Comparative Analysis of the Performance & Emissions Characteristics of a C.I. Engine Fuelled with Three Different Blends of Biodiesel Derived from Waste Mustard Oil

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

Master of Engineering

In

Thermal Engineering

By

Vaneet

Roll No. 801083031

Under the guidance of

Mr. Sumeet Sharma
Associate Professor
Mechanical Engg. Deptt.
Thapar University
Patiala

Dr. K. Kundu
Scientist E-1 and
H.O.D., Deptt. of Biofuel
MERADO,
Ludhiana

Dr. S.K. Mohapatra
Senior Professor
Mechanical Engg. Deptt.
Thapar University
Patiala

DEPARTMENT OF MECHANICAL ENGINEERING,

THAPAR UNIVERSITY, PATIALA-147004, PUNJAB, INDIA

JULY 2012

CERTIFICATE

Certified that the thesis entitled **"COMPARATIVE ANALYSIS OF THE PERFORMANCE & EMISSIONS CHARACTERISTICS OF A C.I. ENGINE FUELLED WITH THREE DIFFERENT BLENDS OF BIODIESEL DERIVED FROM WASTE MUSTARD OIL"** which is being submitted by **Mr. VANEET** to Thapar University, Patiala in fulfilment of the requirements for the award of the degree of M.E. Thermal Engineering is a record of bonafide research work carried out by him under our guidance and supervision. The matter submitted via this report has not been submitted for the award of any other degree to the best of our knowledge.

(VANEET)

Mr. Sumeet Sharma	**Dr. K. Kundu**	**Dr. S.K. Mohapatra**
Associate Professor,	Scientist E-1 and	Senior Professor,
Mechanical Engg. Deptt.,	H.O.D., Deptt. of Biofuel,	Mechanical Engg. Deptt.,
Thapar University,	MERADO,	Thapar University,
Patiala	Ludhiana	Patiala

Countersigned by:

Prof. Ajay Batish	**Prof. S.K. Mohapatra**
Professor and Head,	Dean of Academic Affairs,
Mechanical Engg. Deptt.,	Thapar University,
Thapar University, Patiala	Patiala

ACKNOWLEDGEMENTS

I wish to express my thanks to Dr. S.K. Mohapatra and Mr. Sumeet Sharma, Department of Mechanical Engineering., Thapar University, Patiala, for their guidance and encouragement. The present work is the convergence of their ideas. Working under their guidance is of immense pleasure and very worthful in the context of knowledge.

I also wish to thank Dr. K. Kundu, Scientist-E1 and Head, Department of Bio fuel, Mechanical Engineering Research and Development Organization (MERADO), Ludhiana for his support and the staff at MERADO who supervised me during the production of Biodiesel and staff of Internal combustion engine labortary, Thapar University who supervised me during the estimation of performance and emission characteristics of the C.I. engine.

I also wish to thank Dr. Ajay Batish, Head of department, Mechanical Engineering Department, Thapar University, Patiala.

I am very thankful to my parents, friends and colleagues for their encouragement and support in building up this thesis report.

Vaneet

R. No. 801083031

Thermal Engg.

M.E.D.

TU, PATIALA

ABSTRACT

Decline in fossil fuel resources along with high crude oil prices generated attention towards the development of fuel from alternate sources. Such fuel should be economically attractive and performance competent in order to replace the fossil fuel. Biodiesel offer a very promising alternative to diesel oil since they are renewable and have similar properties. Throughout the world, there is an enormous amount of waste lipids generated from restaurants and food shops posing a challenge for their storage and proper disposal in the environment. Reuse of these oils not only helps in its management but also lowers the production cost of biodiesel. Biowaste cooking oils thus opened a good opportunity to study its suitability to produce biodiesel. Then, problem gets generated from viscosity of these biowaste cooking oils. Transesterification process was used to lower the viscosity of the waste oil. Biodiesel from *waste mustard oil* was prepared. The properties of B100 were studied. Then, Biodiesel was blended with petrodiesel at three different levels i.e. B10, B15 and B20 as the direct use may cease the engine.

In this present research work, waste mustard 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 waste mustard biodiesel and its blends (10%, 15% and 20%). The performance parameters analyzed include brake power, brake thermal efficiency, brake specific fuel consumption, and exhaust gas temperature whereas exhaust emissions include oxides of nitrogen, HC and CO. 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 waste mustard biodiesel-diesel fuel blends were tested in a single cylinder direct injection diesel engine. Engine performance and exhaust emission were measured at no, part and full load condition. This research investigates the scope of utilizing waste mustard oils 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 waste mustard biodiesel and important fuel properties have been determined. It concluded that B10 blend of waste mustard biodiesel 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 waste mustard oil in direct injection CI engine without any substantial hardware modifications.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

NOMENCLATURE

ICE	Internal combustion engine
CI	Compression ignition
D	Diesel
B100	100% biodiesel
B10	10% biodiesel + 90% petrodiesel
B15	15% biodiesel + 85% petrodiesel
B20	20% biodiesel + 80% petrodiesel
BP	Brake power
BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
$\eta_{f,b}$	Brake fuel conversion efficiency
EGT	Exhaust gas temperature
FAME	Fatty acid methyl ester
CO	Carbon monoxide
HC	Hydrocarbons
PM	Particulate matter
EPA	Environmental protection agency
NOx	Nitrous oxide
CFPP	Cold filter plugging point
ASTM	American Society of Testing and Materials
WCO	Waste cooking oil
EGR	Exhaust gas recirculation
FFA	Free fatty acids

CHAPTER 1

INTRODUCTION

1.1 Biodiesel

The large increase in number of automobiles in recent years has resulted in great demand for petroleum products. With crude oil reserves estimated to last for few decades, there has been an active search for alternate fuels. The depletion of crude oil would cause a major impact on the transportation sector**.** [1] To meet ever increasing energy requirements, there has been growing interest in alternative fuels like biodiesel to provide a suitable diesel oil substitute for internal combustion engines. Biodiesels offer a very promising alternative to diesel oil since they are renewable and have similar properties.

The major components of vegetable oils and animal fats are triacylglycerols (TAG). Chemically, TAG are esters of fatty acids (FA) with glycerol (1, 2, 3-propanetriol; glycerol is often also called glycerine).The TAG of vegetable oils and animal fats typically contain several different FA.Thus, different FA can be attached to one glycerol backbone. The different FA that are contained in the TAG comprise the FA profile (or FA composition) of the vegetable oil or animal fat. Because different FA have different physical and chemical properties, the FA profile is probably the most important parameter influencing the corresponding properties of a vegetable oil or animal fat.

Biodiesel is a clean burning alternative fuel, produced from domestic, renewable resources such as plant oils, animal fats, used cooking oil and even new sources such as algae.[2]

Biodiesel does not contain petroleum products but it can be blended at any level with petroleum diesel to create a biodiesel blend. Biodiesel blends can be used in most compression ignition (diesel) engines with little or no modification. Biodiesel may be used in any diesel automotive engines in its pure form or blended with petroleum based diesel. No modifications are required, and the result is less expensive, renewable, clean burning fuel.

1.2 History behind biodiesel

The concept of biofuel firstly came into the picture in 1885 when Dr. Rudolf Diesel built the first diesel compression ignition engine with full intention of running it on vegetative source and developed the first engine to run on peanut oil. In 1912, he observed, “The use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in the course of time as important as the petroleum and coal tar products of the present time.” However, due to cheap petroleum products, and probably due to economic might of the cartels, investigations of such non-conventional fuels never took off to offer any viable ideas. However, it appears the trend has changed, after the world realized that oil resources are almost on the path of exhaustion and cannot sustain the world economy for more than about half a century. In 1970, researchers have found that a simple chemical process could reduce the viscosity of vegetable oils and it could perform like diesel fuel in modern internal combustion engines. Since then the technical developments have come a long way and the plant oil today has been highly established as biofuel, equivalent to diesel.

Recent environmental (e.g. Kyoto Protocol, Cunningham and Cunningham 2002) and economic concerns have prompted resurgence in the use of biodiesel throughout the world. USA and several European countries are already working towards substituting petroleum fuel by such alternatives. In 1991, the European Community proposed a 90 per cent tax reduction for using biofuels, including biodiesel and is targeting to reduce consumption of petroleum fuel at least by around 5 per cent, by substituting with biofuel by the year 2010.Today, 21 countries worldwide produce biodiesel. India is one of the largest petroleum consuming and importing countries. India imports about 70 per cent of its petroleum demands. Currently Indian annual requirement for petroleum products is about 120 million metric tons of which the diesel consumption is approximately 40 million tonnes. [2]

1.3 Economic aspects of biodiesel

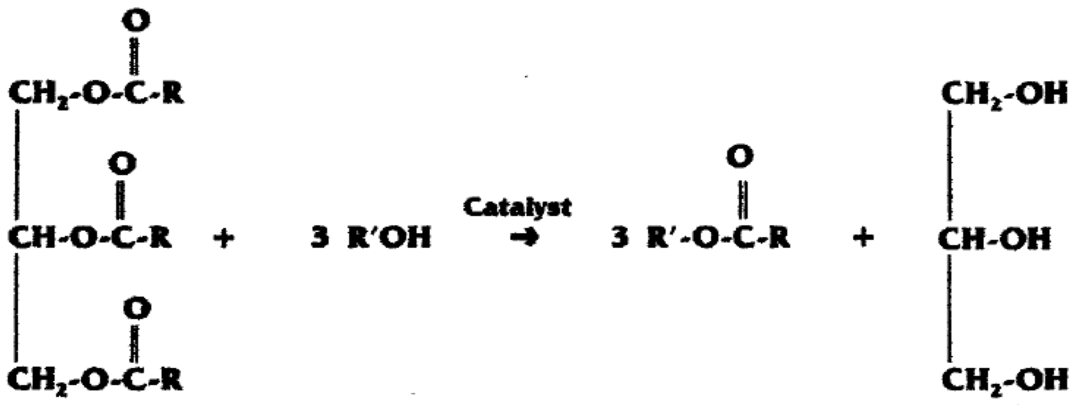
While inventing a new fuel, the economic aspect is also very important to take into account. In Brazil, there is abundance of ethanol, but petro diesel is very costly, so direct blending of ethanol into gasoline fuel is done. Government of Brazil has also legalised the direct blending upto 25% in gasoline in automobiles.

In India, diesel costs about Rs. 40 per litre. But in India, petrodiesel is a highly subsidised fuel due to its vast use in agriculture. If there were no subsidies given to the diesel by the Government of India, the price of diesel would have jumped over the price of even petrol, which is around Rs. 80 per litre now-a-days.

On the other hand, waste mustard oil costs very less, the users of this oil put this oil in the dump after use. Waste cooking oil like mustard oil can be purchased at Rs. 35 per litre and then biodiesel is prepared and blend of that biodiesel with petrodiesel is used, then cost price of the fuel will cut off by some fraction which would be about Rs. 50 per litre. This will also reduce the burden on atleast government's shoulders, which in turn will reduce the tax by some part.

1.4 Method of biodiesel production

To obtain biodiesel, vegetable oil is subjected to a chemical reaction known as ***transesterification*** [5]. In transesterification vegetable oil is treated with in the presence of a catalyst (usually a base) with an alcohol (usually methanol) to give the corresponding alkyl esters (or for methanol, the methyl esters) of the FA mixture that is found in the parent vegetable oil or animal fat.



Triacylglycerols (Vegetable oil) **Alcohol** **Alkyl Ester (Biodiesel)** **Glycerol**

[3]

R is a mixture of various fatty acids chain. Alcohol is generally methanol (methyl alcohol) as it is cheap, but now a days, Ethanol (Ethyl Alcohol) and iso-propanol may yield a biodiesel fuel with better fuel properties. Ethanol is costlier, so methanol is used. Often the resulting products are also called fatty acid methyl esters (FAME) instead of biodiesel. Catalyst is generally base like NaOH, KOH.

Biodiesel can be produced from a great variety of feedstocks. These feedstocks include most common vegetable oils (e.g., soybean, cottonseed, palm, peanut, rapeseed/canola, sunflower, safflower, coconut) and animal fats (usually tallow) as well as waste oils (e.g., used frying oils). The choice of feedstock depends largely on geography. Depending on the origin and quality of the feedstock, changes to the production process may be necessary.

