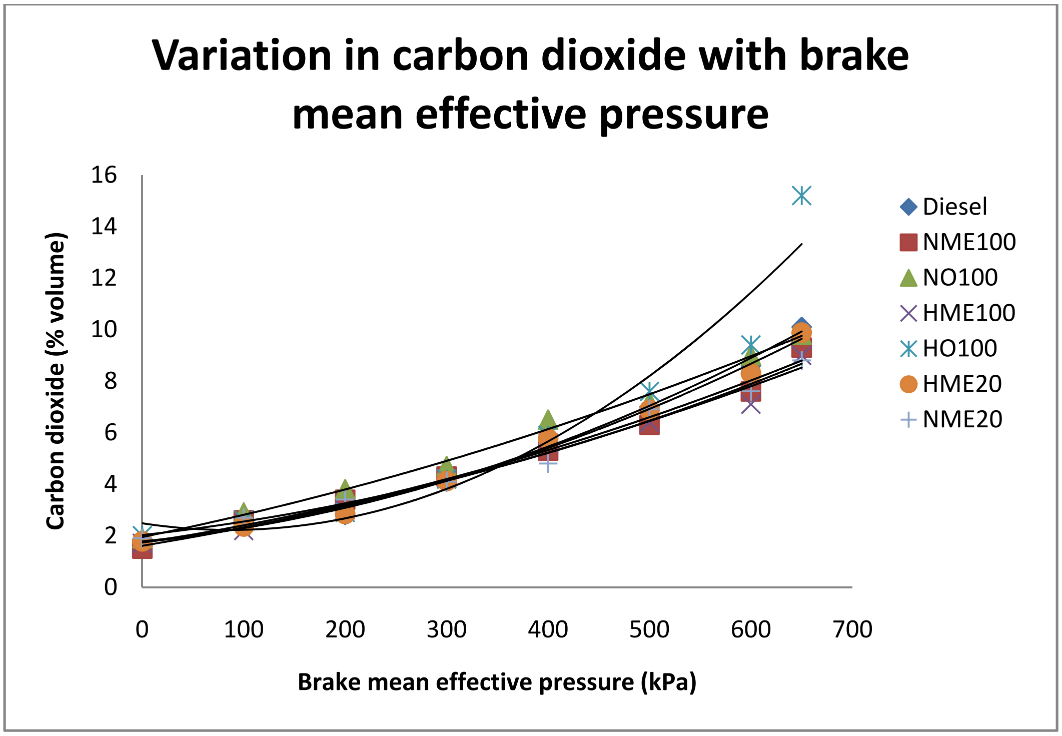


Fig. 4.17 Variation of carbon dioxide with respect to brake mean effective pressure

For neem oil and its 20% blends, the carbon dioxide emission increase with increase in brake mean effective pressure, as expected. At full load, Neem oil and its blends give lower percentage CO_2 emissions which are due to the incomplete combustion. At part load neem oil and its blends give higher percentage of CO_2 emissions as compared to diesel which is due to complete combustion. For hemp methyl ester and its 20% blends, the all fuels decrease slightly at all load condition. For hemp oil and its 20% blends, the carbon dioxide emission increase with increase in brake mean effective pressure, as expected. At part load, hemp oil and its blends give higher percentage of CO_2 emissions as compared to diesel which is due to complete combustion. The combustion of fossil fuels produces CO_2 which are getting accumulated in the atmosphere and leads to many environmental problems. HO increased by 8.33% at part load as well as it also increased by 50.49% at full load. There was increase in 1.66% at part load and 10.1% at full load respectively for HO20.Ultimately it concluded that HO and its blends reported increase in nature at all load condition. By considering above points, finally, HME and HME20 show slightly lower than diesel fuel at all loads. HO show increasing trend at all loads. In case of NME and NME20, it increases at part load and decreases at full load. In case of NO, it increases at part load and it decrease at full load.

4.6.2.6. Oxygen Level

The variation of oxygen level with respect to brake mean effective pressure for different fuels as shown in fig. 4.18.

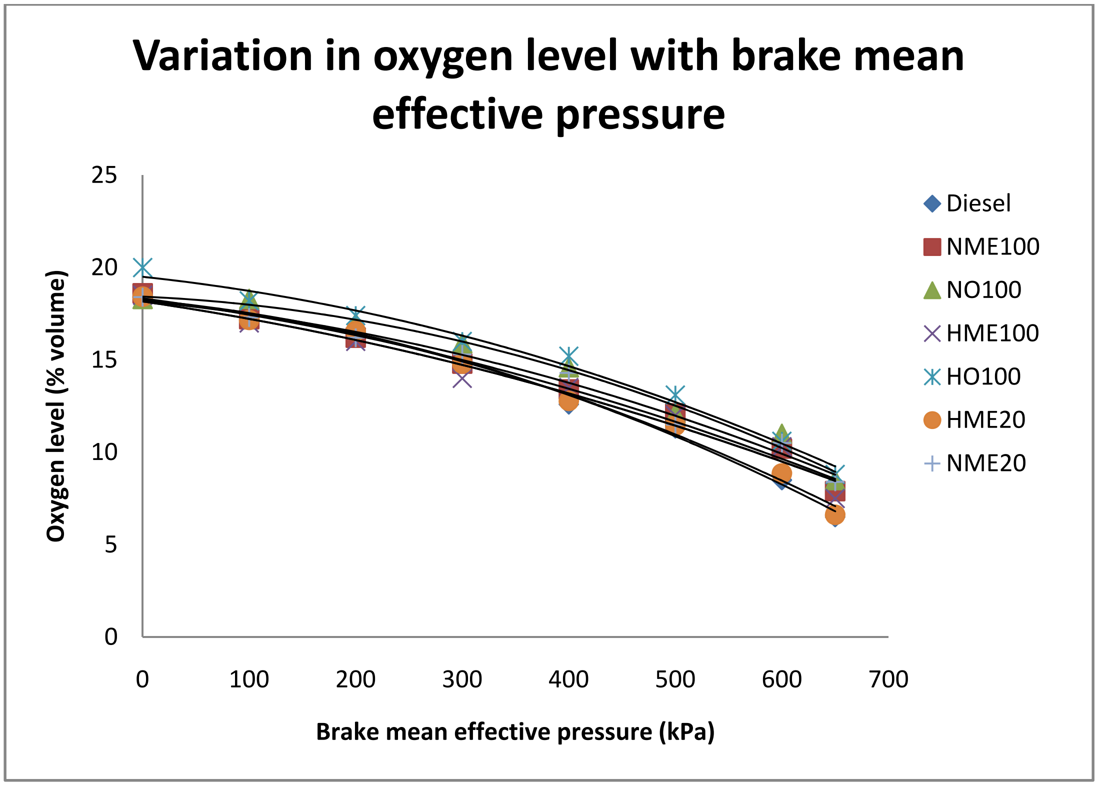


Fig. 4.18 Variation of oxygen level with respect to brake mean effective pressure

For neem methyl ester and 20% blends, the graph indicated that the O_2 level is comparatively similar at all blends of NME100 and NO compared to diesel. At all load condition, NO, NOME100 shows increasing trend with diesel fuel. Level of O_2 for blends of NME100 and NO was slightly increasing order as blend ratio increased. This may be due to the fact that fuels are oxygenated. The fuel have more oxygen content inherent in itself may be the cause of higher O_2 level, compare to diesel. The higher O_2 level in fuel blends is always preferred.

For neem oil and its 20% blends, the variation of oxygen level with respect to brake mean effective pressure for different fuels as shown in figure The graph indicated that the O_2 level is comparatively similar at NO and its blends compare to diesel. At all load condition, NO and its blends show increasing trend with diesel fuel. Level of O_2 for blends of NO and NO was slightly increasing order as blend ratio increased. This may be due to the fact that fuels are oxygenated.

For hemp methyl ester and its 20% blends, all fuels decrease slightly at part load condition. However, it increases slightly at full load condition.

For hemp oil and its 20% blends, the graph indicated that the O_2 level is comparatively similar at HO and its blends compare to diesel. HO increased by 5.81% at part load and 37.5% at full load respectively whereas HO20 increased by 1.16% at part load and 7.5% at full load respectively. At all load condition, HO and its blends show increasing trend with diesel fuel. The level of O_2 for blends of HO and HO was slightly increasing order as blend ratio increased. This may be due to the fact that fuels are oxygenated. By considering above points, finally, HME and HME20 show slightly lower than diesel fuel at part load and higher than diesel fuel at full load. HO show increases in trend with diesel fuel at all loads. In case of NO, it increases with diesel fuel at all loads.

