A Review on Comparative Analysis of Different Methods to Improve the Performance of Cotton Seed Oil Fuelled Diesel Engine

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***Abstract*—** This article is a literature review of use of biodiesel fuel for compression ignition engines. This study is based on the reports of about 25 scientists including (some manufacturers and agencies) who published their results between 2005 and 2014. The scientists and researchers conducted the test, using different types of raw and refined oils. These experiments with raw biodiesel as fuel did not show the satisfactory results, when they used the raw biodiesel. The fuel showed injector coking and piston ring sticking. A vast majority of scientists mixed the transesterified biodiesel oil with diesel with different ratios. When tested in long run, blends of the oil above 20% (B20) caused maintenance problems and even sometimes damaged the engine. Some authors reported success in using vegetable oils as diesel fuel extenders in blends of more than 20% even in long-term studies.

The main conclusion derived by the researchers is that coking is a potentially serious problem with the use of unmodified vegetable biodiesel. work focuses on finding the suitability of cotton seed oil as a fuel for diesel engines by com- paring the different methods to improve the performance of neat cotton seed oil (CSO). Tests were con- ducted with neat CSO and diesel to obtain base data. Transesterification with alcohol, preheating of CSO and diesel–CSO blends; blending of orange oil, diesel, or diethyl ether (DEE) with CSO and the use of semi adiabatic engine concept are the methods which have been investigated

Keywords- *Vegetable oils; Biodiesel; C I engine; Exhaust emission*

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1. INTRODUCTION

In the wake of oil crisis, the world is looking for the alternative source of energy where bio-diesel came into play as an attractive renewable alternative fuel. However, it was realized that extensive utilization of bio-fuel would tax the food chain and could lead to food shortages. So, the use of a blend of bi-fuel with conventional fuel was suggested to balance its usage which still could provide beneficial green house effect. In the hot and cold climate bio-diesel cannot conveniently replace fossil fuel but in the controlled environment with modified combustion equipment, bio-diesel can be used as an alternate fuel. Having lower heating value, bio-diesel is consumed more in comparison to the fossil diesel fuel. Bio-diesel also generates more NO_x emission, which is an adverse environmental pollutant. The raw material source of bio-diesel limits food growing ground which is ultimately becoming a great concern. A dilemma of using bio-diesel as an alternative for mineral fuel has raised a concern about environment, engine performance and involved costs these have to be investigated in depth to provide a recommendation.

This article is a literature review of use of biodiesel fuel for compression ignition engines. This study is based on the reports of about 25 scientists including (some manufacturers and agencies) who published their results between 2005 and 2014. The scientists and researchers conducted the test, using different types of raw and refined oils. These experiments with raw biodiesel as fuel did not show the satisfactory results, when they used the raw biodiesel. The fuel showed injector coking and piston ring sticking.

Some of the scientists mixed with methanol or ethanol in presence of KOH or NaOH and then filtered and washed. The process is called transeterfication and is used to degum, dewax and to remove triglycerides from the vegetable oils. Transeterfication decreases the viscosity, density and flash point of the fuel. The results obtained, by using such oils in compression ignition engines as fuel, were satisfactory only for short term.

A vast majority of scientists mixed the transesterified biodiesel oil with diesel with different ratios. When tested in long run, blends of the oil above 20% (B20) caused maintenance problems and even sometimes damaged the engine. Some authors reported success in using vegetable oils as diesel fuel extenders in blends of more than 20% even in long-term studies.

The main conclusion derived by the researchers is that coking is a potentially serious problem with the use of unmodified vegetable biodiesel. However, the refined, chemically processed and degummed vegetable oil mixed with diesel can be used to run compression ignition engine for longer duration.

It was reported that there was a slight decrease in brake power and a slight increase in fuel consumption. However, the lubricant properties of the biodiesel are better than diesel, which can help to increase the engine life. Moreover, the biodiesel fuel is environment friendly, produces much less NO_x and HC and absolutely no So_x and no increase in CO_2 at global level.

