Study of performance and emission characteristics of different blends of biodiesel prepared from waste cottonseed oil

Thesis submitted in fulfillment of

Masters of Engineering

in

Thermal Engineering

By

Varun singla

Roll No. 801083026

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, INDIA,

July-2012

CERTIFICATE

Certified that the thesis entitled "Study of performance and emission characteristics of different blends of biodiesel prepared from waste cottonseed oil" which is being submitted by **Mr. VARUN SINGLA** 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.

[VARUN SINGLA]

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.

Varun Singla

R. No. 801083026

Thermal Engg.

M.E.D.

TU, PATIALA

Abstract

There is an increasing interest in India to search for suitable alternative fuels that are environmental friendly. Environmental concerns and limited amount of petroleum resources have caused interests in the development of alternative fuels for internal combustion (IC) Engines. As an alternative, biodegradable, renewable and sulphur free biodiesel is receiving increasing attention. The use of biodiesel is rapidly expanding around the world, making it imperative to fully understand the impacts of biodiesel on the diesel engine combustion process and pollutant formation. Biodiesel is known as the mono-alkyl-esters of long chain fatty acids derived from renewable feedstock, such as, vegetable oils or animal's fats, for use in compression ignition engines. Therefore, in this study, different parameters for the optimization of biodiesel production were investigated in the first phase, while in the next phase of the study performance test of a diesel engine with neat diesel fuel and biodiesel mixtures was carried out. Biodiesel was made by the well known transesterification process. Waste cottonseed oil was selected for biodiesel production. The transesterification results showed that with the variation of catalyst, methanol, variation of biodiesel production was realized. A maximum of 76% biodiesel was produced with 20% methanol in presence of 1.0% KOH. The engine experimental results showed that among three different blends of biodiesel (B10, B15 and B20), B10 blend of biodiesel has the highest performance characteristic value of brake power, brake thermal efficiency lowest value of brake specific fuel consumption and exhaust gas temperature. The experimental result also showed that the exhaust emissions including carbon monoxide (CO), hydrocarbons (HC) and smoke emissions were reduced for all biodiesel mixtures and hydrocarbon (HC) and NO_x emissions of B10 blend is lowest among all the three blends of biodiesel there is a slight increase in the carbon monoxide (CO) emission for the B10 blend as compared to B15 and B10. However, a slight increase in oxides of nitrogen (NO_x) emission was experienced for biodiesel mixtures.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Biodiesel

Biodiesel is the name of a clean burning alternative fuel produced from domestic, renewable resources. Biodiesel contains no petroleum, but it can be blended at any level with petroleum diesel to create a biodiesel blend. It can be used in compression ignition (diesel) engines upto 20% with no major modifications. Biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulphur and aromatics.

Technical Definition: Biodiesel is a fuel composed of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100, and meeting the requirements of ASTM (American Society for Testing & Materials) D 6751.

The major components of vegetable oils and animal fats are triacylglycerols (TAG; often also called triglycerides). Chemically, TAG are esters of fatty acids with glycerol (1,2,3-propanetriol; glycerol is often also called glycerine). The TAG of vegetable oils and animal fats typically contain several different fatty acids. Thus, different fatty acids can be attached to one glycerol backbone. The fatty acids profile is probably the most important parameter influencing the corresponding properties of a vegetable oil or animal fat. To obtain biodiesel, the vegetable oil or animal fat is subjected to a chemical reaction termed transesterification. In that reaction, the vegetable oil or animal fat is reacted 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. Figure 1 depicts the transesterification reaction. 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. Biodiesel is miscible with petrodiesel in all ratios. In many countries, this has led to the use of blends of biodiesel with petrodiesel instead of neat biodiesel. It is important to note that these blends with petrodiesel are not biodiesel. Often blends with petrodiesel are denoted by acronyms such as B20, which indicates a blend of 20% biodiesel with petrodiesel. [1]

1.2 Need of biodiesel

Petroleum resources are finite and therefore search for alternative is continuing all over the world. The major energy demand is fulfilled from the conventional energy resources like coal, petroleum and natural gas. Petroleum-based fuels are limited reserves concentrated in certain regions of the world. These sources are in the verge of getting extinct. The scarcity of known petroleum reserves will make renewable energy resources like biodiesel more attractive. Bio- fuels like ethanol and bio-diesel being environment friendly, will help us to conform to the stricter emission norms. International experience has demonstrated the advantages of using ethanol and methanol as automotive fuel. Since blends below 20% of biodiesel do not present any problem and reduce harmful emission.

The gases emitted by petrol and diesel driven vehicles have an adverse effect on the environment and human health. There is universal acceptance of the need for reducing such emissions by adopting ways to reduce emission without affecting the process of growth and development. One of the ways in which this can be achieved is through the use of biodiesel and blending them with diesel.

With domestic crude oil output stagnating, the momentum of growth experienced a quantum jump since 1990s when the economic reforms were introduced paving the way for a much higher rate of development leading the demand for oil to continue to rise at an ever increasing pace. The situation offers us a challenge as well as an opportunity to look for substitutes of fossil fuels for both economic and environmental benefits to the country.

Biofuels are generally considered as offering many priorities, including sustainability, reduction of greenhouse gas emissions, regional development, social structure and agriculture and security of supply. In developed countries there is a growing trend towards employing modern technologies and efficient bioenergy conversion using a range of biofuels, which are becoming cost-wise competitive with fossil fuels. The scarcity of conventional fossil fuels, growing emissions of combustion generated pollutants and their increasing costs will make biomass sources more attractive. [2]

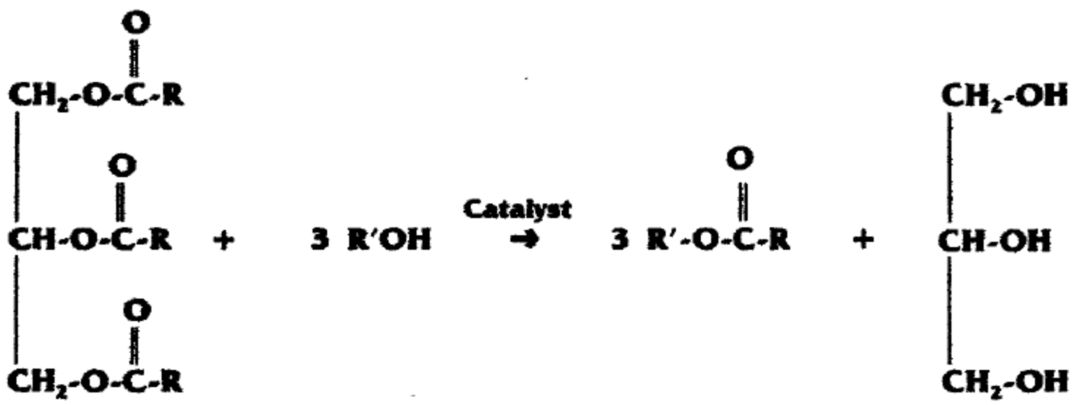
1.3 Different methods for the production of biodiesel

1.3.1 Direct Blending

In this method, vegetable oils are directly mixed with the diesel.

1.3.2 Transesterification

To obtain biodiesel, the vegetable oil or animal fat is subjected to a chemical reaction termed as transesterification. In this reaction, the vegetable oil or animal fat is reacted in the presence of a catalyst (usually a base like KOH) with an alcohol (usually methanol CH_3OH) to give the corresponding alkyl esters (or for methanol, the methyl esters) of the FA(fatty acid) mixture that is found in the parent vegetable oil or animal fat. Figure 1 below depicts the transesterification reaction.



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

Figure 1 [2]

Methodology

- Preparation: care must be taken to monitor the amount of water and free fatty acids in the incoming vegetable oil. If the free fatty acid level or water level is too high it may cause problems with soap formation (saponification) and the separation of the glycerine by-product downstream.

- Catalyst is dissolved in the alcohol using a standard agitator or mixer.

- The alcohol/catalyst mix is then charged into a closed reaction vessel and the vegetable oil is added. The system from here on is totally closed to the atmosphere to prevent the loss of alcohol.

  The reaction mix is kept just above the boiling point of the alcohol (around 70 °C, 158 °F) to speed up the reaction though some systems recommend the reaction take place anywhere from room temperature to 55 °C (131 °F) for safety reasons. Recommended reaction time varies from 1 to 8 hours; under normal conditions the reaction rate will double with every 10 °C increase in reaction temperature. Excess alcohol is normally used to ensure total conversion of the fat or oil to its esters.

- The glycerine phase is much denser than biodiesel phase and the two can be gravity separated with glycerine simply drawn off the bottom of the settling vessel. In some cases, a centrifuge is used to separate the two materials faster.

- Once the glycerine and biodiesel phases have been separated, the excess alcohol in each phase is removed with a flash evaporation process or by distillation. In other systems, the alcohol is removed and the mixture neutralized before the glycerine and esters have been separated. In either case, the alcohol is recovered using distillation equipment and is re-used. Care must be taken to ensure no water accumulates in the recovered alcohol stream.

- The glycerine by-product contains unused catalyst and soaps that are neutralized with an acid and sent to storage as crude glycerine (water and alcohol are removed later, chiefly using evaporation, to produce 80-88% pure glycerine).

- Once separated from the glycerine, the biodiesel is sometimes purified by washing gently with warm water to remove residual catalyst or soaps, dried, and sent to storage. [4]

1.3.3 Pyrolysis (cracking)

Thermal cracking or pyrolysis is the process that causes the break of the molecules by heating at high temperatures that is, by the heating of the substance in the absence of air or oxygen in temperatures superior to 450°C, forming a mixture of chemical compounds with properties very similar to those of petro diesel. In some situations that process is supported by a catalyst for the break of the chemical connections, in order to generate smaller molecules. Fats can be pyrolysized for the production of smaller chain compounds. The pyrolysis of fats has been investigated for more than 100 years, especially in countries with small oil reserves. Typical catalysts to be used in the pyrolysis are the silicon oxide SiO_2 and aluminium oxide Al_2O_3.

The equipment for pyrolysis or thermal cracking is expensive. However, the products are chemically similar to diesel oil. The removal of the oxygen of the process reduces the benefits of an oxygenated fuel, reducing its environmental benefits and usually producing a fuel closer to gasoline than diesel. By the international nomenclature, the fuel produced by thermal cracking is not considered biodiesel, in spite of being a biofuel similar to the diesel oil. Cracking has great applicability in places that need smaller production volume and with smaller availability of qualified work.

The catalytic or thermal cracking produces a mixture of condensed hydrocarbons with output of around 80% in an organic phase. There is an aqueous phase, around 5% to 10% and the remaining are gases. Cracking has as strong point the absence of formation of aromatic compounds, of great pollutant potential.

1.4 Advantages of Biodiesel over Petrodiesel

• Derivation from renewable domestic resources, thus reducing dependence on petroleum.

• Biodegradability.

• Reduction of most exhaust emissions (with the exception of nitrogen oxides, NOx).

• Higher flash point, leading to safer handling and storage.

• Excellent lubricity, a fact that is steadily gaining importance with the advent of low-sulphur petrodiesel fuels, which have greatly reduced lubricity. Adding biodiesel at low levels (1–2%) restores the lubricity. [3]

1.5 History regarding biodiesel and its present need

The history of biodiesel starts in the mid 1800's. In those days the process of transesterification was used to separate glycerine from oil. Glycerine was a useful product in then (and is still useful today) being widely used in the cosmetic, food and explosives industries. When Rudolf Diesel demonstrated his diesel engine at the Paris Show in 1900, he ran it on straight peanut oil – not even biodiesel.

By the early 1900's petroleum fuels were plentiful and cheap. Increasingly more sophisticated fuel injection systems were designed to run these fossil fuel derived oils. Over the years this has meant that vehicles have evolved to run thinner fossil diesels rather than thicker vegetable oils.

Until the oil crisis of the 1970's it was not economically viable to run an engine on anything but fossil diesel. Once the price of crude oil increased though, there was an incentive for research on alternative fuels. It was already pretty much accepted that unmodified vegetable oil was not suitable for modern injection systems. The transesterification process was pretty much old science and was used to reduce the viscosity of the oil, producing biodiesel (biodiesel technically is termed a Fatty Acid Methyl Ester).

In 1983 in Austria, Dr. Mittelbach developed a commercial process to turn old cooking oil into biodiesel. Dr. Thomas Reed is credited as being the first person in the US to turn old cooking oil into biodiesel on a small scale in 1989.

In the 2000's when crude prices started rising again and with a new world awareness on pollution and global warming, bio fuels again become popular. Government subsidy of bio fuel industries became common, especially in the first world. This has given industry the economic security needed to invest in bio fuels.