1.5 Perspective feedstock for biodiesel production around the world

Biodiesel is derived from different oils or animal fats across the world. The use depends upon the sources of oil or animal fats available. Table 1.1 shows the sources for biodiesel (free acid methyl esters) around the world. In the European nations, the biodiesel is mostly derived from rapeseed oil. Asian countries derive biodiesel from Jatropha.Australians derive the biodiesel from either waste oil or animal fat. Brazilians use Soybean, Palm oil, Caster oil, Cotton seed oil as the source of biodiesel. Russians use rapeseed, soybean and sunflower oil for biodiesel production. Due to abundance of soybean oil, U.S.A. use Soybean oil for production of biodiesel. Canadians use canola oil and animal fats for fatty acid methyl esters production. The following table shows the sources of biodiesel in the various nations on the earth.

Table 1.1, Sources for biodiesel (free acid methyl esters) around the world [7]

Country	Feedstock
Australia	Waste oil, Animal fat
Brazil	Soybean oil, Palm oil,
	Castor oil, Cotton oil
Canada	Canola oil, Animal fat
China	Jatropha, Waste oil
Finland	Rapeseed oil, Animal fat
France	Rapeseed oil, Sunflower oil
Germany	Rapeseed Oil
India	Jatropha
Indonesia	Palm oil, Jatropha
Italy	Rapeseed oil

Japan	Waste oil
Korea	Waste oil
Malaysia	Palm oil
Mexico	Waste oil, Animal fat
New Zealand	Waste oil, Animal fat
Philippine	Coconut oil, Jatropha
Russia	Rapeseed, Sunflower,Soybean oil
Spain	Sunflower oil
Sweden	Rapeseed oil
Thailand	Palm oil, Coconut oil, Jatropha
U.K.	Rapeseed oil, Waste oil
U.S.A.	Soybean oil, Waste oil

1.6 Advantages and disadvantages of use of crude vegetable oils and animal fats directly in diesel engine

The main cause behind the use of vegetable oils and animal fats and their derivatives as alternative fuel is ***cetane number***. The other properties of vegetable oils and animal fats and their derivatives match very closely with diesel are heat of combustion, pour point, cloud point, kinematic viscosity, oxidative stability, and lubricity.

The chief reason behind the transesterification of vegetable oils and animal fats into alkyl esters is to reduce the kinematic viscosity of the biodiesel. The high viscosity of transesterified vegetable oils will lead to operational problems in the diesel engine like deposition on various engine parts. There are some engines which can use unesterified oils but most of the engines require low viscosity oil.

1.7 Advantages of biodiesel

(i) Harmful emissions reduction. When biodiesel displaces petroleum, it reduces levels of global warming gases such as CO_2.As plants like soybeans grow; they take CO_2 from the air to make the stems, roots, leaves and seeds. After the oil is extracted from soybeans, it is refined into biodiesel and, when burned, produces CO_2 and other emissions, which are returned to the atmosphere. However, this cycle does not add to the CO_2 level in the air because the next soybean crop will reuse the CO_2 to grow. Another important environmental factor is that biodiesel reduces tailpipe particulate matter (PM), HC and CO emissions. These benefits occur because biodiesel contains 11% oxygen (O_2) by weight. The presence of O_2 allows the fuel to burn more completely, resulting in fewer emissions from unburned fuel. This same principle also reduces air toxicity, which is associated with the unburned or partially burned HC and PM emissions. Testing has shown that PM, HC and CO reductions are independent of the vegetable oil used to make biodiesel. This has been confirmed by the EPA, which reviewed 80 biodiesel emission tests and concluded that the benefits are real and predictable over a wide range of biodiesel blends.

(ii) Low sulfur content. Currently, the sulfur specification for petroleum-based diesel fuel is less than 500 parts per million (ppm). However, by the end of 2006, all US highway diesel has to contain less than 15-ppm sulfur. Most biodiesel fuels being manufactured today contain less than 15-ppm sulfur and some have levels that are too low to measure.

(iii) Improved lubricity. Engine manufacturers depend on good lubrication to keep moving parts, such as fuel pumps, from wearing prematurely. Biodiesel is approximately twice as viscous as petroleum diesel and therefore has better lubricating properties. This is an extremely important property when biodiesel is blended with ultra-low-sulfur diesel, which is known to be a poor lubricant. Even the lubrication properties of dry fuels such as kerosene can be improved by using 2% biodiesel.

(iv) Implementation is seamless. Probably the biggest benefit to using biodiesel is that it is easy to use. No new equipment is necessary and conventional diesel engines can seamlessly run up to 20% biodiesel blends. However, minor modifications to the engine are required to run neat, undiluted biodiesel. Biodiesel/petroleum diesel blends can also be stored in diesel fuel tanks and pumped with diesel equipment.

(v) Versatility: Biodiesel is a versatile fuel. Biodiesel can be used upto a specific limit in the existing engine without any modifications.

1.8 Disadvantages of biodiesel

(i) Price: Its inherent higher price, which in many countries is offset by legislative and regulatory incentives or subsidies in the form of reduced excise taxes. However, the higher price can also be (partially) offset by the use of less expensive feedstocks, which has sparked interest in materials such as waste oils (e.g., used frying oils).

(ii) Increased NO_x emissions: Slightly increased NO_x exhaust emissions than the mineral diesel fuelled engine.

(iii) Stability: Biodiesel is unstable when exposed to air (oxidative stability).

(iv) Cold flow properties: 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 fuelling with 20 percent blends. Same solutions work well with biodiesel blends, as do the use of cold flow improvement additives. Cold flow properties that are especially relevant in North America where the temperature generally remains low.

1.9 Properties of biodiesel

1.9.1 Density/ Specific Gravity

Biodiesel is slightly heavier than the mineral diesel fuel (specific gravity 0.859 compared to 0.850 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.

1.9.2 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.

1.9.3 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 derived from waste mustard oil is 145°C, but it can reduce drastically if the alcohol used in manufacture of bio-diesel is not removed properly. Residual alcohol in the bio-diesel reduces its flashpoint drastically and is harmful to fuel pump, seals etc. It also reduces the combustion quality.

1.9.4 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 but in case of waste mustard oil based biodiesel, the cloud point of biodiesel and petrodiesel is almost comparative.

1.9.5 Pour Point

Pour point is the lowest temperature at which a petroleum product will begin to flow. Normally pour point or Cold Filter Plugging Point (CFPP) is 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.

1.9.6 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.

1.9.7 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.

1.9.8 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.

1.9.9 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.

1.9.10 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.

1.10 Specification 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 glycerine, 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 1.2

Table 1.2, ASTM Specification (D6751) for biodiesel (B100) [21]

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

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 the production of biodiesel sufficient to blend with high speed diesel to the extent of 20% by the year 2011-2012. Utilization of used vegetable oils for production of biodiesel will prevent further wastage of already existing resources, and use of environmentally friendly fuel will create cleaner environment. The work presented in this thesis with respect to study of biodiesel from waste oil based on the availability of raw feedstock. As very less work has been done on deriving the biodiesel from waste mustard oil. The goal of this work is to determine the usefulness of biodiesel in a single cylinder diesel engine. So our aim of study is mainly to conduct 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 five parts. The experimental work based on biodiesel production 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 the world, specification of quality standards of biodiesel. It determines fuel properties, engine performance and emission analysis. It presents biodiesel demand, biodiesel requirement advantages and disadvantages. It is experimentally measured that biodiesel, vegetable oil act as a fuel which provides good results in compression ignition engine. The origin, historical and economical aspects of biodiesel 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 production of biodiesel (transesterification), C. I. engine performance and emission and economic feasibility of tested fuel has been 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 deals with raw material used for conducting experiments such as purchasing of used cooking oils, sample bottles, and diesel etc. The detailed study of 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 process involved in producing biodiesel. 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 engine performance and exhaust emission profiles explained in this chapter. The cost analysis of the biodiesel and comparative study of different biodiesel blends are discussed in this chapter. The engine performance parameters viz., brake thermal efficiency, brake specific fuel consumption, brake mean effective pressure, exhaust gas temperature are also discussed in this chapter. The engine exhaust emission such as unburnt hydrocarbon, carbon-monoxide and oxides of nitrogen are also described in this chapter. An economic evaluation of waste mustard biodiesel are also described that will decide the final cost of biodiesel.

Chapter V

Conclusions regarding C.I.engine testing along with economic evaluation of selected biodiesel are narrated in this chapter. It also includes future scope of work, recommendations and references.

CHAPTER 2

LITERATURE SURVEY

Literature survey is carried out in three areas:

1. Biodiesel.

2. Production and characterization of biodiesel.

3. Production of biodiesel, performance and emission characteristics of C.I. engine fuelled with biodiesel blends.

2.1. Biodiesel

Gerhard Knothe [4] compared biodiesel and renewable diesel. The search for alternatives to petroleum-based fuels has led to the development of fuels from various sources, including renewable feedstocks such as fats and oils. Several types of fuels can be derived from these triacylglycerols containing feedstocks. One of them is biodiesel, which is defined as the mono-alkyl esters of vegetable oils or animal fats. Biodiesel is produced by transesterifying the oil or fat with an alcohol such as methanol under mild conditions in the presence of a base catalyst. Another kind of product that can be obtained from lipid feedstocks is a fuel whose composition simulates that of petroleum-derived diesel fuel. This kind of fuel, probably best termed ‘‘renewable diesel’’, is produced from the fat or oil by a hydrodeoxygenation reaction at elevated temperature and pressure in the presence of a catalyst.

Both biodiesel and renewable diesel possess advantages in terms of carbon renewability compared to petrodiesel but there are advantages and disadvantages to either in terms of fuel properties, environmental issues and energy balance. There is only a limited amount of feedstock available to satisfy potential demand for both fuels. Despite all efforts to develop additional feedstocks, this will likely remain an issue in the future. Therefore, a significant question appears to be if biodiesel and renewable diesel compete with or complement each other. Either fuel can only replace a few percent of the petrodiesel market. A possible aspect is if the use of these fuels should be concentrated in areas where the most benefit is derived from either. In case of biodiesel, this would be taking advantage of environmental benefits and in case of renewable diesel this would be taking advantage of improved cold flow properties mainly for aviation purposes, provided the renewable diesel is of the kind largely composed of smaller and isomerized molecules.

Renewable diesel has been promoted under the aspect of being a ‘‘premium’’ diesel fuel with, for example, a very high cetane number. Blending with conventional petrodiesel would cause the advertised properties to be ‘‘lost’’ as there would be only a marginal improvement of the properties of petrodiesel as a result of the relatively small amounts of the ‘‘premium’’ renewable diesel fuel being available. The other alternative would be to use renewable diesel neat. There appears to be some environmental benefits to renewable diesel vs. petrodiesel, which would be ‘‘lost’’ when blending but would be more available in the neat form. However, the environmental benefits of renewable diesel appear to be less compared to biodiesel. Blending petrodiesel (as ULSD) with biodiesel offers the benefit of restoring lubricity to petrodiesel, although lubricity additives, which may also be lipid-based, can also restore lubricity. While this effect may not be fully clear, an issue with potential impact could be production scale, i.e., would more biodiesel or more renewable diesel be produced.

Ayhan Demirbas [5] discussed progress and recent trends in biodiesel fuels. Fossil fuel resources are decreasing daily. Biodiesel fuels are attracting increasing attention worldwide as blending components or direct replacements for diesel fuel in vehicle engines. Biodiesel fuel typically comprises lower alkyl fatty acid (chain length (C14–C22)), esters of short-chain alcohols, primarily, methanol or ethanol. Various methods have been reported for the production of biodiesel from vegetable oil, such as direct use and blending, micro emulsification, pyrolysis, and transesterification. Among these, transesterification is an attractive and widely accepted technique. The purpose of the transesterification process is to lower the viscosity of the oil. The most important variables affecting methyl ester yield during the transesterification reaction are the molar ratio of alcohol to vegetable oil and the reaction temperature. Methanol is the commonly used alcohol in this process, due in part to its low cost. Methyl esters of vegetable oils have several outstanding advantages over other new-renewable and clean engine fuel alternatives. Biodiesel fuel is a renewable substitute fuel for petroleum diesel or petrodiesel fuel made from vegetable or animal fats; it can be used in any mixture with petrodiesel fuel, as it has very similar characteristics, but it has lower exhaust emissions. Biodiesel fuel has better properties than petrodiesel fuel; it is renewable, biodegradable, non-toxic, and essentially free of sulphur and aromatics. Biodiesel seems to be a realistic fuel for future; it has become more attractive recently because of its environmental benefits. Biodiesel is an environmentally friendly fuel that can be used in any diesel engine without modification.