4.7. Cost Analysis of Hemp and Neem Biodiesel

The cost evaluation of selected methyl esters undertaken in this study includes only costs of selected non-edible oils, filtration process, methanol, catalyst, and transesterification process. By-product like glycerol value is to be considered in the analysis. The raw feedstock cost is the major component contributing to the cost of biodiesel production. The final cost of the biodiesel included raw materials prices, government taxes (excluding fuel taxes), transport and marketing taxes. The glycerol could be sold after refining, however, this would need a purification plant, thus increasing the cost. For this reason, it was recommended to use glycerol without purification, for heating purposes after removing any potassium hydroxide residues. The manufacturing costs included direct costs for seed, oil extraction, reagent and operating supplies, as well as indirect costs related to insurance and storage. In relation to purchasing the selected oils, the overall costs include acquisition and transport costs. Various factors contributing to the cost of biodiesel include raw material, other reactants, nature of purification, its storage etc. However, the major factor which contributes the cost of biodiesel production is the feedstock which is about 80% of the total operating cost. The cost analysis of obtained esters (hemp and neem methyl ester) production comparing to the price of conventional diesel fuel was carried out for last decade. The biodiesel produced from non-edible oil can improve the agriculture economy diminish indecision of fuel availability and make farmers were self-confident besides environmental benefits. Furthermore, it is expected that the prices of esters will be lower than the price of conventional diesel fuel in the near future due to the linear increase in the price of conventional diesel fuel with the increase in its demand and limited supply. Techno-economic feasibility study indicates that the cost of biodiesel derived from neem oil is the cheapest (Rs.34.8 per litre) and that from hemp oil is the costliest (Rs. 37.77 per litre) compared to the diesel cost of Rs. 39 per litre. It is expected that the production of biodiesel from vegetable oils will be technically and economically more feasible provided the cost of vegetable oils comes down substantially in the country.

- Cost Analysis of Hemp Biodiesel (Hemp Methyl Ester)

The indicative cost analysis for the preparation of hemp methyl ester is mentioned below Table 4.13.

Table 4.13 Cost analysis of hemp methyl ester

S.N	Processing Input	Price of output
1	Raw hemp oil	Rs. 55.17 per kg of NME (Refer note *)
2	Cost of transesterification	Rs.5 per kg of NME
3	Total cost of hemp methyl ester	Rs. 60.17 per kg of NME
4	Sell of byproducts (Glycerol)	Rs. 22.4 (Refer note #)
5	Net cost of hemp methyl ester	Rs. 37.77 per kg of NME

* The raw hemp oil required for the preparation of 1 kg of hemp methyl ester is 1.1034 kg
Therefore, the cost of raw oil required is equal to 1.1034 ×Rs. 50 per kg of raw oil i.e. Rs. 55.17
The glycerol obtained during the process of transesterification of 1 kg of hemp methyl ester is 560 gm. Therefore, the recovery observed by selling 560 gm of Glycerol is
0.56 × Rs. 40 i. e. Rs. 22.4.

- Cost Analysis of Neem Biodiesel (Neem Methyl Ester)

The indicative cost analysis for the preparation of neem methyl ester is mentioned below Table 4.14.

Table 4.14 Cost analysis of neem methyl ester

S.N	Processing Input	Price of output
1	Raw neem oil	Rs. 39.2 per kg of NME (Refer note *)
2	Cost of filtering	Rs.5 per kg of NME
3	Cost of transesterification	Rs.5 per kg of NME
4	Total cost of neem methyl ester	Rs. 49.2 per kg of NME
5	Sell of byproducts (Glycerol)	Rs. 14.4 (Refer note #)
6	Net cost of neem methyl ester	Rs. 34.8 per kg of NME

* The raw neem oil required for the preparation of 1 kg of NME is 1.12 kg

Therefore, the cost of raw neem oil required is equal to 1.12 ×Rs. 35 per kg of raw oil i.e. Rs.39.2.

The glycerol obtained during the process of transesterification of 1 kg of NME is 360 gm. Therefore, the recovery observed by selling 360 gm of glycerol is

0.36×Rs. 40 i. e. Rs.14.4.

4.8. Comparative Studies: At a glance (JME/PME/MME/UFME)

4.8.1. Selected fuel properties of different methyl ester

The fuel properties of different methyl esters are listed in Table 4.15.

Table 4.15 Comparative studies of different biodiesels (Different methyl ester)

Name of fuel property	HME	NME	JME	PME	MME	UFME
Relative density, gm/cc^3	858	868	870	890	860	869
Kinematic viscosity, cSt	1.13	2.7	4.5	5	5.5	0.85
Flash point, ℃	47	76	164	145	195	153
Pour point, ℃	-17	2	2	5	6	1
Calorific value, MJ/Kg	42.92	39.81	38.98	36.01	41.13	44.07

4.8.1.1. Relative density

The relative density of hemp methyl ester, neem methyl ester, jartopha methyl ester, mahua methyl ester and used frying methyl ester were observed 3.37, 4.58, 4.82, 3.61 and 4.69 percent higher than that of diesel respectively. The experimental results indicated that the relative density of hemp methyl ester, neem methyl ester, jatropha methyl ester, mahua methyl ester and used frying methyl ester were slightly increased to that of diesel but pongamia methyl ester reveals 7.23 percent higher than that of diesel.

4.8.1.2. Kinematic Viscosity

The kinematic viscosity of diesel, hemp methyl ester, neem methyl ester, jatropha methyl ester, pongamia methyl ester, mahua methyl ester and used frying methyl ester were found as 3.7, 1.13, 2.7,4.5, 5, 5.5 and 0.85 cSt at 40^0C. The results indicated that jatropha methyl ester, pongamia methyl ester, mahua methyl ester were showed kinematic viscosity 21.62, 35.14, 48.65 percent more than that of diesel whereas hemp methyl ester, neem methyl ester and used frying methyl ester were showed kinematic viscosity 69.45, 27.02 and 77.02 percent less than that of diesel.

4.8.1.3. Flash point

The hemp methyl ester, neem methyl ester, jatropha methyl ester, pongamia methyl ester, mahua methyl ester and used frying methyl ester were found to have higher than those of diesel.

4.8.1.4. Pour point

The results thus indicate that pour point of hemp methyl ester is higher than that of diesel whereas pour point of neem methyl ester jatropha methyl ester, pongamia methyl ester, mahua methyl ester and used frying methyl ester were found to have lower than those of diesel.

4.8.1.5. Calorific value

The calorific value of diesel, hemp methyl ester, neem methyl ester, jatropha methyl ester, pongamia methyl ester, mahua methyl ester and used frying methyl were found as 43, 42.92, 39.81, 38.98, 36.01, 41.13 and 44.07 MJ/kg respectively. The calorific value of hemp methyl ester, neem methyl ester, jatropha methyl ester, pongamia methyl ester, and mahua methyl ester are decreased by 0.19 %, 7.42 %, 9.35%, 16.26%, and 4.35% than that of diesel but calorific value of used frying methyl ester increased by 2.49%.

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE OF WORK

5.1 Conclusions

The overall studies based on the production, fuel characterization, engine performance and exhaust emission and economical feasibility of hemp and neem methyl esters were carried out. The following conclusions can be drawn:

- The recovery of esters by transesterification of raw hemp oil and filtered neem oil with methanol are affected by process parameters such as preheating temperature, catalyst concentration, reaction time, molar ratio and reaction temperature.
- The recovery of hemp methyl ester of lowest kinematic viscosity (1.13 cSt) with 90.63 % recovery is possible at the following standardized parametric conditions.
  a) Molar ratio :- 6:1
  b) Preheating temperature :-55^{0}C
  c) Reaction time :- 45 minutes
  d) Catalyst concentration :-2%
  e) Reaction temperature :-60^{0}C
  f) Settling time :- 24 hrs.
- The recovery of neem methyl ester of lowest kinematic viscosity (2.7 cSt) with 80.36 % recovery is possible at the following standardized parametric conditions.
  a) Molar ratio :- 6:1
  b) Preheating temperature :- 55^{0}C
  c) Reaction time :-60 minutes
  d) Catalyst concentration :- 2%
  e) Reaction temperature :- 60^{0}C
  f) Settling time :- 24 hrs.

- The relative density of hemp oil, neem oil, hemp methyl ester and neem methyl ester were observed 6.99, 10.84, 3.37 and 4.58 percent higher than that of diesel respectively. The experimental results indicated that the relative density of hemp methyl ester and neem methyl ester were slightly increased to that of diesel.
- The kinematic viscosity of diesel, hemp oil, neem oil, hemp methyl ester and neem methyl ester were found as 2.6, 42.72, 35.83 1.13 and 2.7 centistokes at 40^{0}C. The results

indicated that the neem methyl ester had the kinematic viscosity 3.846 percent more than that of diesel whereas hemp methyl ester had the kinematic viscosity 56.54 percent less than that of diesel. The results indicated that the hemp oil had the kinematic viscosity 1543.08 percent more than that of diesel whereas neem oil had the kinematic viscosity 1278.08 percent more than that of diesel.

- The calorific value of diesel, hemp oil, neem oil, hemp methyl ester and neem methyl ester were found as 43, 43.52, 44.65, 42.92 and 39.81 MJ/kg respectively. The calorific value of hemp oil and neem oil are increased by 1.21% and 3.84% than that of diesel respectively whereas the calorific value of hemp methyl ester and neem methyl ester are decreased by 0.19% and 7.42% than that of diesel.
- The hemp methyl ester was found to have lower flash and fire pint than those of diesel whereas neem methyl ester was found to have higher than those of diesel. The flash and fire point of hemp and neem oil were found to be higher than those of diesel.
- The results thus indicate that pour point of hemp methyl ester is higher than that of diesel whereas cloud point of hemp methyl ester is lower than that of diesel. The result also reveals that the cloud and pour point of hemp oil, neem oil and neem methyl ester are lower than those of diesel.
- It is clear from the results that hemp oil and neem oil increased the ash content to great extent with diesel respectively. The ash content of hemp and neem methyl ester were obtained to be 0.005 and 0.007%w/w respectively.
- The esters of hemp and neem oil were found to have carbon residue content lower than that of diesel which is better for engine performance and it also prevents carbon deposition inside the combustion chamber. The carbon residue content of hemp and neem methyl esters were obtained to be 0.25 and 0.35 respectively.
- Acid value of hemp and neem oils were found to be increased whereas acid value of hemp methyl ester and neem methyl ester were found to be reduced with diesel. Ester values were found to be less than the maximum limit prescribed by the Bureau of Indian Standards.
- The copper strip corrosion at 3 hr 50°C for diesel, hemp methyl ester and neem methyl ester were found as 1a, 1a and 1a respectively. There is no significant change in copper corrosion test.