It is interesting to note that the history of biodiesel has shown that countries who have government support and subsidy for their bio fuels industry have large scale commercial production (the US, EU) while countries who do not have such subsidies do not.

1.6 Technical Aspects

The kinematic viscosity of vegetable oils is about an order of magnitude greater than that of conventional, petroleum-derived diesel fuel. High viscosity causes poor atomization of the fuel in the engine's combustion chambers and ultimately results in operational problems, such as engine deposits. Since the renewal of interest during the late 1970s in vegetable oil derived fuels, four possible solutions to the problem of high viscosity have been investigated: transesterification, pyrolysis, dilution with conventional petroleum-derived diesel fuel, and micro emulsification.

Transesterification is the most common method and leads to monoalkyl esters of vegetable oils and fats, now called biodiesel when used for fuel purposes. Briefly, it consists of reacting the vegetable oil feedstock with an alcohol, usually methanol, in the presence of a catalyst, usually a base such as sodium or potassium hydroxide, to give the corresponding vegetable oil (usually methyl) esters. Methyl esters are the most common form of biodiesel, largely due to methanol being the least expensive alcohol.

The high viscosity of vegetable oils as a major cause of poor fuel atomization resulting in operational problems such as engine deposits was recognized early. Although engine modifications such as higher injection pressure were considered, reduction of the high viscosity of vegetable oils usually was achieved by heating the vegetable oil fuel. Often the engine was started on petro diesel and, after a few minutes of operation, was then switched to the vegetable oil fuel, although a successful cold-start on high-acidity peanut oil was reported. Advanced injection timing was a technique also employed. Seddon gives an interesting practical account about a truck that operated successfully on different vegetable oils using preheated fuel.

Pyrolysis, cracking, or other methods of decomposition of vegetable oils to yield fuels of varying nature is an approach that accounts for a significant amount of the literature in "historic" times. Artificial "gasoline," "kerosene," and "diesel" were obtained in China from tung oil and other oils. Other oils that were used in such an approach included fish oils, linseed oil, castor oil, palm oil, and cottonseed oil.

The other approaches—micro emulsification and dilution with petro diesel— appear to have received little or no attention during the historic times of studies on vegetable oils as diesel fuel. However, the use of blends of conventional diesel fuel with cottonseed oil, corn oil, and linseed oil has been described. [4]

1.7 Properties of Biodiesel [Data taken from MERADO Ludhiana]

1.7.1 Viscosity of Biodiesel

Viscosity, which is a measure of resistance to flow of a liquid due to internal friction of one part of a fluid moving over another, affects the atomization of a fuel upon injection into the combustion chamber and thereby, ultimately, the formation of engine deposits. The higher the viscosity, the greater the tendency of the fuel to cause such problems. The viscosity of transesterified oil, i.e., biodiesel, is about an order of magnitude lower than that of the parent oil. The kinematic viscosity of B1O, B15, B20 blends and cotton seed methyl ester were found as 2.19, 2.38, 2.28 and 3.6 centistokes at 40^0C. Cotton seed methyl ester had the kinematic viscosity 7.692 percent less than that of diesel. High viscosity is the major fuel property explaining why neat vegetable oils have largely been abandoned as an alternative diesel fuel (DF). Kinematic viscosity (ν), which is related to dynamic viscosity (η) by density as a factor, is included as a specification in biodiesel standards. It can be determined by standards such as ASTM D445 or ISO 3104. Fatty acid methyl esters are Newtonian fluids at temperatures above 5°C (11). The viscosity of petrodiesel fuel is lower than that of biodiesel, which is also reflected in the kinematic viscosity limits (all at 40°C) of petrodiesel standards, which are 1.9–4.1 mm^2/s for DF2 (1.3–2.4 mm^2/s for DF1) in the ASTM petrodiesel standard D975 and 2.0–4.5 mm^2/s. The difference in viscosity between the parent oil and the alkyl ester derivatives can be used to monitor biodiesel production. Viscosity increases with chain length (number of carbon atoms) and with increasing degree of saturation. This holds also for the alcohol moiety because the viscosity of ethyl esters is slightly higher than that of methyl esters. Factors such as double-bond configuration influence viscosity (cis double bond configuration giving a lower viscosity than trans), whereas double-bond position affects viscosity less. Branching in the ester moiety, however, has little or no influence on viscosity.

Redwood viscometer apparatus is used for determining the viscosity of oil expressed as a time of flow in seconds through specified hole made in a metallic piece.

Scope of Redwood viscometer

The Redwood Apparatus measures viscosity in empirical units and not in absolute units such as Centistokes. It is possible to convert Redwood viscometer feadings to 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 that is if it possesses a linear relationship between shearing stress and rate of shear under the test conditions.

Mode of operation

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 is 40^oC

For flux oils the temperature of test be 93^oC

The apparatus Redwood viscometer will correctly indicate the viscosity flow time if it stands between 3 seconds to 2000 seconds.

Sampling

For determinations at temperatures of 93^oC or lower, of the time sample, without stirring, in a loosely stoppered container filled as completely, as possible for a hour at 100^oC by immersions in a suitable liquid bath maintained at the temperature, e.g. a boiling bath. Then adjust the temperature of which is slightly below the test temperature carry out subsequent hearing by using a source of heat not higher than 121^oC or higher do not heat temperature. When a series of viscosities is to be determined at several temperatures being and before those at the lower temperatures. Determine the viscosity within 1 hour of the sample reaching the desired temperatures.

Preparation of Apparatus

(a) Clean the oil cup with a suitable solvent, e.g. carbon tetrachloride and then dry it thoroughly using soft tissue paper or some similar material which will not leave any fluff. Clean the jet hole by any line thread.

(b) Set up the viscometer, using the circular spirit level to ensure that is level. Fill the bath with water for determinations at 93^oC and below, and for higher temperatures, with oil having a suitably low viscosity at the test temperature for determination about 93^oC fill the bath to a level not less than 10mm, below the rim of the oil cup at the test temperature.

Procedure

(a) Viscometer bath was to a few degrees above the desired test temperature. Sample was poured into the oil cup through a filter of metal gauge. Temperature of the bath was adjusted until the sample in the cup is maintained at the test temperature stirring the contents of the bath and cup during this procedure preferably using continuous stirring for the bath. Sample was stirred during the preliminary period e.g. by means of the ball value, closing the bottoms of the jet by suitable means, but did not stir the sample during the actual determination. When the temperature of the sample has become suite steady at the desired value, liquid level was adjusted by allowing the sample to flow out until the surface of the sample touches, the filling point. Oil cup and curved slot was placed in the vocer. Clean, dry, stand 50ml was placed from the bottom of the jet. Flask was not insulated in any way. Ball valve was located and simultaneously supports the oil cup thermometer by means of the hock wire stem. Stop the time recorder at the instant the sample reaches the graduation mark of the flask and the final reading of the coil cup thermometer was noted.

(b) Any determination of the temperature of the sample in the oil cup varies during the run by more than 0.1^{o}C for temperatures of 60^{o}C or below by more than 0.3^{o}C or by more than 8.5^{o}C at 121^{o}C was rejected.

Redwood viscometer used for the measurement of Kinematic viscosity

1.7.2 Cloud Point

The temperature, expressed to the nearest degree Centigrade at which a cloud or haze appears when the oil is cooled under prescribed conditions is known as the cloud point.

1.7.3 Pour Point

The lowest temperature, expressed as a multiple of 3^{o}C at which the oil is observed to flow when cooled and examined under prescribed conditions.

The blends B1O, B15, B20 have higher cloud and pour point as compare to diesel. The cloud and pour point of cotton seed methyl ester was also higher as compared of diesel respectively. The results indicated that the blend B10 was observed the cloud point nearly to that of diesel.

Cloud Point and Pour Point Apparatus

The method of cloud point is intended for use only on oils, which are transparent in layers 40mm in thickness and have cloud point below 40^{o}C. The method for pour point is intended for use on any petroleum oil.

Outline of Methods

In the determination of the cloud point, the sample was cooled under prescribed conditions and was inspected at intervals of one degree centigrade until a cloud or haze appears. In the determination of the pour point, the sample cooled under prescribed conditions and was inspected at intervals of 3^{o}C until it will no longer move when the place of surface was held vertical for 65 seconds, the pour point was then taken as 3^{o}C above the temperature of cessation of flow.

Operate of Cold Refrigeration Bath

The refrigeration bath can be operated from above room temperature to below minus 30^{o}C. Kept the sample to be tested in glass jar, fit the rubber cork and keep vertically in the jacket provided. The test temperature was below 0^{o}C or upto -30^{o}C. The jacket was filled around glass jar with a little quantity of ethyl alcohol for proper contact of cooling media. Thermocouple pin (thermocouple bulb) was fitted in rubber cork upto centre of glass jar. Main switch was put on, red neon lamp indicates its operation. The cooling was occurred within 30 to 40 minutes after start of refrigeration system.

Cloud Point Procedure

Sample was bring to temperature of at least 15^{o}C above the approximate cloud point and then pour it into the jar to a height of the 51 to 57 mm close the jar with the cork so that the thermometer bulb rests on the centre of the bottom of the jar. Jar was inserted into the jacket.

Bath temperature was maintained at minus $1^{o}C$ to $2^{o}C$. At each thermometer reading of the one degree centigrade, jar was removed from the jacket quickly but without disturbing the oil. Material was inspected for cloud, and jar was replaced. This complete operation was not taken more than 3 seconds. If the sample does not show cloud when it has been cooled $10^{o}C$ places the jar in another bath maintained at a temperature of minus $15^{o}C$ to $18^{o}C$. If the sample does not show a cloud when it has been cooled to minus $7^{o}C$ place the jar and jacket in another bath maintained at a temperature of minus $32^{o}C$ to minus $35^{o}C$. When as inspection of the sample first reveals and distinct cloudiness or haze at the bottom of the jar, record the reading of the thermometer as the cloud point.

Reporting

The temperature recorded was reported in corrected for thermometer errors and expressed to the nearest degree centigrade as the cloud point.

Precision

Result of duplicate tests shall not differ by more than the following.

Repeatability	Reproducibility
$6^{o}C$	$6^{o}C$

Cloud and pour point apparatus

Pour Point Procedure

The sample was poured, heated in a water bath into the jar to a height of 51 to 57mm. Jar was closed with the cork carrying thermometer no.1 so that the thermometer bulb was immersed vertically in the sample with the beginning of the capillary 3mm below the surface. Sample was heated without stirring to a temperature of 46^{o}C in a bath maintained at a temperature not higher than 48^{o}C. The sample was cooled to 32^{o}C in air or in water bath at approximately 25^{o}C. If a pour point below minus 35^{o}C is expected, the sample was cooled in air or in water bath to 16^{o}C and replaced the thermometer no.1 by thermometer no.2, fit the gasket on to the jar 25mm from the bottom and insert the jar into the jacket.

When the sample has cooled to allow the formation of wax crystals, great care was not to disturb the mass of sample not to permit the thermometer to shift in the sample, any disturbance of the spongy network of crystals will lead to false results. Bath temperature was maintained at temperature of minus 1^{o}C to plus 2^{o}C. Jacket and jar was supported in a vertical position in the bath beginning at a temperature 12^{o}C above the expected pour point at each thermometer reading which is a multiple of 3^oC, jar was removed from the jacket carefully, and tilt it just enough to see whether the oil will move and replace it. This complete operation was not taken more than 3 seconds, if the oil has not ceased to flow when it has been cooled to 9^oC, place the jar in another bath maintained at a temperature of minus 32^oC to minus 35^oC. If the pour point is very low, maintained additional bathes with successively lower temperature differentials of about 18^oC transfer in the jar and jacket when the temperature of the sample reaches a point 27^oC above the temperature of the new bath. As soon as the sample ceases to flow when the jar is tilted hold the jar in horizontal position for exactly 5 second. If the sample shows any movements replace the jar in the jacket and cool down the sample another 6^oC. If the oil shows no movement during the 5 seconds record the reading of the thermometer.

1.7.4 Flash Point

The temperature at which a material gives so much vapour that this vapour when mixed with air, forms a ignitable mixture and gives a momentary flash on application of a small pilot flame. The blends B1O, B15, B20 have higher flash and fire point as compare to diesel. The flash and fire point of cotton seed methyl ester was found higher than that of diesel respectively. The results indicated that the blend B15 was observed the flash and fire point 16.66 percent higher than that of diesel.

Pensky-Martens Flash Point Apparatus

Outline of Method

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.