The primary problems associated with the straight vegetable oil operation in diesel engine are due to their high fuel viscosity, low volatility, deposit build up and exhaust emissions [1, 2]. High viscosity can cause poor atomization and large droplets resulting in poor combustion. Several researchers have investigated using different methods to improve the performance of neat vegetable oil fuelled diesel engine [3–5]. Transesterification is the process of converting the triglycerides of vegetable oils to their monoester by reacting them with alcohols in the presence of a catalyst.

Transesterification of vegetable oil results in significant reduction in viscosity, thereby enhancing the physical properties and also the cetane number is improved [6].

Vegetable oil freely mixes with diesel or orange oil and these blends can be used in existing diesel engines without any modifications. Blending of vegetable oils with diesel or orange oil results in a reduction in viscosity and density. Volatility is also improved. Experimental results with these blends indicate improvement in brake thermal efficiency and reduction in exhaust smoke emissions compared to neat vegetable oils [7,8].

Diethyl ether (DEE) is a renewable oxygenate which has a high cetane number and also volatile. Hence, this additive can be used to reduce the ignition delay and improve mixture formation with vegetable oil [9, 10].

An adiabatic engine provides higher combustion charge temperature with consequent reduction in ignition delay; this is conducive for multi-fuel capability [11]. This type of engines can be effectively utilized for achieving the best performance from the combustion of vegetable oils [12].

In the present work, different methods have been experimented to improve the performance of cotton seed oil fuelled diesel engine. Cotton seed oil was converted into its ethyl ester by the transesterification process in order to obtain better performance, fuel economy, and combustion and emission characteristics. Subsequently, cotton seed oil was blended with diesel or orange oil in different proportions and has been tested. In the next phase, the engine was modified to work as an adiabatic engine by insulating the piston with partially stabilized zirconia and tests were conducted with cotton seed oil in order to quantify the performance improvement. In the last phase of the work, experiments were conducted by mixing oxygenates like diethyl ether, orange oil with cotton seed oil.

Properties	Standard method	Diesel	Cotton seed oil (CSO)	Ethyl ester of CSO (EECSO)	Diethyl ether (DEE)	Orange oil
Density (kg/m3)	ASTM D4052-91	840	914	870	713	820
Calorific value (kJ/kg)	ASTM D240	42390	39648	42735	33897	42000
Cetane number	ASTM D613	45–55	45	45	>125	10
Viscosity (Cst)	ASTM D445	4.59	50	4.9	0.23	0.95
Flash point (C)	ASTMD93	75	210	180	19	46.1

Table 1 Important property of test fuels.

1.1. Cotton seed oil as a fuel for diesel engines

Cotton seed oil is extracted from the seeds of cotton plant of various species, mainly Gossypium hirsutum and Gossypium herbaceum. Cotton seed has an oil bearing kernel surrounded by a hard outer hull; while processing, the oil is extracted from the kernel.

Cotton seed oil is environmentally safe. It is a byproduct of cotton tree. At present, cotton seed oil has not found any major application and hence the natural production of seeds remains underutilized. As a compression ignition engine fuel, cotton seed oil has a high cetane number of 45, which is very close to diesel. The flash point of cotton seed oil is 210^0C as compared to 75^0C for diesel. Due to its higher flash point, cotton seed oil has certain advantages over petroleum crude like greater safety during storage, handling and transport. The properties of cotton seed oil are very close to diesel. This makes it a suitable alternative fuel for diesel engines [13].

Cotton seed oil (CSO) offers the advantage of freely mixing with orange oil, DEE and these blends can be used in the existing diesel engine without any modifications. Blending of orange oil, DEE with CSO results in significant improvement in physical properties of the mixture. The viscosity of orange oil and DEE is very low compared to CSO. Hence the viscosity and density are considerably reduced with these blends. Volatility is also improved. The calorific value of orange oil is equal to diesel fuel which will improve the combustion when it is mixed with low calorific value fuel of CSO. The cetane number of DEE is very high which will start the combustion early. Table-1 gives some of the important properties of test fuels with standards followed to measure its properties

