Experimental Studies on the Combustion Characteristics and Performance of A Direct Injection Engine Fueled with Biodiesel/Diesel Blends with SCR

A.P. Sathiyagnanam, *Member, IAENG* and C.G. Saravanan

Abstract - **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.**

In this study, the biodiesel produced from cottonseed oil was prepared by a method of transesterification and its blends of 25%, 50%, 75% and 100% 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 DI compression ignition engine were examined. Biodiesel has different properties from diesel fuel. A minor increase in specific fuel consumption (SFC) and brake thermal efficiency (BTE) for biodiesel and its blends were observed compared with diesel fuel. The significant improvement in reduction of Hydro carbon (HC) and smoke emission were found for biodiesel and its blends at high engine loads. Carbon monoxide (CO) 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 (SCR). 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.

keywords: Cottonseed oil, Selective Catalytic Reduction, Emission, Combustion, Carbon dioxide

I INTRODUCTION

Biodiesel has received much attention in the past decade due to its ability to replace fossil fuels, which are likely to run out within a century. Especially, the environmental issues concerned with the exhaust gases emission by the usage of fossil fuels also encourage the usage of biodiesel, which has proved to be ecofriendly far more than fossil fuels [1].

A. P. Sathiyagnanam, Assistant Professor, Department of Mechanical Engineering, Annamalai University, Annamalainagar – 608 002. Tamilnadu, India. (Corresponding author phone: +91 4144 239733; fax: +91 4144 238275; e-mail: apsgnanam@yahoo.co.in).

C.G. Saravanan, Professor, Department of Mechanical Engineering, Annamalai University, Annamalainagar – 608 002. Tamilnadu, India.

Bio-fuels made from agricultural products (oxygenated by nature) reduce the world's dependence on oil imports, support local agricultural industries and enhance farming incomes and, moreover, offer benefits in terms of usually reduced emissions. Among those, vegetable oils, their derived bio-diesels (methyl or ethyl esters) and bio-alcohols are considered as very promising fuels. Experimental works on the use of bio-ethanol in diesel engines have been reported for example in [2, 3, 4]. Bio-fuel production is a rapidly growing industry in many parts of the world. Bio-ethanol is the primary alternative at present to gasoline for spark-ignition engines, and vegetable oils, their derived bio-diesels and bio-ethanol mixed with diesel fuel for compression ignition (diesel) engines. However, other bio-fuels such as biobutanol [5], biomass-derived hydrocarbon fuels and hydrogen are being researched at present, being regarded as next generation bio-fuels [6].

The main disadvantages of vegetable oils, as diesel fuels, are associated with the highly increased viscosity, 10–20 times greater than the normal diesel fuel. Thus, although short-term tests using neat vegetable oils showed promising results, problems appeared after the engine had been operated for longer periods. To solve the problem of the very high viscosity of neat vegetable oils, the following usual methods are adopted: blending in small blend ratios with diesel fuel, micro-emulsification with methanol or ethanol, cracking, and conversion into bio-diesels mainly through the transesterification process [7,8].

The advantages of bio-diesels as diesel fuel are the minimal sulfur and aromatic content, and higher flash point, lubricity, cetane number, biodegradability and non-toxicity. On the other hand, their disadvantages include the higher viscosity and pour point, and the lower calorific value and volatility. Furthermore, their oxidation stability is lower, they are hygroscopic, and as solvents may cause corrosion in various engine components. For all the above reasons, it is generally accepted that blends of diesel fuel, with up to 20% bio-diesels and vegetable oils, can be used in existing diesel engines without modifications. Experimental works on the use of vegetable oils or bio-diesels in blends with diesel fuel for diesel engines have been reported for example in References. [9, 10].

A recent work by the authors [9] studied and compared an extended variety of vegetable oils and bio-diesels of various origins tested in blends with the normal diesel fuel, ranging from the palm oil associated with warm climates to soybean and rapeseed oil associated with temperate climates, incorporating in-between vegetable oils grown in temperate to warm climates (e.g. in the Mediterranean area), such as cottonseed oil, sunflower oil, corn oil, olive kernel oil and their methyl esters. Thus, a clearer picture was produced showing the relative performance and emissions characteristics of these fuels.

