Modern Applied Science
www.ccsenet.org/journal.html
Vol. 2, No. 6
November 2008

Operation and Combustion Characteristics of a Direct Injection Diesel Engine Fuelled with Esterified Cotton Seed Oil

Murugu Mohan Kumar Kandasamy
School of Mechanical Engineering, SASTRA University
Thanjavur 613402, Tamilnadu, India
E-mail: kmohan2001@rediffmail.com
Sarangan Jeganathan
School of Mechanical Engineering, National Institute of Technology
Trichirappalli 620015, Tamilnadu, India
Rajamohan Ganesan
School of Engineering and Science, Curtin University Technology
Sarawak Campus 98009, Miri, Malaysia

Abstract

Vegetable oils are renewable in nature and can be directly used as fuels in diesel engines. However, their high viscosity and poor volatility lead to reduced thermal efficiency and increased hydrocarbon, carbon monoxide and smoke emissions. Transesterification is one of the methods by which viscosity could be drastically reduced and the fuel could be adopted for use in diesel engine. This Esterified vegetable oil is popularly known as Bio-diesel and that is commercially available in the developed countries due to its distinct advantage over the conventional diesel. In this work, neat cotton seed oil was converted into Bio diesel by the transesterification process and the viscosity was reduced from 21.4×10^{-6} m^2/s to 4.8×10^{-6} m^2/s (viscosity of the neat Cotton seed oil). A single cylinder water-cooled, direct injection diesel engine developing a power output of 3.7 kW at 1500 rpm was used for the experimental investigations which include combustion, performance and emission characteristics of the engine. Base data was generated for diesel first and subsequently, it was replaced by the Bio diesel and both the results were compared and discussed.

Keywords: Diesel engine, Esterified cotton seed oil, Bio diesel, Esterification, Operation characteristics, Combustion characteristics, Emissions characteristics

1. Introduction

In the modern and fast moving world, petroleum based fuels have become important for a country's development. Products derived from crude oil continue to be the major and critical sources of energy for fuelling vehicles all over the world. However, petroleum reserves are limited and are non renewable. Diesel is mainly consumed in the transport, industrial and agricultural sectors. The cost of transportation affects the economics of all other consumables that reach common people. A country's development is strongly linked to availability of fuels for transportation and power generation. Most of the countries in the world face the major challenge of meeting the high demand of crude oil to meet the growing energy needs. It is therefore, important to have a long-term plan for development of alternative energy sources in a balanced manner by making optimal use of available land and manpower resources. It is important to explore the feasibility of substitution of diesel with an alternative fuel, which can be produced with in the country on a massive scale for commercial utilization. Vegetable oils are considered as good alternatives to diesel as their properties are close to diesel. Thus, they offer the advantage of being to be used in existing diesel engine without any modifications. They have a reasonably high cetane number. The flash point of vegetable oils is high and hence it is safe to use them. Vegetable oils typically have large molecules, with carbon, hydrogen and oxygen being present. They have a structure similar to diesel fuel, but differ in the type of linkage of the chains and have a higher molecular mass and viscosity. The presence of oxygen in vegetable oils raises the stoichiometric fuel air ratio. Contrary to fossil fuels, vegetable oils are free from sulfur and heavy metals. The heating value is slightly lower than diesel. In this work, the fatty acid methyl esters (Bio diesel) were produced from the neat '**Cotton seed oil'** by the Transesterificaiton process. Transesterification of vegetable oils provides a significant reduction in viscosity, thereby enhancing the physical and chemical properties of vegetable oil to improve the engine performance and also the properties of the transesterified oil (Bio diesel) is almost matching with diesel. It has been reported that the methyl and ethyl esters of vegetable oil can result in superior performance than neat vegetable oils. Larry Wagner et al., (1984) studied the effect of soybean oil esters on performance and emissions of a four-cylinder direct injection turbocharged diesel engine. They found that the engine performance with soybean oil esters did not differ to a great extent from that of diesel fuel performance. Clark et al.,(1984) studied the effect of methyl and ethyl esters of soybean oil on engine performance and durability in a direct injection four cylinder diesel engine. They observed that the engine fuelled with soybean esters resulted in a slightly less power combined with an increase in fuel consumption. Emissions were found to be similar to diesel. Nobukazu Takagi and Koichiro Itow (1984) conducted experiments on a single cylinder direct injection diesel engine with rapeseed oil and palm oil as fuels. Ramesh et al.(1989) investigated the performance of a glow plug assisted hot surface ignition engine using methyl ester of rice bran oil as fuel. Normal and nimonic crown pistons were used for their tests. They reported improvement in brake thermal efficiency about 1% when the glow plug is on. The percentage improvement in brake thermal efficiency was more in the case of normal piston compared to nimonic piston. Brake thermal efficiency was higher with nimonic piston at low power outputs than normal piston. They observed reduced ignition delay in both cases with glow plug assistance. No significant changes in hydrocarbon and carbon monoxide emissions with methyl ester of rice bran oil using glow plug ignition were noted. John Einfait and Carroll Goering (1995) used Soy oil methyl ester produced from soybean oil for evaluation as a fuel in a diesel agricultural tractor engine and reported that the engine produced the same power as that with diesel fuel but had higher specific fuel consumption. Perkins and Peterson (1991) conducted a 1000-hour durability test on a compression ignition engine when fueled with methyl ester of winter rapeseed oil. Based upon the evaluation of engine performance, wear and injector deposits as indication of engine durability, they noted that the methyl ester of winter rape oil appeared to be equal to diesel fuel. They also reported that the major disadvantage for the methyl ester of winter rape oil was its cloud and pour points, which eliminate its use in cold weather. Kyle Scholl and Spencer Sorenson (1993) investigated the combustion characteristics of soybean oil methyl ester in a four cylinder naturally aspirated direct injection diesel engine and compared the results with the conventional diesel fuel. Experimental measurements of performance, emissions and rate of heat release were performed as a function of engine load for different fuel injection timings and injection orifice diameters. They found that the overall performance and combustion of soybean methyl ester behaved comparable to diesel fuel.