S.Jaichandar and K. Annamalai [6] discussed the status of biodiesel as an alternative fuel for diesel engine. To meet increasing energy requirements, there has been growing interest in alternative fuels like biodiesel to provide a suitable diesel oil substitute for internal combustion engines. Biodiesels offer a very promising alternative to diesel oil since they are renewable and have similar properties. Biodiesel is defined as a transesterified renewable fuel derived from vegetable oils or animal fats with properties similar or better than diesel fuel. Extensive research and demonstration projects have shown it can be used pure or in blends with conventional diesel fuel in unmodified diesel engines. This paper reviews the history of biodiesel development and production practices. Fuel-related properties are reviewed and compared with those of conventional diesel fuel. The effect of use of biodiesel fuel on engine power, fuel consumption and thermal efficiency are collected and analyzed with that of conventional diesel fuel. In the subsequent section, the engine emissions from biodiesel and diesel fuels are compared, paying special attention to the most significant emissions such as nitric oxides and particulate matter.

The problems with substituting vegetable oil for diesel fuels are mostly associated with their high viscosities, and low volatilities. The viscosity of vegetable oils can be reduced by transesterification. Transesterification is the most common method and leads to mono alkyl esters of vegetable oils and fats, known as bio-diesel. The production of biodiesel from vegetable oil is very simple. In the production of biodiesel it is observed that the base catalyst performs better than acid catalysts and enzymes. The biodiesel and their blends have similar fuel properties as that of diesel. It is also observed that biodiesel has similar combustion characteristics as diesel. Biodiesel engines offer acceptable engine performance compared to conventional diesel fuelled engines.

The main advantage in biodiesel usage is attributed to lesser exhaust emissions in terms of carbon monoxide, hydrocarbons and particulate matter. Biodiesel is said to be carbon neutral as more carbon dioxide is absorbed by the biodiesel yielding plants than what is added to the atmosphere when [burnt] used as fuel. Even though biodiesel engines emits more NO, these emissions can be controlled by adopting certain strategies such as the addition of cetane improvers, retardation of injection timing, exhaust gas recirculation, etc.

The objectives of acceptable thermal efficiency, fuel economy and reduced emissions using biodiesel in CI engines are attainable, but more investigations under proper operating constraints with improved engine design are required to explore the full potential of biodiesel engines.

Lin Lin *et al.*[7] discussed the opportunities and challenges for biodiesel fuel. Fossil fuel resources are decreasing daily. As a renewable energy, biodiesel has been receiving increasing attention because of the relevance it gains from the rising petroleum price and its environmental advantages. This review highlights some of the perspectives for the biodiesel industry to thrive as an alternative fuel, while discussing opportunities and challenges of biodiesel. This review is divided in three parts. First overview is given on developments of biodiesel in past and present, especially for the different feedstocks and the conversion technologies of biodiesel industry. More specifically, an overview is given on possible environmental and social impacts associated with biodiesel production, such as food security, land change and water source. Further emphasis is given on the need for government's incentives and public awareness for the use and benefits of biodiesel, while promoting policies that will not only endorse the industry, but also promote effective land management.

2.2. Production and characterization of biodiesel

Anh N. Phan *et al.*[8] produced biodiesel from waste cooking oils by alkali catalysed transesterification. Alkali-catalyzed transesterification of waste cooking oils, collected within Ho Chi Minh City, Vietnam, with methanol was carried out in a laboratory scale reactor. The effects of methanol/waste cooking oils ratio, potassium hydroxide concentration and temperature on the biodiesel conversion were investigated. Biodiesel yield of 88–90% was obtained at the methanol/oil ratios of 7:1–8:1, temperatures of 30–50°C and 0.75 wt% KOH. Biodiesel and its blends with diesel were characterized for their physical properties referring to a substitute for diesel fuel. The results showed that the biodiesel experienced a higher but much narrower boiling range than conventional diesel. Carbon residue content was up to 4 wt%. Blends with a percentage of the biodiesel below 30 volume % had their physical properties within EN14214 standard, which indicated that these could be used in engines without a major modification.

J. C. Thompson *et al.*[9] discussed characterization of crude glycerol from biodiesel production from multiple feedstocks. Glycerol is the principal by-product of biodiesel production. For each gallon of biodiesel produced, approximately 0.3 kg of crude glycerol accompanies. Such crude glycerol possesses very low value because of the impurities contained. As the demand and production of biodiesel grow exponentially, the utilization of the glycerol becomes an urgent topic. The make-up of crude glycerol varies depending on the parent feedstock and the biodiesel production process. Before the crude glycerol could be considered for possible value-added utilizations, it is necessary to characterize it on its physical, chemical, and nutritional properties. This article reports the characterization of crude glycerol obtained from different seed oil feedstocks of mustard, rapeseed, canola, crambe, soybean, and waste cooking oils. Batch processes of biodiesel production were used as the means of crude glycerol preparation using unrefined vegetable oils, methanol, and sodium methylate as the catalyst. After separation from biodiesel, the crude glycerol from each of the oils was analyzed using ASTM and other standard test methods. Elemental impurities, nutritional value, and other chemical properties were tested.

In the final analysis there was very little variation in the chemical and physical properties. The only exception was the WVO, which was not exactly representative of the others because of the poor conversion rate under the same operating conditions. The viscosity of the crude glycerols prior to any treatment ranged from 8.46 to 8.80 cSt and 26.5 cSt for the WVO. The heat of combustion of the crude glycerols ranged from 1.86 × 103 to 20.5 × 103 kJ/kg and 25.2 × 103 kJ/kg for the WVO. A The carbon content averaged about 25% and the metals Ca, K, Mg, Na, P, and S were present in small quantities from 4 to 163 ppm with the exception of sodium, which averaged just over 1%. This was due to the residual sodium methylate catalyst. The basic proximates for nutrition were measured for each of the samples as well. There was some variation in the data among the neat oils, and the WVO was again the outlier on fat and carbohydrates. Protein levels ranged from 0.06% to 0.44% with crambe being the highest. Fat content ranged from 1% to 13% and carbohydrates ranged from 75% to 83%.The same values for WVO were 60% and 27%, respectively. When refined to a chemically pure substance, glycerol would be a very valuable by-product of the biodiesel production process with hundreds of uses. Purifying it to that stage, however, is very costly and generally out of the range of economic feasibility for the small to medium sized plants. Alternative uses for the crude glycerol should be explored to make biodiesel more competitive in the growing global market.

Luis Fernando Bautista *et al.*[10] optimised FAME production from waste cooking oil for biodiesel use. This study consists of the development and optimisation of the potassium hydroxide catalysed synthesis of fatty acid methyl esters (FAME) from waste cooking oil. A factorial design of experiments and a central composite design have been used. The variables chosen were fatty acid concentration in the waste cooking oil, temperature and initial catalyst concentration by weight of waste cooking oil, while the responses were FAME purity and yield. The initial catalyst concentration is the most important factor, having a positive influence on FAME purity, but a negative one on FAME yield due to the positive influences of the yield losses (triglyceride saponification and methyl ester dissolution in glycerol). Fatty acid concentration in the waste cooking oil is the second factor of importance, having negative influences in FAME purity and yield. Temperature has an insignificant effect on FAME purity, but it has a significant negative influence on FAME yield due to the positive effect of temperature on the yield losses. Second order models were obtained to predict the responses analysed as a function of these variables.

A fully central composite design has been applied to optimise the synthesis process of fatty acid methyl ester from waste cooking oil using potassium hydroxide as the catalyst. This design procedure has been followed to optimise the variables that determine the maximum FAME purity and yield. A three factorial design proved effective in studying the influence on the reaction process of the free fatty acid concentration in the waste cooking oil, initial catalyst concentration and temperature on the process. A response equation has been obtained for the FAME purity and yields and the yield losses due to triglyceride saponification and methyl ester dissolution in glycerol. From these equations, it is possible to accurately predict the operating conditions required to obtain a given value of these responses. A first order approach did not adequately fit the data for the responses studied and quadratic models were required. Second order models were developed to predict the FAME purity and yield and the yield losses as a function of the variables. Analysis of the residuals demonstrated the efficiency of the models obtained.

2.3. Production of biodiesel, performance and emission characteristics of C.I. engine fuelled with biodiesel blends.

Ya-fen Lin *et al.*[11] examined combustion characteristics of waste-oil produced biodiesel/diesel fuel blends. In this study, wasted cooking oil from restaurants was used to produce neat (pure) biodiesel through transesterification, and this converted biodiesel was then used to prepare biodiesel/diesel blends. The goal of this study was to compare the trace formation from the exhaust tail gas of a diesel engine when operated using the different fuel type: neat biodiesel, biodiesel/diesel blends, and normal diesel fuels. B20 produced the lowest CO concentration for all engine speeds. B50 produced higher CO_2 than other fuels for all engine speeds, except at 2000 rpm where B20 gave the highest. The biodiesel and biodiesel/diesel blend fuels produced higher NOx for various engine speeds as expected. SO_2 formation not only showed an increasing trend with increased engine speed but also showed an increasing trend as the percentage of diesel increased in the fuels. Among the collected data, the PM concentrations from B100 engines were higher than from other fuelled engines for the tested engine speed and most biodiesel-contained fuels produced higher PM than the pure diesel fuel did. Overall, we may conclude that B20 and B50 are the optimum fuel blends.

B20 produced the lowest CO concentration for all engine speeds. B50 produced the higher CO_2 concentration than other fuels for all engine speeds, except at 2000 rpm where B20 gave the highest. B100, B80, and diesel showed more HC emissions than other fuels did. The biodiesel and biodiesel/diesel blend fuels produced higher NOx for various engine speeds as expected. Among these fuels, B100 produced highest NOx for engine speeds higher than 1200 while B20 gave the highest NOx at engine speeds of 1000 and 1200 rpm. SO_2 formation not only shows an increasing trend with increased engine speed, but also shows an increasing trend with the percentage of diesel in the fuels. Among the collected data, the PM concentrations from B100 engines were higher than from the other fuelled engines for the tested engine speed, and most biodiesel-containing fuels produced higher PM than the pure diesel fuel did. Overall, we may conclude that B20 and B50 are the optimum blends.

S. Kent Hoekman *et al.*[12] reviewed the effects of biodiesel on NOx emissions. Compared to conventional diesel fuel, use of biodiesel is generally found to reduce emissions of hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM); but to increase oxides of nitrogen (NOx) emissions. This paper reviews and summarizes relevant literature regarding the so-called “biodiesel NOx effect, and presents theories” to explain this effect. In modern diesel engines, several factors related to fuel composition and engine control strategies are important, though no single theory provides an adequate explanation of the biodiesel NOx effect under all conditions. There is evidence to suggest that effect on injection timing, ignition delay, adiabatic flame temperature, radiative heat loss, and other combustion phenomena all play some role. The biodiesel NOx effect can be mitigated by modifying engine control settings — particularly by retarding injection timing and increasing exhaust gas recirculation (EGR). The absolute magnitude of the biodiesel NOx effect appears to be reduced with modern engines, although there are cases where the percentage change is still substantial. Sophisticated after-treatment systems required to achieve the 2010 diesel engine emissions standards do not appear to be significantly affected by use of biodiesel. However, longer term study is warranted, as such systems have only been in commercial use for a short time.

Sukumar Puhan *et al.*[13] discussed the effect of biodiesel unsaturated fatty acid on combustion characteristics of a DI compression ignition engine. In this study, main focus is put on the effect of biodiesel molecular weight, structure (Cis & Trans), and the number of double bonds on the diesel engine operation characteristics. Three types of biodiesel with different molecular weight and number of double bond were selected for the experimental studies. The biodiesels were prepared and analyzed for fuel properties according to the standards. A constant speed diesel engine, which develops 4.4 kW of power, was run with biodiesels and its performance was compared with diesel fuel. The results show that Linseed oil methyl ester with high linolenic (unsaturated fatty acid ester) does not suit best for diesel engine due to high oxides of nitrogen emission and low thermal efficiency.