Preparation of sample

Biodiesel containing dissolved or free water may be dehydrated with calcium chloride or by filtering through a suitable filter paper or a loose plug of dry absorbent cotton. Warming the biodiesel is permitted, but it shall not be heated for prolonged periods or above a temperature of 16^oC below its expected flash point.

Procedure

1) Thorough clean and dry all parts of the cup and its accessories before starting the test, being sure to remove any solvent which has been used to clean the apparatus. Support the tester on a level, steady table. Fill the cup with the sample to be tested to the level indicated by the filling mark. Place the lid on the cup and set the latter in the stove. Take care that the locating devices are properly engaged. Insert the thermometer. Light the test flame and adjust it to 4.0mm in diameter. Supply host at such a rate that the temperature recorded by the thermometer increases not less than 5^oC nor more than 6^oC per minute. Turn the stirrer 90 to 120 rev/min stirring in a downward direction.
2) If the biodiesel is known to have a flash point of 105^oC or below, apply the test flame when the temperature of the biodiesel is a whole number not higher than 17^oC below the flash point, and thereafter at each degree rise of temperature. Apply the test flame by operating the mechanism on the cover which controls the shutter and test flame burner so that the flame is lowered into the vapour space of the cup in 0.5 seconds, left in its lowered position for one second and quickly raised to its high position. Do not stir the biodiesel while applying the test flame.
3) If the biodiesel is known to have a flash point above 105^oC apply the test flame in the manner prescribed in above paragraph at each temperature, that is, a multiple of 3^oC, beginning at a whole number temperature reading not higher than 17^oC below the flash point.
4) Record as the flash point the temperature read on the thermometer at the time and test flame application causes a distinct flash in the interior of the cup. Do not confuse the true flash point with the bluish halo that sometimes surrounds the test flame at applications preceding the one that cause the actual flash.

Procedure for Suspensions of Solids

Bring the material to be tested and the tester to a temperature of 15^oC+5^oC or 11^oC lower than the estimated flash point, whichever is lower. Completely fill the air space between the cup and the interior of the air-bath with water at the temperature of the tester and biodiesel. Turn the stirrer at 250+10 rev/min, stirring in a downward direction. Raise the temperature throughout the duration of the test at a rate of not less than 1^{o}C nor more than 1.5^{o}C per minutes.

Pensky Martin Flash Point Apparatus

1.7.5 Calorific Value or Gross Heat of Combustion

The heat of combustion or calorific value of a fuel is an important measure since it is the heat produced by the fuel within the engine that enables the engine to do the useful work. The gross heat of combustion of fuel samples was determined with the help of a widson scientific works make isothermal 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.

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

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

where,

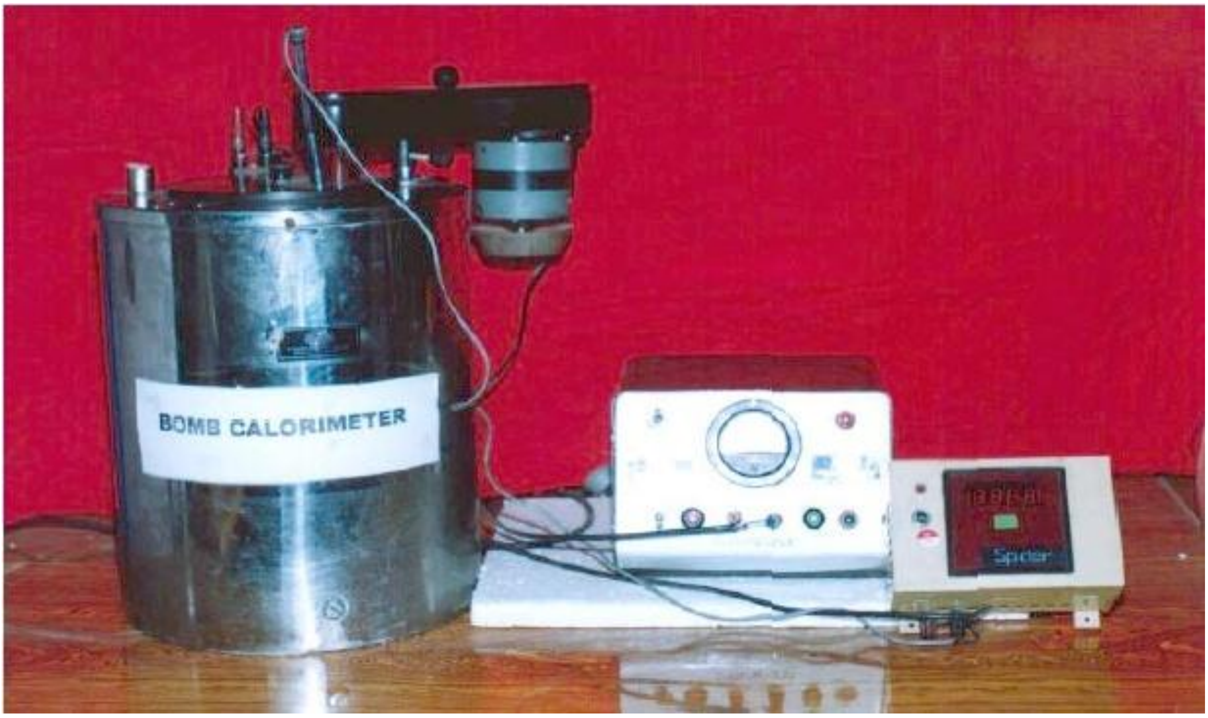
H_c = Heat of combustion of the fuel sample, Cal / g

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

ΔT = Rise in temperature, ^{0}C

M_s = Mass of sample burnt, g

The calorific value of diesel, cotton seed methyl ester and blend B10 were found as 43,000, 40,000 and 40,300 KJ/Kg respectively. The calorific value of blend B10 is decreased by 6.27% than that of diesel whereas the calorific value of cotton seed methyl ester is decreased by 6.97% than that of diesel. The result shows that the calorific value of B10 blend is lower than diesel fuel.



Isothermal bomb calorimeter used for measurement of calorific value

1.7.6 Ash Content

Ash in a fuel can result from oil, water soluble material compounds or extraneous solids, such as dirt and rust. The ash content of diesel, 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. The ash content was obtained using the equation given below

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

where,

A_s = Ash content, percent (%)

W_a = Weight of ash (gm)

W_s = Weight of sample (gm)

Muffle furnace used for measurement of ash content

1.7.7 Carbon Residue

Carbon residue was determined for different fuels by using a carbon residue apparatus. The measurement was made in accordance with the ASTM D189-IP 13 of institute of petroleum, London. 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. The percentage of carbon residue on the original sample was then calculated using the equation as given below:

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

where,

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

The ester of cotton seed and their blends 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 blend B20 has lowest carbon residue content as compare to B10 and B15.

Carbon Residue (Rams Bottom) Apparatus

1.7.8 Free Fatty Acid Content (FFA Content)

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

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

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

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

Where V = volume of NaOH consumed in the titration

And N = Normality of NaOH

The FFA content of B1O, B15, B20 blends and cotton seed methyl ester were observed 0.090%, 0.10%, 0.109% and 0.112%.

1.8 Benefits of Biodiesel

1.8.1 Environmental Benefits

In 2000, biodiesel became the only alternative fuel in the country to have successfully completed the EPA-required Tier I and Tier II health effects testing under the Clean Air Act. These independent tests conclusively demonstrated biodiesel's significant reduction of virtually all regulated emissions, and showed biodiesel does not pose a threat to human health.

Biodiesel contains virtually no sulphur or aromatics, and use of biodiesel in a conventional diesel engine results in substantial reduction of unburned hydrocarbons, carbon monoxide and particulate matter. Study showed that the production and use of biodiesel, compared to petroleum diesel, resulted in a 78.5% reduction in carbon dioxide emissions. Moreover, biodiesel has a positive energy balance. For every unit of energy needed to produce a gallon of biodiesel, at least 4.5 units of energy are gained.

1.8.2 Energy Security Benefits

With agricultural commodity prices approaching record lows, and petroleum prices approaching record highs, it is clear that more can be done to utilize domestic surpluses of vegetable oils while enhancing our energy security. Because biodiesel can be manufactured using existing industrial production capacity, and used with conventional equipment, it provides substantial opportunity for immediately addressing our energy security issues. [4]

CHAPTER 2

LITERATURE SURVEY

S.S. Ragit *et al.*[8] worked at the standardization of transesterification process parameters for the production of methyl ester of filtered neem oil and fuel characterization for engine performance. The effect of process parameters such as molar ratio, preheating temperature, catalyst concentration and reaction time was studied to standardize the transesterification process for estimating the highest recovery of ester with lowest possible viscosity. Based on the observations of the ester recovery and kinematic viscosity, it was found that filtered neem oil at 6:1 M ratio (methanol to oil) preheated at 55^{o}C temperature and maintaining 60^{o}C reaction temperature for 60 min in the presence of 2 percent KOH and then allowed to settle for 24 h in order to get lowest kinematic viscosity (2.7 cSt) with ester recovery (83.36%). Different fuel properties of the neem methyl ester and neem oil were also measured. Results show that the methyl ester of neem obtained under the optimum condition is an excellent substitute for fossil fuels.

Based on the observations of the ester recovery and kinematic viscosity, it was found that filtered neem oil at 6:1 M ratio (methanol to oil) preheated at 55^{o}C temperature and maintaining 60^{o}C reaction temperature for 60 min in the presence of 2 percent KOH and then allowed to settle for 24 h gave lowest kinematic viscosity (2.7 cSt) with ester recovery (83.36%). The lowest viscosity is considered better for engine performance in internal combustion engine in this research study. The density, flash and fire points of neem methyl ester gave good results but calorific value was slightly less as compared to diesel.

D.Royon *et al.*[19] enzymaticaly produced biodiesel from cotton seed oil using *t*-butanol as a solvent. The enzymatic production of biodiesel by methanolysis of cottonseed oil was studied using immobilized *Candida antarctica* lipase as catalyst in *t*-butanol solvent. Methyl ester production and triacylglycerols disappearance were followed by HPLC chromatography. It was found, using a batch system, that enzyme inhibition caused by undissolved methanol was eliminated by adding *t*-butanol to the reaction medium, which also gave a noticeable increase of reaction rate and ester yield. The evict of *t*-butanol, methanol concentration and temperature on this system was determined. A methanolysis yield of 97% was observed after 24 h at 50°C with a reaction mixture containing 32.5% *t*-butanol, 13.5% methanol, 54% oil and 0.017 g enzyme (g oil)¡1. With the same mixture, a 95% ester yield was obtained using a one step Waxed bed continuous reactor with a low rate of 9.6ml h¡1 (g enzyme)¡1. Experiments with the continuous reactor over 500 h did not show any appreciable decrease in ester yields.

The operational stability of the catalyst in the continuous process was tested at a methanol to oil molar ratio of 6:1, a solvent concentration of 32.5% and a Xow rate of 9.6ml h¡1 (g enzyme)¡1, producing an oil conversion of 95%. This corresponds to a productivity of methyl ester of 4 g h¡1 (g enzyme)¡1. The system was operated over 500 h without an appreciable loss in substrate conversion, which maintained a value of 95% during all the experiment. This is an essential result for the practical application of the process, since cost of the enzyme is high and its reuse appreciably reduces the Wnal cost of the biodiesel. He concluded that the use of *t*butanol as a solvent in the enzymatic biodiesel production from cotton seed oil has the following advantages: (a) In the presence of this solvent, high reaction rates and yield are obtained. The quantity of enzyme needed to catalyze the reaction within a reasonable time periods is lower than that of other systems. (b) A very simple, one step continuous reactor can be used for the biodiesel production. (c) No catalyst regeneration steps are needed for lipase reuse. (d) The operational stability of the catalyst is high even at 50°C. The necessity of solvent recovery can be a draw back to the process. However, the following aspects should be considered: *t*-butanol concentration for optimum conversion is not high and consequently the energy expense required for its recovery can be acceptable; solvent recovery is a common practice in the chemical catalyzed production of biodiesel and it is necessary in all cases to remove the excess methanol; the low boiling point of *t*-butanol makes for an easy separation of the solvent together with the methanol.

David M. Fernandes *et al.*[18] works on the preparation and characterization of methylic and ethylic biodiesel from cottonseed oil and effect of tert-butylhydroquinone on its oxidative stability. Biodiesel was prepared by a transesterification process involving the reaction of the oil with methanol or ethanol using KOH as catalyst. The conversion of triglycerides to the corresponding methyl and ethyl ester was 91.5 and 88.5 (wt%). All the physical–chemical properties of the obtained biodiesels met the minimum or maximum limits of the EN 14214 except oxidation stability. The addition of the synthetic antioxidant tert-butylhydroquinone at the concentration of 300 mg was sufficient to obtain acceptable oxidation stability values (>6 h). Thermogravimetric analysis was also performed and similar profiles were verified for both ethylic and methylic biodiesels. Therefore, this work demonstrates the feasibility of using the ethanolic route to produce cottonseed oil biodiesel.