They also found that the methyl ester gave lower HC and smoke emissions than diesel at optimum operating conditions. They observed a longer ignition delay by 2 ° crank angle with the ester than diesel. They also observed that the premixed portion of the combustion process had a lower maximum rate of combustion with the ester as compared to neat diesel. Masjuki and Abdulmuin (1996 a),(1996 b) conducted experiments on a water-cooled direct injection, ISUZU, four-cylinder, four-stroke engine. They reported that palm oil derived fuels result in performance comparable to diesel with improved combustion stability of the engine. They observed that the emission characteristics were good except that CO levels. They suggested that by supplemental intake air preheating, the emissions can be reduced with improved efficiency. Jajoo and Keoti (1997) carried out experiments on a single cylinder diesel engine using rapeseed oil and soybean oil and their methyl esters as fuel and revealed that the engine performance is comparable to that of diesel operation.

Ken Friis Hansen and Michel Grouleff Jensen (1997) conducted several studies on a six cylinder direct injection horizontal turbocharged diesel engine. They used methyl ester of rapeseed oil for their experiments. They found that there was a decrease in hydrocarbon and carbon monoxide emissions but an increase in NO_X and particulate emission. Varaprasad et al. (1997) studied the effect of using Jatropha oil and esterified Jatropha oil on a single cylinder diesel engine. They found that the brake thermal efficiency was higher with esterified Jatropha oil as compared to raw Jatropha oil but inferior to diesel and also reported low NO_X emissions and high smoke levels with neat Jatropha oil as compared to etserified Jatropha oil and diesel. David Chang and Van Gerpen (1998) tested a four cylinder direct injection diesel engine with soybean methyl ester as fuel. They measured the diesel engine particulate emissions with a double dilution tunnel system and they found that the bio diesel fueled diesel engine produced higher fraction of soluble organic material in its exhaust particulate emission. However, hydrocarbon emissions were lowered when the engine was fueled with bio diesel blends. They reported that the soluble organic fraction was increased when the fraction of Biodiesel was increased in the blend. Shaheed and Swain (1999) conducted the experiments on a single cylinder air cooled naturally aspirated direct injection diesel engine using coconut oil and methyl ester of coconut oil and diesel. They reported that the engine performed well on the three fuels except for the initial engine starting problems with coconut oil. Swain and Shaheed (2000) also conducted experiments on a single cylinder direct injection Lister Petter diesel engine with the same oil. They observed that the esters derived from coconut oil have many characteristics similar to diesel fuel with little performance and emission differences. They concluded that the fuel derived from the coconut oil is a potential alternative for operating a standard diesel engine without any engine modifications. Abdul Moneyem and Van Gerpen (2001) conducted experiments to characterize the effect of oxidized Bio diesel on engine performance and emissions. They used methyl soyate (Bio diesel) for testing a turbocharged direct injection diesel engine. They found that the performance of neat Bio diesel and it's blend with diesel were similar to neat diesel fuel operation. They also found a significant reduction in Bosch smoke number with neat Bio diesel and it's blend when compared with diesel.

Recep Altin et al. (2001) conducted experiments on a single cylinder direct injection diesel engine to evaluate the performance and exhaust emissions using refined sunflower oil, cottonseed oil, soybean oil and their methyl esters. They found little power loss, higher particulate emissions and less NO_X emissions with neat vegetable oils. Kalligeros et al.(2003) conducted experiments on a single cylinder indirect injection Petter diesel engine using olive oil and sunflower oil as fuels in different proportions with marine diesel. They reported lower unburned hydrocarbon, carbon monoxide, particulate and nitrogen oxide emissions with blends than neat vegetable oils.

The ideal diesel fuel is a saturated and non- branched hydrocarbon molecule with carbon number of 14, where as vegetable oil molecules (as shown below) are Triglycerides generally with non branched chains of different lengths and different degrees of saturation with the carbon number of 18 to 57 and it depends on the type of vegetable oils. The vegetable oil contains a substantial amount of oxygen in their structure and so it is naturally oxygenated.

```
  H     O H H H H H H H H H H H H H H H H H H
  |    || | | | | | | | | | | | | | | | | | |
H-C-OH HO-C-C-C-C-C-C-C-C-C=C-C-C-C-C-C-C-C-C-H (OLEIC-UNSATURATED
  |      | | | | | | | |     | | | | | | | |
  |      H H H H H H H H     H H H H H H H H
  |
  |
  |    O H H H H H H H H H H H H H H H H H H
  |   || | | | | | | | | | | | | | | | | | |
H-C-OH HO-C-C-C-C-C-C-C-C-C-C-C-C-C-C-C-C-C-C-H (STEARIC-SATURATED
  |    | | | | | | | | | | | | | | | | | |
  |    H H H H H H H H H H H H H H H H H H
  |
  |
  |    O H H H H H H H H H H H H H H H H H H
  |   || | | | | | | | | | | | | | | | | | |
H-C-OH HO-C-C-C-C-C-C=C-C-C=C-C-C-C-C-C-C-C-C-H (LINOLEIC-MORE
  |      | | | | |     |     | | | | | | | |          UNSATURATED)
  H      H H H H H     H     H H H H H H H H
```