Baljinder Singh *et al.*[14] studied production of biodiesel from used mustard oil and analysed its performance in internal combustion Engine. The authors said that decline in fossil fuel resources along with high crude oil prices generated attention toward the development of fuel from alternate sources. Such fuel should be economically attractive and performance competent in order to replace the fossil fuel. Mustard oil from Indian mustard, Brassica campestris, is commonly used for cooking in Indian households and restaurants. Cooking produces spent mustard oil waste, which is generally drained as garbage. The authors explored the possibility of using such spent mustard oil for making biodiesel. Transesterification of spent oil was carried out using methanol and sulphuric acid (95%) as catalysts followed by bubble washing. Clear biodiesel was obtained from esterified oil after five bubble washings. Methyl ester formations were calculated by measuring its density at 15°C and viscosity at 40°C and were found to be 89 g/cm^3 and 4.83 mm^2 / s, respectively. Studies on engine performance were conducted using a Prony brake internal combustion (IC) diesel engine using various blending ratios of biodiesel with commercial diesel. The fuel blends were evaluated for parameters such as speed of engine, fuel consumption, and torque against pure diesel. Brake power, specific fuel consumption, and thermal efficiency were also measured. The results indicate that dual fuel with a blend of 8% biodiesel yielded good efficiency in the IC-diesel engines without the need for making any modifications in the engine.

Jomir Hossain [15] derived biodiesel from mustard oil: A renewable alternative fuel for small diesel engines. The paper represented the prospect of mustard oil as a renewable and alternative fuel. Since diesel engines have versatile uses including small irrigation pumping systems, and standby small electricity generators, use of diesel fuel is much higher than any other gasoline fuels. In Bangladesh mustard oil has been in use as edible oil throughout the country. Mustard is a widely growing plant in Bangladesh and every year the production of mustard seed exceeds the demand. So the endeavour was to use the surplus mustard oil as an alternative to diesel fuel. Fuel properties were determined in the fuel testing laboratory with standard procedure. An experimental set-up was then made to study the performance of a small diesel engine in the heat engine laboratory using different blends of bio-diesel converted from mustard oil. It was found that bio-diesel has slightly different properties than diesel fuel. It was also observed that with bio-diesel, the engine is capable of running without difficulty but with a deviation from its optimum performance. Initially different blends of bio-diesel (*i.e.* B20, B30, B50 etc,) had been used to avoid complicated modification of the engine or the fuel supply system. Finally, a comparison of engine performance for different blends of bio-diesel had been carried out to determine the optimum blend for different operating conditions.

Experiment was conducted on a small four stroke diesel engine to determine the feasibility of mustard oil as an alternative to diesel engine. Bsfc for biodiesel increased for higher blending of biodiesel, because of the lower heating value of biodiesel as compared to diesel fuel. For using higher blending of biodiesel, the fuel must be preheated in order to reduce the density and viscosity of the fuel. Compared to diesel fuel, a little amount of power loss occurs for biodiesel blends.

P. McCarthy *et al.*[16] did analysis and comparison of performance and emissions of an internal combustion engine fuelled with petroleum diesel and different bio-diesels. The performance and emissions of an internal combustion engine (ICE) engine fuelled with two bio-diesels were experimentally measured and analysed according to ISO 8178 standard and compared with that of the petroleum diesel. Two types of bio-diesel, type A (80% tallow (beef, pork and sheep) and 20% canola oil methyl ester) and type B (70% chicken tallow and 30% waste cooking oil methyl ester) with their blends of B5, B10, B20, B50 and B100 were tested and analysed. This study found that the performance of both bio-diesel fuels reduces with increasing blend ratio, with a torque decrease of 5% for both bio-diesels, and a fuel consumption increase of 7–10%. This can be attributed to the lower energy content of bio-diesel when compared with petroleum diesel. For both the bio-diesels, some emissions were found to be higher than petroleum diesel, while some were lower. Nitrogen Oxide (NO) emissions decreased by 14% for bio-diesel A, but increased by 17% for bio-diesel B. Carbon monoxides (CO) emissions were significantly reduced for both bio-diesel A and B, with reductions of 58% and 27% respectively. Hydrocarbon (HC) emissions were found to increase with increasing blend ratio for both bio-diesels, with an increase of 10% for bio-diesel A and 80% for bio-diesel B. Lastly, Carbon dioxides (CO_{2x}) emissions were found to increase, with an increase of 6% for bio-diesel A and 18% for bio-diesel B. The study clearly found that each of the bio-diesels has different scale of effect on ICE performance and emissions and hence, it is essential to test bio-diesels before it can be recommended for mass scale production and for commercial use in ICE. However, the study indicates that the two major pollutant gas emissions are generally reduced when using bio-diesel, therefore bio-diesel can be considered to be a more environmentally friendly, secure and renewable approach of obtaining energy in the long run.

B.K. Highina *et al.*[17] compared performance of biodiesel to conventional diesel fuel in stationary internal combustion engines; the technical specification of an internal combustion engine designed for diesel fuel was used for biodiesel. The changes in engine performance, and cycle by cycle (CBC) variations were observed, and their causes were studied. When biodiesel was used as the fuel, acceptable changes occurred in the performance values. The maximum brake mean effective pressure (BMEP) obtained with the biodiesel was slightly higher than that obtained with the diesel fuel, with the difference being just slight under maximum power. While biodiesel increase the maximum engine power, it reduces the brake specific fuel consumption. Changes of maximum cylinder pressure have occurred at the same magnitude for both fuels for the same engine speeds. The best engine performance for biodiesel operates at the engine speed of 2000 rpm to 2500 rpm. The overall analysis has shown that biodiesel has potential as an alternative fuel in conventional diesel internal combustion engines. The maximum brake mean effective pressure (BMEP) obtained with the biodiesel was slightly higher than that obtained with the diesel fuel, with the difference being just slight under maximum power. While biodiesel increase the maximum engine power, it reduces the brake specific fuel consumption. Changes of maximum cylinder pressure have occurred at the same magnitude for both fuels for the same engine speeds. The best engine performance for biodiesel operates at the engine speed of 2000 rpm to 2500 rpm. The overall analysis has shown that biodiesel has potential as an alternative fuel in conventional internal combustion engines.

Magin Lapuerta *et al.*[18] discussed effect of biodiesel fuels on diesel engine emissions. The call for the use of biofuels which is being made by most governments following international energy policies is presently finding some resistance from car and components manufacturing companies, private users and local administrations. This opposition makes it more difficult to reach the targets of increased shares of use of biofuels in internal combustion engines. One of the reasons for this resistance is a certain lack of knowledge about the effect of biofuels on engine emissions. This paper collects and analyzes the body of work written mainly in scientific journals about diesel engine emissions when using biodiesel fuels as opposed to conventional diesel fuels. Since the basis for comparison is to maintain engine performance, the first section is dedicated to the effect of biodiesel fuel on engine power, fuel consumption and thermal efficiency. The highest consensus lies in an increase in fuel consumption in approximate proportion to the loss of heating value. In the subsequent sections, the engine emissions from biodiesel and diesel fuels are compared, paying special attention to the most concerning emissions: nitric oxides and particulate matter, the latter not only in mass and composition but also in size distributions. In this case the highest consensus was found in the sharp reduction in particulate emissions. A wide disparity of results has been found in general concerning emissions from biodiesel. Although a dominant trend has been found in most cases, there have always been opposing trends proposed elsewhere by contrast. One reason for this is the large number of different engine technologies tested, the varying operating conditions or driving cycles followed, the different biodiesel fuels used (from different feedstocks and with different qualities), and the various measurement techniques and procedures applied. Especially with regard to the instrumentation or the methodology used for measurements, several studies have been found wanting in fulfilling the expected quality requirements. The following general conclusions could however be proposed from the present literature review:

- At partial load operation, no differences in power output should be expected, since an increase in fuel consumption in the case of biodiesel would compensate its reduced heating value. At full-load conditions, a certain decrease in power has been found with biodiesel, but such a decrease is lower than that corresponding to the decrease in heating value, which means that a small power recovery is often observed.
- An increase in bsfc has been found when using biodiesel in most of the reviewed studies. Such an increase is generally in proportion to the reduction in heating value (9% in volume basis, 14% in mass basis). Consequently, the thermal efficiency of diesel engines is not appreciably affected when substituting diesel by biodiesel fuel either pure or blended.

- Most of studies report slight increases in NO emissions when using biodiesel fuels. The reason most frequently pointed out is that the injection process is slightly advanced with biodiesel. The physical properties of biodiesel or the response of the electronic unit could cause such an advance. Some authors propose delaying injection as a mean to eliminate the increase in NO emissions, with a minor penalty in particulate emissions.
- The majority of studies have found sharp reductions in particulate emissions with biodiesel as compared to diesel fuel. This reduction is mainly caused by reduced soot formation and enhanced soot oxidation. The oxygen content and the absence of aromatic content in biodiesel have been pointed out as the main reasons. Under cold-start conditions the mentioned reduction could be eliminated or even reversed to result in a certain increase.
- The majority of authors have reported decreases in the mean diameter of the PSDs obtained when biodiesel fuels are used. Although such a shift is mainly caused by a sharp decrease in the number of large particles, some studies have also found a certain increase in the number of the smallest ones.
- Other regulated emissions such as those of THCs and CO are usually found to significantly decrease with biodiesel. A more complete combustion caused by the increased oxygen content in the flame coming from the biodiesel molecules has been pointed out as the main reason in both cases.
- The emission of aromatic and polyaromatic compounds, as well as their toxic and mutagenic effect, has been generally considered to be reduced with biodiesel. However, no conclusive trend has been found regarding the emissions of oxygenated compounds such as aldehydes and ketones. Further studies should be performed in this field in the future.

M.G. Bannikov [19] analysed combustion and emission characteristics of mustard biodiesel. Mustard methyl esters and regular diesel fuel were tested in direct injection diesel engine. Analysis of experimental data was supported by an analysis of fuel injection and combustion characteristics. Engine fuelled with biodiesel had increased brake specific fuel consumption (Bsfc), reduced nitrogen oxides (NO_x) emission and smoke opacity, moderate increase in carbon monoxide (CO) emission with essentially unchanged unburned hydrocarbons emission. Increase in fuel consumption was attributed to lesser heating value of biodiesel and partially to decreased fuel conversion efficiency. Analysis of combustion characteristics revealed earlier start of injection and shorter ignition delay period of biodiesel. Resulting decrease in maximum rate of heat release and cylinder pressure was the most probable reason for reduced emission of nitrogen oxides. Analysis of combustion characteristics also showed that cetane index is not a proper measure of ignition quality of biodiesel. Conclusion was made on applicability of mustard oil as a source for commercial production of biodiesel in Pakistan. Potentialities of on improving combustion and emissions characteristics of biodiesel were discussed.

Fig. 2.1 shows performance characteristics of mustard biodiesel and diesel fuel at rated speed over range of load. As seen from Fig.1, averaged over load brake specific fuel consumption (Bsfc) of biodiesel was increased by about 15% and brake fuel conversion efficiency ($\eta_{f,b}$) reduced by about 3% compared to diesel fuel. Mechanical efficiency and exhaust temperature were essentially unchanged.

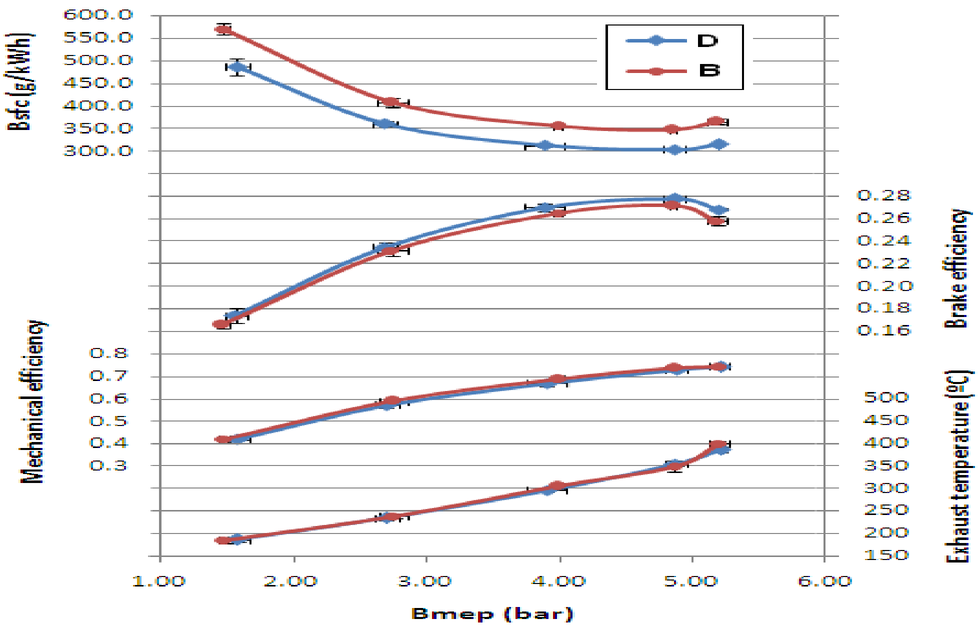


Fig. 2.1. Engine performance characteristics of mustard biodiesel and diesel fuel

Engine emissions characteristics are given in Fig. 2.2. Inspection of data of Fig. 2.2 reveals that with biodiesel NO_x emission was decreased at all loads. CO and HC emissions were essentially unchanged but CO concentration was increased by about 25% at full load. Exhaust opacity was decreased by about 40% at all loads except of rated power where it was the same for both fuels.