- The cetane number of diesel, neem oil and neem methyl ester were found as 55, 57.83 and 51 respectively. The cetane numbers of hemp and neem methyl ester were obtained to be 52 and 51.
- The FFA content of hemp oil and neem oil were found as 0.175% and 0.403% respectively whereas the FFA content of hemp methyl ester and neem methyl ester were found as 0.05% and 0.07% respectively.
- The moisture content of diesel was found to be 0.02%. The moisture content of hemp and neem methyl ester were reduced as compared to diesel fuel whereas moisture content of neem oil and hemp methyl ester were higher than that of diesel fuel.
- The hemp methyl ester was 1.13 cSt which is increased to 1.56 cSt on 30th day and 1.93 cSt on 60th day whereas neem methyl ester was 2.67 cSt which is 3.53 cSt on 30th day and 3.91 cSt on 60th day. The kinematic viscosity of hemp methyl ester and neem methyl ester were increased by 70.8 % and 46.44 % in a period of 60th day. Hemp oil, neem oil, hemp methyl ester and neem methyl ester were found to be stable in terms of oxidative stability even after two month and their kinematic viscosity remained within the prescribed limit for the diesel as stated by the Bureau of Indian Standards.
- It is evident that the iodine value of diesel fuel was observed as 38.3. The iodine values of hemp oil and neem oil were observed to be 91.7 and 69.3 whereas the iodine values of hemp and neem methyl ester were achieved to be 95 and 74 respectively.
- The saponification values of hemp oil and neem oil were observed to be 193 and 196 whereas the saponification values of hemp and neem methyl ester were obtained to be 190 and 192.
- Free glycerine contents of hemp and neem methyl ester were obtained to be 0.00 and 0.00. The total glycerine content of hemp and neem methyl ester were achieved to be 0.020 and 0.025
- The net cost of neem methyl ester is Rs. 34.8/kg whereas net cost of hemp methyl ester is Rs. 37.7/g. Present cost of diesel is Rs. 39. The result shows that hemp methyl ester is 7.86 % higher than that of neem methyl ester. Ultimately, we can say that neem methyl ester is best than that of hemp methyl ester in economics point of view.
- The economics of HME and NME is more promising with integrated approach.
- Transesterification has proved to be the effective technical route adopted for modifying hemp and neem oil.

- HME and NME are non-toxic, biodegradable, environment-friendly, renewable fuels and do not add to global warming.
- Use of 20% blends of HME and NME as partial diesel substitutes can go a long way in conservation measure, boosting economy, reducing uncertainty of fuel availability and making more self-reliant.
- The economics can be further improved if other benefits are also taken into account i.e. public health cost may decrease, as per protocol CO_2 tax may be saved, foreign exchange may be saved, there is continuous increase in import of crude petroleum and price of it, huge potential for employment generation, waste land development is possible, self sufficiency may be achieved, engines may meet stringent emission norms with biodiesel fuels and hence cost of diesel fuel development may be saved, less engine maintenance cost etc.

5.2 Scope of Future 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 program and storing information and database for wider information dissemination among the public at large should be taken up at a larger scale.
- The technique of transesterification can be extended to various non-edible vegetable oils. Further investigation can be carried out to prepare ethyl ester from various non-edible vegetable oils and to conduct various engine tests.
- Performance and emission tests can be carried out on multi-cylinder generator engines and surface transportation engines like tractor, car, jeep, bus, trucks etc. Emission studies for measurement of particulate matter, and regulated emissions as well as unregulated emissions such as polyaromatic hydrocarbons, volatile organic compounds, aldehydes etc. has to be carried out to reveal a total picture of environmental impact using biodiesel vis-à-vis diesel fuel.
- A detailed long-term endurance test can be carried out to study physical condition of various surfaces reflecting extent of wear and carbon depositions due to difference in performance of the different fuels and to conduct through tribological investigations
- Further studies can also be carried out on material compatibility, storage and utilization of by-product from biodiesel.

REFERENCES

---

[1] S. Karmee, A. Chadha. Preparation of biodiesel from crude oil of Pongamia pinnata. Bioresource Technology 96 (2005) pp. 1425-1429.

[2] A.Bouaid, Y.D. Martinez, J. Aracil. Pilot plant studies of biodiesel production using Brassica carinata as raw material. Catalysis Today 106 (2005) pp. 193-196.

[3] C.L. Meher, N.S. Naik. Optimization of alkali-catalyzed transesterification of Pongamia pinnata oil for production of biodiesel. Bioresource Technology 97 (2006) pp. 1392-1397.

[4] G. Antolin, V.F. Briceno. Optimization of biodiesel production by sunflower oil transesterification. Bioresource Technology 83 (2002) pp. 111-114.

[5] L.F. Razon et al. Alternative crops for biodiesel feedstock. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources (2009) **4**, No. 056.

[6] K. A. Subramanian, S. K. Singal and M. Saxena. Utilization of liquid biofuels in automotive diesel engines: An Indian perspective. Biomass and bioenergy 29 (2005) pp. 65-72.

[7] A.N. Phan, T.M. Phan. Biodiesel production from waste cooking oils. Fuel (2008) doi:10.1016/j.fuel.2008.07.008.

[8] A.V. Tomasevic, S.S. Siler-Marinkovic. Methanolysis of used frying oil. Fuel processing Technology 81 (2003) pp. 1-6.

[9] R.A. Holser, R. Harry-O’Kuru. Transesterified milkweed seed oil as a biodiesel fuel. Fuel 2 (2006).

[10] R.A. Korus, D.S. Hoffman, D.C. Drown. Transesterification process to manufacture ethyl ester of rape oil. Deptt of Chemical Engg University of Idaho Moscow ID 83844-1021.

[11] A. Srivastava, R. Prasad. Triglycerides-based diesel fuels. Renewable and Sustainable Energy Reviews 4 (2000) pp. 111-133.

[12] F. Ma, M.A. Hanna. Biodiesel production: A review. Bioresourse Technology 70(1999) pp. 1-15.

[13] J.M. Marchetti, V.U. Migue, A.F. Errazu. Possible methods for biodiesel production. Renewable and Sustainable Energy Reviews 24 (2005)

[14] V.J. Gerpen. Biodiesel processing and production. Fuel Processing Technology 86 (2005) pp. 1097-1107.

[15] G. Vicente, M. Martinez, J. Aracil. Integrated biodiesel production: A comparison of different homogenous catalysts systems. Bioresourse Technology 92 (2004) pp. 297-305.

[16] H. Lu, Y. Liu, and H. Zhou. Production of biodiesel from jatropha curcas L. oil. Computers and Chemical Engineering 33 (2009) pp. 1091-1096.

[17] L.C. Meher, S.N. Naik, and L.M. Das. Methanolysis of pongamia pinnata (Karanja) oil for production of biodiesel. Journal of Scientific and Industrial research Volume 63, November 2004 pp 913-918.

[18] A.K. Gupta and Vivek et al. Biodiesel production from Karanja oil. Journal of Scientific and Industrial research Volume 63, November 2004 pp. 39-47.

[19] M.C. Math and G. Irfan. Optimization of restaurant waste oil methyl ester yield. Journal of Scientific and Industrial research Volume 66, November 2007 pp. 772-776.

[20] O.J. Alamu, T.A. Akintola and C.C. Enweremadu. Characterization of palm-kernel oil biodiesel produced through NaOH-catalysed transesterification process. Scientific Research and Essay Volume 3 (7), (2008) pp. 308-311.

[21] M.Ahmad, S. Rashid and M. Khan. Optimization of base catalyzed transesterification of peanut oil biodiesel. African Journal of Biotechnology Volume 8 (3), (2009) pp. 441-446.

[22] F. Ullah, A. Nosheen, and I. Hussain. Base catalyzed transesterification of wild apricot kernel oil for biodiesel production. African Journal of Biotechnology Volume 8 (14), (2009) pp. 3289-3293.

[23] M.C. Sekhar, V.R. Mamilla and M.V. Mallikarjun. Production of biodiesel from neem oil. International Journal of Engineering Studies ISSN 0975-6469 Volume 4, (2009) pp. 295-302.

[24] L.Lin, D. Ying, S. Chaitep, S. Vittayapadung. Biodiesel production from crude rice bran oil and properties as fuel. Applied Energy 86 (2009) pp. 681-688.

[25] S. Sinha, A.K. Agarwal, S. Garg. Biodiesel development from rice bran oil: Transesterigfication process optimization and fuel characterization. Energy Conversion and Management 49 (2008) pp. 1248-1257.

[26] T. Eevera, K. Rajendran, S. Saradha. Biodiesel production process optimization and characterization to assess the suitability of the product for varied environmental conditions. Renewable Energy 34 (2009) pp. 762-765.