Structure of Vegetable Oil Molecules

2. Production of Bio diesel

2.1 Steps followed for the production of Bio diesel:

- Solvent was prepared by dissolving the calculated amount of NaOH (catalyst) with calculated amount of Methanol for 1 lit. of cotton seed oil
- Measured amount of raw cotton seed oil was taken in the three way conical flask and heated up to 60°C to 65°C
- The prepared solution was added to the heated oil.
- The mixture was continuously stirred throughout the process and was maintained at constant temperature.
- This process was carried out for two hours.
- The conical flask was left for natural cooling for eight hours
- The Glycerin settled at the bottom of the flask and it was separated using the separating funnel.
- The remaining in the flask was the **Ester of cotton seed oil (Bio diesel)**

Fig.1 shows the schematic diagram of the setup for Transesterification process, fig.2 shows the photograph of Bio diesel comparing with the neat cotton seed oil and diesel and the fig.3 shows the photograph of Glycerin that was settled at the bottom of the flask during the process of transesterification. Table 1 show the comparison of some of the important properties of Bio diesel which was produced with neat cotton seed oil and with diesel. It is found that the properties are closely matching with 'United states-ASTM standard' and also with 'German Bio diesel standard'.

Table 1.

Properties	**Neat cotton Seed oil**	**Bio diesel**	**Diesel**	**US ASTM * Specification**	**DIN ** specification**
Gross calorific value (kJ/kg)	39,982	40,207	43,500	36,000 to 42,000	38,000 to 41,000
Flash Point (°C)	260	120	46	100 to 130	100 to 120
Kinematic viscosity at 50°C ($\times 10^6$ m^2/s)	21.4	4.8	7	1.9 to 6.5	3.5 to 5
Relative density at 27°C (g/cc)	0.9146	0.8813	0.86	0.8 to 0.88	0.8 to 0.85
Sediments (Toluene Insoluble) (%)	0.003	0.005	0.05	0.05 max	-
Sulphur (%w/w)	0.38	0.00	0.25	0.05 max	0.01 max
Cetane Number	35	54.5	45	40 min	49 min
Ash (%w/w)	0.01	0.01	0.01	0.02 max	-

*** German Bio diesel standard; ** United States Bio diesel ASTM standard**

3. Experimental setup

An experimental set up was made with necessary instruments to evaluate the performance, emission and combustion parameters of the compression ignition engine at different operating conditions. The overall view of the experimental setup is shown in figs.4 & 5 and the specifications of the engine are as given below:

Make	:	COMET
No. of Cylinder	:	one
Orientation	:	vertical
Cycle	:	4 strokes
Ignition System	:	compression Ignition
Bore and stroke	:	80 mm × 110 mm
Displacement volume	:	553 cc
Compression ratio	:	18:1
Arrangement of valves	:	overhead
Combustion Chamber	:	hemi spherical open Chamber (Direct Injection)
Rated power	:	3.5 kW @ 1500 rpm
Cooling Medium	:	water cooled

A provision was made to mount a piezoelectric pressure transducer flush with the cylinder head surface in order to measure the cylinder pressure. Fig.6 indicates the view of pressure transducer mounted flush with the cylinder head and data acquisition system. A piezoelectric type pressure sensor was fitted on Diesel injection line to determine the actual start of injection indicated by the needle lift of the injection nozzle and it is shown in fig.7. The engine was coupled to an eddy current dynamometer and a strain gauge based load cell sensor is mounted on the dynamometer to measure the load. This sensor is connected to load transmitter. A Rotary encoder which is an optical sensor was used for speed and crank-angle measurement and it is indicated in fig.8. It will give a voltage pulse exactly when the TDC position was reached. The voltage signals from the optical sensor were fed to an Analog to Digital converter and then to the data acquisition system along with pressure signals for recording.

One Differential pressure transmitter fitted to fuel measuring unit was used for fuel flow and another Differential pressure transmitter was used as air flow transmitter and it senses the differential pressure across the orifice plate. Rota meters were used for measuring the water flow rate to engine and calorimeter. Temperature sensors were used for measurement of engine and calorimeter water temperatures and they are indicated in fig.9. Thermocouple type temperature sensors were used for measurement of the exhaust gas temperatures.

All the exhaust emission measurements including the smoke were made with the help of an engine exhaust gas analyzer. The probe of the analyzer was fitted in the engine exhaust pipe and all the parameters were measured at different loads in on line mode.

4. Results and discussions

The performance, combustion and emissions characteristics of the engine under variable load conditions have been observed for Bio diesel and compared with diesel.

4.1 Performance Parameters

The variation of **brake thermal efficiency** with power output for Bio diesel and diesel are shown in fig.10. The thermal efficiency is always lower with Bio diesel as compared with diesel. The maximum thermal efficiency of the bio diesel is about 30 % where as it is 32% with diesel at full load. This is due to high density of the Bio diesel (0.8813g/cc) as compared to diesel (0.86g/cc) and affects the mixture formation. This leads to slow combustion and thus the lesser thermal efficiency with Bio diesel. No drop in maximum power is observed with Bio diesel. The variation of **volumetric efficiency** with Bio diesel and diesel are shown in fig.11. The volumetric efficiency with Bio diesel is lower than diesel. It may be noted that the volumetric efficiency curve is closely related to the exhaust temperature curves shown in fig.12.