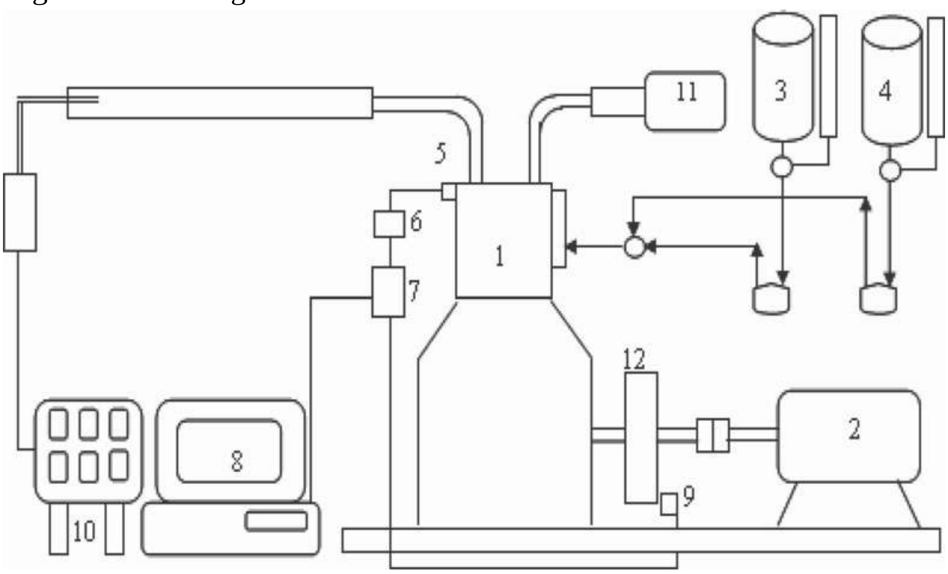
2. Experimental setup

The engine used for the test was a Kirloskar (TV1), single cylinder, four stroke, direct injection, water cooled and naturally aspirated compression ignition engine with 5.2 kW of power at the rated speed of 1500 rpm. The specifications of test engine are given in Table 2. The engine was connected to a Saj Fraud eddy current dynamometer and suitable arrangements were made to acquire all the controlling parameters. The engine cylinder liner, head and piston were coated with the insulating material of 8% Y_2O_3– PSZ with the thickness of 0.5 mm to convert semi adiabatic engine. The important properties of insulting materials are given in Table 3.

A Kane Auto 1 series NO portable exhaust gas analyser was used to measure NO. Smoke was measured with a Bosch smoke meter. CO and HC emissions were measured with a Crypton exhaust gas analyzer.

In-cylinder pressure was measured with a water-cooled piezoelectric transducer. The charge output of the transducer was amplified into anequivalent voltage using a suitable charge amplifier. The transducer was flush mounted on the cylinder head surface for avoiding passage effects.

A KISTLER make transducer with a sensitivity of 80.5 pC/bar was used for the purpose. The de tails of the pressure measuring instruments are given in Appendix A. The piezoelectric transducer produces a charge output, which is proportional to the in-cylinder pressure. The system was periodically checked for drift and corrected suitably [14]. Since the signals from a piezoelectric transducer indicate only relative pressures, it is necessary to have a means of determining the absolute pressure at some point in the cycle. Hence, it had to be referenced to get the actual pressure. This was done by assuming that the cylinder pressure at suction BDC is equal to the mean intake manifold pressure [14].The piezoelectric transducer produces a charge output



1.	Engine	7.	Analog to digital converter
2.	Eddy current dynamometer	8.	Computer
3.	Diesel fuel tank	9.	TDC pickup
4.	CSO fuel tank	10.	Exhaust gas analyzer
5.	Pressure transducer	11.	Air surge tank
6.	Charge amplifier	12.	Flywheel

Fig. 1. Schematic diagram of experimental setup.

The charge output was supplied to a charge amplifier where it was amplified for an equivalent voltage. An online data acquisition system was used to connect the probes through an A/D converter and the data is fed to the computer. Specialized software (Engine Soft) for the engine analysis gives the output in the graphical as well as in numerical form. The experimental setup is shown in Fig. 1.