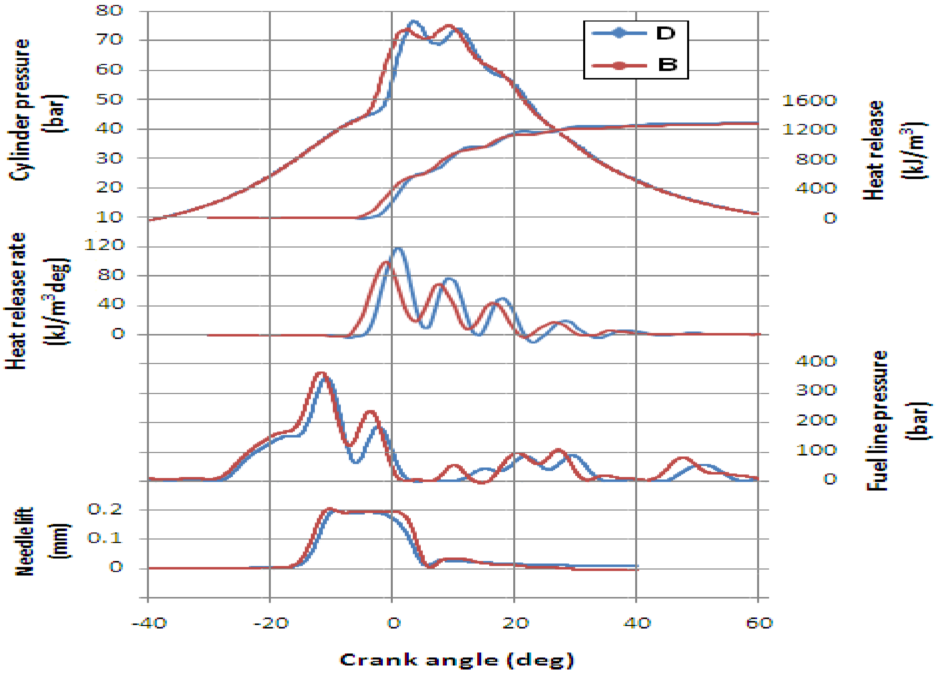


Fig. 2.2. Engine emissions characteristics of mustard biodiesel and diesel fuel

Xiangmei Meng *et al*.[20] produced biodiesel from waste cooking oil via alkali catalyst and its engine test. Waste cooking oils (WCO), which contain large amounts of free fatty acids produced in restaurants, are collected by the environmental protection agency in the main cities of China and should be disposed in a suitable way. Biodiesel production from WCO was studied in this paper through experimental investigation of reaction conditions such as methanol/oil molar ratio, alkaline catalyst amount, reaction time and reaction temperature which are deemed to have main impact on reaction conversion efficiency. Experiments have been performed to determine the optimum conditions for this transesterification process by orthogonal analysis of parameters in a four-factor and three-level test. The optimum experimental conditions, which were obtained from the orthogonal test, were methanol/oil molar ratio 9:1, with 1.0 wt. % sodium hydroxide, temperature of 50 °C and 90 min. Verified experiments showed methanol/oil molar ratio 6:1 was more suitable in the process, and under that condition WCO conversion efficiency led to 89.8% and the physical and chemical properties of biodiesel sample satisfied the requirement of relevant international standards. After the analysis main characteristics of biodiesel sample, the impact of biodiesel/diesel blend fuels on an YC6M220G turbo-charged diesel engine exhaust emissions was evaluated compared with diesel. The testing results show without any modification to diesel engine, under all conditions dynamical performance kept normal, and the B20, B50 blend fuels (include 20%, 50% crude biodiesel respectively) led to unsatisfactory emissions whilst the

B20 blend fuel (include 20% refined biodiesel) reduced significantly particles, HC and CO etc. emissions. For example CO, HC and particles were reduced by 18.6%, 26.7% and 20.58%, respectively.

Jinlin Xue *et al.*[22] reviewed the effect of biodiesel on engine performances and emissions. In this work, reports about biodiesel engine performances and emissions, published by highly rated journals in scientific indexes, were cited preferentially since 2000 year. From these reports, the effect of biodiesel on engine power, economy, durability and emissions including regulated and non-regulated emissions, and the corresponding effect factors are surveyed and analyzed in detail. The use of biodiesel leads to the substantial reduction in PM, HC and CO emissions accompanying with the imperceptible power loss, the increase in fuel consumption and the increase in NOx emission on conventional diesel engines with no or fewer modification. And it favors to reduce carbon deposit and wear of the key engine parts. Therefore, the blends of biodiesel with small content in place of petroleum diesel can help in controlling air pollution and easing the pressure on scarce resources without significantly sacrificing engine power and economy. However, many further researches about optimization and modification on engine, low temperature performances of engine, new instrumentation and methodology for measurements etc., should be performed when petroleum diesel is substituted completely by biodiesel.

CHAPTER 3

METHODOLOGY

3.1 Objective

Due to the continuous use of fossil fuels and rise in the number of automobiles on the planet, biodiesel has emerged as a good option as an alternative fuel. Biodiesel from *waste mustard oil* is to be prepared. Biodiesel used as such without engine modifications will lead to ceasing of the engine operation. Therefore, it was then blended with petrodiesel at three different levels i.e. B10, B15 and B20. These three blends were fuelled in a compression ignition (C.I.) engine. The performance characteristics like brake power (B.P.), indicated power (I.P.), brake specific fuel consumption (BSFC), indicated specific fuel consumption (ISFC) and the emission characteristics like nitrogen oxide(NO_x) formation, carbon monoxide(CO) & unburnt hydrocarbons (HC) in the smoke were measured. These performance and emission characteristics were then compared with that of petro diesel.

3.2 Methodology to be adopted

The work performed can be divided into following steps:-

1. Production of biodiesel.
2. Estimating the properties of the biodiesel produced.
3. Blending of biodiesel with petro diesel.
4. Performance and Emission characteristics.
5. Comparison of performance and emission characteristics of biodiesel with that of petro diesel.

3.2.1 Production of biodiesel

First step is to prepare biodiesel. Biodiesel was prepared by *transesterification.* In this work, Biodiesel was derived from waste mustard oil which underwent single stage transesterification process. Waste mustard oil can be purchased or collected easily from any restaurant, sweet shops, and pakorawalas in our nation.

3.2.1.1. Standard process adopted

i) A known quantity of waste mustard oil was taken. as shown in plate 3.1.It is almost black in colour.

ii) Neutralizing the free fatty acids using 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 KOH as a catalyst.

iii) Creating an alcohol ester under desired temperature with suitable speed. Stir for agitating the mixture.

iv) Within a process period of 1 hr, biodiesel is formed as shown in along with the glycerine with clear phase separation.

v) Then the biodiesel can be collected in a vessel as shown in plate 3.2. It is *light black (Coffee)* coloured liquid. The change in colour is due to elimination of glycerine from the oil during the separation process that has taken place at the end of transesterification process..

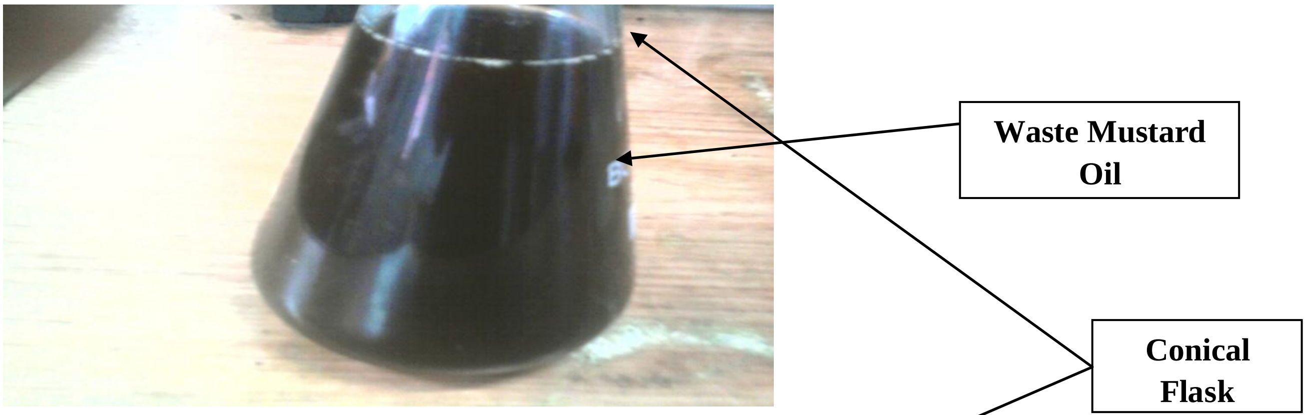


Plate 3.1. Waste mustard oil in a conical flask.

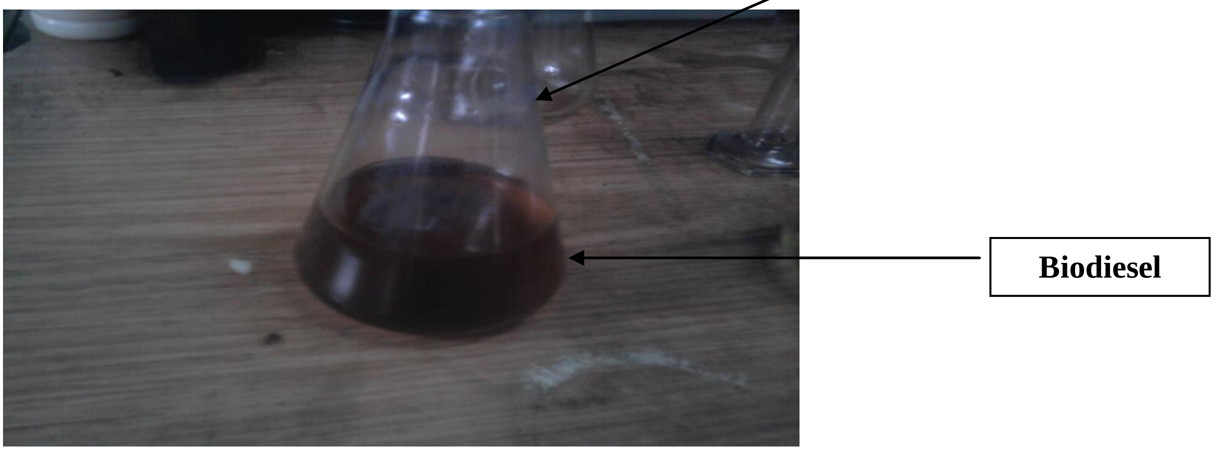


Plate 3.2. Biodiesel derived from waste mustard oil.