A higher exhaust temperature leads to a lower volumetric efficiency. This is because the temperature of the retained exhaust gases will be higher when the exhaust gas temperature rises. A high-retained exhaust gas temperature will heat the incoming fresh air and lower the volumetric efficiency. The fig.12 shows the **exhaust gas temperature** and it is more for Bio diesel than diesel particularly at high loads. More dominant diffusion combustion phase is the reason for more exhaust gas temperature for Bio diesel. The maximum temperature of exhaust gas at full load is 430 ° C with the Bio diesel and is 410 ° C with diesel.

4.2 Combustion parameters

The variation of **delay period** is shown in fig.13 and it was calculated based on the dynamic injection timing measured with piezoelectric transducer. The delay period is lower for Bio diesel as compared to diesel. At full load, the delay period for Bio diesel is 5°24’ of crank angle and for diesel, it is 5°54’ of crank angle from the start of injection. The lower delay period has a higher Cetane rating and is more acceptable as diesel. Better atomization of the fuel droplet leads to minimizing the time for start of combustion and hence there is a reduction in the delay period for Bio diesel. Better atomization of the Bio diesel is possible only by the reduction of viscosity drastically by the Transesterification process. The variation of **peak pressure** is shown in fig.14. The Peak Pressure depends on the amount of fuel taking part in the uncontrolled combustion phase that is governed by the delay period and the spray envelope of the injected fuel. Since the delay period for Bio diesel is lesser than diesel, the fuel taking part in the uncontrolled combustion phase is less and hence the peak pressure is lesser than the diesel for all the load of operations. The peak pressure with Bio diesel is 74 bar and with diesel it is 81 bar at full load.

The **rate of pressure rise** is shown in fig.15 and it is due to the domination effects of the premixed phase of combustion. For the Bio diesel, this effect is less and so the rate of pressure rise is slightly lower than diesel. For Bio diesel, it is 3.6 bar /°CA and for diesel, it is 3.9 bar / ° CA at full load. The **duration of Injection** is shown in fig.16 and there is no considerable change in the duration of Injection with Bio diesel as compared to diesel.

It is 36˚24’ with Bio diesel and 36˚with diesel at full load. The variation is only within 1° to 2° of crank angle. Similarly there is no considerable change in the dynamic injection timing for both the fuels. The **combustion duration** shown in fig.17 was calculated based on the duration between the start of combustion and 90% cumulative heat release. It is seen that the combustion duration is increased with rise in power output with diesel and as well as with Bio diesel due to increase in the quantity of fuel injected. Higher combustion duration is observed with Bio diesel than diesel due to the longer diffusion combustion phase.

4.3 Emission Parameters

The variation of **smoke emission** with power output with Bio diesel and diesel is shown in fig.18. It is less with Bio diesel as compared to diesel. Smoke number is 3.9 for Bio diesel and 4.2 for diesel at full load. Generally the cause for smoke in diesel is due to the presence of heavy petroleum oil residues in it. In the case of Bio diesel, there is no presence of such residues and that resulting in less some with Bio diesel. The % of variation in the **carbon monoxide emission** with Bio diesel and diesel is shown in fig.19. It is less with Bio diesel at lower load when compare to diesel, because, the Bio diesel is oxygenated in the molecular structure and that helps in complete combustion to carbon dioxide rather than leading to the formation of Carbon monoxide at lower loads. However CO emission is more at higher loads for the Bio diesel. It is because of more carbon present in the Bio diesel (18 number of Carbon in one molecule), the oxygen supplied is insufficient even though the oxygen available in the fuel is compensated. This leads to the suffocation and ends up with incomplete combustion. The carbon monoxide emission is 0.15% at lower load and 0.6% at higher loads for Bio diesel. For diesel, it is 0.17% at lower load and 0.4% at higher loads. The variation in the **Hydro carbon emissions** with Bio diesel and with diesel is shown in fig.20. It is found that these emissions are more with Bio diesel as compared to diesel. More quantity of injected fuel and lesser availability of air is the reason for more hydrocarbon emissions. The variation in the **Nitric oxide emission** with Bio diesel and with diesel is shown in the fig.21. It is found to be lower with Bio diesel as compared to diesel at lower loads. At lower loads, it is 84 ppm for Bio diesel and 104 ppm for diesel. This reduction in NO emission is mainly associated with the reduced premixed burning rate following the delay period at lower loads. It may also be noted that the rate of heat release (during the premixed burning phase) and the calculated cylinder gas temperature are lesser at lower loads with Bio diesel as compared to diesel. However at higher loads, there is an increase in the combustion temperature and that leads to more NO emission with Bio diesel as compared to diesel. The variation in the **particulate emissions** with Bio diesel and diesel are shown in fig.22. Particulate emissions are greatly increased in all cases with load. Trends are similar to that of smoke. The particulate emission is found to be more with Bio diesel compared to diesel. The main cause of particulate emission is known to be inadequate mixing of the fuel and air at high loads. Over rich fuel air mixtures in the localized regions of the combustion chamber will lead to particulate emissions. The variation in the **heat release rate** with Bio diesel and with diesel is shown in the fig.23. It is seen that the premixed burning phase, which is associated with a high heat release rate, is most significant with diesel. This is the reason for the thermal efficiency being highest with diesel. The diffusion-burning phase indicated under the second peak is greater for Bio diesel compared to diesel. This is consistent with the expected effects of reduction of air entrainment and fuel air mixing rates. This leads to less fuel being prepared for rapid combustion with Bio diesel after the delay period. Therefore, more burning occurs in the diffusion phase rater than in the premixed phase with Bio diesel. The significantly higher combustion rates during the later stages with Bio diesel leads to high exhaust temperatures and lower thermal efficiency.