In the present study, raw cottonseed oil was considered as a potential alternative fuel for an unmodified diesel engine because it has high oil content (around 40%) for biodiesel production. Main aim of this study is to investigate the engine performance, emission and combustion characteristics of a diesel engine fuelled with cottonseed oil and its diesel blends compared to those of standard diesel. It is also hoped that the new data presented here will help in developing new predictive methods or procedures for this actual problem.

II The Biodiesel Production and Characterization

A. *Biodiesel Production Procedure*

The biodiesel fuel used in this study was produced from the transesterification of raw cottonseed oil with methanol (CH_3OH) catalyzed by potassium hydroxide (KOH). A titration was performed to determine the amount of KOH needed to neutralize the free fatty acids in raw cottonseed oil. The amount of KOH needed as catalyst for every liter of raw cottonseed oil was determined as 12 g. For transesterification, 210 mL CH_3OH plus the required amount of KOH were added for every liter of raw cottonseed oil, and the reactions were carried out at 45^0C. The water wash process was performed by using a sprinkler which slowly sprinkled water into the biodiesel container until there was an equal amount of water and biodiesel in the container. The water biodiesel mixture was then agitated gently for 20 min, allowing the water to settle out of the biodiesel. After the mixture had settled, the water was drained out.

B. *Biodiesel Properties*

A series of tests were performed to characterize the compositions and properties of the produced biodiesel. The fuel properties of biodiesel and its blends with diesel fuel are shown in Table 1. It is shown that the viscosity of biodiesel is evidently higher than that of diesel fuel. The density of the biodiesel is approximately 6.02% higher than that of diesel fuel. The lower heating value is approximately 9.08% lower than that of diesel fuel. Therefore, it is necessary to increase the fuel amount to be injected into the combustion chamber to produce same amount of power. Fuels with flash point above 52^0C are regarded as safe. Thus, biodiesel is an extremely safe fuel to handle compared to diesel fuel. Even 25% biodiesel blend has a flash point much above that of diesel fuel, making biodiesel a preferable choice as far as safety is concerned. The analysis results of cold filter clogging temperature, a criterion used for low temperature performance of the fuels, suggest that the performance of biodiesel is as good as diesel fuel in cold surroundings. With the increase of biodiesel percentage in blends, solidifying point of blends increases [11]

Table 1 Properties of biodiesel in comparison with commercial diesel and best blends
(Source: Laboratory evaluation at Etalab –Chennai)

Properties	**Commercial Diesel**	**B 50**	**B100**
Density @ 15 °C in gm/cc	0.8344	0.8610	0.8835
Specific gravity @ 15° /15°C	0.8360	0.8610	0.8848
Kinematic viscosity @ 40 °C (mm^2/s)	3.07	4.12	6.83
Flash point (°C)	60	108	150
Fire Point (°C)	69	118	161
Cloud Point (°C)	15	21	27
Calorific value (kJ/kg)	44125	43124	40789
Cetane Number	51	52	52

III Experiment

A. *Equipment and method*

The engine kirloskar TV1 was used, its main parameters are shown in Table 2.

The engine bench is shown in Figure 1. An eddy-current dynamometer was connected with the engine and used to measure the engine power. An exhaust gas analyzer (AVL Di-gas analyser) was employed to measure NOx, HC, CO, O_2 and CO_2 emission on line. To insure that the accuracy of the measured values was high, the gas analyzer was calibrated before each measurement using reference gases. The AVL smoke meter was measured the smoke density. The smoke meter was also allowed to adjust its zero point before each measurement. The AVL combustion analyser is used to measure the combustion characteristics of the engine.

Table 2 Specification of the test engine

Type	:	Vertical, Water cooled, Four stroke
Number of cylinder	:	One
Bore	:	87.5 mm
Stroke	:	110 mm
Compression ratio	:	17.5:1
Maximum power	:	5.2 kW
Speed	:	1500 rev/min
Dynamometer	:	Eddy current
Injection timing	:	23° before TDC
Injection pressure	:	220 kgf/cm^2