He concluded that the production of biodiesel from cottonseed oil through methylic and ethylic routes shows satisfactory performance for both cases. The physical–chemical characteristics of both biodiesels were closely similar and met the limits established by EN 14214, with the exception of oxidative stability. To overcome such a drawback, the addition of 300 mg TBHQ was sufficient to attend the oxidation stability parameter. Thus, the ethylic route can be employed for biodiesel production from cottonseed oils within acceptable limits for commercialization of the biofuel. Additional advantage is related to the use of bioethanol for biodiesel production, which is a less toxic and renewable source and has its production fully consolidated in Brazil.

L. Ranganathan *et al.*[11] did experimental investigation of a diesel engine fuelled with optimum biodiesel produced from cotton seed oil. They found that biodiesel is best substitute for petro diesel and also most advantageous over petro-diesel for its environmental friendliness. The continuous increasing demand for energy and the diminishing tendency of petroleum resources has led to the search for alternative renewable and sustainable fuel. Different parameters for the optimization of the biodiesel produced from cotton seed oil was prepared by transesterification and then experiments were conducted to study the combustion and emission characteristics of a four-stroke, single cylinder, direct injection (DI), naturally aspirated (NA) diesel engine. The results showed that biodiesel exhibited the similar combustion stages to that of diesel, however, biodiesel showed an earlier start of combustion. The engine combustion parameters such as burning rate, heat release rate and ignition delay were computed. The power output of biodiesel was almost identical with that of diesel. The brake thermal efficiency was lower for biodiesel due to its lower heating value. The NOx and CO2 emissions of the cotton seed methyl ester and its blends are slightly higher than diesel oil while the emissions of HC, CO and soot concentrations are lower. Based on this study, biodiesel can be used as a substitute for diesel in diesel engine.

The optimum production of biodiesel from CSO is determined and then combustion and emission study of diesel fuel and biodiesel mixtures in a direct injection diesel engine is carried out and the results of the work are summarized be follow:

1. A maximum of 77.5% biodiesel production was achieved at 20% methanol and 0.5% NaOH at 55^{o}C reaction temperature.

2. The brake thermal efficiency of the CSOME and its blends are slightly lower than diesel oil.

3. The NO_x and CO_2 emissions of the cotton seed methyl ester and its blends are slightly higher than diesel oil while the emissions of HC, CO and soot concentrations are lower.

4. The ignition delay for CSOME and its blends is found to be lower than that of diesel oil. The ignition delay decreases with increase in load for all the fuels. The peak rate of pressure rise is found to be higher for diesel oil when compared to CSOME and its blends. The peak rate of pressure rise occurs earlier for CSOME and its blends when compared to diesel. The burning rate is found to be maximum for diesel oil when compared to CSOME. Heat release is found to be higher for diesel oil owing to its intense pre combustion phase. The angle of Maximum heat release occurs earlier for CSOME and its blends than that of diesel oil.

From the above analysis it can be concluded that cotton seed oil and its blends are a potential substitute for diesel oil. They produce lesser emissions than petroleum diesel and have satisfactory combustion and emission characteristics.

R. Anand *et al.*[13] works on the performance and emissions of a variable compression ratio diesel engine fuelled with bio-diesel from cotton seed oil. A methyl ester of cottonseed oil was prepared and blended with diesel in four different compositions varying from 5% to 20% in steps of 5%. Tests were conducted in a single cylinder variable compression ratio diesel engine at a constant speed of 1500 rpm. Highest brake thermal efficiency and lowest specific fuel consumption were observed for 5% biodiesel blend for compression ratio of 15 and 17 and 20% biodiesel blend for compression ratio of 19. The 20% biodiesel blend at a compression ratio of 17 had maximum nitric oxide emission as 205 ppm, while it was 155 ppm for diesel. Substantial reduction in carbon monoxide emissions and smoke in the full range of compression ratio and loads was observed. Improved heat release characteristics were observed for the prepared biodiesels. The results reveal that the biodiesels can be used safely without any modification to the engine.

The experimental conclusions of this investigation can be summarized as follows:

Brake specific fuel consumption was found to have minimum for neat diesel as compared to biodiesel blends at all loads. However at lower compression ratios (15:1, 17:1) biodiesel blend B5 has minimum specific fuel consumption and at compression ratio of 19:1, B20 has least specific fuel consumption compare to diesel. At 15: 1 compression ratio, the bsfc is increased by 2.5% and 4.92% for the B5 and B20 blends. At 17:1 compression ratio, it is increased by 3.5% for both the B5 and B10 blends, whereas at 19:1 compression ratio, the B20 blend suggests slightly better fuel economy.

The brake thermal efficiency was found to increase with increase in compression ratio and there is no large difference in the brake thermal efficiency of bio diesel blends and neat diesel. However at high loads B5 was found to have maximum thermal efficiency at compression ratio 15:1 and B20 at compression ratio 19:1. At compression ratio 17:1, B10 and B5 have almost equal efficiencies at full load. The maximum brake thermal efficiency values vary between 27.37-29.28% for COME-diesel blends and 26.65-27.92% for diesel fuel. The maximum NO emissions increase proportionally with the mass percent of oxygen in the biofuel and compression ratio, at 17: 1 CR reaching the highest, 205 ppm, value for the B20 blend and 197 ppm for B5. At the 15:1 CR, the NO emissions for all fuels are slightly lower, ranging from 75 ppm (B10) to 146 ppm (diesel fuel).

Smoke opacity emitted by biodiesel blends is lower than neat diesel at low load and lower compression ratios. The visible smoke and carbon monoxide emissions emerging from the biodiesel over all loads and compression ratios are lowered by up to 71.7% and 24% to 63.6%, respectively. The carbon dioxide CO_2 emissions, along with the fuel consumption are slightly higher for the B5 and B10 blends. The emission of unburned hydrocarbons HC for all fuels is low, 15–80 ppm, showing slightly milder values for COME-diesel blends compared with diesel fuel.

Overall combustion characteristics for all blends were found quite similar to diesel at all compression ratios. Peak pressure increases with increase in compression ratio for all biodiesel blends and neat diesel. At compression ratio of 17:1, ignition delay is shorter for all biodiesel blends than neat diesel due to higher cetane number and peak pressure is highest for B20.

Biodiesel blends have more heat release rate than mineral diesel at compression ratios of 17:1 and 19:1. And diesel fuel shows lowest heat release rate at initial stage and longer combustion duration at 75% load and at compression ratio of 15:1. However, maximum heat release is same for neat diesel and B10 at that compression ratio. Also biodiesel blends have large negative heat release rate due to cooling effect of the liquid fuel injected into the cylinder at all compression ratios.

Peak pressure increases with increase in loads for all fuels at all compression ratios. Blends have more peak pressure than neat diesel at higher compression ratio(17:1 and 19:1) and blend B20 has maximum peak pressure and it decreases with decrease in biodiesel percentages at all compression ratios and a general practical conclusion is that, all tested biodiesel blends can be used safely without any modification in engine. So, blends of methyl ester of cotton seed could be successfully used.

Y. Zhang *et al.*[4] reported biodiesel production from waste cooking oil. Four different continuous process flow sheets for biodiesel production from virgin vegetable oil or waste cooking oil under alkaline or acidic conditions on a commercial scale were developed. Detailed operating conditions and equipment designs for each process were obtained. A technological assessment of these four processes was carried out to evaluate their technical benefits and limitations. Analysis showed that the alkali-catalyzed process using virgin vegetable oil as the raw material required the fewest and smallest process equipment units but at a higher raw material cost than the other processes. The use of waste cooking oil to produce biodiesel reduced the raw material cost. The acid-catalyzed process using waste cooking oil proved to be technically feasible with less complexity than the alkali-catalyzed process using waste cooking oil, thereby making it a competitive alternative to commercial biodiesel production by the alkali-catalyzed process.

Md. Nurun Nabi et al.[2] reported biodiesel production from cotton seed oil and its effect on engine performance and exhaust emissions. The use of biodiesel is rapidly expanding around the world, making it imperative to fully understand the impacts of biodiesel on the diesel engine combustion process and pollutant formation. Biodiesel is known as the mono-alkyl-esters of long chain fatty acids derived from renewable feedstocks, such as, vegetable oils or animal fats, for use in compression ignition engines. Different parameters for the optimization of biodiesel production were investigated in the first phase of this study, while in the next phase of the study performance test of a diesel engine with neat diesel fuel and biodiesel mixtures were carried out. Biodiesel was made by the well known transesterification process. Waste cottonseed oil (CSO) was selected for biodiesel production. The transesterification results showed that with the variation of catalyst, methanol or ethanol, variation of biodiesel production was realized. A maximum of 77% biodiesel was produced with 20% methanol in presence of 0.5% sodium hydroxide. The engine experimental results showed that exhaust emissions including carbon monoxide (CO), particulate matter (PM) and smoke emissions were reduced for all biodiesel mixtures. However, a slight increase in oxides of nitrogen (NOx) emission was experienced for biodiesel mixtures.

This work investigated the production of biodiesel from cottonseed oil and performance study of diesel engine with diesel fuel and biodiesel mixtures. The results of this report are summarized as follows:

1. Biodiesel was prepared from cottonseed oil by transesterification process.
2. A maximum of 77% BD production was found at 20% methanol and 0.5% NaOH at 55 ^{o}C reaction temperature.
3. Biodiesel mixtures showed less carbon monoxide, particulate matter, smoke emissions than those of neat diesel fuel. NOx emission with biodiesel mixtures showed higher values when compared with neat diesel fuel. Compared to the neat diesel fuel, 10% biodiesel mixtures reduced particulate matter, smoke emissions by 24% and 14%, respectively. Biodiesel mixtures (30%) reduced carbon monoxide emissions by 24%, while 10% increase in the NOx emission was experienced with the same blend. The reason for reducing three emissions (particulate matter, smoke and carbon monoxide) and increasing NOx emission with biodiesel mixtures was mainly due to the presence of oxygen in their molecular structure. Also low aromatics in the biodiesel mixtures may be an additional reason for reducing these emissions.

4. Thermal efficiency with biodiesel mixtures was slightly lower than that of neat diesel fuel due to lower heating value of the mixtures. However, volatility, higher viscosity, higher density may be additional reasons for efficiency reduction with biodiesel mixtures.

Christos E. Papadopoulos *et al.*[3] reported optimization of cotton seed biodiesel quality (critical properties) through modification of its FAME composition by highly selective homogeneous hydrogenation. The catalytic (homogeneous) hydrogenation of biodiesel's polyunsaturated fatty acid methyl esters (FAME), synthesized by transesterification of vegetable (cotton seed) oil, selectively to monounsaturated FAME, could upgrade the final quality of biodiesel. The final fuel can be optimized to have a higher cetane number and improved oxidative stability. The low-temperature performance after hydrogenation might be worst, but this, could be further improved through selective wintering and/or blending. The homogeneous hydrogenation of FAMEs of cotton seed biodiesel was catalyzed by the catalyst precursor $RhCl_3$.3H20 and STPP-TiOA. Four groups of hydrogenation experiments were carried out regarding the effects of pressure, temperature, reaction time and molecular ratio C=C/Rh. Partial hydrogenation of cotton seed FAMEs took place under mild conditions of pressure and temperature and high catalytic activities were observed in very short reaction times, and for high molecular ratios C=C/Rh. Biodiesel's quality optimization studies, based on existing empirical models of biodiesel properties, were carried out in order to identify optimum FAME compositions and those hydrogenation conditions that could possibly supply them.

The partial hydrogenation of the different vegetable oils based biodiesels can provide an enormous variety of FAME mixtures and thus of blending possibilities for their further optimization. Several models exist in the literature for the prediction of biodiesel FAME properties, though most of them are simplified and generic linear models of these properties and thus are not able to cover the variety of possible existing conditions. So, they may perform significant differences in their results when they are compared with each other under different conditions. One of the main reasons for this is that most, if not all, of the properties in question are not additive in the end and thus non-linear effects may play a significant role in many cases. The authors have developed in the past such non-linear models and they intend to exercise their further application to other mixtures and properties in the near future, as well as to develop more specific ones for these mixtures.

Ayhan Demirbas[5] reported the 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 C_{14}–C_{22}), 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 sulfur 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.