3.2.2 Estimation of the properties of the biodiesel produced

After producing the biodiesel, the properties of the biodiesel were determined by using various methods. The methods used are tabulated in the table 3.1. The following properties were tested:-

1. Density
2. Kinematic viscosity
3. Free fatty acids (FFA)
4. Carbon residue
5. Cloud point
6. Pour point
7. Flash point
8. Fire point
9. Calorific value

Table 3.1, Standard methods for calculating the properties [21]

Property	Method used
Kinematic Viscosity	IS: 1448 [P: 25] 1976
Flash point and Fire point	IS: 1448 [P: 32]: 1992
Ash Content	ASTM D482-IP 4 of IIP
Cloud point and Pour point	IS: 1448 [P: 10]: 1970
Carbon Residues	ASTM D189-IP 13 of IIP
Calorific Value	IS: 1350

3.2.2.1. Various apparatus used for calculation of the properties of the biodiesel

Properties of the biodiesel were determined on different apparatus. These apparatus are described below:

i) **Redwood viscometer:** Redwood viscometer measures viscosity in empirical units and not in absolute units such as centistokes. It is possible to convert Redwood viscometer readings into absolute units for which the specification issued by the institute of petroleum London, may be consulted. The method is primarily applicable for viscosity determination of oil which flows in a Newtonian manner i.e. if it possesses a linear relationship between shearing stress and rate of shear under the test conditions. The flow time measurements for petroleum products should be made at the following temperatures. 21°C, 37.8°C, 40°C, 60°C, 93°C, 121°C, 149°C, 204°C. For fuel oils, the minimum temperature at which the time measurements can be taken is 40°C. For flux oils the temperature of test is 93°C. Redwood viscometer will correctly indicate the viscosity flow time if it stands between 3 seconds to 2000 seconds.

Plate 3.3. Redwood viscometer

ii) **Cloud and pour point apparatus:** The method of cloud point is intended for use only on oils, which are transparent in layers 40 mm in thickness and have cloud point below 40^0C.The method for pour point is intended for use on any petroleum oil. The refrigeration bath can be operated from above room temperature to below minus 30^0C. Keep the sample to be tested in glass jar, fit the rubber cork and keep vertically in the jacket provided. In case of test temperature is below 0^0C or upto -30^0C. Fill the jacket around glass jar with a little quantity of ethyl alcohol for proper contact of cooling media. Fit the thermocouple pin (thermocouple bulb) in rubber cork upto centre of glass jar. Put on main switch, Red neon lamp indicates its operation. The cooling will occur within 30 to 40 minutes after start of refrigeration system.

Plate 3.4. Cloud and pour point apparatus

iii) Flash point apparatus: The sample is heated in a test cup at a slow and constant rate with continual stirring. A small test flame is directed into the cup at regular intervals with simultaneous interruption of stirring. The flash point is taken as the lowest temperature at which the application of the test flame causes the vapour above the sample to ignite momentarily. Fire point is taken as the lowest temperature at which the application of the test flame causes the vapour above the sample to ignite momentarily.

Plate 3.5. Flash point apparatus

iv) Bomb calorimeter: 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 with the help of a widson scientific works make bomb calorimeter. 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.

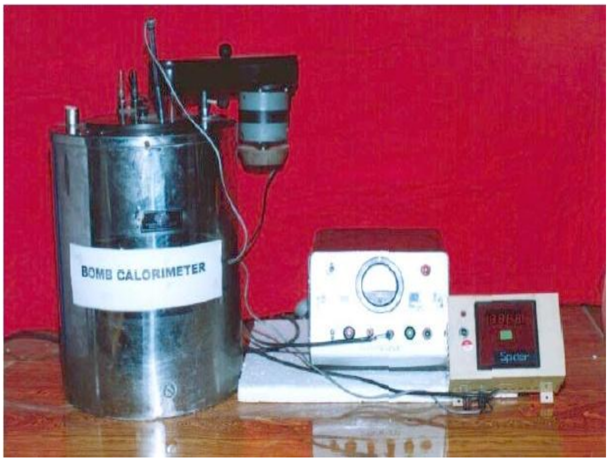


Plate 3.6. Bomb calorimeter

v) **Muffle furnace**: 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, cottonseed oil and cottonseed oil ester 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. In order to measure to ash content, sample was taken in a silica dish. The dish was first weighted 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 ^{o}C for two hours. Each sample was replicated three times.

Plate 3.7. Muffle furnace

vi) **Carbon residue (rams bottom) apparatus:** Carbon residue was determined by using a carbon residue apparatus. The measurement was made in accordance with the ASTM D189-IP 13 of institute of petroleum, London. The 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. The crucible was then placed in the centre of skidmore crucible of the apparatus and the sand was levelled 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.

Plate 3.8. Carbon residue(rams bottom) apparatus

Table 3.2 shows the list of the apparatus on which properties were tested.

Table 3.2, Apparatus used for calculating the properties

Property	Apparatus used
Density	Weighing balance
Kinematic Viscosity	Redwood viscometer

Flash point	Flash and fire point apparatus
Fire point	Flash and fire point apparatus
Ash Content	Muffle furnace
Cloud point	Cloud and pour point apparatus
Pour point	Cloud and pour point apparatus
Carbon Residues	Carbon residue (rams bottom) apparatus
Calorific Value	Bomb calorimeter

After estimating the properties of the biodiesel, the properties were compared with the properties of the diesel. The comparative properties of the mineral diesel and mineral biodiesel are as shown in the table 3.1 as given below. The properties were tested at Mechanical Engineering Research and Development organization, Ludhiana, India & at Research & Development centre, Thapar University, Patiala, India.

Table 3.3, Comparative properties of the mineral diesel and mineral biodiesel

Property of oil	**ASTM Standard**	**Diesel**	**Waste mustard biodiesel**
Density (30^0C), kg/m^3	-	850	859.57
Kinematic Viscosity, cSt	<5	2.049	3.575
FFA, %	<2.5	-	0.1974
Carbon residue, %(m/m)	<0.05	0.0214	0.0138
Cloud point, ^{0}C	-3 to 12	-12	4
Pour Point, ^{0}C	-15 to 10	-16	-12
Flash point, ^{0}C	>130	60	145
Fire point, ^{0}C	>53	67	150
Calorific value, KJ/kg	>33000	42000	39542.98

3.2.3 Blending of biodiesel with petro diesel

Blending of biodiesel with petro diesel was to be done. Three different blends B10, B15, B20 of waste mustard biodiesel were prepared.

3.2.4 Performance and emission characteristics

The three blends were fuelled in a C.I. engine to read the performance characteristics. The engine was computerized single cylinder, water cooled compression ignition engine. The following five engine performances were determined:-

i) Brake Power (BP)

ii) Brake specific fuel consumption (BSFC)

iii) Brake thermal efficiency (BTE)

iv) Exhaust gas temperature (EGT)

Emission characteristics were estimated with the aid of flue gas analyser (FGA) and Horiba analyser (HA). The following three Emission characteristics were analysed.

i) Carbon monoxide (CO)

ii) Nitrogen oxides (NO_x)

iii) Unburnt hydrocarbons(HC)

CO and NOx were estimated with the help of flue gas analyser whereas Horiba analyser was used to measure the unburnt hydrocarbons.

3.2.4.1 Specifications of the engine

The performance characteristics were carried out on variable compression diesel engine. The specifications of the engine are as stated in the table 3.4.

Table 3.4, Specifications of the engine

Make and Model	Kirloskar, TV1
Type of engine	4 stroke, Variable compression diesel engine
No. of cylinders	Single cylinder
Cooling media	Water cooled
Rated capacity	3.5 kW @ 1500 RPM
Cylinder diameter	87.5 mm
Stroke length	110 mm
Connecting rod length	234 mm
Compression ratio	12:1-18:1
Orifice diameter	20 mm
Dynamometer	Eddy current dynamometer
Dynamometer arm length	145 mm

Plate 3.5. Variable compression diesel engine

An eddy current dynamometer is coupled with the engine to measure power and torque. Various loads i.e. 0 kg, 2 kg, 4 kg, 6 kg were applied on the engine with the help of a load cell connected to the dynamometer. Load sensor was connected with load cell which indicates the load on the load indicator.

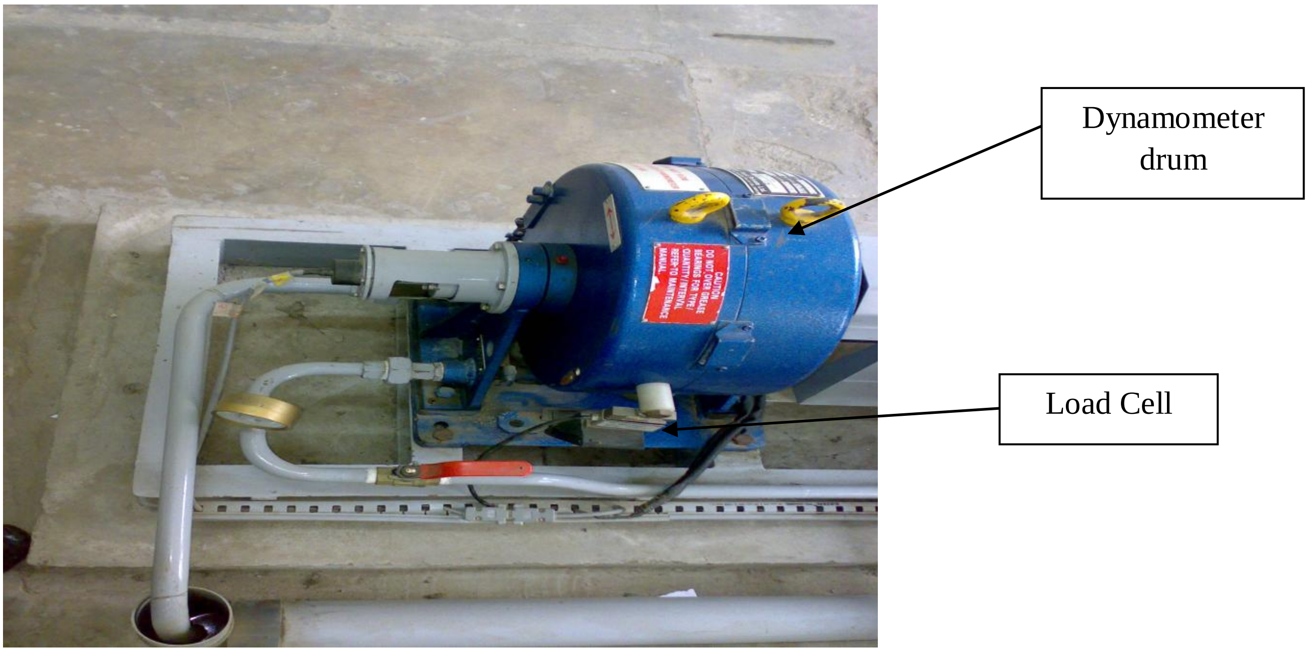


Plate 3.6. Eddy current dynamometer

3.2.4.2. Experimentation

First the experimentation is performed with diesel (for getting the base line data of the engine) and then three blends of waste mustard biodiesel i.e. B10, B15 and B20 at 18 compression ratio. 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 HC, CO and NOx.

3.2.5. Comparison of performance and emission characteristics of biodiesel with that of petro diesel

After obtaining the performance and emission characteristics results from all the three blends, graphs are plotted. These results were then compared with the performance and emission characteristics of petro diesel.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Performance Results

Worldwide, biodiesel is largely produced by methyl transesterification of oils. The concept of methyl transesterification is gaining attention as ethanol is derived from renewable biomass sources. The fuel consumption test and rating test of a 3.5 kW constant speed CI engine was conducted to evaluate the performance of the engine on diesel and waste mustard biodiesel with diesel.

4.1.1. Brake Power

Change in B.P. of blends B10, B15, B20 and diesel with respect to change in load is shown in the fig 4.1.