ISBN: 978-988-19251-5-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

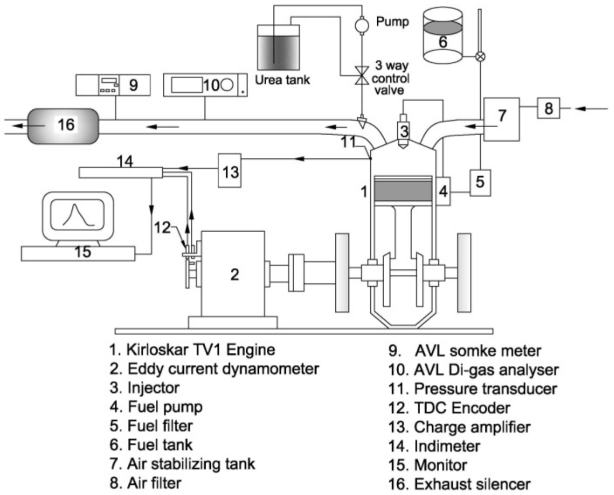


Figure 1. The layout of the engine test bench

B. Engine Test Procedure

The experiments were carried out by using neat diesel as the base line fuel (denoted as B0), 25% biodiesel + 75% diesel (denoted as B25), 50% biodiesel + 50% diesel (denoted as B50), 75% biodiesel + 25% diesel (denoted as B75) and 100% neat biodiesel (denoted as B100) at different engine loads from 0% to 100% rated engine load in approximate steps of 25%. Before running the engine to a new fuel, it was allowed to run for sufficient time to consume the remaining fuel from the previous experiment. To evaluate the performance parameters, important operating parameters such as engine speed, power output, fuel consumption, exhaust emissions and cylinder pressure were measured. Significant engine performance parameters such as specific fuel consumption (SFC), and brake thermal efficiency (BTE) for biodiesel and its blends were calculated.

IV RESULT AND DISCUSSION

4.1 Performance and emission characteristics

The addition of biodiesel as an oxygenated fuel was most effective in rich combustion at high engine loads. At low engine loads, the amount of fuel supplied to the engine was decreased, and the overall mixture was further leaned out. Therefore, the biodiesel addition resulted in different effects on the performance and the emissions at different engine loads.

SFC is the ratio between mass flow of the tested fuel and effective power. Figure 2 shows the SFC variation of the biodiesel and its blends with respect to brake power of the engine. In general, the SFC values of the biodiesel and its blends are slightly higher than those of diesel fuel under all range of engine loads. The lowest SFCs are 0.258, 0.279, 0.285, 0.292, and 0.290 kg/kW h for B0, B25, B50, B75 and B100 respectively. The SFC of diesel engine depends on the relationship among volumetric fuel injection system, fuel density, viscosity and lower heating value. More biodiesel and its blends are needed to produce the same amount of energy due to its lower heating value in comparison with diesel fuel. As found by Ekrem Buyukkaya [1] the SFC was increased with the increasing proportion of biodiesel in the blends.

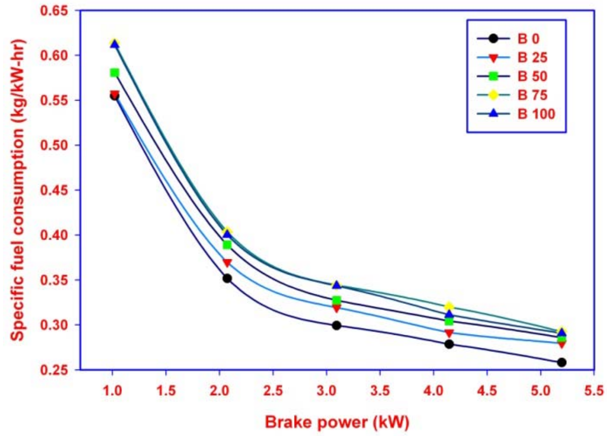


Figure 2. Variation of SFC with brake power for various biodiesel blends

Brake thermal efficiency (BTE) is the ratio between the power output and the energy introduced through fuel injection, the latter being the product of the injected fuel mass flow rate and the lower heating value. BTE calculated for biodiesel and its blends with diesel fuel are shown in Figure 3. The brake thermal efficiency of the B25% blend was better than that of other blends. The reduction in viscosity leads to improved atomization, fuel vaporization and combustion. It may also be due to better utilization of heat energy, and better air entrainment. In addition, the ignition delay time of the above blend is closer to that of diesel. Due to faster burning of biodiesel in the blend, the thermal efficiency was improved. This will be shown later in the heat release curves. The efficiency of the B25% at full load is 32.987%.