3. Test procedure

Initially, experiments were conducted with different injection timings at the rated speed of 1500 rpm under variable load conditions to optimize the injection timing for CSO and EECSO. Load, speed, air flow rate, fuel flow rate, exhaust gas temperature, ex- haust emissions of hydrocarbon, carbon monoxide, nitric oxide and smoke have been observed. Cylinder pressure and top dead center (TDC) position signals were recorded for processing to obtain combustion parameters.

In the first phase experiments were conducted with diesel, CSO and EECSO for base line data generation.

In the second phase of the work, the engine was operated CSO– diesel blend ratio of CSO100:D0, CSO80:D20,CSO60:D40,CSO40:D60 and CSO20:D80 with and without preheating. The preheated fuel temperature was varied from room temperature to 110 C in steps of 10 C. The viscosity of test fuels at different temperature was measured and it is given in Table 4.

In the third phase, orange oil in different proportions of 5%, 10% and 15% was blended with cotton seed oil to analyze the performance, emissions and combustion parameters. In the fourth phase experiments were carried out to obtain performance, emission and combustion parameters using the oxygenate diethyl ether (DEE) as an additive with CSO in various proportions of 10%, 20% and 30%.

During the final phase, experiments were conducted with adia- -batic engine components with neat cotton seed oil as fuel.

Finally the results of performance, emission and combustion characteristics of different methods were compared with the base values.

Table 2
Specifications of test engine.

Make and model	Kirloskar, TV1
No. of cylinder	1
Cycle	4 stroke
Bore stroke	87.5 mm 110 mm
Displacement volume	661 cm^3
Compression ratio	17.5:1
Combustion chamber	Hemispherical Rated power
	5.2 kW @ 1500 rpm Injection
timing	27 BTDC

Table 3 Important properties of insulation materials.

Material used for insulting piston crown and head 8% Y2O3–PSZ

Type of treatment Pretreatment: shot-blasting ,
Post- treatment: grinding and honing

Properties of yttrium oxide (Y_2O_3):

Density (gm/cm^3)	3.05
Coefficient of thermal expansion :	(10^6/K) 8.1 @ 20–1000 C
Melting point (0C)	2400
Thermal conductivity (W/mK)	8–12 @ 20 C

Properties of partially stabilized zirconia (PSZ)

Chemical formula	ZrO2–MgO
Coefficient of thermal expansion (10^6/ C)	10.1
Thermal conductivity	(1.8–3)
Maximum working temperature (0C)	1100
Density (gm/cm3)	5.75
Tensile strength	65
Modulus of elasticity (N/m2)	29–30 * 10^6
Flexural strength (kN/m2)	100
Poisson's ratio	0.23–0.31
Compressive strength (kN/m2)	268

4.1. Performance parameters

Fig. 2 shows the variation of brake thermal efficiency of cotton seed oil (CSO) with different methods. The brake thermal efficien- cies are always lower with single fuel operation. Neat cotton seed oil shows the lowest brake thermal efficiency due to its high vis- cosity and poor mixture formation tendency which leads to reduce combustion rate as seen in the heat release rate curve (Fig. 8). The brake thermal efficiency increases from 28% to 30.4% with ethyl ester of cotton seed oil. The blend of cotton seed oil and orange oil (CSO85:OO15 by mass) is much better than cotton seed oil with diesel. The brake thermal efficiency is 30.5% with CSO85:OO15 and 29.9% with CSO60:D40. Preheating CSO and diesel mixture (CSO60:D40) to a temperature of 90 C, when its viscosity is the same as that of diesel at 40 C is found to be very effective com- pared to neat CSO at 110 ^{0}C. However, preheating CSO diesel mixture requires some electrical energy, which will reduce the overall engine efficiency. In the case of adiabatic CSO operation the brake thermal efficiency is lower than CSO–DEE operation at full load. The blending of CSO with orange oil is the most effective method of all the methods investigated and the brake thermal efficiency is 30.5% which is close to diesel operation of 32.3%. The increase in brake thermal efficiency is due to the high combustion rate and improved flame propagation through the mixture, which has resulted in a rapid heat release. The variation of volumetric efficiency of different fuels at full load is shown in Fig. 3. Volumetric efficiency is lower with neat CSO than diesel due to the high temperature of the retained gases. The hot exhaust gases inside the cylinder heat the incoming fresh air; reduces the quantity of air intake and lowers the volumetric efficiency. A marginal improvement in the volumetric efficiency is noticed with orange oil and diesel addition. There is an improvement of volumetric efficiency with preheated CSO and blends com- pared to CSO at room temperature. The exhaust gas temperature decreases, when the fuel mixture is heated. Due to that, there is improvement in volumetric efficiency with preheated fuels, but it is still lower compared with diesel. There is an improvement with the blend of DEE as compared to neat CSO operation. The volumetric efficiency of the engine with adiabatic CSO operation at full load is very low compared to all test fuels. This is due to the hot exhaust gases retained inside the combustion chamber and the hot cylinder walls have made the fresh charge to expand as soon as it enters the cylinder preventing more quantity to enter the cylinder.