[27] I.C.F. D. Santos, S.H.V.D. Carvalho, J.I. Solleti. Studies of Terminalia catappa L. oil: Characterization and biodiesel production. Bioresourse Technology 99 (2008) pp. 6545-6549.

[28] S.M. Radwan, A.M.Ismail, S.M. Elfeky, M.S.O. Abu-Elyazeed. Jojoba methyl ester as a diesel fuel substitute: Preparation and Characterization. Applied Thermal Engineering 27 (2007) pp. 314-322.

[29] L. Canoira, R. Alcantara, J. Carrasco. Biodiesel from Jojoba oil-wax: Transesterification with methanol and properties as a fuel. Biomass and Bioenergy 30 (2006) pp. 76-81.

[30] C.Kaya, C. Hamamci, A. Baysal. Methyl ester of peanut seed oil as a potential feedstock for biodiesel production. Renewable Energy 34 (2009) pp.1257-1260.

[31] A. Saydut, M.Z. Duz, C. Kaya. Transesterified sesame seed oil as a biodiesel fuel. Bioresourse Technology 99 (2008) pp. 6656-6660.

[32] I. Mohamad, A. Widyan, O.Ali O, A. Shyoukh. Experimental evaluation of the transesterification of waste palm oil into biodiesel. Bioresourse Technology 85 (2002) pp. 253-256.

[33] C. Allen, A.C. Watts, M.J. Pegg. Predicting the viscosity of biodiesel fuels from their fatty acid ester composition. Fuel 78 (1999) pp. 1319-1326.

[34] S.A. Ramadhas, S. Jayaraj, C. Muraleedharan. Use of vegetable oils as I. C. engine fuels: – A review. Renewable Energy 29 (2004) pp. 727-742.

[35] A. Demirbas. Biodiesel production from vegetable oils via catalytic and non-catalytic supercritical methanol transesterification methods. Progress in Energy and Combustion Science 31 (2005) pp. 466-487.

[36] T.T. Kywe and M.M. Oo. Production of biodiesel from jatropha oil in pilot plant. World Academy of Science, Engineering and Technology 50 (2009).

[37] S.R. Kalbande and S.D. Vikhe. Jatropha and karanj bio-fuel: An alternative fuel for diesel engine. APRN Journal of Engineering and Applied Sciences, Volume 3 NO.1, February 2008.

[38] D.K. Bora. Performance of single cylinder diesel engine with karabi seed biodiesel. Journal of Scientific and Industrial Research, Volume 68, November 2009, pp. 960-963.

[39] N. Stalin and H.J. Prabhu. Performance test of I.C. engine using Karanja biodiesel blending with diesel. APRN Journal of Engineering and Applied Sciences, Volume 2 NO.5 October 2007.

[40] M.M.K. Kandasamy and M. Thangavelu. Investigation on the performance of diesel engine using various biofuels and the effect of temperature variation. Journal of Sustainable Development, Volume 2, NO.3, November 2009.

[41] T. Balusamy and R. Marappan. Performance evaluation of direct injection diesel engine with blends of Thevetia peruviana seed oil and diesel. Journal of Scientific and Industrial Research, Volume 66, December 2007, pp. 1035-1040.
[42] J.A.A. Yamin, N. Sakhnini and A. Sakhrieh. Performance of CI engines using biodiesel as fuel. GCREEDER 2009, Amman-Jordan, March 31st –April 2nd 2009.
[43] S. Puhan, N. Vedaraman, G. Sankaranarayan, V. Boppana, B. Ram. Performance and emission study of Mahua oil (madhuca indica oil) ethyl ester in a 4-stroke natural aspirated direct injection diesel engine. Renewable Energy 30 (2005) pp. 1269-1278.
[44] S. Puhan, N. Vedaraman, G. Sankarnarayanan. Mahua oil (Madhuca Indica seed oil) methyl ester as biodiesel-preparation and emission characteristics. Biomass and Bioenergy 28 (2005) pp. 87-93.
[45] D. Altiparmak, A. Keskin, A. Koca, M. Guru. Alternative fuel properties of tall oil fatty acid methyl ester-diesel fuel blends. Bioresourse Technology 20 (2006).
[46] L.N. Rao, S. Sampath, K. Rajagopal. Experimental studies on the combustion and emission characteristics of a diesel engine fuelled with used cooking oil methyl ester and its diesel blends. International Journal of Applied Science, Engineering and Technology Vol. 4 Number 2 2007 ISSN pp. 1307-4318.
[47] M. Gumus. Evaluation of hazelnut kernel oil of Turkish origin as alternative fuel in diesel engines. Renewable Energy 33 (2008) pp. 2448-2457.
[48] Y.C. Sharma, B. Singh, S.N. Upadhyay. Advancements in development and characterization of biodiesel: A review. Fuel 87 (2008) pp. 2355-2373.
[49] B.K. Barnwal, M.P. Sharma. Prospects of biodiesel production from vegetable oils in India. Renewable and Sustainable Energy Reviews 9 (2005) pp. 363-378.
[50] D. Agarwal, L. Kumar , A.K. Agarwal. Performance evaluation of a vegetable oil fuelled compression ignition engine. Renewable Energy 33 (2008) pp. 1147-1156.
[51] M.P. Dorado, F. Cruz, J.M. Palomar, F.J. Lopez. An approach to the economics of two vegetable oil-based biofuels in Spain. Renewable Energy 31 (2006) pp. 1231-1237.
[52] M.K. Sangha, S.R. Verma, P.K. Gupta, V.K. Thapar. Characteristics of selected plant oils and their esters. Agricultural Mechanization In Asia, Africa and Latin America 2000 Vol. 31 No.1 50-53.
[53] M.C.G. Albuquerque, Y.L. Machado, A.E.B. Torres, D.C.S. Azevedo. Properties of biodiesel oils formulated using different biomass sources and their blends. Renewable Energy 34 (2009) pp. 857-859.
[54] K. Pramanik. Properties and use of Jatropha curcas oil and diesel fuel blends in CI engine. Department of Mechanical Engineering, Regional Engineering College, Warangal 506004, India.
[55] A.S. Ramadhas, S. Jayaraj, C. Muraleedharan. Characterization and effect of using rubber seed oil as fuel in the CI engines. Renewable Energy 30 (2005) pp. 795-803.
[56] O. Hebbal, K.V. Reddy, K. Rajagopal. Performance characteristics of a diesel engine with Deccan hemp oil. Fuel (2006) doi:10.1016/j.fuel.2006.03.011.
[57] S. Altun, H. Bulut, C. Oner. The comparison of engine performance and exhaust emission characteristics of sesame oil-diesel fuel mixture with diesel fuel in a direct injection diesel engine. Renewable Energy 33 (2008) pp. 1791-1795.
[58] K. Purushothaman, G. Nagarajan. Performance, emission and combustion characteristics of a compression ignition engine operating on neat orange oil. Renewable Energy 34 (2009) pp. 242-245.
[59] S. Puhan, R. Jegan, K. Balasubbramanian, G. Nagarajan. Effect of injection pressure on performance, emission and combustion characteristics of high linolenic linseed oil methyl ester in a DI diesel engine. Renewable Energy 34 (2009) pp. 1277-1233.
[60] N.R. Banapurmath, P.G. Tewari, R.S. Hosmath. Performance and emission

characteristics of a DI compression ignition engine operated on Honge, Jatropha and Sesame oil methyl esters. Renewable Energy 33 (2008) pp. 1982-1988.

[61] K. Sureshkumar, R. Velraj, R. Ganeshan. Performance and exhaust emission characteristics of a CI engine fueled with Pongamia pinnata methyl ester and its blends with diesel Renewable Energy 33 (2008) pp. 2294-2302.

[62] B. Baiju, M.K. Naik, L.M. Das. A comparative evaluation of compression ignition engine characteristics using methyl and ethyl esters of Karanja oil. Renewable Energy 34 (2009) pp. 1616-1621.

[63] A.S. Ramadhas, C. Muraleedharan, S. Jayaraj. Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. Renewable Energy 30 (2005) pp. 1789-1800.

[64] H.T.C. Machacon, S. Shiga, T. Karasawa, H. Nakamura. Performance and emission characteristics of a diesel engine fueled with coconut oil-diesel fuel blend. Biomass and Bioenergy 20 (2001) pp. 63-69.

[65] A. Keskin, M. Guru, D. Altiparmak, K. Aydin. Using of cotton oil soapstock biodiesel-diesel fuel blends as an alternative diesel fuel. Renewable Energy doi:10.1016/jrenene.2007.03.025.

[66] M.N. Nabi, M.S. Akhter, M.M.Z. Shahadat. Improvement of engine emissions with conventional diesel fuel and diesel-biodiesel blends. Bioresourse Technology 97 (2006) pp. 372-378.

[67] M. Pugazhvadivu, K. Jeyachandran. Investigations on the performance and exhaust emissions of a diesel engine using preheated waste frying oil as fuel. Renewable Energy 30 (2005) pp. 2189-2202.

[68] P.K. Sahoo, L.M. Das, M.K.G. Babu, S.N. Naik. Biodiesel development from high acid value polanga seed oil and performance evaluation in a CI engine. Fuel 86 (2007) pp. 448-454.