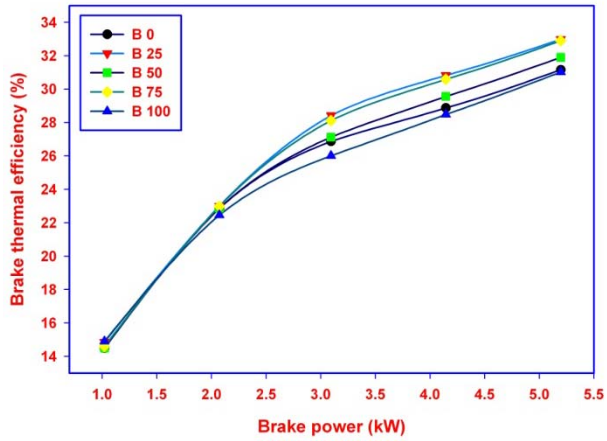


Figure 3. Variation of Brake thermal efficiency with brake power for various biodiesel blends

Figure 4 shows the variations of CO emissions with respect to brake power of the engine. The air–fuel mixing process is affected by the difficulty in atomization of biodiesel due to its higher viscosity. Also, the resulting locally rich mixtures of biodiesel cause more CO to be produced during combustion. However, biodiesel, which contains more number of oxygen atoms, leads to more complete combustion. At low and middle engine loads, the biodiesel has only a slight effect on the CO emissions due to the dominant premixed lean combustion with excess air. The differences between the CO emissions of biodiesel and its blends with diesel fuel are fairly small. At high engine loads, the CO emissions of biodiesel and its blends are evidently lower than those of diesel fuel. The CO emission of diesel fuel is 0.11%, but those of biodiesel and its blends are less than 0.089% at high engine load. This may be due to more oxygen content of biodiesel compared with diesel fuel. In addition, it is likely that this is because the biodiesel has C/H ratio that is less than for diesel fuel [12]. However, the amount of decrease in CO emissions does not depend on biodiesel percentage in the blends. Last et al. [13] also reported that a decrease in CO emissions can be observed when using biodiesel and its blends with diesel fuel but trend in reduction is not linear [14]

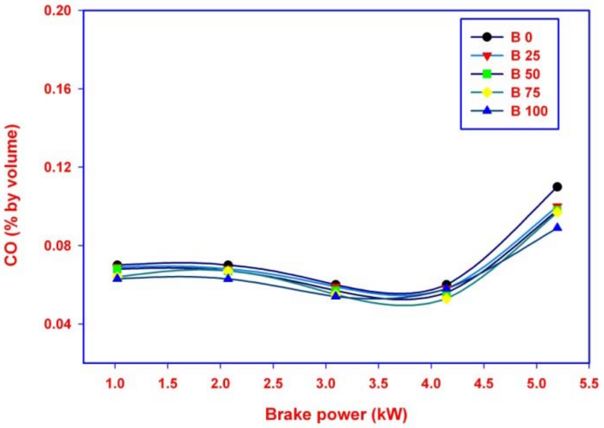


Figure 4. Variation of carbon monoxide with brake power for various biodiesel blends

The variation of HC emission for cottonseed biodiesel blend fuels under various engine loads is shown in figure 5. At a lower load, the blends containing higher percentages of diesel will have higher HC emission. It may be due to the lower viscosity of higher percentages of diesel in the blends, and a larger diesel dispersion region in the combustion chamber. However, at full load, diesel had the highest HC emission. There was a reduction of 25% HC emission for the B 100 blend.