4.2. Emission parameters

Fig. 4 shows the variation of smoke level with different modes of operation. Neat cotton seed oil has the highest smoke level as the higher viscosity of oil leads to poor mixture formation. It is seen that the smoke level reduces with all methods of operation. Neat CSO results in a smoke level of 3.9 BSU at full load and for die sel it is 3.4 BSU. Methods like CSO–diesel blend and preheating of neat CSO also reduce smoke level considerably. Adiabatic CSO leads to a very high smoke level of 4.4 BSU at full load. Even though the temperature inside the combustion chamber is high at full load, poor availability of oxygen results in incomplete combustion and high smoke density for adiabatic CSO operation. From volu metric efficiency curve (Fig. 3), it is clear that volumetric efficiency is very low (79.4%) with adiabatic CSO which conveys that avail ability of oxygen inside the combustion chamber is very less at full load. Maximum reduction in smoke level is noticed with CSO–OO operation, preheating of CSO–diesel mixture and CSO–DEE opera tion. It is about 3.5 BSU at full load. The smoke reduction is due to the improved combustion due to reduction in viscosity.

The variation of CO emission for different modes of operation is shown in Fig. 5. CO emission is reduced with all the methods of operation. But CSO operation in adiabatic engine causes a slight in crease in the CO emission. Neat CSO results in high CO emission and the value is 0.28%. The higher density and viscosity of CSO cause poor mixture formation which results in partial burning during combustion process. So the CO emission is higher for CSO. Ethyl ester of CSO, diesel–CSO blend and preheating of neat CSO at 110 C also reduce CO emission considerably. Lowest value of CO emissions is noticed with CSO–OO blend, CSO–diesel at 0 ^{0}C and CSO–DEE blend. The value of CO is 0.22%, 0.212% and 0.21% respect to HC emission as in the case of CO emission in all modes of operation.

NO level for the different modes of engine operation is shown in Fig. 6. NO level is noticed low as expected as the combustion temperatures are reduced for neat CSO operation. This reduction in NO with CSO operation is due to the less intense premixed combustion following the delay period. Ethyl ester of CSO leads to higher NO than all modes of operation due to the high combustion rate and temperature reached. Addition of orange oil, DEE, preheated CSO–diesel mixture and adiabatic engine increase the NO significantly. NO level rises with the addition of orange oil mainly due to an increase in the temperature on account of the enhanced combustion rate with orange oil. This is also due to high combustion temperature reached during the initial stage of combustion. The NO level for CSO–diesel blend and preheated neat CSO increases slightly compared to neat CSO operation, but it is very low com pared to other methods. This increase in NO level is due to higher premixed combustion rate. It is also due to the rapid burning with an increase in fuel inlet temperature

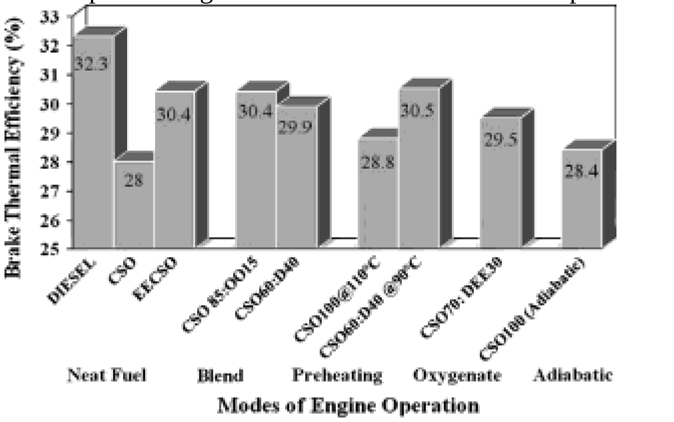


Fig. 2. Variation of brake thermal efficiency with different modes of engine operation..

