An Analysis on Combustion and Emission Characteristics of CI Engine Using Blends of Cotton Seed Biodiesel

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Abstract- The use of non-edible vegetable oils as an alternative fuel for diesel engine is a highly debated notion. The high energy crisis and increased environmental concerns make it a hot topic. In this present work experimental study has been carried out to determine the combustion and emission characteristics of Cotton Seed Methyl Ester (CSME) blends with diesel. Tests were conducted for B10, B20, B30(10%, 20%, 30% blend of CSME with diesel) and was compared with diesel fuel. At rated power the brake thermal efficiency of blend B20 and diesel were 29.6% and 30.2% respectively. Ignition delay, net heat release and in cylinder pressure for blends were found to be higher than diesel at rated power. There was a slight increase in the amount of NO_X (Nitrogen Oxides) for B20, but HC (Hydrocarbon), CO (Carbon monoxide) and smoke opacity were reduced by 32.3%, 10% and 7.7% respectively than that of diesel. The test results show that B20 gives almost equal performance to that of diesel with significant reduction in emission.

Keywords: Biodiesel, Diesel engine, Cotton seed Methyl Ester, Combustion, Ignition delay, Emission.

1. Introduction

Biofuels generally have been proposed as an alternative for conventional internal combustion engine fuels. In this category, biodiesel has received great attention because it is biodegradable, renewable, and non-toxic nature. Previous studies show that use of biodiesel can significantly reduce exhaust emissions from the engine when burned as a fuel. Many investigators have reported that using biodiesel in compression ignition engines can reduce carbon monoxide (CO), hydrocarbon (HC) and particulate matter (PM) emissions, but there is an increased emission of nitrogen oxide (NOx) [1,2]. Researches were carried out to determine the reason for this increase in the NOx emission and identified that it is the result of a number of factors such as lower aromatic content in the fuel, higher temperature during combustion, increased oxygen content and high cetane number [3, 4].

Any fuel, which is 100% pure in composition that meets the requirements of the American Society for Testing and Materials (ASTM) for biodiesel in their D 6751 standard can be called as a biodiesel. Even though straight vegetable oils can be directly used in diesel engine it will pose problems such as excessive carbon deposits and ring sticking in the long run [5]. In order to avoid this, the viscosity of the oil should be reduced before using in the engine [6].

There are many methods available to reduce the viscosity of vegetable oils such as blending, pyrolysis, transesterification and micro emulsion [7, 8]. Out of this transesterification is the cheapest and best way to convert vegetable oil into biodiesel. Transesterification is basically a reversible reaction in which the triglyceride molecules of vegetable oil are converted into its corresponding esters [9]. According to the amount of fatty acid present in the vegetable oil the nature of biodiesel will also change. If there is more unsaturated free fatty acid content, then the biodiesel shows poor oxidation stability and on the other hand, if it has more saturated fatty acid content the biodiesel will be having poor cold flow properties [10]. In this reaction vegetable oil is allowed to react with alcohol in the presence of a catalyst which yields the ester and glycerol as by-product [7]. Even after transesterification reaction the viscosity of the biodiesel will be slightly higher than that of diesel. The properties of cotton seed oil before and after the transesterification process is compared with diesel fuel in Table 1.

Table 1. Properties of Diesel, CSO and CSME

Properties	Diesel	CSO	CSME
Density (kg/m^3)	840	912	865
Viscosity (cSt)	4.29	50	4.9
Calorific Value (MJ/kg)	43.4	39.6	42.7
Cetane Number	45-55	42	45
Flash Point (^{0}C)	75	210	180

Apart from the higher viscosity, biodiesel has disadvantages such as low calorific value, higher NO_X. This is due to the difference in the physical and chemical properties of biodiesel from conventional diesel fuel. This causes variations in the combustion characteristics of engine while using biodiesel as fuel. Study of combustion of vegetable oil by varying the injection timing of fuel indicate that the effects on combustion of fuel due to slower burning rate and longer ignition delay can be compensated by advancing the injection timing [11]. Also the higher viscosity of biodiesel increases the combustion duration of biodiesel fuelled engine [12, 13]. These problems together with higher oxygen content results in higher peak pressure and heat release rate in the combustion phase [2].