[69] Y.D. Wang, T. Al-Shemmeri, P. Eames, S. Rezvani. An experimental investigation of the performance and gaseous exhaust emissions of a diesel engine using blends. Applied Thermal Engineering (2005) doi:10.1016/j.applthermaleng.2005.11.013.

[70] J. Singh, T.N. Mishra, T.K. Bhattacharya, M.P.Singh. Emission characteristics of Methyl ester of rice bran oil as fuel in compression ignition engine. International Journal of Chemical and Bimolecular Engineering Volume 1 Number 2 pp. 63-67.

[71] A. Shaheed, E. Swain. Combustion analysis of coconut oil and its methyl esters in a diesel engine. Proc Instn Mech Engrs Vol. 213 part A, pp. 417-425.

[72] S. Sundarapandian, G. Devaradjane. Performance and emission analysis of biodiesel operated CI engine. Journal of Engineering, Computing, and Architecture Vol. 1 Issue 2 2007.

[73] S. Bari, T.H. Lim, C.W. Yu. Effects of preheating of crude palm oil on injection system, performance and emission of a diesel engine. Renewable Energy 27 (2002) pp.339-351.

[74] P.S.Rao, K.V. Gopalkrishnan. Vegetable oils and their methyl esters as fuels for diesel engines. Indian Journal of Technology Vol. 29 June 1991 pp. 292-297.

[75] R. Altin, S. Cetinkaya, H.S. Yucesu. The potential of using vegetable oil fuels as fuel for diesel engines. Energy Conversion and Management 42 (2001) pp. 529-538.

[76] A.K. Agarwal. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. Progress in Energy and Combustion Science 33 (2007) pp. 233-271.

[77] M.N.Nabi, M.M. Rahman and M.S. Akhter. Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions. Applied Thermal Engineering 29 (2009) pp. 2265-2270.

[78] M. Karabektas, G. Ergen, and M. Hosoz. The effects of preheated cottonseed oil methyl ester on the performance and exhaust emissions of a diesel engine. Applied Thermal Engineering 28 (2008) pp. 2136-2143.

[79] D.H.Qi, L.M. Geng, and H. Chen. Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crude oil. Renewable Energy (2009) pp. 1-8.

[80] O.M.I. Nwafor et al. Emission characteristics of diesel engine operating on rapeseed methyl ester. Renewable Energy 29 (2004) pp. 119-129.

[81] N. Usta et al. Use of tobacco seed oil methyl ester in a turbocharged indirect injection diesel engine. Biomass and Bioenergy 28 (2005) pp. 77-86.

[82] N. Usta. An experimental study on performance and exhaust emissions of a diesel engine fuelled with tobacco seed oil methyl ester. Energy Conversion and Management 46 (2005) pp. 2373-2386.

[83] S. Murugan, M.C. Ramaswamy and G. Nagarajan. A Comparative study on the performance, emission and combustion studies of a DI diesel engine using distilled tyre pyrolysis oil-diesel blends. Fuel 87 (2008) pp. 2111-2121.

[84] K.C. Velappan. Less NOx biodiesel: CI engine studies fuelled with rice bran oil biodiesel and its five blends. Journal of Scientific and Industrial research Volume 66 November 2007, pp 60-71.

[85] N. Kumar. Production of biodiesel from high FFA rice bran oil and its utilization in a small capacity diesel engine. Journal of Scientific and Industrial research Volume 66 May 2007, pp. 399-402.

[86] H. Hazar and H. Aydin. Performance and emission evaluation of a CI engine fueled with preheated raw rapeseed oil-diesel blends. Applied Energy (2009), doi:10.1016/japerergy.2009.05.021.

[87] D. Agarwal and A.K. Agarwal. Performance and emissions characteristics of jatropha oil in a direct injection compression ignition engine. Applied Thermal Engineering 27 (2007) pp. 2314-2323.

[88] A.K. Agarwal and K. Rajamanoharan. Experimental investigations of performance and emissions of karanja oil and its blends in a single cylinder agricultural diesel engine. Applied Energy 86 (2009) pp. 106-112.

[89] C. Oner and S. Altun. Biodiesel production from inedible animal tallow and an experimental investigation of its use as alternative fuel in a direct injection diesel engine. Applied Energy 86 (2009) pp. 2114-2120.

[90] S. Godiganur, C.H.S. Murthy and R.P. Reddy. 6BTA 5.9 G2-1 Cummins engine performance and emission tests using methyl ester mahua oil/diesel blends. Renewable Energy 34 (2009) pp. 2172-2177.

[91] P.K. Devan and N.V. Mahalakshmi. A study of the performance, emission and combustion characteristics of a CI engine using methyl ester of paradise oil-eucalyptus oil blends. Applied Energy 86 (2009) pp. 675-680.

[92] D. Ramesh and A. Sampathrajan. Investigations on performance and emission characteristics of diesel engine with jatropha biodiesel and its blends. Agricultural Engineering International: The CIGR Ejournal. Manuscript EE 07 013. Vol.X. March, 2008.

[93] S. Ghai, L.M. Das and M.K.G. Babu. Emissions and performance study with sunflower methyl ester as diesel engine fuel. APRN Journal of Engineering and Applied Sciences, Vol. 3, NO. 5, October 2008.

[94] J.G.Suryawanshi. Palm oil methyl ester: A new fuel for CI engines. ISESCO Science and Technology Vision Vol. 5, No. 7, May 2009, pp. 36-40.

[95] C.V. Sudhir, N.Y. Sharma, and P. Mohanan. Potential of waste cooking oils a biodiesel feed stock. Emirates Journal of Engineering Research, 12 (3), 2007, pp. 69-75.

[96] D. Sharma, S.L. Soni, and S.C. Pathak. Performance and emission characteristics of direct injection diesel engine using neem-diesel blends. IE (I) Journal-MC, Vol. 86, July 2005.

[97] Y.V.Hanumantha, R.S. Voleti, and V.S. Hariharan. Jatropha oil methyl ester and its blends used as an alternative fuel in diesel engine. International Journal of Agricultural and Biological Engineering, Vol. 1 No. 2, December 2008.

[98] S. Saravanan, G. Nagarajan, and G. Lakshmi Narayana Rao. Investigation on nonedible vegetable oil as a compression ignition engine fuel in sustaining the energy and environment. Journal of Renewable and Sustainable Energy **2**, 013108 (2010).

[99] M.Gumus and M. Atmaca. Use of Hazelnut Kernel oil methyl ester and its blends as alternative fuels in diesel engines. Turkish Journal of Engineering and Environmental Sciences 32 (2008), pp. 133-141.

[100] N. R. Banapurmath., P.G. Tewari and V.V. Kumar. Combustion and emission characteristics of a direct injection CI engine when operated on Marotti oil methyl ester and blends of Marotti oil methyl ester and diesel. International Journal of Sustainable Engineering, Vol. 2, No. 3, September 2009, pp. 192-200.

[101] T.V. Rao., G.P.Rao and K.H.C. Reddy. Experimental investigation of methyl esters of non-edible oils as biodiesel on C.I. engine. International Journal of Material Science, Vol.3, No. 2, 2008, pp. 199-209.

[102] IS: 1448 [P: 32]: 1992. Petroleum and its products. Methods of test-density and relative density. Bureau of Indian Standards, New Delhi.

[103] IS: 1448 [P: 25]: 1976. Methods of test for petroleum and its products. Determination of kinematic and dynamic viscosity. Bureau of Indian Standards, New Delhi.

[104] IS: 1448 [P: 6]: 1984. Methods of test for petroleum and its products. Heat of combustion of liquid hydrocarbon fuels by bomb calorimeter method. Bureau of Indian Standards, New Delhi.

[105] IS: 1448 [P: 10]: 1970. Methods of test for petroleum and its products. Cloud point and pour point. Bureau of Indian Standards, New Delhi.

[106] Determination of Iodine and Saponification Value, A book on "Standard methods of biochemical analysis", Thimmaiah K.S, University of Agricultural Sciences, Bangalore, Kalyani Publishers. pp 139-141.

[107] ASTM - D 189-IP 13. Carbon Residue of Petroleum Products. IP Standards for Petroleum and its Products, P-1, Methods for Analysis and Testing. The Institute of Petroleum, London.

[108] ASTM - D 482-IP 4. Ash Content of Petroleum Products. IP Standards for Petroleum and its Products, P-1, Methods for Analysis and Testing. The Institute of Petroleum, London.

APPENDIX

A.1.0. 6 TON/DAY EXPELLER FOR NEEM OIL EXTRACTION FROM NEEM SEED

A. 1.1. Salient Features

- Totally enclosed, double reduction oil filled gear box comprising helical gears made of case hardening steel, heat treated for longer life
- Hard faced reversible worms, spacers and cone
- Cold drawn induction hardened cage bars
- Water cooled chamber for temperature controlled crushing
- Automatic conveying system for cake
- Two stage container for seed and cake for continuous operation

A. 1.2. Technical Specification

Capacity : 6 Ton/24 hrs

Chamber bore : 152.4 mm (6″)
Chamber length : 838 mm (30″)
Worm shaft speed : 18∼20 RPM
Worm arrangement : Set of 5∼7 worms
Power requirement : 30 H.P., 960 RPM
Cost : 3.01 Lacs

A.2.0. Water Bath Shaker

A.2.1. Installation

Do not exceed the electrical ratings given in the specifications of the instrument. For this connect the equipment to the correct power source. Incorrect voltage can result in improper functioning of the equipment. Also any improper operation of the equipment could result in dangerous conditions. Kindly follow the instructions given in this manual and also operate the equipment within design limits.