Alternative fuels for diesel engines have been becoming increasingly important due to diminishing petroleum reserves and the growing environmental concerns have made renewable fuels an exceptionally attractive alternative as a fuel for the future. Biodiesel is derived from a varied range of edible and inedible vegetable oil, animal fats, used frying oil and waste cooking oil. The edible oil in use at present is soyabean, sunflower, rapeseed and palm. The inedible oil used as feedstock for biodiesel production includes J. curcas, M. indica, F. elastica, A. indica, C. inophyllum jatropha, neem, P. pinnata, rubber seed, mahua, silk cotton tree, waste cooking, microalgae, etc. Transesterification is a chemical reaction between triglyceride and alcohol in the presence of catalyst or without catalyst. The purpose of the transesterification process is to lower the viscosity of the oil. Methanol being cheaper is the commonly used alcohol during transesterification reaction. Homogeneous catalysts such as sulphuric acid, sodium hydroxide, potassium hydroxide and heterogeneous catalysts such as calcium oxide, magnesium oxide and others can be used in transesterification reaction. Noncatalyzed transesterification processes are the BIOX process and the supercritical alcohol (methanol) process. The advantage in its usage is attributed to lesser exhaust emissions in terms of carbon monoxide, hydrocarbons, particulate matter, polycyclic aromatic hydrocarbon compounds and nitrited polycyclic aromatic hydrocarbon compounds. The main advantages of biodiesel given in the literature include its domestic origin, its potential for reducing a given economy's dependency on imported petroleum, biodegradability, high flash point, and inherent lubricity in the neat form. The biodiesel policy will help reducing of petroleum imports and saving of foreign exchange. The biodiesel high flash point makes it possible for its easy storage and transportation. The main disadvantages of biodiesel are its higher viscosity, lower energy content, higher cloud point and pour point, higher nitrogen oxide emissions, lower engine speed and power, injector coking, engine compatibility, and high price. Blends of up to 20% biodiesel mixed with petroleum diesel fuels can be used in nearly all diesel equipment and are compatible with most storage and distribution equipment. Biodiesel can be used directly or as blends with diesel fuel in a diesel engine. Biodiesel is a biodegradable and renewable fuel. It contributes no net carbon dioxide or sulfur to the atmosphere and emits less gaseous pollutants than normal diesel. Carbon monoxide, aromatics, polycyclic aromatic hydrocarbons (PAHs) and partially burned or unburned hydrocarbon emissions are all reduced in vehicles operating on biodiesel. Recently, biodiesel has been receiving increasing attention due to its less polluting nature and because it is a renewable energy resource as against the conventional diesel, which is a fossil fuel leading to a potential exhaustion. Biodiesel 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. Biodiesel fuels have generally been found to be nontoxic and are biodegradable, which may promote their use in applications where biodegradability is desired. Neat biodiesel and biodiesel blends reduce particulate matter (PM), hydrocarbons (HC) and carbon monoxide (CO) emissions and slightly increase nitrogen oxides (NOx) emissions compared with petroleum-based diesel fuel used in an unmodified diesel engine. The brake power of biodiesel was nearly the same as with petrodiesel, while the specific fuel consumption was higher than that of petrodiesel. Carbon deposits inside the engine were normal, with the exception of intake valve deposits. Biodiesel fuels can be performance improving additives in compression ignition engines. Performance testing showed that while the power decreased and the brake specific fuel consumption increased for all of the biodiesel samples, compared with diesel fuel, the amount of the changes were in direct proportion to the lower energy content of the biodiesel.

A. Siva Kumar[10] reported comparison of diesel engine performance and emissions from neat and transesterified cotton seed oil. There is an increasing interest in India to search for suitable alternative fuels that are environmental friendly. Environmental concerns and limited amount of petroleum resources have caused interests in the development of alternative fuels for internal combustion (IC) engines. As an alternative, biodegradable, renewable and sulphur free biodiesel is receiving increasing attention. The use of biodiesel is rapidly expanding around the world, making it imperative to fully understand the impacts of biodiesel on the diesel engine combustion process and pollutant formation. Biodiesel is known as the mono-alkyl-esters of long chain fatty acids derived from renewable feedstock, such as, vegetable oils or animal’s fats, for use in compression ignition engines. Therefore, in this study, different parameters for the optimization of biodiesel production were investigated in the first phase, while in the next phase of the study performance test of a diesel engine with neat diesel fuel and biodiesel mixtures was carried out. Biodiesel was made by the well known transesterification process. Cottonseed oil (CSO) was selected for biodiesel production. The transesterification results showed that with the variation of catalyst, methanol, variation of biodiesel production was realized. However, the optimum conditions for biodiesel production are suggested in this paper. A maximum of 76% biodiesel was produced with 20% methanol in presence of 0.5% sodium methaoxide. The engine experimental results showed that exhaust emissions including carbon monoxide (CO), particulate matter (PM) and smoke emissions were reduced for all biodiesel mixtures.

However, a slight increase in oxides of nitrogen (NOx) emission was experienced for biodiesel mixtures.

Cottonseed oil methyl ester (CSOME) was produced by means of transesterification process using cottonseed oil, which can be described as a renewable energy sources. The viscosity of CSOME was reduced by preheating it before supplying it to the test engine. After the fuel properties of CSOME have been determined, various performance parameters and exhaust emission of the engine were investigated and compared with those diesel fuels.

A.P. Sathiyagnanam[9] reported experimental studies on the combustion characteristics and performance of a direct injection engine fuelled with Biodiesel/Diesel Blends. Biodiesel is an alternative diesel fuel that can be produced from different kinds of vegetable oils. It is an oxygenated non-toxic, sulphur-free, biodegradable, and renewable fuel and can be used in diesel engines without significant modification. However, the performance, emissions and combustion characteristics will be different for the same biodiesel used in different types of engine. The biodiesel produced from cottonseed oil was prepared by a method of transesterification and its blends of 10%, 15% and 20% in volume, and standard diesel fuel separately. The effects of biodiesel addition to diesel fuel on the performance, emissions and combustion characteristics of a naturally aspirated direct injection compression ignition engine were examined. Biodiesel has different properties from diesel fuel. A minor increase in specific fuel consumption and brake thermal efficiency for biodiesel and its blends were observed compared with diesel fuel. The significant improvement in reduction of Hydro carbon and smoke emission were found for biodiesel and its blends at high engine loads. Carbon monoxide had no evident variation for all tested fuels. Nitrogen oxides (NOx) were slightly higher for biodiesel and its blends. The significant improvement in reduction of NOx and a minor increase in CO_2 and O_2 were identified use of selective catalytic reduction. Biodiesel and its blends exhibited similar combustion stages to diesel fuel. The use of transesterified cottonseed oil can be partially substituted for the diesel fuel at most operating conditions in terms of the performance parameters and emissions without any engine modification.

Ayhan Demirbas[7] reported study on importance of biodiesel as transportation fuel. The scarcity of known petroleum reserves will make renewable energy resources more attractive. The most feasible way to meet this growing demand is by utilizing alternative fuels. Biodiesel is defined as the monoalkyl esters of vegetable oils or animal fats. Biodiesel is the best candidate for diesel fuels in diesel engines. The biggest advantage that biodiesel has over gasoline and petroleum diesel is its environmental friendliness. Biodiesel burns similar to petroleum diesel as it concerns regulated pollutants. On the other hand, biodiesel probably has better efficiency than gasoline. One such fuel for compression-ignition engines that exhibit great potential is biodiesel. Diesel fuel can also be replaced by biodiesel made from vegetable oils. Biodiesel is now mainly being produced from soybean, rapeseed and palm oils. The higher heating values of biodiesels are relatively high. The higher heating values of biodiesels (39–41 MJ/kg) are slightly lower than that of gasoline (46 MJ/kg), petrodiesel (43 MJ/kg) or petroleum (42 MJ/kg), but higher than coal (32–37 MJ/kg). Biodiesel has over double the price of petrodiesel. The major economic factor to consider for input costs of biodiesel production is the feedstock, which is about 80% of the total operating cost. The high price of biodiesel is in large part due to the high price of the feedstock. Economic benefits of a biodiesel industry would include value added to the feedstock, an increased number of rural manufacturing jobs, an increased income taxes and investments in plant and equipment.

CHAPTER 3

METHODOLOGY

3.1 Objective

Biodiesel, an alternative fuel is derived from the fats of animals and plants. As energy demands increase and fossil fuels are limited, research is directed towards alternative renewable fuels. The main advantages of using this alternative fuel are its renewability, biodegradability and better quality of exhaust gases. It is technically competitive and environmentally friendly alternative to conventional petrodiesel fuel for use in CI engines. The use of biodiesel reduces the dependence on imported fossil fuels which continue to decrease in availability and affordability. Vegetable oils for biodiesel production vary considerably with location according to climate and feedstock availability. Generally the most abundant vegetable oil in a particular region is the most common feedstock. Nowadays, most of the commercial biodiesel comes from the transesterification of vegetable oil using a basic catalyst KOH. So in this report, biodiesel is prepared from waste cotton seed oil. Three different blends of biodiesel were prepared 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.), brake specific fuel consumption (BSFC) and brake thermal efficiency 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 proposed work can be divided into following steps:-

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

First of all a sample of waste cooking cottonseed oil is to be collected from various sources. This cottonseed sample will be taken to MERADO (Mechanical Engineering

Research and Development Organisation) Laboratory situated at Ludhiana (Punjab). The main parameter for any sample of vegetable oil or animal fat to convert it into biodiesel is to check its FFA (free fatty acid) value. FFA value should be less than 0.5 for any sample of vegetable oil or animal fat to convert it into biodiesel. If the FFA value of any sample is greater than 0.5 than it cannot be converted into the biodiesel and hence rejected. If the FFA is values is 0.5 or less then only it can be converted into biodiesel. Otherwise the free fatty acid value can also be decreased to some extent by the use of some acid like hydrochloric acid (HCL). Now then take the required quantity of the sample of waste cooking cottonseed oil and convert that waste cooking cottonseed oil sample to biodiesel by the process known as transesterification. After the biodiesel is prepared from transesterification process, now the viscosity is the main parameter to be checked to use it as a fuel for an internal combustion engine. The viscosity of biodiesel should be equal to or less than 5.0 centistokes (cSt) to use it as a fuel in internal combustion engine. The yield of biodiesel from waste cooking cottonseed oil should also be checked whether it is appropriate or not.

After the biodiesel is prepared, make three different blend samples of that biodiesel i.e. B10, B15 and B20. B10 means the sample contains 10% biodiesel and 90% petrodiesel and so B15 and B20. For a short term time period up to B20 blend can directly be used in an internal combustion engine without any further modification in the engine. But after B20 one has to be done some engine modifications to use it as a fuel in the internal combustion engine.

3.3 Estimation of properties of the biodiesel produced

After producing the biodiesel, the properties of the biodiesel were determined by using various methods. 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 [20]

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 residue	ASTM D189-IP 13 of IIP
Calorific value	IS: 1350

Table 3.2, Apparatus used for calculating the properties [MERADO, Ldh]

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 residue	Carbon residue (rams bottom) apparatus
Calorific value	Bomb calorimeter

Table 3.3, Comparative properties of the petrodiesel and biodiesel

Property of oil	ASTM Standard	Diesel	Biodiesel B100 (from Waste CSO)
Density (30^0C), kg/m^3	-	850	910
Kinematic viscosity, cSt	<5	2.049	3.6
FFA, %	<2.5	-	0.112
Carbon residue, %(m/m)	<0.05	0.0214	0.0112
Cloud point, ^{0}C	-3 to 12	<10	-3
Pour Point, ^{0}C	-15 to 10	-6	-8
Flash point, ^{0}C	>130	78	160
Fire point, ^{0}C	>53	83	165
Calorific value, KJ/kg	>33000	42000	40000

3.4 Engine test Procedure [Data taken from internal combustion engine lab and R & D centre, Thapar Univ. Patiala]

A four stroke, single cylinder variable compression ratio diesel engine is employed for the present study. The detail specification of the engine used is given in table 3.4 below and experimental set up as shown below. AVL 437 Smoke meter is employed to measure the smoke opacity of exhaust gas emitted from the diesel engine. AVL DiGas 4000 Five gas analyzer was used to measure the concentration of gaseous emissions such as Oxides of nitrogen, unburned hydrocarbon, smoke opacity and carbon monoxide. The performance and emission tests are carried out on the C.I. engine using various blends of biodiesel and diesel as fuels. The tests are conducted at the constant speed of 1500rpm at various loads. The experimental data generated are documented and presented here using appropriate graphs. These tests are aimed at optimizing the concentration of ester to be used in the biodiesel-diesel mixture for 1 hr engine test operation. In each experiment, engine parameters related to thermal performance of engine such as brake power, brake thermal efficiency, brake specific fuel consumption, exhaust gas temperature and applied load are measured. In addition to that, the engine emission parameters such as Oxides of nitrogen, unburned hydrocarbon, smoke opacity and carbon monoxide are also measured.