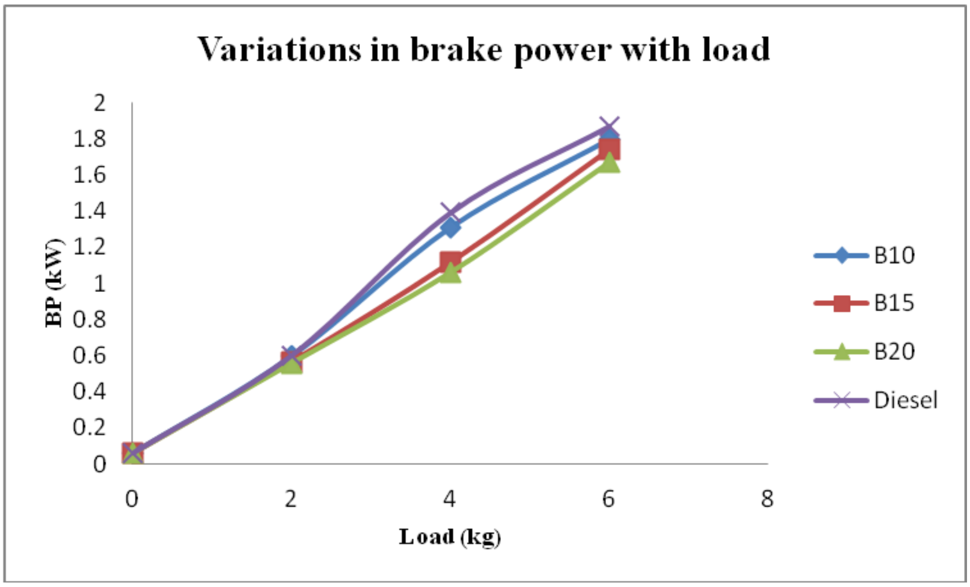


Fig. 4.1. Variations in brake power with change in load

Brake power of the engine increases with increase in the load on the engine. At no load conditions,the brake power of diesel, B10, B15 and B20 is almost same. As the load increases, B.P. of the engine starts to be less for biodiesel blends as compared to diesel.The decrease in B.P. is due to the higher viscosity and density and lower heating value of biodiesel than diesel. As the quantity of the biodiesel increses in the blend, B.P. of the engine decreases due to decrease in the heating value of the fuel. Diesel is having the highest heating value amongst D, B10, B15 and B20. So, maximum brake power is obtained in fuelling diesel in comparison to B10, B15 and B20 respectively. At full load conditions, the brake power produced by B10 is 3.74%,B15 is 6.9% and B20 is 10.1% less than diesel.

4.1.2. Brake specific fuel consumption

Change in BSFC of blends B10, B15, B20 and diesel with respect to change in load is shown in the fig 4.2.

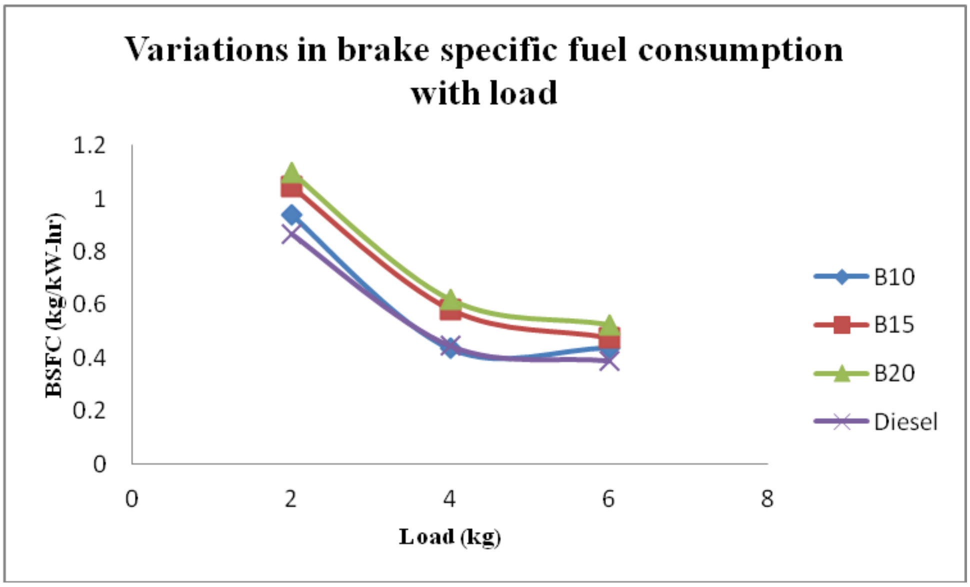


Fig. 4.2. Variation in brake specific fuel consumption with change in load

At 2 kg load conditions, BSFC of diesel is least. BSFC of B10, B15 and B20 is more than that of diesel respectively. After that the brake specific fuel consumption decreases continuously with increase in load. But BSFC in case of waste mustard biodiesel remains more than in case of diesel. It is due to lower energy content of waste mustard biodiesel. At part load conditions BSFC of B10 and diesel is almost same whereas BSFC of B15 is 23.4%, B20 is 28.05% more than that of diesel. At full load conditions, BSFC of B10 is 10.9%, B15 is 18.23%, B20 is 25.5% more than that of diesel.

4.1.3. Brake thermal efficiency

Change in BTE of blends B10, B15, B20 and diesel with respect to change in load is shown in the fig 4.4. At no load condition, brake thermal efficiency of B10, B15, B20 and diesel is same. As the load on the engine increases, brake thermal efficiency increases because brake thermal efficiency is the function of brake power and brake power increases as the load on the engine increases. At part load conditions, the brake thermal efficiency of B10 is more than diesel because mass of B10 supplied is 19.35% less than that of diesel and calorific value of B10 is also less than that of diesel. Brake thermal efficiency of B15 and B20 is almost same

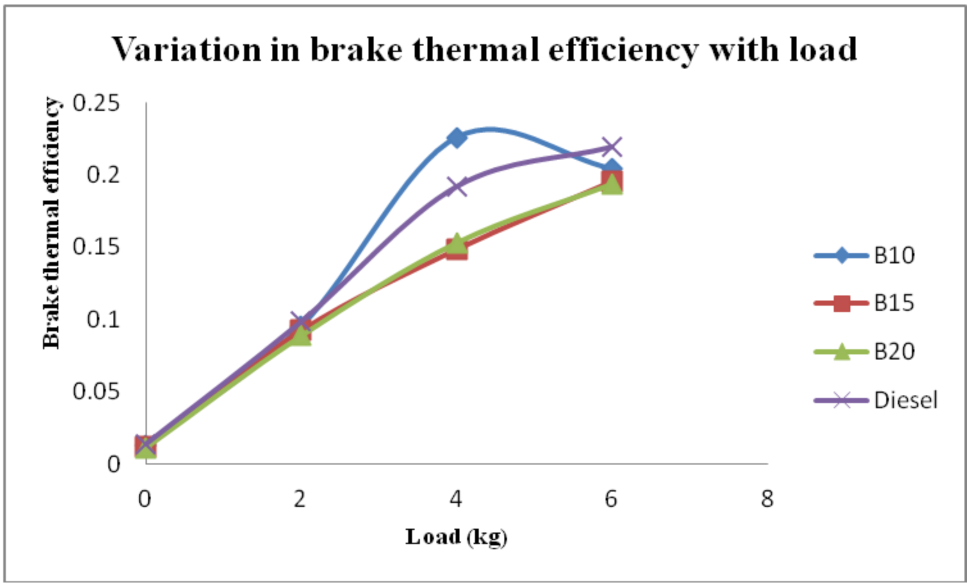


Fig. 4.3. Change in brake thermal efficiency with respect to change in load

at part loads and is 16.67% less than diesel because of lower brake power and higher amount of fuel supplied. At full load conditions, brake thermal efficiency of B10, B15 and B20 is almost same but is less than diesel.

4.1.4. Exhaust gas temperature

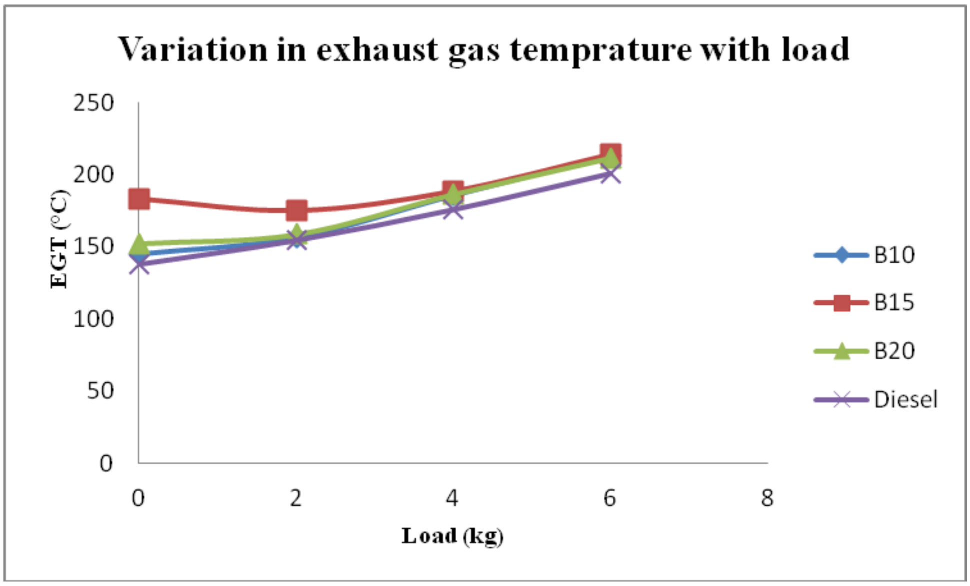


Fig. 4.4. Change in exhaust gas temperature with respect to change in load

Change in EGT of blends B10, B15, B20 and diesel with respect to change in load is shown in the fig 4.4. Exhaust gas temperature rises as the load on the engine increases. Diesel has the least EGT among the B10, B15, B20 and D. The reason of EGT being more in the case of biodiesel blends is the presence of more oxygen atoms in the biodiesel. More oxygen atoms cause more closeness towards the complete combustion. So, the exhaust gas temperature increases and it increases with increase in load. As the load on the engine increases, more fuel is burnt. So, EGT increases continuously with rise in load.

At no load conditions i.e. at 0 kg load on the engine, EGT of diesel is least whereas then comes B10, B20 and B15 being the highest, respectively. At part load conditions i.e. at 4 kg load on the engine, EGT of B10 and B20 is almost same and B15 being the highest and EGT of diesel being least. At full load conditions, the EGT of B10, B15 and B20 is almost same whereas EGT of diesel being the least.

4.2 Emission Results

The emissions of carbon monoxide, unburned hydrocarbons and nitrogen oxide were examined and the results are shown below. Carbon monoxide and unburned hydrocarbons are the products of incomplete combustion whereas oxides of nitrogen are produced at very high temperatures.

4.2.1. HC Emissions

Fig.4.5. shows the variation in the quantity of unburnt hydrocarbons with change in load at 18 compression ratio.

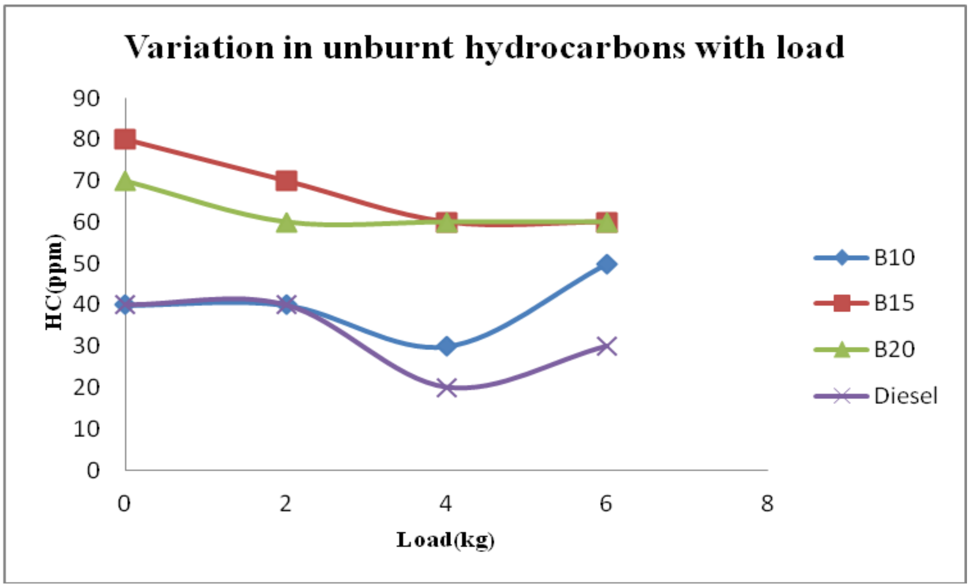


Fig. 4.5. Change in quantity of unburnt hydrocarbons with load variations

At no load conditions, diesel and B10 emits same amount of unburnt hydrocarbons whereas, maximum unburnt hydrocarbons are emitted by B15. At part and full loads, B15, B20 resulted in maximum unburnt hydrocarbons followed by B10 whereas diesel resulted in least unburnt hydrocarbons. This trend may be partially due to the presence of methanol in crude biodiesel which result in low cetane number value of the waste mustard biodiesel. Because unburned hydrocarbons are the products of incomplete combustion, the lower cetane number of blend fuels results in lower tendency to form ignitable mixture, and thus, higher unburned hydrocarbons. Higher viscosity of the waste mustard biodiesel also plays a key role in increasing the unburnt hydrocarbons in the exhaust emissions. Due to the higher viscosity, all of the hydrocarbons present in the waste mustard biodiesel do not get completely burnt, so come out in the engine exhaust in the form of carbon particles.