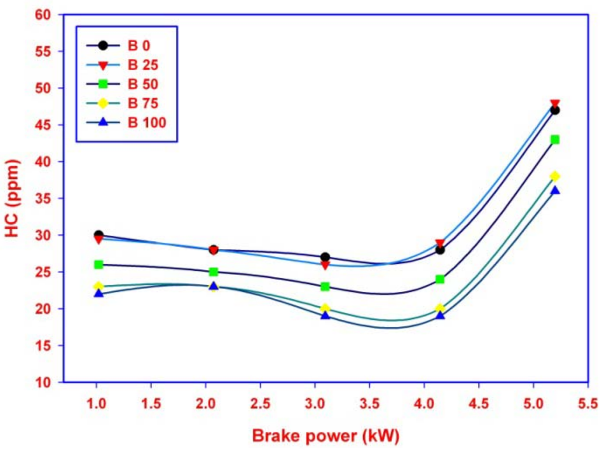


Figure 5. Variation of Hydrocarbon with brake power for various biodiesel blends

Figure 6 shows the variations of NOx emissions with respected to engine loads. There are mainly three factors, oxygen concentration, combustion temperature and time, affecting the NOx emissions. NOx emissions of biodiesel and its blends are slightly higher than those of diesel fuel. The difference of NOx emission between diesel fuel and biodiesel and its blends is no more than 75 ppm. The higher temperature of combustion and the presence of oxygen with biodiesel cause higher NOx emissions, especially at high engine loads. In the same way, Nabi et al. [15] has reported NOx emissions were found to increase due to the presence of extra oxygen in the molecules of biodiesel blends. Approximately 4% increase in NOx emission was realized with 25% biodiesel blends. It has also been reported by Zheng et al. [16] that the biodiesel with a cetane number similar to the diesel fuel produced higher NOx emissions than the diesel fuel. However, the biodiesel with a higher cetane number had comparable NOx emissions with the diesel fuel. A higher cetane number would result in a shortened ignition delay period thereby allowing less time for the air/fuel mixing before the premixed burning phase. Consequently, a weaker mixture would be generated and burnt during the premixed burning phase resulting in relatively reduced NOx formation. Reduction of NOx with biodiesel may be possible with the proper adjustment of injection timing and introducing to exhaust gas recirculation (EGR) or Selective catalytic reduction technology (SCR).

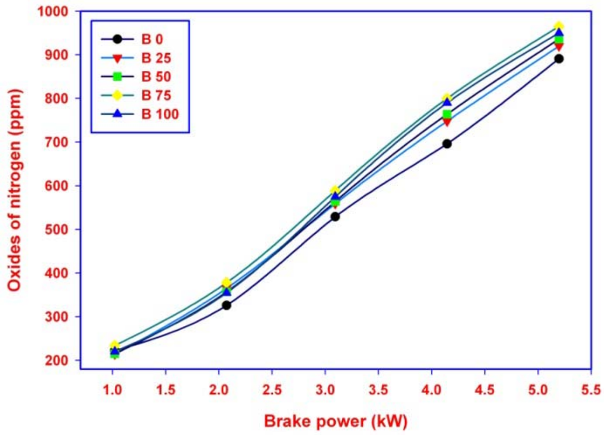


Figure 6. Variation of Oxides of nitrogen with brake power for various biodiesel blends

The variation of smoke emission at different loads for biodiesel blends is shown in figure 7. The significant reduction in smoke emission may be due to the oxygenated blends. Smoke is mainly produced in the diffusive combustion phase; the oxygenated fuel blends lead to an improvement in diffusive combustion for the B 75 blend. Reduction in smoke emission about 36% was recorded at full load for the B 75 blend. Another reason of smoke reduction when using biodiesel is lower C/H ratio and absence of aromatics compounds as compared with diesel fuel. The carbon content in biodiesel is lower than diesel fuel. The more carbon a fuel molecule contains, the more likely it is to produce soot. Conversely, oxygen within a fuel decreases the tendency of a fuel to produce soot [17].

ISBN: 978-988-19251-5-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

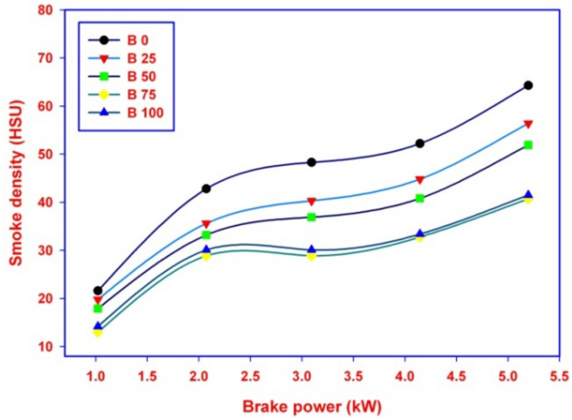


Figure 7. Variation of Smoke density with brake power for various biodiesel blends