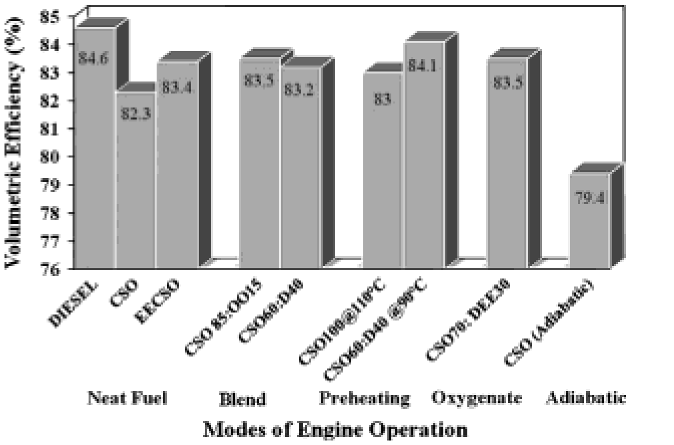


Fig. 3. Variation of volumetric efficiency with different modes of engine operation.

.4.3. Combustion parameters

The maximum rate of pressure rise is shown in Fig. 7. Lowest values are seen with CSO, even though its ignition delay is higher. It is because the accumulated fuel in the ignition delay period does not get prepared well to burn rapidly in the early combustion period. Ethyl ester of CSO shows a higher rate of pressure rise, due to the mixture is well prepared to burn rapidly in the premixed phase. Preheating the neat oil and adiabatic CSO reduce the maximum rate of pressure rise marginally compared to other methods. The increase in the maximum rate of pressure rise is due to the cracking of the double bond of the carbon chain, which might have been produced light volatile compounds. Addition of orange oil, DEE and diesel with CSO increase the rate of maximum

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pressure rise be cause it is mainly due to faster combustion of fuel during the pre mixed period. These values are higher with heating of diesel CSO mixture at 110 C. Similar trend is observed with respect to maxi mum cylinder pressure as in the case of maximum rate of pressure rise in all modes of operation investigated.
The variation of heat release rate at different crank angles with different modes of operation is shown in Fig. 8. It can be observed that the high heat release rate of diesel is a consequence of pre mixed combustion phase. It is clear that premixed combustion phase of CSO is significantly lower in comparison with all methods. This is due to lesser fuel being prepared for rapid combustion with CSO during ignition delay. The premixed heat release is high in the case of adiabatic CSO followed by neat CSO. In the semi-adiabatic engine, heat release profile is shifted from the premixed to diffusion combustion with accompanying drop in peak pressure. Higher peak values of CSO60-D40 blend indicates better atomization and mixing. Addition of DEE with CSO (CSO70:DEE30) increases the premixed combustion phase compared with neat CSO due to reduced ignition delay and early burning of DEE. The oxygen content and number of ignition centers created by DEE in the combustion chamber during the combustion period increases the rate of combustion. Preheating of blended fuel (60% of CSO and 40% diesel at 90 C) reduces the delay period. Hence, the combustion starts earlier than CSO. It is also observed that higher premixed combustion for orange oil addition with CSO is due to more quantity of fuel being prepared during ignition delay period leads to bulk burning of fuel in the initial stage of combustion (premixed combustion).
Fig. 9 shows the variation of combustion duration for different modes of engine operation. The values are the highest with neat CSO on account of the slow diffusion combustion phase. In the pre heating mode there is a considerable drop in the combustion duration due to the enhanced combustion rates. Combustion duration is also lower with blending of DEE and orange oil with CSO as com pared to neat CSO operation mode. The value (40 CA) is almost same for both the methods. The blend of orange oil and diesel injection lead to strong ignition centers and faster combustion. The high flame propagation of orange oil will also lead to a reduction in combustion duration. It is lower with CSO–diesel bend (38 CA) and it is equal to diesel value. It is due to better rate of combustion of blended CSO with low viscosity fuels.