Variable Compression Ratio, 4 Stroke, Single Cylinder Diesel Engine

3.4.1 Specifications of the engine

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

Table 3.4, Specifications of the engine [IC Engine lab, TU]

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

3.5 Eddy Current Dynamometer

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

Eddy Current Dynamometer

3.6 Control Panel

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

Control Panel of Computerised Compression Ignition Engine

3.7 Software

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

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

3.8 Installation requirements for the Machine

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

Precautions

1. Before starting the engine, check all nuts and bolt for are proper tightening and ensure proper oil level in the engine.

2. During the experimentation, power failure may stop the cooling water circulation pump. This will stop the cooling water for the engine, dynamometer and piezo sensor. In such a case the engine should be stopped immediately. Never leave the engine unattended from this point of view.

3. Use clean water; any suspended matter may clog piping and rotameter float.

4. Pressure crank angle and other sensors are delicate instruments and should be handled carefully.

3.9 Experimentation Methodology

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

Experimentation Procedure

1. All electrical connections were checked and proper earthing for the equipments.

2. Water was ensured in the main water supply tank.

3. Selected fuel about 2 litre was ensured in quantity in the fuel supply tank and fuel knob on regular position.

4. Water pump was started. Cooling water flow was checked for engine at 300 LPH and calorimeter flow at 80 LPH. This flow rate was maintained throughout the experiment. Adequate water flow rate was ensured for dynamometer cooling and piezo sensor cooling.

5. Electric-supply to the computer was started through the stabilizer and the engine software was opened.

6. Two power switches provided on the set-up were started and channel selector was set to '7' (load) position. The load was set to minimum position using the rotary knob.

7. Electric power was supplied to the smoke meter and 5-gas analyzer.

8. The engine was started by rotating the handle and operating the decompression lever. The engine was run on the minimum load and smoke meter and gas analyzer to get warmed up simultaneously.

9. Fuel properties (calorific value and specific gravity) were changed in the software in the configure option as per the fuel selected for test.

10. Run option was chosen in the software. The engine was run for fifteen minutes so that engine gets stabilized. It was ensured that smoke meter and gas analyzer have reached their default display and then the fuel supply switch was turned to metering position. Log option of the software was chosen. After 1 minute the display changed to input mode then the values of water flow in cooling jacket was entered and calorimeter and then the file name (applicable only for the first reading) in the software. The first reading for the engine gets logged for the no load condition. The fuel knob was turned back to regular position.

11. The handle of the exhaust connection was opened for inserting the gas sample probe of the 5-gas analyzer. The probe was inserted. NO_x mode of the instrument was chosen from the display. After the reading was stabilized the print outs were got by choosing the print option. The fuel name was noted and load value on the print out for future reference.

12. Valve of the smoke meter connection was opened. The back-pressure was adjusted to 75 mm of Hg. By closing the back-pressure valve and the readings for smoke were taken when the value had stabilized. The fuel reference and load value on the print out were noted for future reference.

13. The load was changed to 1 bar BMEP gradually by rotating the loading knob and observing in the monitor for load value. The engine was allowed to run for 10 minutes for stabilization at new load. After stabilization again the fuel knob was turned to metering position and the log option from software was chosen. After one minute after the fuel logging was over, the cooling water was fed and calorimeter flow rates and the fuel knob was turned back to regular position. The readings of 5-gas analyzer and smoke meter were taken as mentioned above.

14. The procedure was repeated for loads of 0, 2, 4 and 6 kg.

15. The load was reduced to minimum position (no load condition) gradually ensuring that the RPM's were not shooting beyond 1550 RPM and the engine was allowed to stabilize.

16. The files were saved with appropriate names.

17. The engine and computer were put off.

18. The water pumps were allowed to be on for 15 minutes so that engine got cooled down and then the pump was put off.

3.10 Measurement of parameters regarding engine performance and exhaust emission

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

1. Brake power (BP)
2. Brake specific fuel consumption (BSFC)
3. Exhaust gas temperature
5. Cooling water temperature (inlet and outlet)
6. Speed of the engine
7. Exhaust gas analysis (NO_x, HC, CO).

Measurements of Performances

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

3.10.1 Brake mean effective pressure

The BMEP is an important concept for improving different fuels. It is the average pressure the engine can exert on the piston through one complete operating cycle. It is the average pressure of the gas inside the engine cylinder based on neat power. BMEP is important because it is independent of the RPM and the size of the engine.

3.10.2 Brake specific fuel consumption

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

3.10.3 Brake thermal efficiency

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

3.10.4 Exhaust gas temperature

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

Now the comparative study of performance characteristics such as brake power (BP), Brake specific fuel consumption (BSFC), brake thermal efficiency (BTE) and emission characteristics such as carbon monoxide (CO), nitrogen oxides (NO_x), and unburnt hydrocarbons (HC) of different blends of biodiesel prepared from waste cottonseed oil with petrodiesel were done.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Performance Parameters

Worldwide, biodiesel is largely produced by methyl transesterification of oils. The recovery of ester as well as its kinematic viscosity is affected by the transesterification process parameters such as catalyst concentration, reaction temperature and reaction time. The above parameters were standardized to obtain methyl ester of waste cotton seed oil with lowest possible kinematic viscosity and highest level of recovery. The engine performance parameters and exhaust gas emission characteristics of B10, B15, B20 and diesel were compared.

4.1.1 Brake Power (BP)

Graph of the brake power (BP) as a function of load obtained during engine operation on different blends of biodiesel i.e. B10, B15 and B20 with diesel (petrodiesel) at compression ratio of 18:1 has been shown in Figure 4.1.

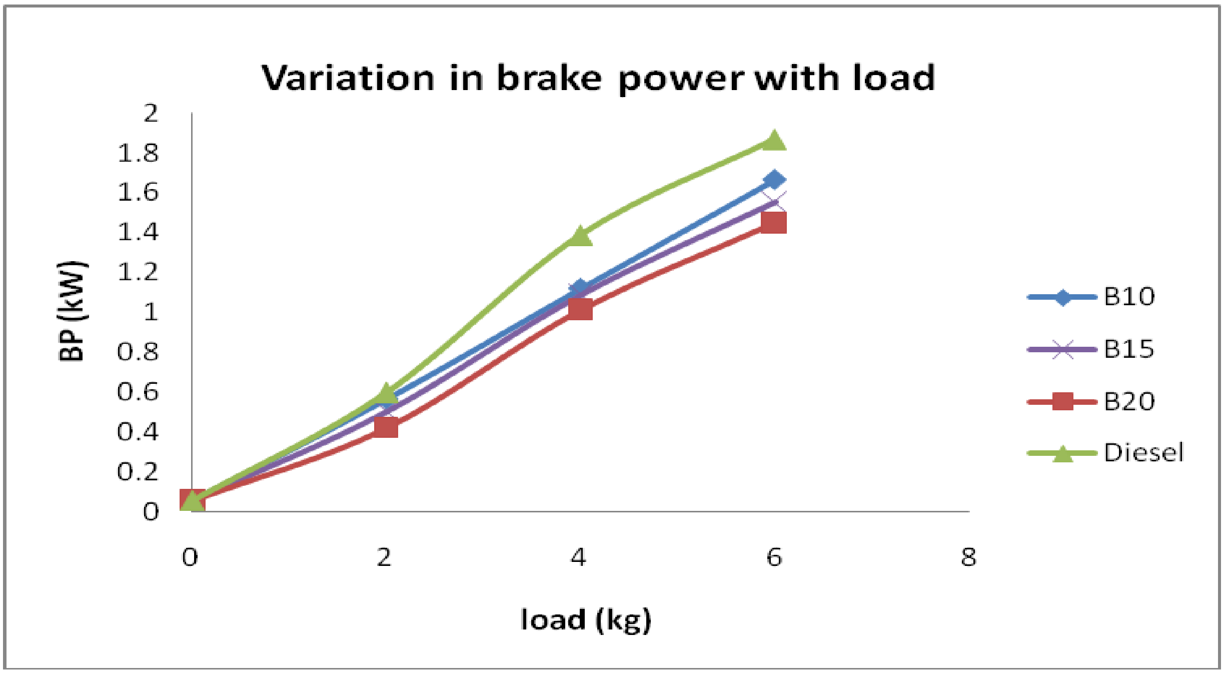


Fig 4.1, Variation in brake power with change in load

Brake power of the engine increases with increase in the load on the engine. Brake power is the function of calorific value and the torque applied. Diesel has more calorific value than the biodiesel, so diesel has the highest brake power among the different blends of biodiesel. Due to the more calorific value of B10 blend of biodiesel than B15 and B20, it has the more brake power as shown in figure 4.1. It can also be seen that as we increases the load, torque increases and thus there is an increase in brake power with the load.

4.1.2 Brake specific fuel consumption (BSFC)

Graph of the brake specific fuel consumption (bsfc) as a function of load obtained during engine operation on different blends of biodiesel i.e. B10, B15 and B20 with diesel (petrodiesel) at compression ratio of 18:1 has been shown in Figure 4.2.

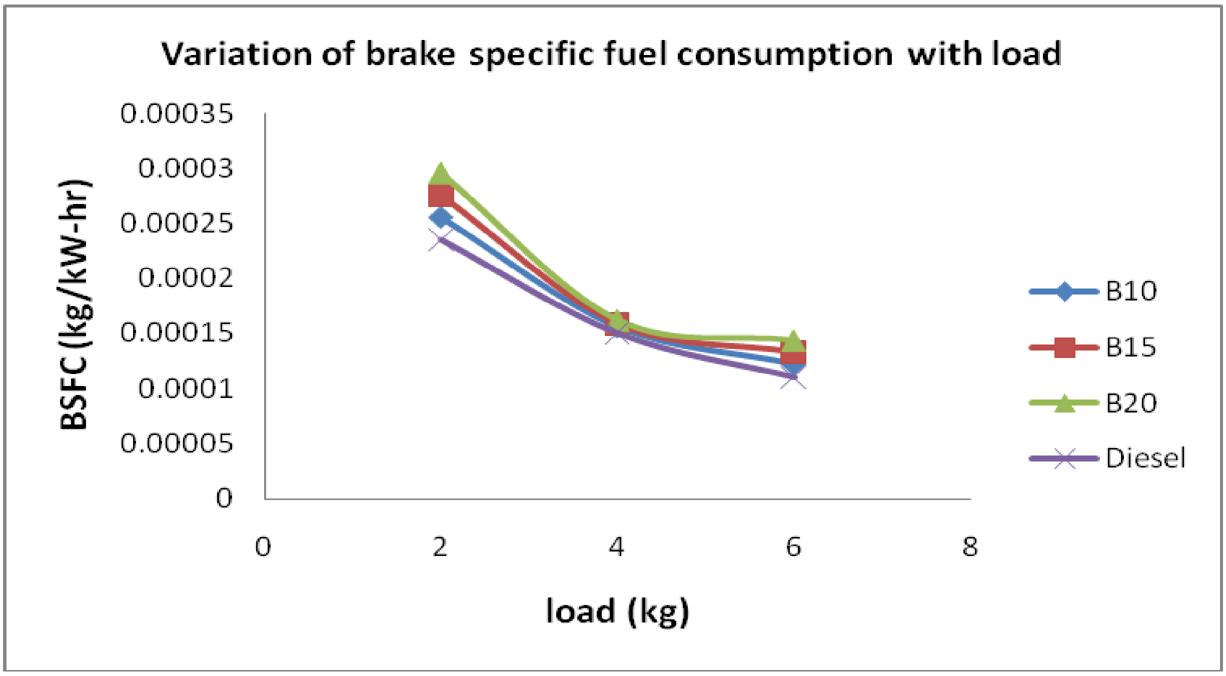


Fig 4.2, Variation in brake specific fuel consumption with change in load

For all blends and petrodiesel tested, bsfc decreased with increase in load. One possible explanation for this reduction is the higher percentage of increase in brake power with load as compared to fuel consumption. It can be seen from the figure 4.2 that in case of biodiesel mixtures, the BSFC values were determined to be higher than those of neat diesel fuel. This trend was observed owing to the fact that biodiesel mixtures have a lower heating value than does neat diesel fuel, and thus more biodiesel mixtures was required for the maintenance of a constant power output. It is well known that brake specific fuel consumption is inversely proportional to the brake thermal efficiency. So diesel has the lowest brake specific fuel consumption. Among the three different blends of biodiesel B10 has the lowest value of brake specific fuel consumption.