In this present work test were conducted on a single cylinder, constant speed diesel engine running from no load to full load conditions at rated speed of 1500 RPM and the performance, combustion and emission parameters were analysed in order to find out which blend is the best substitute for diesel.

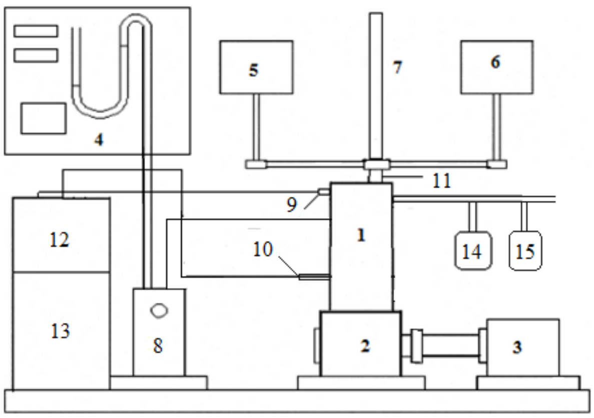
2. Experimental Setup

The experiment was conducted on a constant speed, single cylinder, direct injection, water cooled diesel engine generating 3.7 kW. The schematic diagram of the test setup is shown in Fig. 1 and the engine specifications are given in Table 2.

Table 2. Engine Specifications

Engine	Kirloskar
Type	4 stroke, single cylinder
Stroke	110
Bore	80
Rated Power	3.7 kW
Compression ratio	16.5:1
Speed	1500 rpm

The engine was electrically loaded with a rheostat and to detect the engine crank angle a TDC (Top Dead Centre) encoder was used. A pressure pickup was mounted on the cylinder head. A digital online data acquisition system was used to record the pressure signals from the transducers and this data is fed to the computers with the help of KISTLER amplifier. All tests were conducted at rated speed of 1500 RPM and an injection pressure of 180 bar with an injection timing of 23° before TDC. Tests were conducted for diesel fuel and the blends B10, B20, B30. The engine was started using diesel fuel and after attaining steady state it was switched to CSME blends. The engine was again run on diesel fuel at the end of the experiment to remove the biodiesel from the fuel line.



1. Engine 2. Generator 3. Rheostat 4. Reading Panel Board 5. Diesel tank 6. CSME tank 7. Fuel Burette 8. Air Box 9.Pressure Transducer 10.TDC encoder 11. Fuel switch valve 12. DAQ card 13. Computer 14. Exhaust Gas Analyser 15. Smoke meter

Fig. 1. Experimental Setup

3. Results and Discussion

3.1. Performance Analysis

3.1.1Brake thermal efficiency

The variation of brake thermal efficiency with respect load is shown in the Fig 2. It can be observed that the brake thermal efficiency of Diesel, B10, B20 and B30 blends at rated power were 30.2%, 28.3%, 29.6% and 27.9% respectively. The performance of CSME B20 in terms of brake thermal efficiency is almost equal to that of diesel fuel. The slight decrease in thermal efficiency of B20 may be due to lower calorific value and higher fuel consumption. Also the higher viscosity of blends reduces the mixing and atomization which affects the quality of combustion.

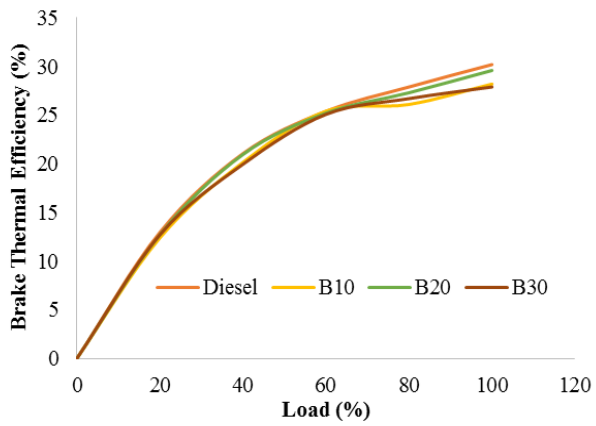


Fig. 2. Brake thermal efficiency Vs Load

3.1.2 Exhaust Gas Analysis

Fig. 3 shows the exhaust gas temperature variation with load. For all the blends exhaust gas temperature was higher than that of diesel at all load conditions. This may be due to the larger ignition delay period, which in turn increases the rate of rapid combustion, causing an increased heat release during the combustion. At rated power the exhaust gas temperature of B20 was 210˚C which is slightly greater than diesel with 195 ˚C. This is because of the higher oxygen content in the blend leading to better combustion.