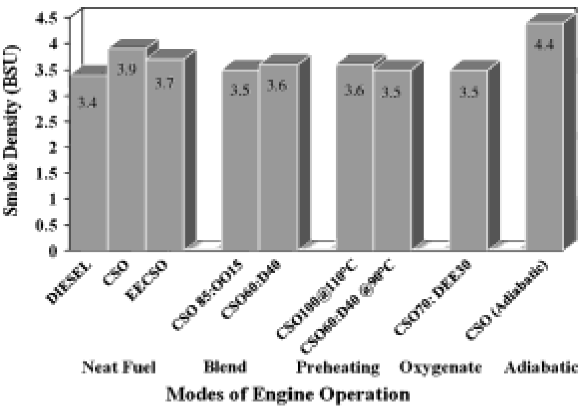

Fig. 4. Variation of smoke density with different modes of engine operation

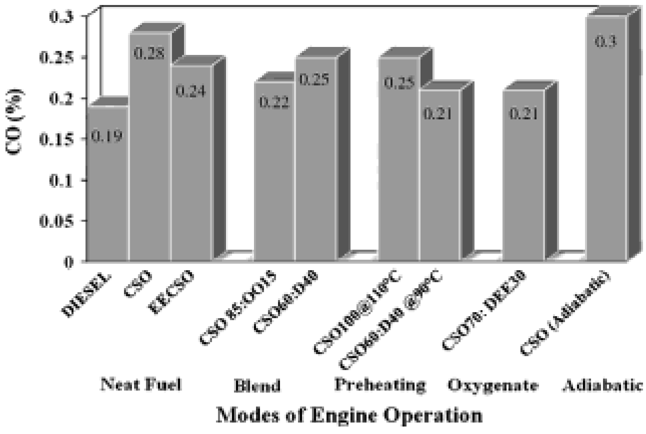

Fig. 5. Variation of CO with different modes of engine operation.

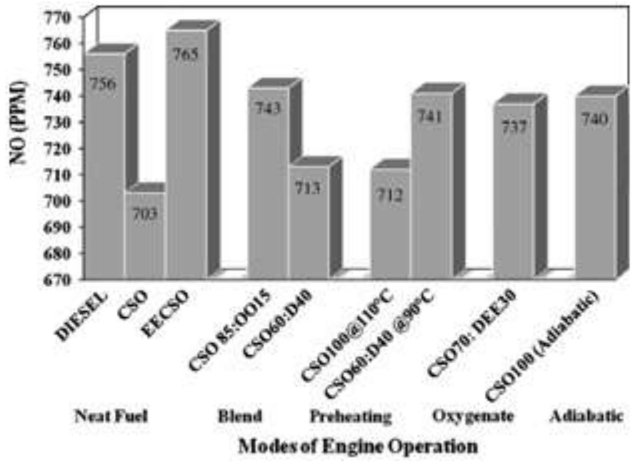

Fig. 6. Variation of NO with different modes of engine operation.

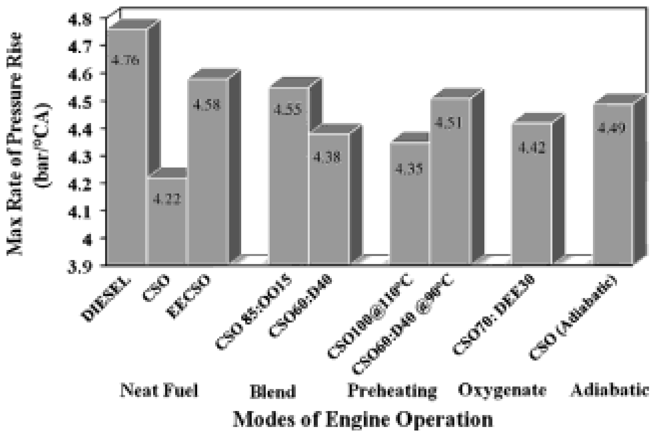

Fig. 7. Variation of maximum rate of pressure rise with different modes of engine operation