5. Conclusions

This work was aimed to evaluate the suitability of Bio diesel as an alternative fuel in a diesel engine by studying the performance, combustion and emission characteristics of the engine. Initially the experiment was conducted at a constant speed of 1500 rev/min under variable load conditions with diesel. In the next phase, the engine was operated with Bio diesel (ester of cotton seed oil). Experiments were conducted at 0%, 25%, 50%, 75% and 100% of the rated load. Based on the results the following conclusions are made.

- Bio diesel leads to better performance with reduced emissions as compared to diesel.
- For Bio diesel, the brake thermal efficiency is inferior to diesel. The maximum brake thermal efficiency of the bio diesel is about 30 % where as it is 32% with diesel at full load.
- Exhaust gas temperature is more for Bio diesel than diesel particularly at high loads.
- The delay period is lower for Bio diesel as compared to diesel.
- The peak pressure is lesser with Bio diesel as compared to diesel for the entire loads of operations.
- Smoke intensity is greatly increased with loads for Bio diesel and as well as for diesel, but however it is lesser with Bio diesel as compared to diesel.
- The carbon monoxide emission is lesser with Bio diesel at lower loads as compared to diesel. However it is more at higher loads.
- The conclusions clearly indicates that the Bio diesel derived from the cotton seed oil can be very well used as an alternative fuel in a diesel engine without any engine modifications.

References

Abdul Monyem., Jon, H and Van Gerpen. (2001) ‘The effect of Biodiesel oxidation on Engine Performance and Emissions’, *International Journal of Biomass and Bio Energy*, No.20, pp. 317-325.

Clark, S.J., Wagner, L., Schorck, M.D. and Piennaar, P.G. (1984) ‘Methyl and Ethyl Soybean Esters as Renewable Fuels for Diesel Engines’, *Journal of American Oil Chemist Society*, Vol. 61, No.10, pp.1632-1638 .

David y. Chang and Jon H. Van Gerpen. (1998) ‘Determination of Particulate and Hydrocarbon Emissions from Diesel Engines Fueled with Bio diesel’, *Society of Automotive Engineers*, Paper No. 982527.

John Einfalt and Carroll E. Goering (1995) ‘Methyl Soyate as a fuel in a Diesel Tractor’ *Transactions of American society of automotive engineers*,Vol.85, pp. 70-74.

Jajoo,B.N and Keoti, R.S. (1997) ‘Evaluation of Vegetable Oil as Supplementary fuels for Diesel Engines’, *Proceedings of the XV National Conference on I.C. Engines and Combustion*, Anna University, Chennai, Tamil Nadu state, India.

Kyle W Scholl, and Spencer C Sorenson (1993) 'Combustion Analysis of Soybean |oil Methyl Ester in a Direct Injection Diesel Engine', *Society of Automotive engineers*, Paper No. 930934.

Ken Friis Hansen and Michael Grouleff Jensen (1997) 'Chemical and Biological Characteristics of Exhaust Emissions from a DI Diesel Engine Fuelled with Rapeseed Oil Methyl Ester (RME)', *Society of Automotive Engineers*, Paper No. 971689.

Kaligeros, S., Zannikos, F., Stournas, S., Lois, E., Anastopoulosd, G., Teas Ch and Sakellaropoulos, F. (2003) 'An Investigation of Using Bio diesel/Marine Diesel blends on the Performance of a Stationary Diesel Engine', *Journal of Biomass and Bio energy*, No.24, pp. 141-149.

Larry E. Wagner., Stanley J. Clark and Mark D. Schrock (1984) 'Effect of Soybean Oil Esters on the Performance, Lubrication Oil and Water of Diesel Engines', *Society of Automotive engineers*, Paper No. 841385.

Masjuki, H., Abdulmuin, M.Z. and Sii, H.S. (1996 a) 'Indirect Injection Diesel Engine Operation on Palm Oil Methyl Esters and Its Emulsions', *Proceedings of Institute of Mechanical Engineers*, No. 211, pp.291 – 299.

Masjuki, H., Abdulmuin M.Z and Sii, H.S. (1996 b) 'Investigation on Preheated Palm Oil Methyl Esters in the Diesel Engine', *Proceedings of Institute of Mechanical Engineers*, No.210, pp.131 – 138.

Nobukazu Takagi, and Koichiro Itow (1984) 'Low Carbon Flower Buildup Low Smoke and Efficient Diesel Operation with Vegetable Oils by Conversion to Monoesters and Blending with Diesel Oil or alcohols', *Society of automotive engineers*, Paper No.841161.

Perkins, L.A. and Peterson, C.L. (1991) 'Durability Testing of Transesteified Winter Rape Oil (Brassica Napus) as fuel in Small Bore, Multi Cylinder, DI, CI engine', *Society of Automotive engineers*, Paper No. 911764.

Ramesh, A., Nagalingam, B. and Goparakrishnan, K.V. (1989) 'Performance of Glow Plug Surface Ignition Engine with Methyl ester of Rice Bran Oil as Fuel', *Proceedings of XI National Conference on I.C. Engines and Combustion*, Indian Institute of Technology Madras, Tamil Nadu state, India.

Recep Altin., Selim Cetinkaya and Huseyin Serdas Yucesu. (2001) 'The Potential of Using Vegetable oil Fuels as Fuel for Diesel Engines', *International Journal of Energy Conversion management*, No.42, pp.529 – 538.