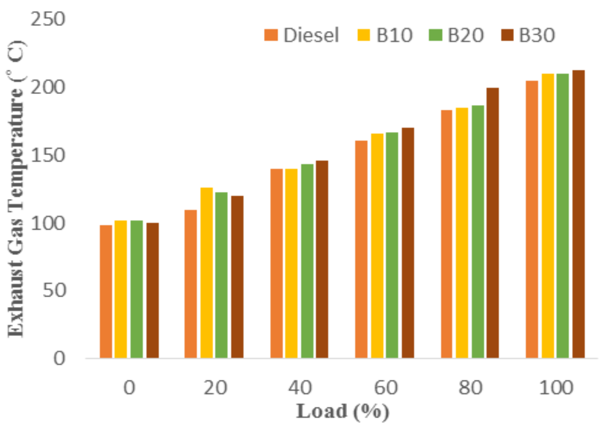


Fig. 3. Exhaust Gas Temperature Vs Load

3.2 Combustion Analysis

3.2.1 Pressure Crank Angle Diagram

Fig. 4 shows the variation of cylinder pressure with crank angle for the blends and diesel at full load condition. The peak cylinder pressure of B30 was 67.2 bar compared to 65.3, 66.1 and 64.14 bar for B10, B20 and diesel respectively at rated power. It is evident from plot that the peak pressure of B30 is higher than other blends. This variation is due to the higher ignition delay of the blends. Also, higher viscosity of blends creates very little combustible mixture in premixed combustion phase. This leads to a slightly increased in cylinder pressure during the late combustion period.

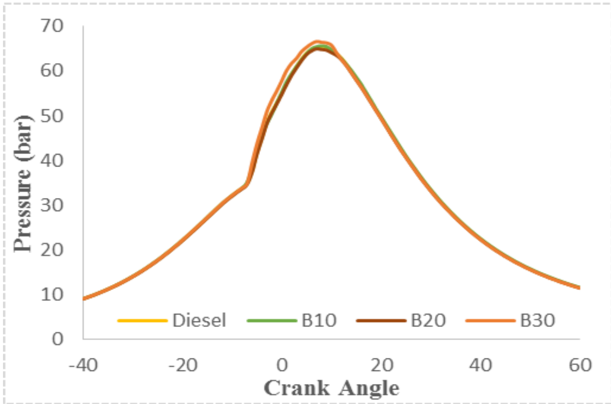


Fig. 4. Pressure Vs Crank Angle

3.2.2 Heat Release Rate

The heat release rate represents the rate of burning of fuel inside the cylinder during combustion. Fig. 5 indicates the rate of heat release with respect to crank angle and it can be noticed that B30 is having a higher heat release rate followed by B10, B20 and diesel at full load. The higher heat release of B30 is due to higher viscosity and higher oxygen content which generates more heat release during pre-mixed combustion phase. The higher heat release during the late combustion period of blends contributes to a higher exhaust gas temperature. The lower heat release rate of B20 when compared to B30 is due to its lower ignition delay and better atomization which helps to maintain less NO_X in the exhaust.