4.2.2 CO Emissions

Fig. 4.6. shows variation in the quantity of carbon monoxide (in ppm) with change in load (in kgs.) at 18 compression ratio.

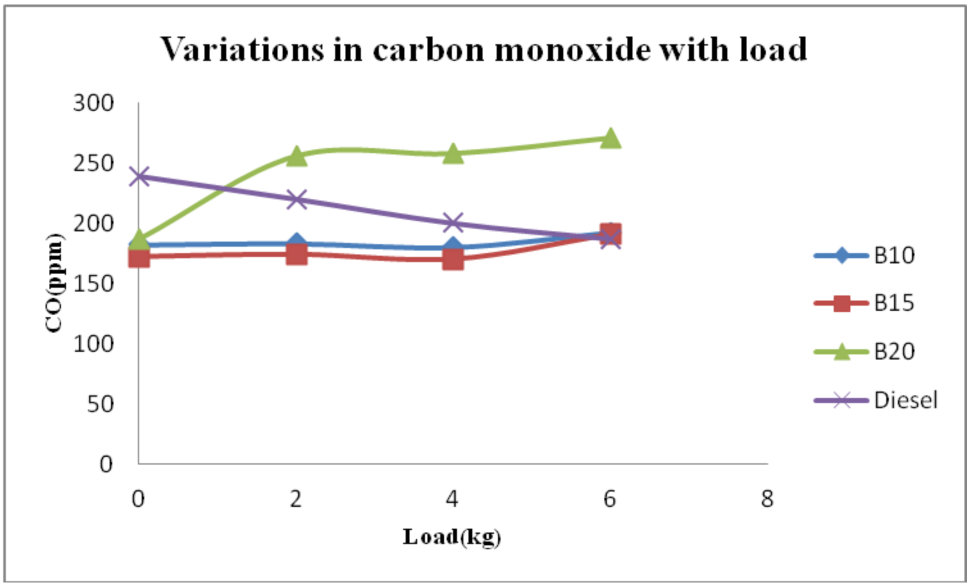


Fig. 4.6. Change in quantity of CO with load variations

At no load B10, B15 and B20 exhibits almost same amount of CO in the engine exhaust which is almost 30% less than that exhibited by diesel.After that amount of CO exhibited by biodiesel starts to increase whereas amount of CO emission by diesel increases.At part loads, amount of CO emissions by B10 is 14.28%, B15 is 19.1% less than that emitted by diesel, but B20 produces 20% more emissions than diesel.At full load conditions, amount of CO emitted by B10, B15 and diesel is almost same whereas amount of

CO emissions produced by B20 increases by 28.5% than diesel. CO is mainly produced due to incomplete combustion.In case of B10 and B15, there is less amount of methyl esters present as compared to B20. So, B10 and B15 gets required amount of oxygen to get converted into CO_2,thus resulting in less CO as compared to diesel and B20. B20 does not get required amount of oxygen to get converted into CO_2,so results in more quantity of CO in the engine exhaust.

4.2.3. NO_x Emissions

Fig. 4.7. shows variation in the quantity of nitrous oxides (in ppm) with change in load (in kgs.) at 18 compression ratio.

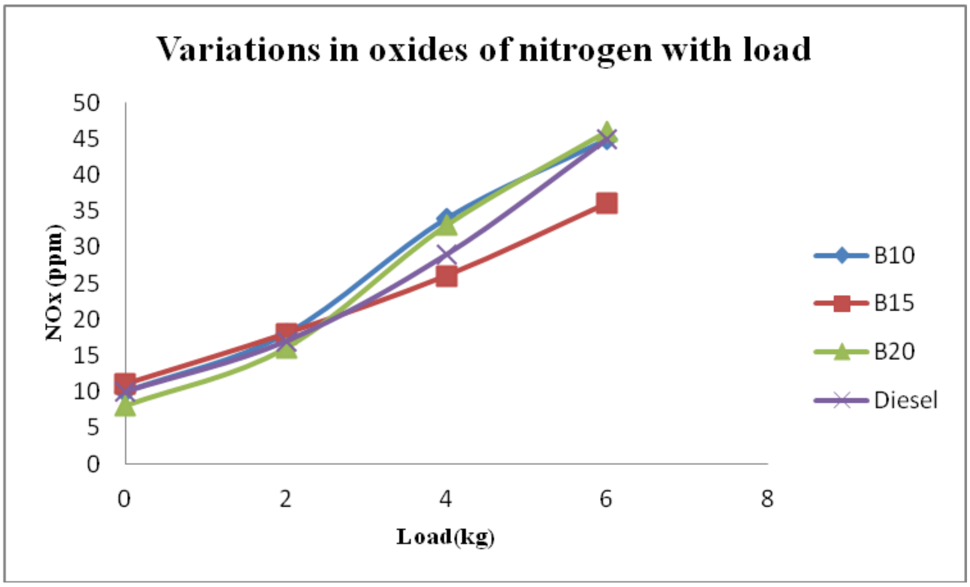


Fig. 4.7. Change in quantity of NOx with load variations

At no load conditions, B10, B15 and diesel emits almost same amount of NO_x whereas B20 emits comparatively less NO_x in the exhaust.As the load on the engine increases,amount of NO_x increases. because the temprature in the combustion chamber increases and at the higher temperatures,more amount of NO_x is produced.At full load conditions,there is increase in the amount of NO_x emitted by biodiesel blends and diesel.The amount of NO_x produced by B10,B20 and diesel is almost same at full load conditions and the amount of NO_x produced by B15 is 22.2% less as compared to the other blends and diesel.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE OF WORK

5.1. Conclusion

The overall studies based on the production, engine performance and exhaust emission of waste mustard biodiesel were carried out. The following conclusions can be drawn:

- The kinematic viscosity of diesel, waste mustard oil biodiesel were found as 2.049, 3.575 centistokes at 40^0C. The results indicated that the waste mustard biodiesel had the kinematic viscosity 74.4 percent more than that of diesel.
- The calorific value of diesel, waste mustard biodiesel were found as 42, 39.54 MJ/kg respectively. The calorific value of waste mustard biodiesel is decreased by 5.85% than that of diesel.
- The waste mustard biodiesel was found to have higher flash and fire point than those of diesel.
- The results thus indicate that pour point and cloud point of waste mustard biodiesel is higher than that of diesel.
- The waste mustard biodiesel 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 waste mustard biodiesel was obtained to be 0.0138 %.
- Waste mustard biodiesel are non-toxic, biodegradable, environment-friendly, renewable fuels and do not add to global warming.
- At full load conditions, the brake power produced by B10 is 3.74%,B15 is 6.9% and B20 is 10.1% less than diesel.
- At part load conditions BSFC of B10 and diesel is almost same whereas BSFC of B15 is 23.4%, B20 is 28.05% more than that of diesel. At full load conditions, BSFC of B10 is 10.9%, B15 is 18.23%, and B20 is 25.5% more than that of diesel.
- At full load conditions, brake thermal efficiency of B10, B15 and B20 is almost same but is less than diesel.
- B10 emits almost same amount of CO and NOx but more unburnt hydrocarbons than that by diesel.

- Use of 10% blends of waste mustard biodiesel as partial diesel substitutes can go a long way in conservation measure, reducing uncertainty of fuel availability and making more self-reliant.

5.2. Future scope of work

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

- Biodiesel may be introduced as a diesel fuel extender or blends (WMB 10, WMB 20) and not as a sole diesel engine fuel (WMB 100) without engine modifications.
- Government may consider providing support to the activities production of oil from waste oil 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 blend.
- 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 waste and non-edible vegetable oils. Further investigation can be carried out to prepare ethyl ester from various waste and 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 volatile organic compounds, aldehydes etc. has to be carried out to reveal a total picture of environmental impact using biodiesel blended 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] G Lakshmi Narayana Rao, S Sampath and 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, *World Academy of Science, Engineering and Technology*, 2008; 37, pp 1-7.

[2] B. Anjan Kumar Prusty, Rachna Chandra and P. A. Azeez, "Biodiesel: Freedom from dependence on fossil fuels", *Nature Precedings*, 2008; pp. 1-27.

[3] Gerhard Knothe, Jon Van Gerpen and Jurgen Krahl., "The Biodiesel Handbook"; 2005.

[4] Gerhard Knothe, "Biodiesel and renewable diesel: A comparison", *Progress in Energy and Combustion Science*, 2010; 36, pp. 364–373.

[5] Ayhan Demirbas, "Progress and recent trends in biodiesel fuels", *Progress in Energy and Combustion Science*, 2007; 33, pp. 1-16.

[6] S. Jaichandar and K. Annamalai, "The status of Biodiesel as an Alternative Fuel for diesel engine", *Journal of Sustainable Energy and Environment*, 2011; 2, pp.71-75.

[7] Lin Lin, Zhou Cunshan , Saritporn Vittayapadung , Shen Xiangqian, Dong Mingdong, "Opportunities and challenges for biodiesel fuel", *Applied Energy*, 2011; 88, pp.1020–1031.

[8] Anh N. Phan and Tan M. Phan, "Biodiesel production from waste cooking oils", *Fuel*, 2008; 87, pp. 3490–3496.

[9] J.C. Thompson, B.B. He, "Characterization of crude glycerol from biodiesel production from multiple feedstocks", Applied Engineering in Agriculture, *American Society of Agricultural and Biological Engineers*, 2006; 22, pp. 261-265.

[10] Luis Fernando Bautista, Gemma Vicente, Rosalia Rodriguez, Maria Pacheco, "Optimisation of FAME production from waste cooking oil for biodiesel use", *Biomass and Bio energy*, 2009; 33, pp.862-872.

[11] Ya-fen Lin, Yo-ping Greg Wu, Chang-Tang Chang, "Combustion characteristics of waste-oil produced biodiesel/diesel fuel blends", *Fuel*, 2007; 86, pp. 1772–1780.

[12] S. Kent Hoekman and Curtis Robbins, “Review of the effects of biodiesel on NOx emissions”, *Fuel Processing Technology*, 2012; 96, pp. 237–249.

[13] Sukumar Puhan, N. Saravanan, G. Nagarajan and N. Vedaraman, “Effect of biodiesel unsaturated fatty acid on combustion characteristics of a DI compression ignition engine”, *Biomass and Bioenergy* ,2010; 34, pp. 1079 –1088.

[14] Baljinder Singh, Jagdeep Kaur and Kashmir Singh “Production of biodiesel from used mustard oil and its performance analysis in internal combustion engine”, *Journal of Energy Resources Technology*, 2010; 132, pp. 1-4.

[15] Jomir Hossain, Saikat Biswas and Asif Islam “Biodiesel from Mustard Oil: A Renewable Alternative Fuel for Small Diesel Engines”, *Modern Mechanical Engineering*, 2011; 1, pp. 77-83.

[16] P. McCarthy, “Analysis and comparison of performance and emissions of an internal combustion engine fuelled with petroleum diesel and different bio-diesels”, *Fuel,* 2011; 90, pp. 2147-2157.

[17] B.K. Highina, I.M. Bugaje and B. Umar, “Performance of biodiesel compared to conventional diesel fuel in stationary internal combustion engines”, *Journal of Applied Technology in Environment Sanitation*, 2011; 2, pp. 199-205.

[18] Magin Lapuerta, Octavio Armas, Jose Rodriguez-Fernandez, “Effect of biodiesel fuels on diesel engine emissions”, *Progress in Energy and Combustion Science,* 2008; 34, pp.198–223.

[19] M.G. Bannikov, “Combustion and Emission Characteristics of Mustard Biodiesel”, *6th International Advanced Technologies Symposium (IATS’11), Turkey,* 2011; pp. 1-5.

[20] Xiangmei Meng, Guanyi Chen, Yonghong Wang, “Biodiesel production from waste cooking oil via alkali catalyst and its engine test”, *Fuel Processing Technology*, 2008; 89, pp. 851 – 857.

[21] Specifications for blends B5 – B20, www.astm.org

[22] Jinlin Xue, Tony E. Grift and Alan C. Hansen, “Effect of biodiesel on engine performances and emissions”, *Renewable and Sustainable Energy Reviews*, 2011; 15, pp. 1098‑1116.