A.2.2. Technical Specification

Interior Material : SS 304

Exterior Material : MS Epoxy powder coated

Working Space Dimensions : 350×300×160mm
Temperature Range : (Ambient+5) to 95℃
Temperature Controller : Solid State Time Proportional Digital Controller
Temperature Uniformity : Achieved by circulator fitted inside
Shaking movement : Reciprocating
Shaking Speed : 10-100 RPM
Tray Material : SS 304
Tray Dimensions : 325×325 mm
Cover Material : SS 304
Input voltage : 230 V AC, 50 Hz

A.2.3. Operating Instructions

1. Connect the unit to 230 V AC supply.
2. Pour the water into bath to its 2/3 level of the bath capacity and till it touches to the temperature sensor mounted inside.
3. Place the flasks to be heated and shake inside the bath in the clamps fitted on the tray.
4. Switch ON the mains switch.
5. The digital temperature controller display will illuminate and shall indicate temperature reading of ambient temperature.
6. Press the button marked as “SET TEMP” and with this switch pressed, set the temperature by “MULTI TURN TEMP SET” knob.
7. The set temperature can be varied to any point within the full range of (Ambient + 5)℃ to 95℃.
8. Once the required temperature is set, release the button. Now the digital temperature controller display will show actual temperature within the chamber.
9. If the temperature is to be set above 50-55℃， the boost heaters can be selected by the switch provided.
10. To start the carrier, press SHAKER. By the switch marked as “RPM”, speed of the carrier can be adjusted.

A.3.0. 600 litre/day capacity semi-continuous type biodiesel plant

- The plant has been designed based upon process timing and simulation so that all the components can work for the designated time and ultimately produces 600 litre of biodiesel per day (24 hr working basis).

- The plant comprises of one oil preheating tank with heater, one methoxide tank with agitator and motor, one reactor vessel with heater, temperature controller, agitation, recirculator, motor and pump, four numbers of separating vessel, one washing cum heating vessel, one stepney vessel for reaction /separation/washing, pipelines, motors, pumps and mounting frame with wheels for easy movement of the whole system.
- The solenoid valves, motors and pumps are operated by switches mounted on as single control panel so as to enable minimum manual intervention during biodiesel production process. The maximum power consumption of the plant is only 3 kW at peak time.

Technical Specification

Type : Semi continuous

Capacity : 600 litre/day (24 hr basis)
Batch capacity : 40 litre/batch
Feedstock suitable : Any vegetable oil (edible and non-edible) irrespective of FFA content
Type of washing : Water washing
Peak power consumption : 3 kW
Final product (biodiesel) : Compliance with ASTM and BIS

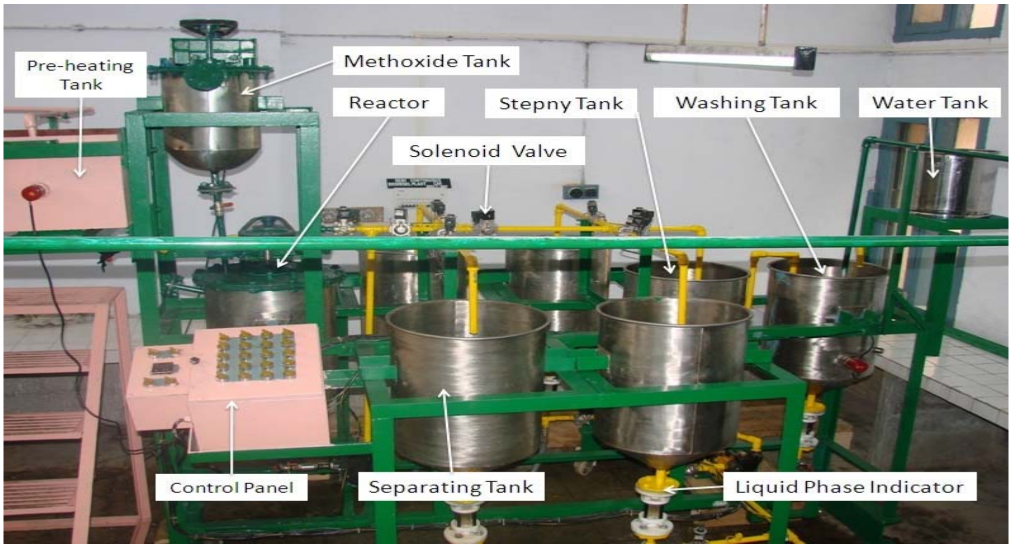


Plate A.3.0**:** Plant view of 600 litre/day capacity semi-continuous type biodiesel plant

4.0. Hot Air Oven (ISO: 2000 Certified Company)

A. 4.1. Precautions

- The hot air chamber should be cleaned at regular intervals from inside.
- Main cord should be connected to a suitably rated and earthed power source (i.e. 5 Amp)
- The hot air chamber should always be kept near the window or exhaust in order to ventilate gasses and fumes.
- Check the voltage to maintain proper temperature. (Use voltage stabilizer if required)
- Keep the hot air chamber away from moisture and cold drafts.

A. 4.2. Operation

1. Slide the shelves into the runners as per the requirement of the material you want to head or dry.
2. Keep the material on the shelves.
3. Close the door and ventilators in order to reach the required temperature.
4. Connect the three-pin plug top to a suitably rated and earthed power source.
5. Switch on the ON/OFF switch; pilot lamp for power will grow.
6. Set the rotary switch in order to increase and decrease the heat, normally it kept on the three no. for maximum heat.
7. Slowly turn the graduated thermostat knob clockwise from its extreme counter position, to desired set point. The pilot lamp for heater will grow.
8. Please allow a few minutes for it to stabilize.
9. Open the ventilator provided for gases and fumes as per your requirements.
10. If after stabilization the temperature reached is less than the required temperature, adjust the thermostat knob slightly by turning it clockwise of vice versa, till the desired temperature attained.
11. Please note that the graduations of the thermostat knob are indicative only. The actual desired temperature will have to be attained by trial as per method outlined in 6 to 10.
12. We can check the temperature on the thermometer provided on the top of oven.
13. If the circulating fan is available with your hot air chamber, than switch on the fan after the 8th operation. The air will be circulating throughout the chamber and the same temperature will be maintained on every corner of the chamber.
14. Instruction manual for digital temperature controller will be provided separately.

A. 4.3 Overview of Components

- Hot air double walled insulated chamber available in Aluminum or Stainless Steel.
- Two or three removable shelves.
- Main cords
- Digital temperature control cum indicator
- Air circulating fan
- Timer

Plate A. 4.0: Hot air oven used for moisture content

A. 5.0 Muffle Furnace

A. 5.1 Precautions

1. The hot air furnace should be cleaned at regular intervals from inside with rough cotton cloth.
2. This is not an explosion proof chamber so do not test any product which is capable of generating combustible mixtures.
3. The muffle furnace must be operated at a maximum of 900°C and Industrial Furnace Grooved type must be operated at a maximum of 1000°C.
4. Place the furnace on the levelled surface.
5. Main cord should be connected to a suitable rated and earthed power source i.e. 15 Amp.

6. The furnace should always be kept neat the window on exhaust in order to ventilate gasses and fumes.
7. Check the voltage to maintain proper temperature (Use voltage stabilizer; if required)

A.5.2 Overview of Components

- High temperature imported kanthal wire
- Front open single door
- Digital temperature control cum indicator / Pyrometer with energy regulator
- Thermal fuse
- High resistance lead wire

A.5.3 Operating Instructions

1. Keep the material in Silica / Platinum crucible or Dish inside the muffle.
2. Close the door and ventilator in order to reach the required temperature.
3. Connect the three core wire to a suitably rated and earthed power source. i.e. 15 Amp.
4. Switch on the ON/OFF switch; Pilot lamp for power will grow.
5. Temperature control through Digital temperature Controller:-

- Digital temperature controller will display the present (Ambient) temperature.
- Set the desired temperature through SET button in Digital temperature controller. Press the SET button and simultaneously rotate the COARSE and FINE knobs till you reaches the required temperature.
- Digital display will show the set temperature value.
- The fine knob is used for setting the temperature by smaller steps.
- Release the SET button; the display will show the actual temperature of the chamber.
- The value of SET button can be know at any time by pressing the SET button without disturbing any working conditions.
- Please allow a few minutes for it to stabilize.
- Open the ventilation provided for gases and fumes as per your requirements.

6. Temperature control through energy regulator
    - Pyrometer fitted in the front panel is showing the present ambient temperature.
    - Slowly turn the energy regulator knob clockwise from its extreme counter to desired set point. The pilot lamp for heater will grow. i. e. If you required 500 deg then set the energy regulator knob at 50 deg and allow a few minutes to stabilize. When the

pyrometer reaches at 400 deg then turn the energy regulator knob anticlockwise at its start point (i.e. 10).

- If after stabilization the temperature reached is less than the required; adjust the regulator knob slightly by turning it clockwise or vice versa till the desired temperature is attained.

Note:- The energy regulator is marked from 0-100 in which 100 indicates maximum electric flow and 0 indicates minimum electric flow. This marking does not indicate temperature.