Shaheed, A and Swain, E. (1999) 'Combustion Analysis of Coconut Oil and Its Methyl Esters in a Diesel Engine', *Proceedings of Institute of Mechanical Engineers*, Vol 213, Part A, pp. 417-425.

Swain, E and Shaheed, A. (2000) 'An Experimental Study to Evaluate the Use of Coconut Based Fuels as Alternatives to Diesel Oil', *Journal of the Institute of Energy*, No.73, pp. 100-105.

Varaprasad, C.M., Muralikrishna, M.V.S and Prabhakar reddy, C. (1997) 'Investigations on Bio diesel (Esterified Jatropha Curcus Oil) in Diesel Engines' *XV National Conference on I.C. Engines and Combustion*, Anna University, Chennai, Tamil Nadu, India.

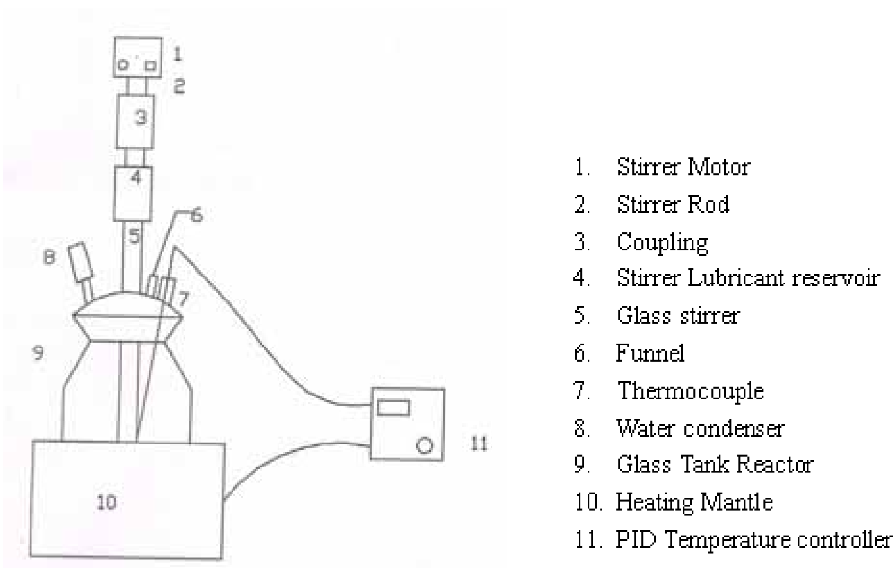

Figure 1. Setup for Transesterification

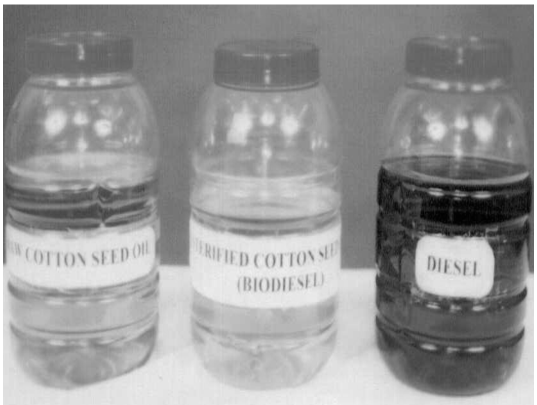

Figure 2. Neat Cotton Seed Oil, Bio Diesel & Diesel (comparison)

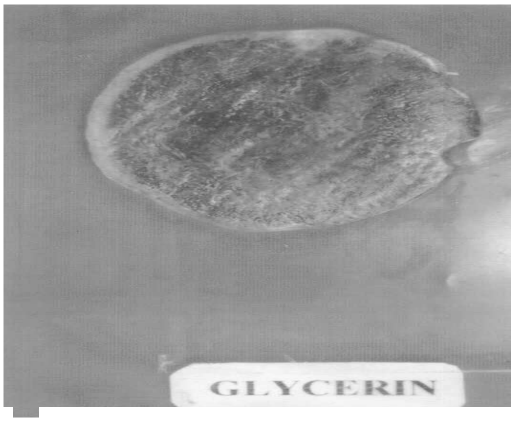

Figure 3. Glycerin (By product)

Figure 4 & 5. Overall View of the Experimental Setup

Figure 6. Pressure Transducer

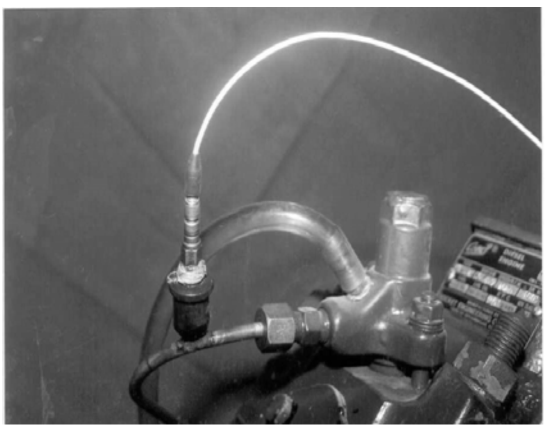

Figure 7. Injection Sensor

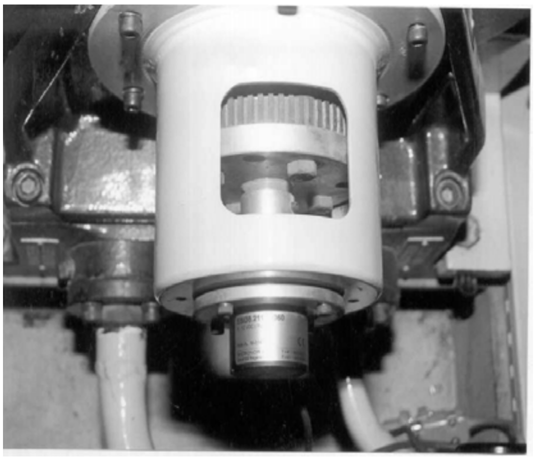

Figure 8. Rotary Encoder (Optical sensor)