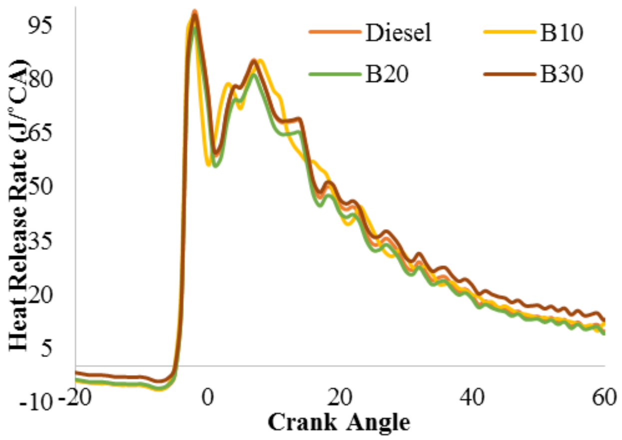


Fig. 5. Heat Release Rate Vs Crank Angle

3.2.3 Ignition Delay

The variation of ignition delay with varying load conditions is given in Fig. 6. It can be seen that the ignition delay of cotton seed oil blends is longer than that of diesel. Ignition delay for diesel at rated power was 10˚CA (Crank Angle) while for B10, B20 and B30 were 12.4˚CA, 12˚CA and 12.8˚CA respectively.The longer delay period of blends shows the effect of higher viscosity which causes difficulty in atomization leading to poor mixing of fuel and air in the combustion chamber. As the blend ratio increases the delay period also increases, causing an increased combustion rate in premixed combustion phase.

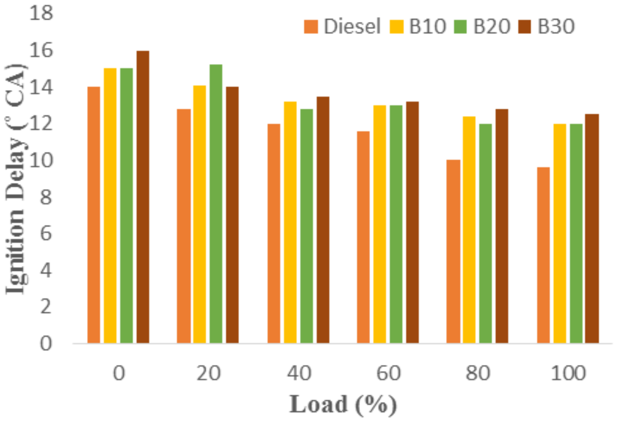


Fig. 6. Ignition Delay Vs Load

3.3 Emission Analysis

3.3.1 Hydrocarbon Emission

Hydrocarbon emissions are generally the unburned HC residue of fuel after combustion, which indicate the combustion inefficiency of the engine. Fig.7 shows a comparison of HC emission with load. It can be seen that the HC emission of B20 is lower than all other blends at all loads. At rated power the HC emission for B20 was reduced by 32.3% when compared to that of diesel. This is due to the increased oxygen content in the cotton seed blend which helps in getting better combustion quality. The reason for increased HC emission for B30 than B20 is the poor volatility of mixture and increased aromatic content which reduces the combustion quality.

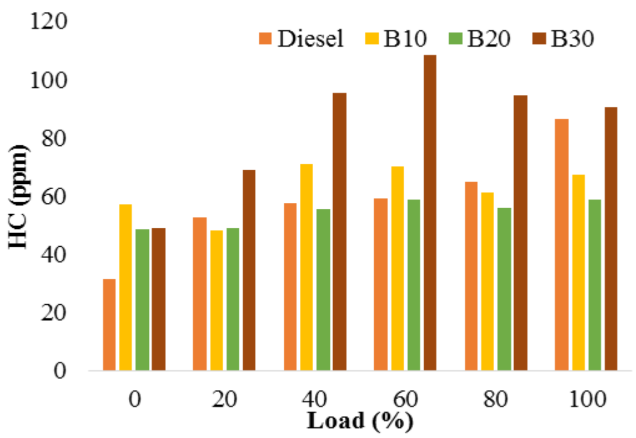


Fig 7. HC Vs Load

3.3.2 *Carbon monoxide*

Normally for diesel engine the amount of CO in the emission will be less since it works with lean air-fuel mixture. The reason for CO in the emission is due to lack of oxygen causing incomplete combustion. In Fig. 8 the variation of carbon monoxide with load is given. The amount of CO decreases with the load. The higher oxygen content in the cotton seed methyl ester reduces the CO emission for the blends at all loads. At full load condition B20 gives about 10% reduction in CO compared to that of diesel. The higher CO emission for B30 is because of the high carbon to oxygen content ratio.