Plate A. 5. : Muffle furnace used for measurement of ash content

A.6.0 Instrument Description of Gas Chromatograph (NUCON MODEL-5765)

With flame ionization Detector and thermal conductivity detector, gas chromatograph can be utilized for separations, isolation or confirmation of component present in a complex mixture for qualitative and quantitative analysis. The flame ionization detector responds to all organic compounds. Fields of application are fatty acid profile of biodiesel, oil analysis, environmental and biomedical analysis. The thermal conductivity detector can be used for the estimation of gaseous component like methane, carbon dioxide, sulphur dioxide and various hydrocarbons and other gaseous pollutant resulting from industry and automobile exhaust.

- SPECIFICATION
- TEMPERTURE CONTROL MODULE
- THERMAL CONDUCTIVITY MODULE
- FLAME IONISATION DETECTOR MODULE
- SAMPLE INTRODUCTION
- SPARES AND CONSUMABLES

- RECORDER
- PRELIMINARIES

A.6.1 SPECIFICATIONS

- COLUMN OVEN: Half circular shape scientifically designed with double wall construction and large volume. The oven can accept 1/4″ or 1/8″ metal or 1/4″ glass packed or capillary columns.
- OVEN TEMPERATURE: Set by front panel mounted Thumbwheel Switches upto 399℃ in 1℃ steps.
- INJECTOR DETECTOR TEMPERATURE: Set by front panel mounted Thumbwheel Switches upto 390℃ in 10℃ steps.
- TEMPERATURE PROGRAMMER: Solid stage linear temperature programmer with rates 1, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20$℃/min$.
- BUILT IN VOLTMETERA.D.C. : Voltmeter with range upto 20 volts on a 3 ½ digit display is designed into the instrument for both internal and external use.
- TEMPERATURE READOUT: Digital with 1℃ resolution.
- OVEN LIMIT CUT OUT: This is a safety system for oven that trips power to oven heater in the event of oven Triac or Controller malfunction. This should be kept higher than normal maximum operation temperature.

A.6.2 TEMPERATURE CONTROL MODULE

This houses three independent control channels for the heating of

1. Oven
2. Injectors
3. Detectors-either T.C.D. or F.I.D.

The controller for the Oven, Injectors and Detectors is solid state and proportional. The Neons starts flickering when equilibrium is attained. Sensing circulatory is isolated from the mains by means of a Trigger Pulse Isolation Transformer. The feedback of existing temperature information is provided by Platinum Resistance Thermometer that gives a large differential signal. Integrated circuit performs the logic function for control of Triacs placed in series with the Nichrome heater to either allow or restrict the heater power.

A solid state temperature programmer is also provided. The programming rate can be selected say 1, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20$℃/min$. The selection switch has to be put in appropriate Isothermal or Programming Mode, depending upon which one is desired.

A.6.3 THERMAL CONDUCTIVITY DETECTOR MODULE

This houses the electronics for thermal conductivity detector, A-4 core cable connects this module to the T.C. Detector. The Detector filaments are supplied power from and I.C. Regulated D.C. power supply about 18 volts.

T. C. D. CONTROLS:

1. ON/OFF Switch.
2. Current adjustment varies current from 80 mA to 300 mA.
3. Coarse and fine balance controls: Facilities balancing of the system to pre-selected recorder baseline.
4. Attenuator in binary steps from X1 to X 1024 short position. The last position is marked infinity and helps shorting of recorder input terminals to select check recorder zero. The linear binary attenuator helps produce on recorder an expanded graphical representation of weaker signal and vice versa for stronger signal which are relative to the level of concentration of component being analysed.
5. Polarity Switch: It reverses the polarity of the signal.
6. Mark Event: It is a ‘Press to make contact’ type switch upon press and release of which the recorder pen would deflect 20-30 mm leaving visible mark on recorder chart. This facility is corporate in the module to mark on recorder chart the event of injection of sample so that retention time of peaks could be directly calculated from the graph.

A.6.4 FLAME IONISATION DETECTOR MODULE

This houses the electronics for the two essential requirements.

1. Power supply: Regulated to + 180 and -180 volt D.C.
2. Amplifier and its double ended I.C. Regulated power supply±12 volts D.C. This is a high impedence high stability amplifier for measurement of very small currents.

F. I. D. CONTROLS :

1. ON/OFF Switch.
2. Sensitivity: In steps X1, X10, X100 and X 1000. The last position giving a selection 1000 times more sensitive than the first.

3. Attenuator in binary steps from X 1 to X 1024 and short position. The last position is marked infinity and helps shorting of recorder input terminals to select/check recorder zero. The linear binary attenuator helps produce on recorder an expanded graphical presentation of weak signal and vice versa for stronger signal which are a relative to the level of concentration of component being analysed.
4. Balance to be used for bringing base line to zero position.
5. Polarity Switch :It reverses the polarity of the signal.
6. Mark Event: It is a ‘Press to make contact’ type switch upon press and release of which the recorder pen would deflect 20-30 mm leaving visible mark on recorder chart. This facility is incorporated in the module to mark on recorder chart the event of injection of sample so that retention time of peaks could be directly calculated from the graph.

A.6.5 SAMPLE INTRODUCTION

Liquid samples are injected by means of a Microlitre Syringe and Gas samples by means of either a Gas Tight Syringe or a Gas Sampling Valve.

A.6.6 SPARES AND CONSUMABLES

Syringes, Septums, Valves, Special sample preparation and collection attachments for various applications, Colums, Fitting/Connectors, Stainless Steel Tubing, Chart Paper, Ink etc. Are generally available ex-stock with the company.

A.6.7 RECORDER

A potentiometric strip chart self balancing recorder of sensitivity 1 mV full scale deflection, response time around one second, chart width around 250 mm and high input impendence is recommended for gas chromatography work.

The following services are required for Installation of Gas Chromatography

1. Carrier Gas : The most widely used carrier gases are Nitrogen, Hydrogen, Argon and Helium. High purity gas cylinder with two stage pressure regulator is essential.
2. Fuel and Air for F.I.D : High purity Hydrogen and Compressed Air Cylinder with two stage pressure regulators essential.
3. Mains Supply : 3 Nos. 2 pin 5 Amp and 1 No. 2 pin socket are required for Mains supply. There should be no leakage in Main Supply and a good earth point is essential. Power requirement is less than 1 KVA at 220 V A.C. 1Ø 50 Hz. In case the supply fluctuates or deviates more than 20 V (±10 V), we recommend use of a Servo type Stabilizer.

4. Soap solution capable of good bubble formation and a small point brush.
5. General Solvents: Small clean breakers or test tubes.

A.6.8 PRELIMINARIES

- Carefully unpack all units and check against accompanying delivery note/challan. A convenient table height for placing/laying out the instrument is 3 ft. For optimum performance the environment should be neat, clean, free from air draught, high humidity and rapid changes of ambient temperature. Wherever possible, an air conditioned room should be selected.
- Mains supply wiring should conform to I.S.I recommend configuration i.e. live on R.H.S., Neutral on L.H.S. and Earth on top of the socket, looking from top.
- The high purity gas cylinder should be tested for leakage and should be placed firmly adjacent to the instrument in a manner that makes it convenient to open and close the gas supply. The two stage pressure regulators should be tested for leakage and proper regulation.

A.7.0 Procedure for Measurement of Smoke Opacity

1. Plug the equipment to the main power socket.
2. Place the sampling hose in the ascending gradient from the probe to the sensor unit.
3. Clean the glass in the light and the detector assembly with soft cloth (for the first reading of the day).
4. Switch on the equipment by pressing power key.
5. Fans get switched on immediately after the power switch is made on. The light source and the cross over valve for automatic calibration get activated. In first 20 second zero point calibration is carried out automatically. After switching on, the heating element of the measurement chamber starts to heat up. The instantaneous temperature is continuously displayed on the operating unit. A temperature of 70 deg is reached after approximately 20 minutes. The equipment goes to CAL mode automatically.
6. Press DISPLAY SELECT button to select type of display required depending on what you want to measure (opacity/extinction coefficient/pressure/temperature). Press LINEAR CHECK button and the equipment carries out internal linearity check using calibration screen of the range of 48.4% to 53.1% (1.54 m^{-1} to 1.74 m^{-1}) and prints out the result.

Check the results from the print out for the tolerance. The equipment goes to CAL mode automatically, corresponding LED lights up and equipment is ready for taking first reading.

7. Press TEST button and current value is displayed.
8. At a stable value press MAN switch to get the print out. Press CAL switch or the equipment otherwise also goes to CAL mode automatically in 10 seconds.
9. For the next reading (after ensuring 75 mm of pressure in the chamber) Press TEST switch again and repeat the procedure.