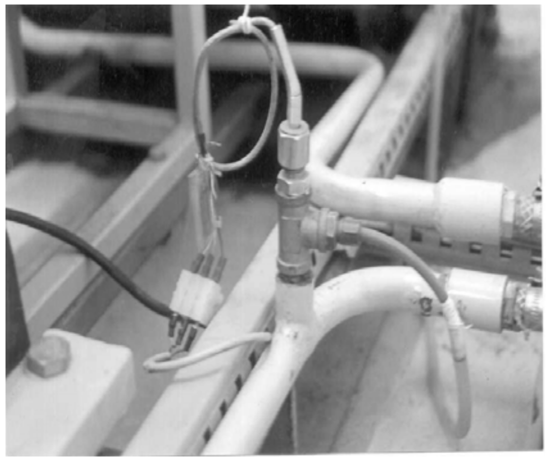

Figure 9. Temperature Sensor for Coolant Water Temperature

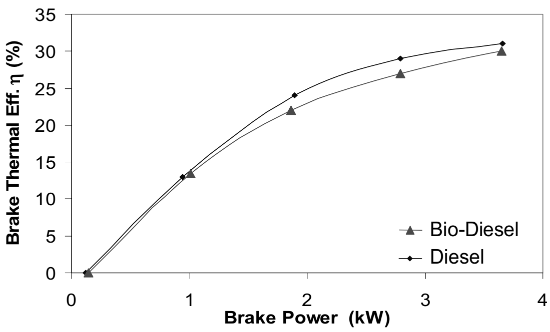

Fig.10 Brake Power Vs Break Thermal Eff.