4.2 Combustion characteristics

Figure 8 shows the variation of cylinder pressure with crank angle for diesel, biodiesel and its blends at 1500 rpm and full load conditions. From this figure, it is clear that the peak cylinder pressure is decreased with the increase of biodiesel addition in the blends. However, the combustion process of the test fuels is similar, consisting of a phase of premixed combustion following by a phase of diffusion combustion. Premixed combustion phase is controlled by the ignition delay period and spray envelope of the injected fuel [18, 19]. Therefore, the viscosity and volatility of the fuel have very important role to increase atomization rate and to improve air fuel mixing formation. The cylinder peak pressure because of the high viscosity and low volatility of biodiesel and its blends is slightly higher than that of standard diesel. It is observed that the peak pressures of 72.76, 77.76, 75.15, 73.61 and 72.905 bar were recorded for standard diesel, B25, B50, B75 and B100, respectively. Similar conclusions were drawn by other authors in the literature [18, 20]. However, the cylinder peak pressure of biodiesel fuels was close to diesel fuel due to the improvement in the preparation of air fuel mixture as a result of low fuel viscosity [20, 21].

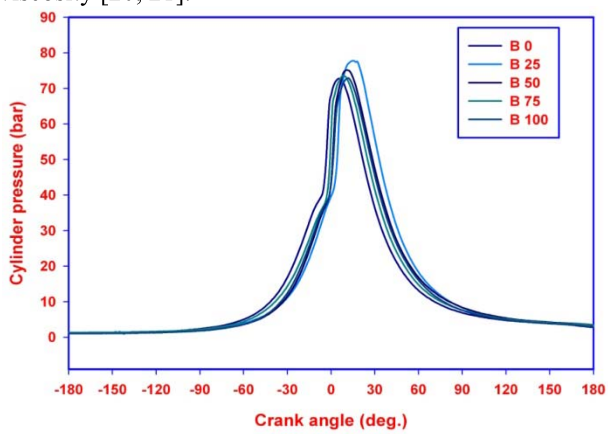


Figure 8. Variation of Cylinder pressure with crank angle

The heat release rate is used to identify the start of combustion, the fraction of fuel burned in the premixed mode, and differences in combustion rates of fuels [22]. Analyses of cylinder pressure data to obtain the heat release rate for biodiesel and its blends were conducted. Figure 9 shows heat release rate indicating that the ignition delay for B100 and its blends was longer than that for diesel. The maximum heat release rate of standard diesel, B25, B50, B75 and B100 is 86.58, 95.96, 94.24, 92.89 and 90.26 respectively. This is because, increased accumulation of fuel during the relatively longer delay period resulted in higher rate of heat release. For B25, B50, B75 blends, the heat release peak was higher than that of B100 due to reduced viscosity and better spray formation. The less intense premixed combustion phase was due to the shorter ignition delay of biodiesel compared with that of diesel. This was probably the result of the chemical reactions during the injection of vegetable oil at high temperature. The similar conclusions were drawn by other authors in the literature, there were at different conclusions. Ozsezen et al. [22] explained that the crude sunflower-oil exhibited, in average, 2.08^0 longer ignition delay due to its lower cetane number when compared with diesel fuel.

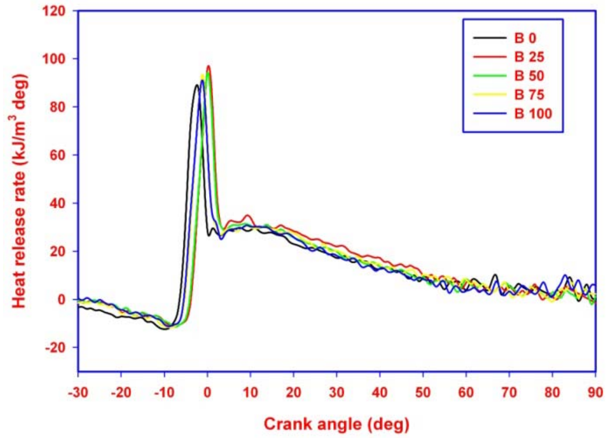
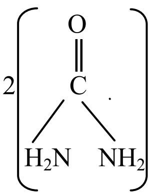


Figure 9. Variation of Heat release with crank angle

4.3 Use of SCR technology

NOx emission of biodiesel and its blends are slightly higher than those of diesel fuel. The higher temperature of combustion and the presence of oxygen with biodiesel cause higher NOx emissions, especially at high engine loads. However, the biodiesel with a higher cetane number had comparable NOx emissions with the diesel fuel. However to reduce the NOx emission the selective catalytic reduction (Urea) is sprayed in the exhaust pipe.