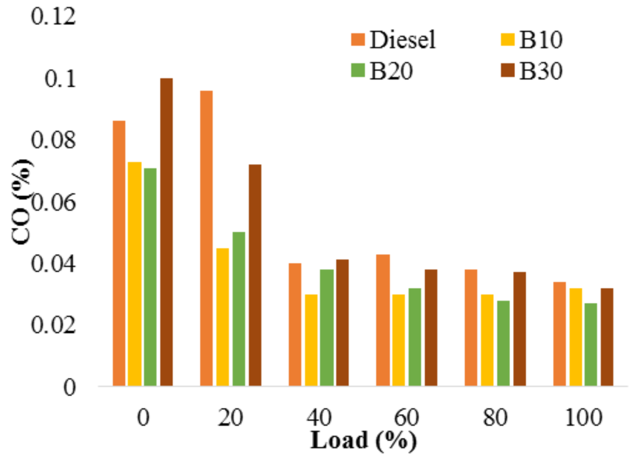


Fig. 8. CO Vs Load

3.3.3 Oxides of Nitrogen

The formation of oxides of nitrogen in the exhaust depends on in cylinder temperature and the amount of oxygen available during combustion. The plot shown in Fig. 9 indicates how NO_X varies with load. It can be noticed that the amount of NO_X increases with load for all fuels. At full load the NO_X for B10, B20 and B30 were increased by 5.3%, 6.5% and 7.4% compared to diesel. This is due to the higher heat release rate and higher oxygen content in the blends which contributes to the higher NO_X emission.

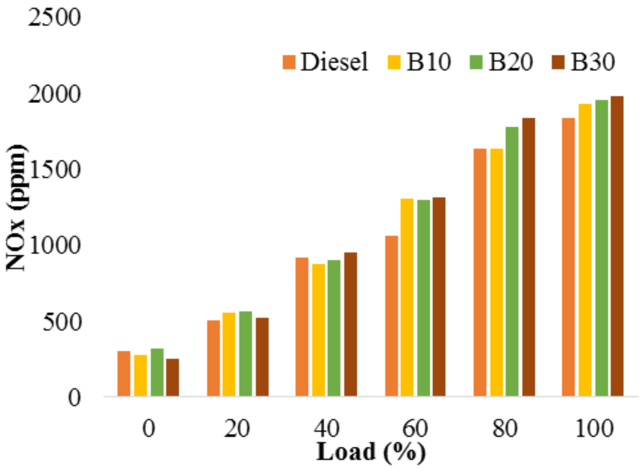


Fig. 9. NO_X Vs Load

3.3.4 Smoke Opacity

Smoke is a measure of elemental carbon due to incomplete combustion. The Fig. 10 shows the changes in the amount of smoke in exhaust with load. It can be observed that smoke is less for the blends than diesel at rated power. This is because of the enhanced combustion due to the higher oxygen content in the blends. The smoke opacity of B10, B20, B30 were reduced by 2.7%, 7.7% and 2 % respectively when compared to diesel. The reduction in smoke may also be due to the extended after burning period of the blends which oxidises the carbon particles during post combustion phase.

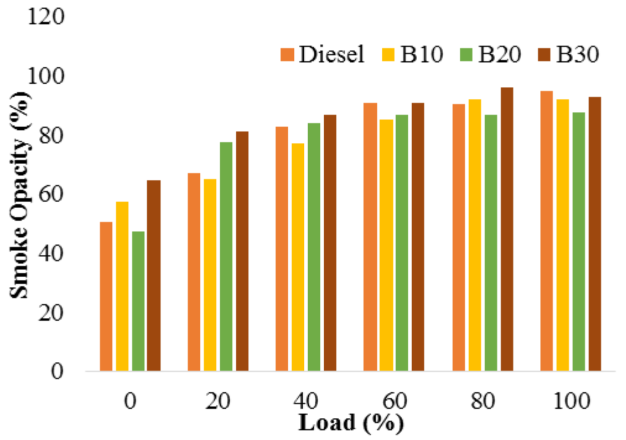


Fig.10. Smoke Opacity Vs Load

4. Conclusion

A single cylinder diesel engine was operated successfully using 10%, 20% and 30% blends of cotton seed methyl ester with diesel and their performance, emission and combustion characteristics were compared with diesel. The following conclusions are drawn from the results based on the experiment:

- The blend B20 gives a brake thermal efficiency of 29.6%, which is higher than other blends and closer to that of diesel.
- Peak pressure and net heat release rate for B30 is high when compared to other blends because of its higher viscosity and higher ignition delay period. The higher heat release rate of B30 also contributes to higher exhaust gas temperatures and higher NO_X.
- Higher NO_X content in the exhaust for the blends is due to the higher oxygen content and higher heat release rate during premixed combustion. NO_X is maximum for B30 and minimum for diesel because of its higher volatility.
- HC, CO and Smoke have reduced considerably at rated power when compared to diesel. This is because of the higher oxygen content in the blends which helps to carry out more complete combustion than diesel. For B20 at rated power HC, CO and Smoke are reduced by 32.3%, 10% and 7.7% respectively when compared to diesel.

The blend B20 gives comparable performance and combustion characteristics with considerable reduction in emissions when compared to diesel, hence it can be considered as a potential substitute for the diesel fuel.

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References

[1] Zheng M, Mulenga MC, Reader GT, Wang M, Ting DSK. Influence of biodiesel fuel on diesel engine performance and emissions in low temperature combustion 2006. SAE 2006-01-3281.
[2] Qi DH, Geng LM, Chen H, Bian YZH, Liu J, Ren XCH. Combustion and performance evaluation of a diesel engine fuelled biodiesel produced from soybean crude oil. Renewable Energy 2009; 34:2706–13.
[3] Ahmet NO, Mustafa C, Ali T, Cenk S. Performance and combustion characteristics of a DI diesel engine fuelled with waste palm oil and canola oil methyl esters. Fuel 2009; 88:629–36.
[4] Mueller CJ, Boehman AL, Martin GC. An experimental investigation of the origin of increased NOx emissions in a heavy-duty compression-ignition engine fuelled with soy biodiesel. 2009, SAE No 2009-01-1792, (Technical Paper)
[5] Nwafor O.M.I and G. Rice, "Performance of rapeseed oil blends in a diesel engine", International Journal of Applied Energy, Vol.54, No.4, 1996, 345-354.
[6] Nadir Yilmaz, Byron Morton, Effects of preheating vegetable oils on performance and emission characteristics of two diesel engines. Biomass and Bioenergy 35 2011, 2028-2033.
[7] Sun JF, Caton JA, Jacobs TJ. Oxides of nitrogen emissions from biodiesel-fuelled diesel engines. Progress in Energy Combustion Science 2010; 36:677–95.
[8] Canakci M. Combustion characteristics of a turbocharged DI compression ignition engine fuelled with petroleum diesel fuels and biodiesel. Bio resource Technology 2007;98:1167–75
[9] Gerhard V. Performance of vegetable oils and their monoesters as fuel for diesel engines. SAE Paper 1983, No 831358, (Technical Paper)
[10] Kolhe AV, Nistane VM, Dahake RJ, Experimental evaluation and exhaust emission characteristics of CI engine using biodiesel as a supplementary fuel. Jaipur: Proceedings of the International Conference on Energy Technologies for Sustainable Development; 2003: 275–280.
[11] N. Vedaraman, SukumarPuhan, G. Nagarajan, B.V. Ramabrahmama, Methyl ester of Sal oil (Shorearobusta) as a substitute to diesel fuel—A study on its preparation, performance and emissions in direct injection diesel engine, Industrial Crops and Products 2012; 282–288.
[12] Yamane K, Kawasaki K, Sone K, Hara T, Prakoso T, Oxidation stability of biodiesel and its effects on diesel combustion and emission characteristics. IMechE 2007. Int. J. Engine Res. 8, 307–319
[13] Senthil Kumar M, Ramesh A, Nagalingam B, An experimental comparison of methods to use methanol and Jatropha oil in a compression ignition engine. Biomass Bio energy 25, 2003, 309–318.