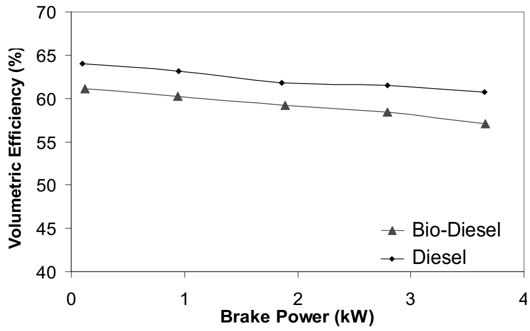

Fig. 11 Brake Power Vs Volumetric Efficiency

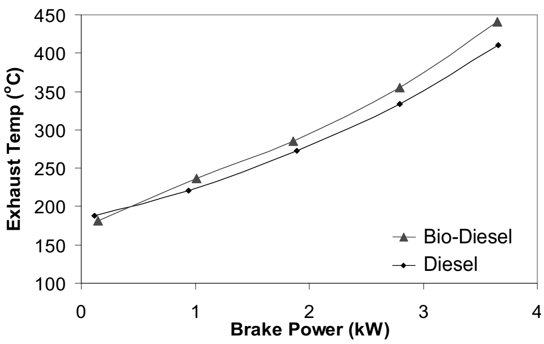

Fig. 12 Brake Power Vs Exhaust Temp

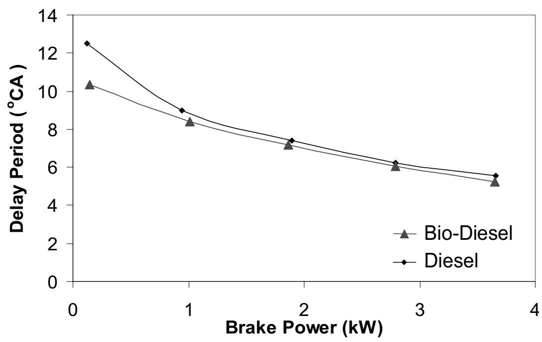

Fig. 13 Brake Power Vs Delay Period

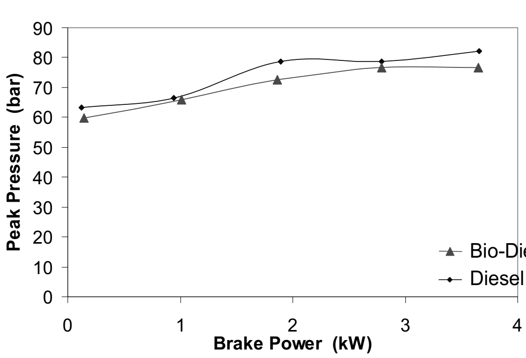

Fig. 14 Brake Power vs Peak Pressure

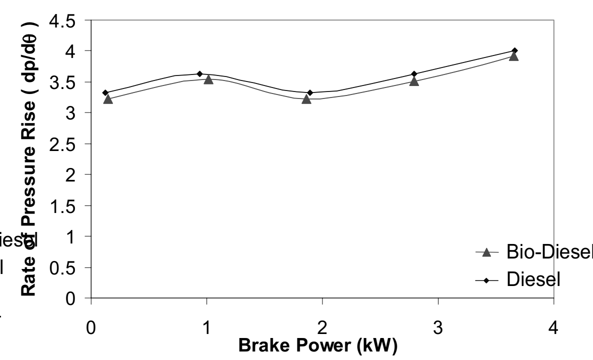

Fig. 15 Brake Power vs Rate of Pressure Rise

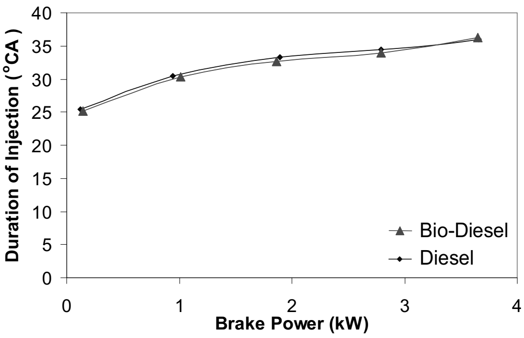

Fig. 16 Brake Power Vs Duration of injection

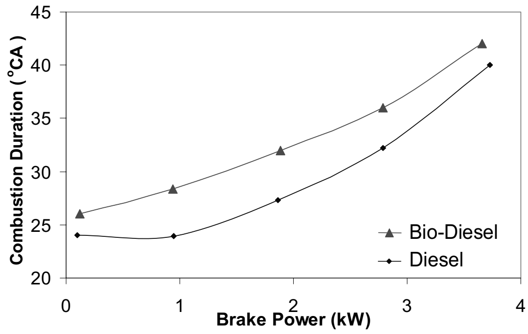

Fig. 17 Brake Power Vs Combustion Duration

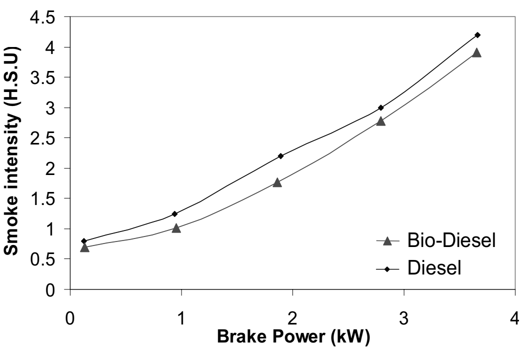

Fig. 18 Brake Power Vs Smoke

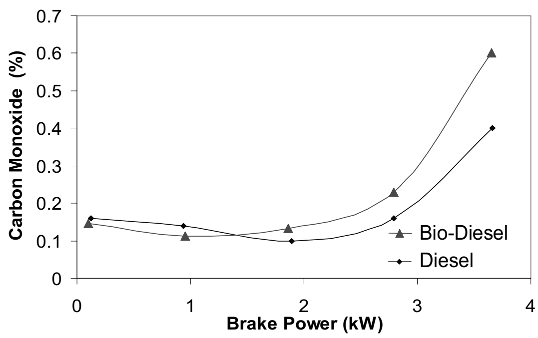

Fig. 19 Brake Power Vs Carbon Monoxide

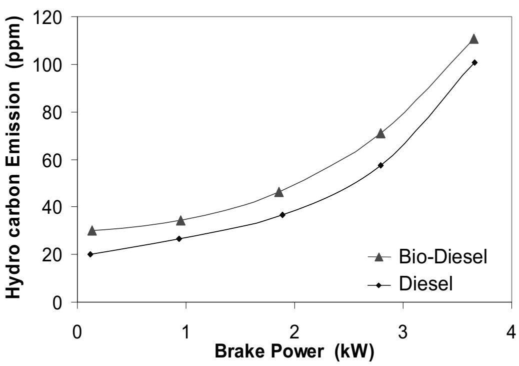

Fig. 20 Brake Power Vs Hydro carbon Emission

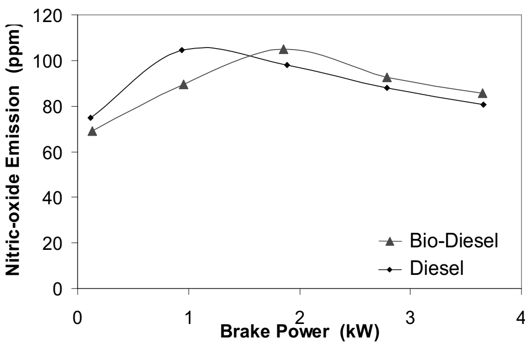

Fig. 21 Brake Power Vs Nitric-oxide Emision

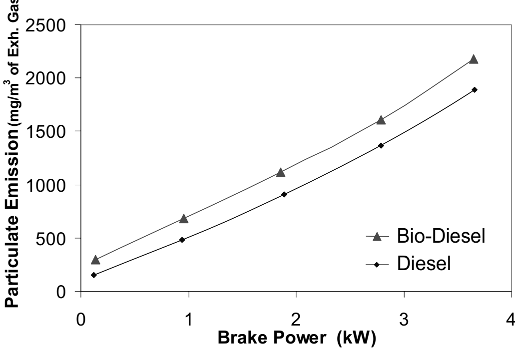

Fig. 22 Brake Power Vs Particulate Emission

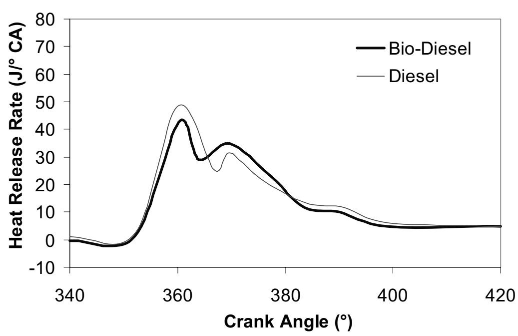

Fig. 23 Crank Angle Vs Heat Realease Rate