2 

$$+2NO_x+2H_2O \rightarrow 2CO_2+4NH_3+2N_2O_{(x-1)}+O_2$$

[When X should be an even number]

The various percentages of urea sprayed in the engine exhaust to find the optimum percentage. Among the percentage the 30% urea gives the maximum reduction of NOx emission. Based on the trials experimental work was carried out with biodiesel and its blends. Using urea, the onset of NOx reduction is shifted to higher temperatures compared to the use of ammonia, even though the effective temperature 250^{o}C to 350^{o}C for NOx reduction roughly coincides for both selective reduction agents. The efficiency of NOx reduction and NOx to $N_2O_{(x-1)}$ emission increases as the Urea/NOx ratio increases. At high temperature the excess of urea can be oxidized to NOx. Results of this work as well as other literature data suggested [23] that the method chosen for urea injection is important with respect to the $N_2O_{(x-1)}$ emission attained, adding urea at least partially decomposed prior to its interaction with NOx results in similar NO reduction efficiencies but in considerably lower $N_2O_{(x-1)}$ concentrations.

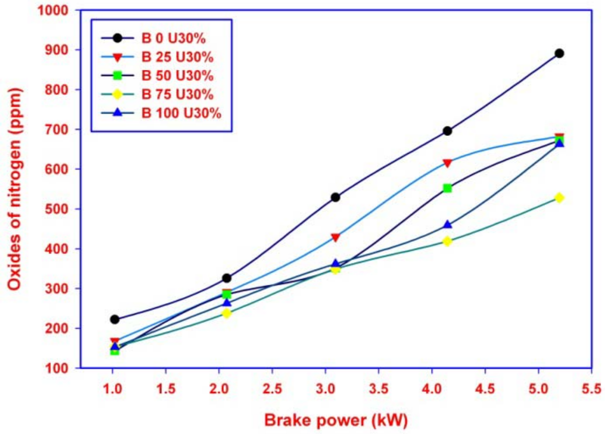


Figure 10. Variation of Oxides of nitrogen with brake power effect of urea 30%

V Conclusions

The performance, emissions and combustion characteristics of a direct injection compression ignition engine fueled with biodiesel and its blends have been analyzed, and compared with the diesel fuel. The biodiesel is produced from raw cotton seed oil by a method of transesterification. The tests for properties of biodiesel demonstrate that almost all the important properties of biodiesel are in close agreement with the diesel engine. This diesel engine can perform satisfactorily on biodiesel and its blends with diesel fuel without any engine modifications.

1. The SFC increases with increase in percentage of biodiesel in the blends due to the lower heating value of biodiesel. The BTE of biodiesel and its blends are slightly higher than that of diesel at high engine loads, and keep almost same at lower engine loads.
2. The oxygen content in the biodiesel results in better combustion and increases the combustion chamber temperature, which leads to higher NOx emissions, especially at high engine loads. The significant improvement in reduction of NOx and a minor increase in CO were identified use of selective catalytic reduction (SCR).
3. HC emissions of biodiesel and its blendes have little difference from diesel fuel. It is also observed that there is a significant reduction in CO and smoke emissions at high engine loads.
4. The combustion starts earlier for biodiesel and its blends than for diesel. The peak cylinder pressure of biodiesel and its blends is higher than that of diesel fuel, and almost identical at high engine loads. The peak pressure rise rate and peak heat release rate of biodiesel are higher than those of diesel fuel.

The study tacitly suggests that excess oxygen contents of biodiesel play a key role in engine performance and biodiesel is proved to be a potential fuel for complete or partially replacement of diesel fuel.