4.1.3 Brake thermal efficiency (BTE)

Graph of the brake thermal efficiency as a function of load obtained during engine operation on different blends of biodiesel i.e. B10, B15 and B20 with diesel (petrodiesel) at compression ratio of 18:1 have been shown in Figure 4.3.

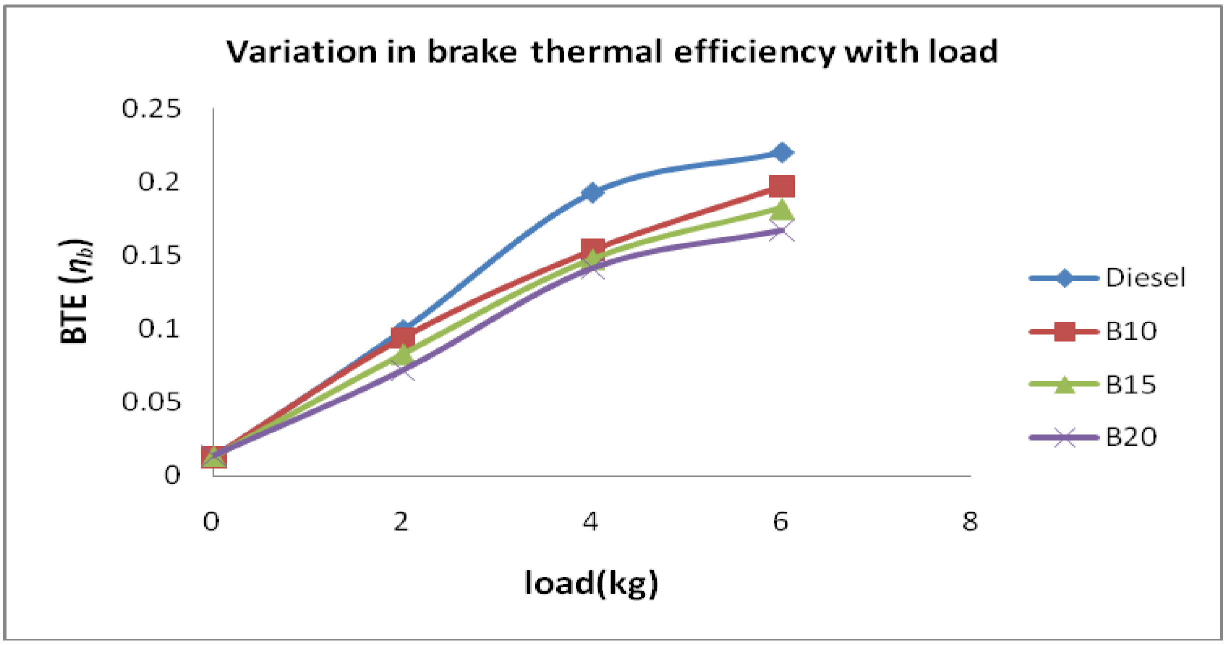


Fig 4.3, Variation in brake thermal efficiency with change in load

In all cases, brake thermal efficiency increases with an increase in load. This can be attributed to reduction in heat loss and increase in power with increase in load. It is also observed that diesel exhibits slightly higher thermal efficiency at most of the loads than CSOME and its blends. The factors like lower heating values and higher viscosity of the esters may affect the mixture formation process and hence result in slow combustion hence reducing the brake thermal efficiency. The molecules of bio-diesel (i.e. methyl ester of the oil) contain some amount of oxygen, which takes part in the combustion process. Test results indicate that when the mass percent of fuel oxygen exceeds beyond some limit, the oxygen loses its positive influence on the fuel energy conversion efficiency in this particular engine. So the brake thermal efficiency of diesel is more than that of biodiesel blends.

Among the three different blends of biodiesel, B10 has higher brake thermal efficiency than B15 and B20.

4.1.4 Exhaust gas temperature (EGT)

Graph of the brake thermal efficiency as a function of load obtained during engine operation on different blends of biodiesel i.e. B10, B15 and B20 with diesel (petrodiesel) at compression ratio of 18:1 have been shown in Figure 4.4.

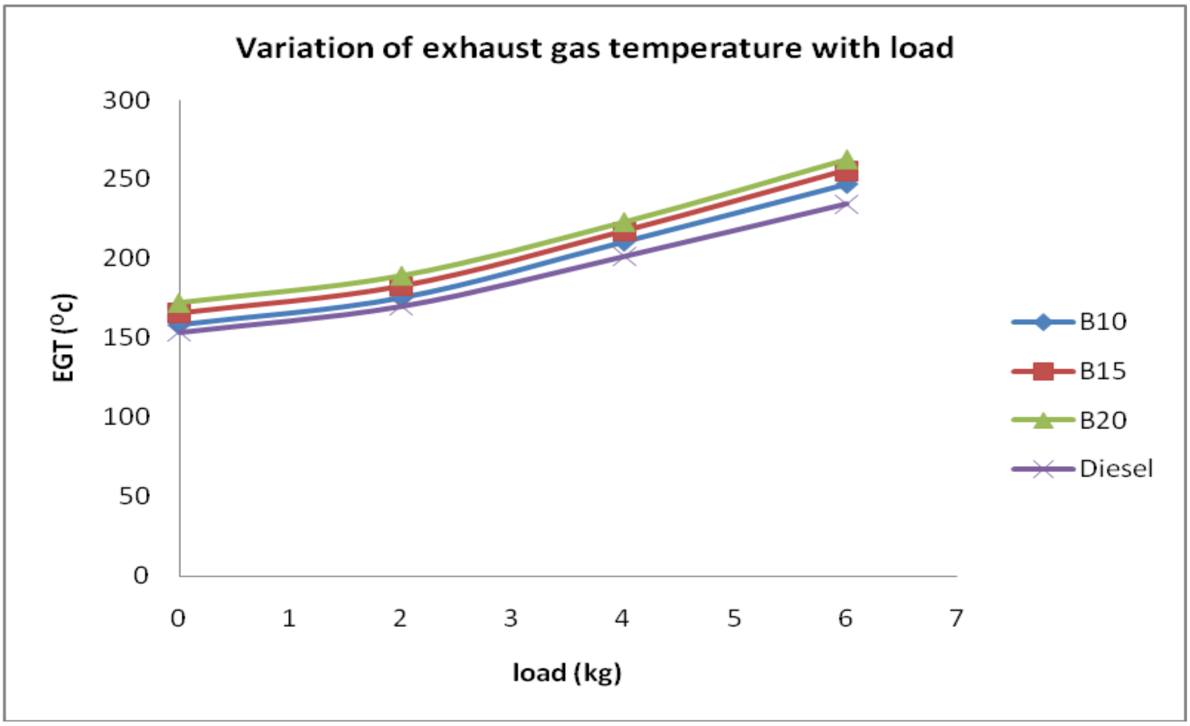


Fig 4.4, Variation in exhaust gas temperature with change in load

The biodiesel contains some amount of oxygen molecules in the ester form. It is also taking part in combustion. When biodiesel concentration is increased, the exhaust gas temperature increases by small value. Using different blends of biodiesel of cotton seed methyl ester, higher exhaust gas temperature is attained at full load, which is indicating more energy loss in this case. The exhaust gas temperature increases with increase in load. Diesel has the least exhaust gas temperature 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. 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 exhaust gas temperature increases continuously with rise in load.

4.2 Exhaust Emission characteristics

4.2.1 CO Emissions

The variation of carbon monoxide with respect to load for different blends of biodiesel is shown in fig 4.5.

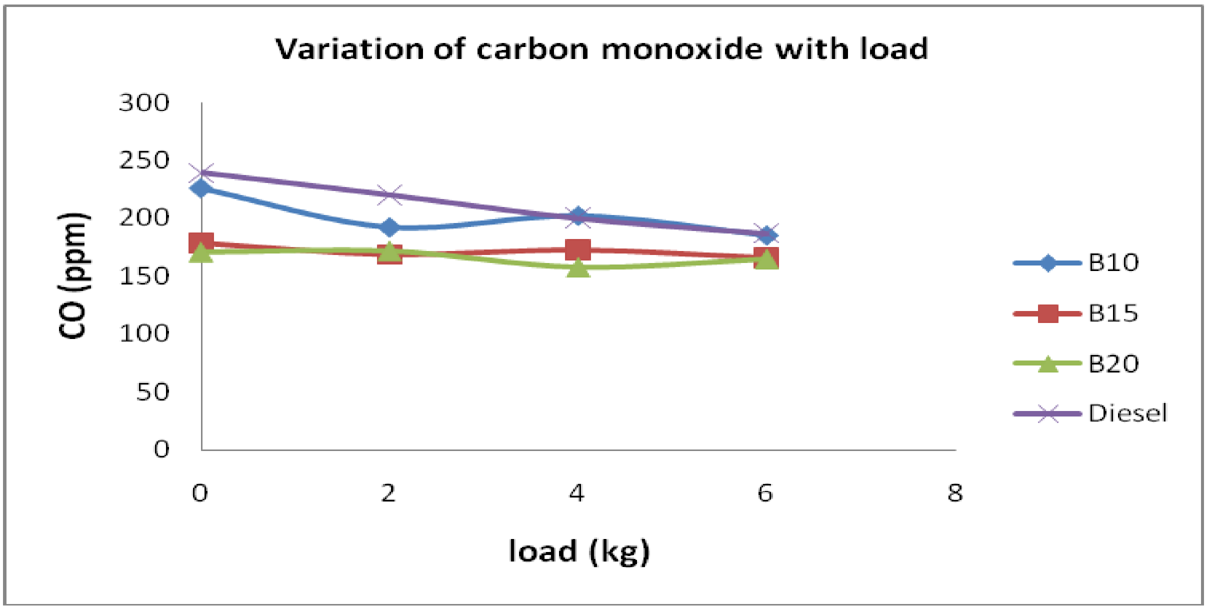


Fig 4.5, Variation of carbon monoxide with respect to load

Carbon monoxide (CO) in diesel engines is formed during the intermediate combustion stages. Diesel engine operates well on the lean side of the stoichiometric ratio. Figure 4.5 shows the CO emissions of diesel oil and CSOME and its blends. The carbon monoxide decreases with increase in CSOME in fuel. Owing to the oxygen content in the CSOME, in addition to that in the air supplied during induction CO is reduced by combining oxygen with CO to form CO_2. B10 blend has higher CO emission than B15 and B20 due to its high viscosity and poor atomization tendency leads to poor combustion and higher carbon monoxide emission. The carbon monoxide emissions increase as the fuel-air ratio becomes greater than the stoichiometric value. Carbon monoxide concentration in the exhaust emission is negligibly small when a homogenous mixture is burned at stoichiometric air-fuel ratio mixture or on the lean side stoichiometric. It is interesting to note that, the engine emits more carbon monoxide using diesel as compared to that of biodiesel blends under all loading conditions. With increasing biodiesel percentage, carbon monoxide emission decreases. Biodiesel itself has about 11% oxygen content in it. This helps for the complete combustion. Hence, carbon monoxide emission decreases with increasing biodiesel percentage in the fuel.

4.2.2 Unburned Hydrocarbons (HC)

The variation of unburnt hydrocarbon with respect to load for different blends of biodiesel is shown in fig 4.6.