The technical specifications of AVL make 437 smoke meter are given in Table A.7.1

Table A.7.1: Technical Specification of Smoke Meter

S.N.	Parameter	Details
1	Accuracy and reproducibility	±1% full scale reading
2	Measuring range	0 to 100% opacity in percentage, 0 to infinity absorption in m^{-1}
3	Measurement chamber	Effective length 0.430±0.005
4	Heating time	20 m minutes approximately
5	Light source	Halogen bulb 12 V/ 5W
6	Measurement value indication	Processor control LED, Display 4× 15 mm
7	Detector	Selenium photocell of 45 mm diameter
8	Colour temperature	3000±150 K
9	Temperature gauge	Electric temperature measuring instrument
10	Power consumption	600 W
11	Weight	50 kg
12	Dimensions	570(width) × 500(breadth) × 1250 (height)

A.8.0 Procedure for Measurement of Five-Gas Analyzer

1. Switch on the machine, tester then carries out initialization test. The name of the software version is displayed for a minute. Choose ‘ ≫ option from the screen. Main menu is then displayed.
2. Choose Standard measurement option from the main menu. Tester takes about 15 minutes to stabilize if it has not been use for long time (Time left to wait is continuously displayed). The tester goes through warm up phase every time it is switched on.
3. Instruction to perform leak check of the probe is displayed. Perform the leak check as per the procedure given in the manual. Tester then needs time to stabilize and the time left to wait is displayed on the screen. The tester automatically checks HC residue in the sampling hose and lines. Probe must be in fresh air for this check. If the HC concentration

value shown is more than 20 ppm there may be high residue in the hose. Allow it to suck fresh air till the value is less than 20 ppm. Then tester goes through stabilization phase and starts displaying values of λ, CO, CO_2, HC, O_2 and NOx values. When values become stable press the print option to get the print out of the values.

The technical specifications and measurement parameters of AVL DiGas 4000 five gas exhaust analyser are given in Table A.8.1 and Table A.8.2.

Table A.8.1: Technical Specification of the 5-Gas Analyzer

Measurement principal	CO, HC, CO2- Infrared Measurement and O2 and Nox-Electrochemical measurement
Voltage	195-253 V
Power input	150 W
Dimensions	360 mm × 370 mm × 220 mm
Weight	14 kg
Rated flow rate	360 litres/hr
Minimum flow rate	180 litres/hr

Table A.8.2: Measurement parameters of the 5-Gas Analyzer

S.N.	Measurement parameter	Measurement range	Resolution
1	CO	0-10% by vol.	0.01% by vol.
2	CO_2	0-20% by vol.	0.1% by vol.
3	HC	0-20000 ppm vol.	1ppm vol.
4	O_2	0-4% by vol. and 4-22% by vol.	0.01% by vol. and 0.1% by vol.
5	NOx	0-4000 ppm vol.	1 ppm vol.

A.9.0 Specification of Engine set up and its constants

The experimentation has been conducted with diesel, hemp oil, neem oil, hemp methyl ester, neem methyl ester and 20% blends of selected methyl ester in Compression ignition engine. The specification of compression ignition engine set up and its constants are shown in Table A.9.1 and Table A.9.2

Table A.9.1: Engine Set-up Constants

Engine stroke length	0.110 m
Engine connecting rod length	0.234 m
Engine cylinder diameter	0.875 m
Number of cylinders	1
Number of strokes	4
Engine compression ratio	17.5
Orifice plate diameter for air box	0.020 m

Table A.9.1: Engine Set-up Constants (Continue)

Coefficient of discharge for air	0.6
Fuel calibration factor	0.012
Calorific value	42000 (changeable for different fuels)
Dynamometer arm length	0.195 m
Specific heat of exhaust gases(Maximum)	1.25 kJ/kg.K
Specific heat of exhaust gases(Minimum)	1.10 kJ/kg.K
Ambient temperature	30 ℃
Pulses per revolution for encoder	180

Table A.9.2: Specifications of the engine test set-up

S.N.	Components	Specifications
1	Engine	Model 224, Single cylinder, 4-stroke, water cooled, Diesel, make: Kirloskar, model TV1, rated power 5.2 kW, speed 1500 RPM, bore 87.5 mm, stroke 110 mm, compression ratio 17.5, capacity 661 cc.
2	Dynamometer	Eddy current type, SAJ make AG 20 model
3	Piezo-Sensor	Range 5000psi, PSB USA make, water cooled type
4	Crank angle sensor	Resolution 1 degree, speed 5000 RPM, with TDC marker pulse
5	Engine indicator	Receiving data and interfacing, with speed indicator
6	Engine-soft software	For P-Theta, and P-V diagram, HP, Efficiency and MEP calculations, data logging and printing, Made by Apex Engineers, Sangli.
7	Air box	With orifice meter and manometer
8	Fuel tank	10 litre capacity, with graduated glass fuel metering column
9	Rotameter	For water flow measurements
10	Calorimeter	Pipe in pipe type
11	Temperature indicators	Digital PT-100 type, temperature sensor (6 point)
12	Overall size	2 m by 2.5 m by 1.5 m
13	Weight	300 kg (Approximately)
14	Electric supply	230 V AC, Single Phase
15	Foundation	PCC foundation
16	Computer	P-III, 20 GB HDD, 64 MB RAM, with floppy drive and CD writer, SVGA colour monitor

ABOUT THE AUTHOR

Author was born on 26th September 1979 in Chandrapur district in state of Maharashtra, India. He passed his S.S.C examination in 1995 with 83.14% marks and H.S.S.C examination in 1997 with 73.50% marks from Nagpur board, Maharashtra. He did his Bachelors of Engineering (Mechanical branch) from Government College of Engineering at Chandrapur in 2001. He did his Masters of Technology (Heat Power Engineering) from V.N.I.T at Nagpur in 2006. Presently he is working as a Teaching Associate (Mechanical Engineering Department) in Thapar University at Patiala since 2007.

Address:
Satishchandra S Ragit
C/o Shri Shamrao S Ragit
Near Pathanpura Sub-post office,
Near Dr. Lonare home, Chandrapur-442 402
State: Maharashtra
Email ID: satish_ragit@yahoo.com

PUBLICATIONS FROM THE RESEARCH WORK

INTERNATIONAL JOURNAL PUBLICATIONS

1. Paper entitled "Optimization of neem methyl ester from transesterification process and fuel characterization as a diesel substitute" published in the Journal of Biomass and Bioenergy, 35 (2011) 1138-1144.
2. Paper entitled "Performance and emission evaluation of an compression ignition engine fuelled with neem methyl ester and its respective blends" published in International Journal of Fluid Engineering, ISSN 0974-3138, Vol.2, Number 1 (2011), pp. 29-40.
3. Paper entitled "Biodiesel production from used frying oil and properties as an alternative fuel" published in International Journal of Fluid Engineering, ISSN 0974-3138, Vol.2, Number 1 (2011), pp. 21-27.

NATIONAL JOURNAL PUBLICATION

1. Paper entitled "Performance and emission evaluation of a diesel engine fuelled with methyl ester of neem oil and filtered neem oil" published in the Journal of Scientific and Industrial Research, Vol. 69, January 2010, pp. 62-66 (New Delhi, India).

NATIONAL JOURNAL ACCEPTANCE

1. Paper entitled "Comparative studies on performance characteristics of CI engine fuelled with neem methyl ester and mahua methyl ester and its respective blends with diesel fuel" has been accepted to the Indian Journal of Environmental Science and Engineering, Nagpur (December 2010).

NATIONAL CONFERENCE PUBLICATIONS

1. Paper entitled "Production, optimization and characterization of neem biodiesel" presented at the National Workshop on Production Methodologies Utilization Techniques and Challengers Ahead held at Mechanical Engineering Research and Development Organization, Ludhiana (Punjab) during 22-23rd March, 2007.
2. Paper entitled "Neem biodiesel as a alternative fuel" presented at the Renewable Energy Club held at Thapar University, Patiala (Punjab) 30th March, 2007.
3. Paper entitled "Characterization of neem oil and experimental study on performance and exhaust emission of a diesel engine fuelled with neem oil and neem oil-diesel blends" presented at the National Workshop on Recent Developments and Futuristic Trends in

Mechanical Engineering held at Shriram College of Engineering and Management, Banmore (M.P) during 28-29th April, 2007.

4. Paper entitled "Production Technology and Economic Evaluation of Neem Biodiesel" presented at the National Workshop on Emerging Trends in Mechanical Engineering held at SVNIT, Surat (Gujarat) during 4-5th June 2007.
5. Paper entitled "Experimental Evaluation of Performance and Exhaust Emission of Neem Methyl Ester and Neem Ethyl ester fuelled with Diesel Engine" presented at the National Workshop on STEM held at G. B. Pant University, Pantanagar (Uttrakhand) during 2-4th August, 2007.
6. Paper entitled "A comparative analysis on the performance and exhaust emission characteristics using raw hemp oil and filtered neem oil in diesel engine presented at the National Conference on Futuristic Trends in Mechanical Engineering held at GNDEC, Ludhiana (Punjab) during 29-30th October, 2010.
7. Paper entitled "Experimental investigation of performance and emission of hemp biodiesel and its blends with diesel in a single cylinder 4 stroke diesel engine" presented at the National Conference on Advancements and Futuristic Trends in Mechanical and Industrial Engineering held at Ganpati Institute of Technology and Management, Bilaspur, Yamuna Nagar (Haryana) during 12-13thNovember, 2010.
8. Paper entitled "Optimization of Mahua biodiesel by different production technique" presented at the National Conference on Advance in Chemical Engineering held at Thapar University, Patiala (Punjab) during 27-28th February, 2011.
9. Paper entitled " Performance and emission characteristics of a diesel engine fuelled with hemp oil and 20% blends of hemp oil with diesel fuel" presented at the National Conference on Emerging Trends in Mechanical Engineering at Vallabh Vidyanagar, Anand (Gujarat) during 18-19th March, 2011.