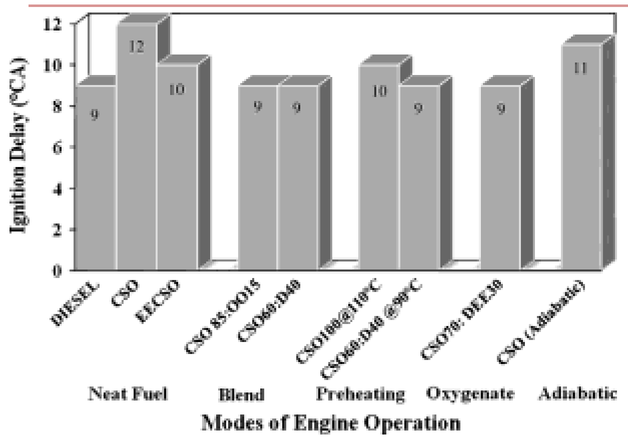

Fig. 8. Variation of ignition delay with different modes of engine operation

5. Error analysis

In measuring any quantity, the results will always differ from the true value even with careful experimentation. This error in measurement may be either random or systematic. By adding a correction value, the systematic error can be removed. Random error can only be estimated statistically and cannot be predicted in advance. Its presence only can be detected when the same quantity is measured again and again under the same conditions.

The uncertainty can be estimated based on Gaussian distribu tion method with confidence level of +2σ (95.45% of measured data lie within the limits of +2σ of mean). Thus uncertainty is estimated using the following equation.

Uncertainty of any measured parameter (ΔX) =2σ i/X *100

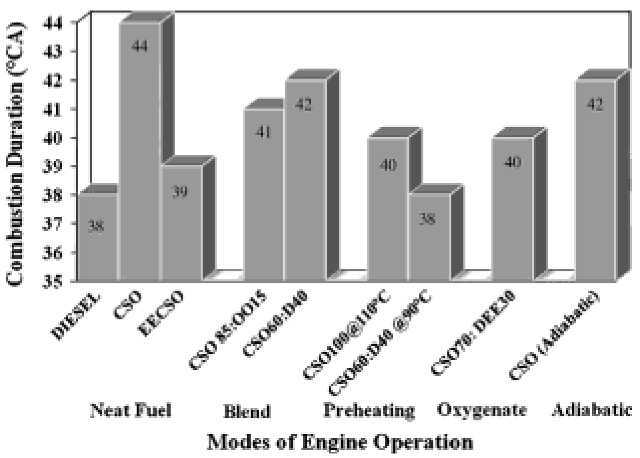

Fig. 9. Variation of combustion duration with different modes of engine operation

6. Conclusion

A single cylinder compression ignition engine was operated successfully using cotton seed oil with different methods. The following conclusions are made based on the experimental results:

Ethyl ester of cotton seed oil results in a higher thermal efficiency of 30.4% where as CSO results in 28%. The maximum efficiency with diesel is about 32.3%. NO emissions are higher with EECSO than CSO because of higher combustion temperature. High viscosity and poor volatility of CSO lead to higher HC and CO levels than diesel. Smoke level of EECSO is lower as com- pared to neat CSO. The smoke level for neat CSO is 3.9 BSU and 3.7 BSU for its ester at full load. In the case of diesel it is 3.4 BSU.

At full load, the brake thermal efficiency with of orange oil in the blend, NO is 743 ppm. There is reduction in smoke level with orange oil – CSO blend in comparison to neat CSO From the above results, Ethyl ester of cotton seed oil can lead to overall good performance with respect to fuel economy and emissions. However, preparation of the ethyl ester is a cumbersome process and also leads to certain byproducts that cannot be used in the engine. CSO60:Diesel40 at 90 C method needs electrical energy to heat the CSO and diesel blend. Of all the methods investigated, CSO85: Orange Oil 15 blend is the best method to use cotton seed oil in a diesel engine with respect to performance, fuel economy, emissions, combustion characteristics and simplicity in using the CSO 85:Orange Oil 15 blend.

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