Reference

[1] Ekrem Buyukkaya. Effect of biodiesel on a DI diesel engine performance, emission and combustion characteristics. Fuel 89 (2010) 3099-3105.
[2] Hansen AC, Zhang Q, Lyne PWL. Ethanol–diesel fuel blends – a review. Bioresource Technol 2005;96:277–85.
[3] Ecklund EE, Bechtold RL, Timbario TJ, McCallum PW. State-of-the-art report on the use of alcohols in diesel engines. SAE paper no. 840118; 1984.
[4] Rakopoulos DC, Rakopoulos CD, Kakaras EC, Giakoumis EG. Effects of ethanol– diesel fuel blends on the performance and exhaust emissions of heavy duty DI diesel engine. Energy Convers Manage 2008;49:3155–62.
[5] Miers SA, Carlson RW, McConnell SS, Ng HK, Wallner T, Esper JL. Drive cycle analysis of butanol/diesel blends in a light-duty vehicle. SAE paper no. 2008- 01-2381; 2008.
[6] Hansen AC, Kyritsis DC, Lee CF. Characteristics of biofuels and renewable fuel standards. In: VertesBlaschek AA, Blaschek HP, Yukawa H, Qureshi N, editors. Biomass to biofuels – strategies for global industries. New York: John Wiley; 2009.
[7] Graboski MS, McCormick RL. Combustion of fat and vegetable oil derived fuels in Diesel engines. Prog Energy Combust Sci 1998;24:125–64.
[8] Demirbas A. Biodiesel fuels from vegetable oils via catalytic and non-catalytic supercritical alcohol transesterifications and other methods: a survey. Energy Convers Manage 2003;44:2093–109.
[9] Rakopoulos CD, Antonopoulos KA, Rakopoulos DC, Hountalas DT, Giakoumis EG. Comparative performance and emissions study of a direct injection diesel engine using blends of diesel fuel with vegetable oils or bio-diesels of various origins. Energy Convers Manage 2006;47:3272–87.
[10] Bueno AV, Velasquez JA, Milanez LF. Heat release and engine performance effects of soybean oil ethyl ester blending into diesel fuel. In: Proceedings of the 22nd International Conference on 'ECOS 2009', Foz do Iguacu/Parana, Brazil, August 31–September 3; 2009. p. 2009–18.
[11] 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. Renew Energy 2009;34:2706–13.
[12] Nabi N, Akhter S, Shahadat MZ. Improvement of engine emissions with conventional diesel fuel and diesel–biodiesel blends. Bioresour Technol 2006;97:372–8.
[13] Last RJ, Kruger M, Durnholz M. Emissions and performance characteristics of a 4-stroke, direct injected diesel engine fuelled with blends of biodiesel and low sulphur diesel fuel. SAE paper, no. 950054; 1995.
[14] Lapuerta M, Armas O, Rodriguez-Fernandez J. Effect of biodiesel fuels on engine emissions. Prog Energy Combust Sci 2008;34:198–223.
[15] Nabi N, Rahman M, Akhter S. Biodiesel from cotton seed oil and its effect on engine performance and exhaust emissions. Appl herm Eng 2009;29:2265–70.
[16] Zheng M, Mulenga MC, Reader GT, Wang M, Ting DSK, Tjong J. Biodiesel engine performance and emissions in low temperature combustion. Fuel 2008;87(6):714–22.
[17] Tree DR, Svensson KI. Soot processes in compression ignition engines. Prog Energy Combust Sci 2007;33:272–309.
[18] Senthil KM, Kerihuel A, Bellettre J, Tazerout M. Experimental investigations on the use of preheated animal fat as fuel in a compression ignition engine. Renew Energy 2005;30:2314–23.
[19] Devan PK, Mahalakshmi NV. Study of the performance, emission and combustion characteristics of a diesel engine using poon oil-based fuels. Fuel Process Technol 2009;90:513–9.
[20] Devan PK, Mahalakshmi NV. Performance, emission and combustion characteristics of poon oil and its blends in a DI diesel engine. Fuel 2009;88:861–7.
[21] Ozsezen AN, Canakci M, Turkcan A, Sayin C. Performance and combustion characteristics of a DI diesel engine fueled with waste palm oil and canola oil methyl esters. Fuel 2009;88:629–36.
[22] Canakcı M, Ozsezen AN, Turkcan A. Combustion analysis of preheated crude sunflower oil in an IDI diesel engine. Biomass Bioenergy 2009;33:760–7.
[23] Maria U. Alzueta, Hanne Røjel, Per G. Kristensen, Peter Glarborg, and Kim Dam-Johansen. Laboratory study of the co/nh3/no/o2 system: implications for hybrid reburn/sncr strategies. Energy & Fuels 1998 12(5) PP1001-1007.