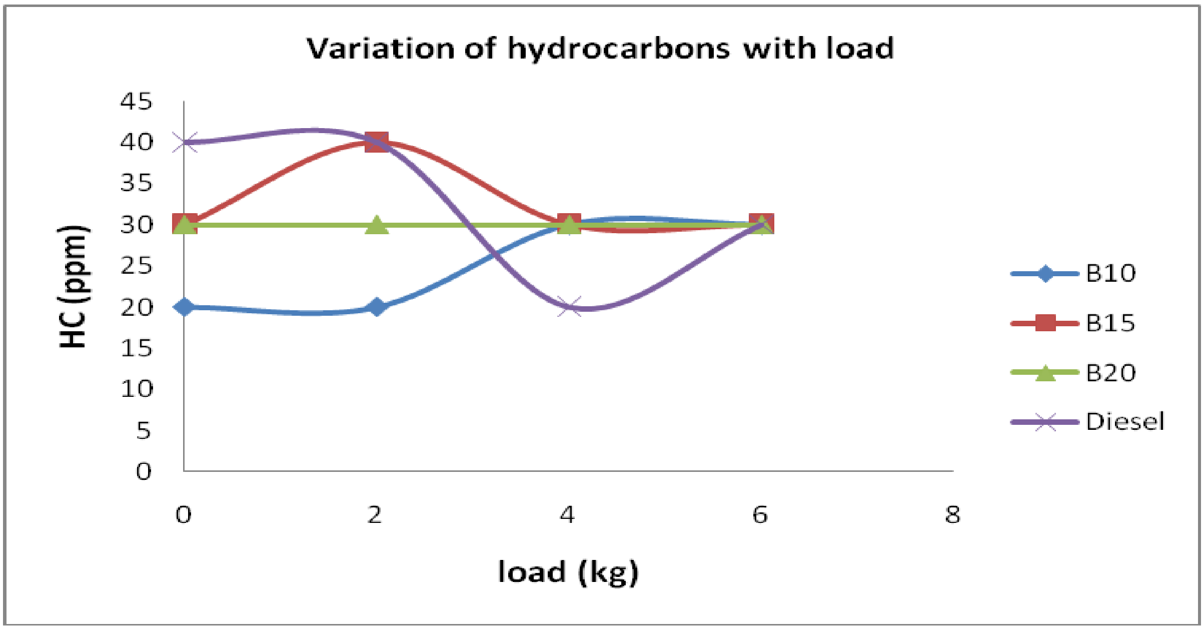


Fig 4.6, Variation of unburnt hydrocarbons with respect to load

The hydrocarbon emissions decrease with increase in percentage of CSOME in the fuel. It is observed that there is a sharp increase in HC emissions after 25% load for B10 blend which either have the lowest hydrocarbon emission at load less than 25%. It is observed that there is also a sharp decrease in HC emission of diesel at load of 25% but there is a sharp increase in the HC emission for diesel fuel after 75% load. This is due to the presence of fuel rich mixture at higher loads. Higher oxygen content and combustion temperature of CSOME and its blends promote the oxidation of UBHC, which results in lower HC emission when compared to diesel. This unexpected variation may be due to the experimental errors.

4.2.3 Oxides of Nitrogen (NO_x)

The variation of carbon monoxide with respect to load for different blends of biodiesel is shown in fig 4.7.

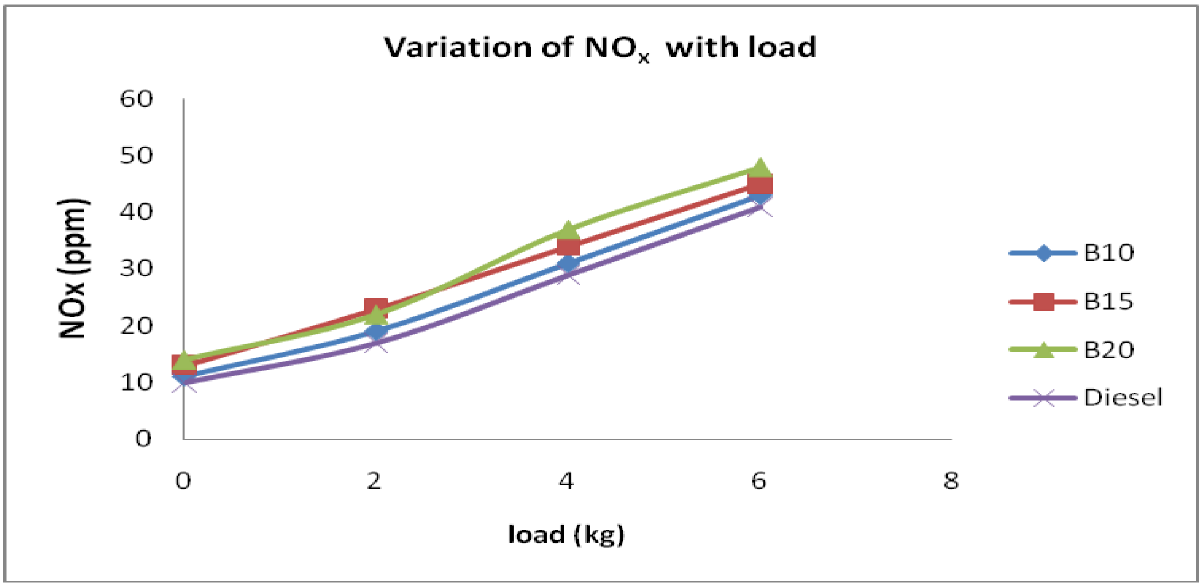


Fig 4.7, Variation of NO_x with respect to load

Blends of CSOME exhibited slightly higher NO_x characteristics than diesel oil at most of the loads. It was observed that NO_x emissions increase with increase in load**.** As an oxygenated fuel CSOME and its blends also supply oxygen in addition to the air inducted into the combustion chamber. These may produce higher NO_x emissions. NO_X formation is a temperature dependent phenomenon. It increased due to increase in fuel inlet temperature. It increases because it is associated with the oxygen content of the given ester since the oxygen present in the fuel may provide additional oxygen for NO_X formation. It could be possibility of higher combustion temperature arising from improved combustion. It has to be noted that a larger part of the combustion is completed before TDC for ester and it blends compared to diesel due to their lower ignition delay. However NO_X can be controlled by adopting EGR and by employing suitable catalytic converters. Reduced oxygen and flame temperature leads to lower NO_X formation.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE OF WORK

5.1. Conclusions

The overall studies based on the production, fuel characterization, engine performance and exhaust emission of different biodiesel blends of waste cotton seed oil methyl esters were carried out. The following conclusions can be drawn:

- The recovery of ester by transesterification of waste cotton seed oil with methanol is affected by process parameters such as catalyst concentration and reaction temperature.
- The kinematic viscosity of diesel, waste cotton seed oil biodiesel were found as 2.049, 3.6 centistokes respectively at 40^0C. The results indicated that the waste cotton seed oil biodiesel had the kinematic viscosity 75.69 percent more than that of diesel.
- The calorific value of diesel is 42000 KJ/kg and that of waste cotton seed oil is 40000KJ/kg. So the calorific value of waste cotton seed biodiesel is 4.76% less than that of mineral diesel.
- The waste cotton seed oil biodiesel was found to have higher flash and fire point than those of mineral diesel.
- The waste cotton seed oil 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 cotton seed oil biodiesel was obtained to be 0.0138%.
- Waste cotton seed oil biodiesel is non-toxic, biodegradable, environment-friendly, renewable fuels and do not add to global warming.
- The graphical results show that diesel has better performance characteristics than biodiesel and biodiesel blends. Among the three different blends of biodiesel, B10 has the better performance characteristics than B15 and B20 blend of biodiesel when fuelled in an internal combustion engine.

- The graphical results also show that the emissions such as carbon monoxide (CO) and hydrocarbons (HC) of biodiesel are less than that of engine fuelled with neat diesel.
- However an increase in NO_x emission is found in case of an engine fuelled with biodiesel and biodiesel blends with comparison with an engine fuelled with neat diesel and the B10 blend of biodiesel has the least NO_x emission among B15 and B20.

5.2. Scope of Future Work

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

The following points may be considered before introducing the fuel in India:

- Biodiesel may be introduced as a diesel fuel extender or blends (B10, B15, B20) and not as a sole diesel engine fuel (B100).
- Proper planning, streamlining, quality control logistics and institutional arrangements need to be worked out before introduction of the fuel.
- Government may consider providing support to the activities related to collection of seeds, production of oil from non-edible sources, production of bio-fuels and its utilization for cleaner environment.
- Legal framework should be there to enforce regulations on bio-fuels.
- The blends prepared for this project work were utilized within short time span. Thus, long term stability of blends was not studied. So there is scope for study of long term stability of blends.
- Long-term performance and endurance test evaluate the durability of the engine with prolonged operation on these blends.
- 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.
- Further studies can also be carried out on material compatibility, storage and utilization of by-product from biodiesel.

REFERENCES

1) Knothe, Van Gerpen and Krahl, Michael J. Haas and Thomas A. Foglia, “The Biodiesel Handbook”,2005.
2) Md. Nurun Nabi, Md. Mustafizur Rahman, Md. Shamim Akhter, “Biodiesel from cottonseed oil and its effect on engine performance and exhaust emissions”, *Applied Thermal Engineering* 29 (2009) 2265–2270.
3) Christos E. Papadopoulos, Anastasia Lazaridou, Asimina Koutsoumba, Nikolaos Kokkinos, Achilleas Christoforidis, Nikolaos Nikolaou, “Optimization of cotton seed biodiesel quality (critical properties) through modification of its FAME composition by highly selective homogeneous hydrogenation”, *Bioresource Technology*, 101 (2010) 1812–1819.
4) Y. Zhang, M.A. Dube, D.D. McLean, M. Kates, “Biodiesel production from waste cooking oil, Process design and technological assessment”, *Bioresource Technology*, 89 (2003) 1–16.
5) Ayhan Demirbas, “The Progress and recent trends in biodiesel fuels”, *Energy Conversion and Management*, 50 (2009) 14–34.
6) M.E. Borgesa, L. Diaza, M.C. Alvarez-Galvanb, A. Brito, “High performance heterogeneous catalyst for biodiesel production from vegetal and waste oil at low temperature”, *Applied Catalysis B: Environmental*, 102 (2011) 310–315.
7) Ayhan Demirbas, “importance of biodiesel as transportation fuel”, *Energy Policy*, 35 (2007) 4661–4670.
8) S.S. Ragit, S.K. Mohapatra, K. Kundu, Prashant Gill, “Optimization of neem methyl ester from transesterification process and fuel characterization as a diesel substitute”, *Biomass and Bioenergy*, 35 (2011) 1138-1144.
9) A.P. Sathiyagnanam, and C.G. Saravanan, “Experimental Studies on the Combustion Characteristics and Performance of A Direct Injection Engine Fueled with Biodiesel/Diesel Blends”, vol III,2011.
10) A. Siva Kumar, D. Maheswar, K. Vijaya Kumar Reddy, “ Comparision of Diesel Engine Performance and Emissions from Neat and Transesterified Cotton Seed Oil”, *Jordan*

Journal of Mechanical and Industrial Engineering, Volume 3, Number 3, September 2009 ISSN 1995-6665;pp. 190 – 197.

11) L.Ranganathan, G.Lakshmi Narayana Rao, S.Sampath, "Experimental Investigation of a Diesel Engine Fuelled With Optimum Biodiesel Produced From Cotton Seed Oil" *European Journal of Scientific Research*, Vol.62(2011), pp. 101-115.

12) Satishchandra Shamrao Ragit, "Process standardization, characterization and experimental investigation on the performance of biodiesel fuelled C.I.Engine", PhD. Thesis, Department of mechanical engineering, Thapar university, Patiala.

13) R.Anand, G.R.Kannan, K.Rajasekhar Reddy and S.Velmathi, "The performance and emissions of a variable compression ratio diesel engine fuelled with biodiesel from cottonseed oil", Vol. 4, no. 9, November 2009, *ARPN Journal of Engineering and Applied Sciences*, pp. 72-87.

14) M. L. Karont and A. M. Altschul, "Effect of moisture and of treatments with acid and alkali on rate of formation of free fatty acids in stored cottonseed", with seven figures.

15) V.Sitaram Prasad, S.K.Mohapatra, J.K.Sharma, P.L.Bali, "Performance and Evaluation of a Diesel Engine Fuelled with Filtered Pongamia oil and its Standardization Characteristics", pp. 65-74, *SGI Reflections*, July 2011.

16) K.Anbumani and Ajit Pal Singh, "Performance of Mustard and Neem oil Blends with Diesel Fuel in C.I.Engine", vol.5, no. 4, april 2010, *ARPN Journal of Engineering and Applied Sciences*, pp. 14-20.

17) SS Ragit, S.K.Mohapatra, K.Kundu, "Comparative study of engine performance and exhaust emission characteristics of a single cylinder 4-stroke CI ingine operated on the esters of hemp oil and neem oil", *Indian Journal of Engineering & Material Sciences*, Vol.18, June 2011, pp. 204-210.

18) David M. Fernandes, Dalyelli S. Serqueira, Flaysner M. Portela, Rosana M.N.Assuncao, Rodrigo A.A.Munoz, Manuel G.H.Terrones, "Preparation and characterization of methylic and ethylic biodiesel from cottonseed oil and effect of tert-butylhydroquinane on its oxidative stability", *Fuel*, 97 (2012) 658-661.

19) D. Royon, M. Daz, G. Ellenrieder, S. Locatelli, "Enzymatic production of biodiesel from cotton seed oil using *t*-butanol as a solvent", *Bioresource Technology*, 98 (2007) 648–653.

20) Specifications for blends B6 – B20, www.astm.org.