International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 12, December - 2013

# Experimental Studies on the Combustion Characteristics and Performance of A Direct Injection Diesel Engine Fueled with Rice-Bran Oil Derived Biodiesel/Diesel Blends

K. Ashok[1*], N. Alagumurthi[2], K. Palaniradja[3], C. G. Saravanan[4]
[1]Associate Professor, [2]Professor, [3]Associate Professor, [4]Professor
[1,2,3]Department of Mechanical Engineering, Pondicherry Engineering College, Puducherry-605 014.
[4]Department of Mechanical Engineering, Annamalai University, Annamalainagar-608 002.

***Abstract -*** Biodiesel is an oxygenated, sulfur-free, biodegradable, non-toxic, and environmentally friendly alternative diesel fuel. It is consisting of the alkyl monoesters of fatty acids from vegetable oils or animal fats. Biodiesel can be derived from renewable resources, such as vegetable oils, animal fats, and waste restaurant greases.

Currently, most biodiesel is made from vegetable oil, methanol, and an alkaline catalyst. One of the attractive characteristics of biodiesel is that its use does not require any significant modifications to the diesel engine, so the engine does not have to be dedicated for biodiesel. However, due to its different properties, biodiesel will cause some changes in the engine performance and emissions including lower power and higher oxides of nitrogen. Biodiesel can be blended in any proportion with petroleum-based diesel fuel and the impact of the changes is usually proportional to the fraction of biodiesel being used. The objective of this study was the investigation of the effect of biodiesel blend level on diesel engine.

In this study, the biodiesel produced from rice-bran oil was prepared by a method of trans-esterification and its blends of 20%, 40%, 60%, 80% and 100% in volume and standard diesel separately were used as fuel. The effects of biodiesel addition to diesel fuel on the performance, emission and combustion characteristics of a naturally aspirated direct injection compression ignition engine were examined.

***Keywords*.**Alternative fuel, diesel, biodiesel, fuel, methyl ester, rice-bran oil.

## I.INTRODUCTION

Limited energy resources and increasingly strict emission regulations have motivated an intense search for alternative transportation fuels over the last three decades. However, similar to alcohol fuels, biodiesel has slightly lower energy content and different physical properties than diesel fuel [1,2,3]. Biodiesel has received much attention in the past decade due to its ability to replace fossil fuels, which is a deplete-able source of energy. The concern for environmental issues with the emission of exhaust gases by burning fossil fuels has encouraged the usage of biodiesel, which is ecofriendly in nature [4]. With exception of hydroelectricity and nuclear energy, the major part of all energy consumed worldwide comes from petroleum, charcoal and natural gas. However these sources are limited, and will be exhausted by the end of the next century. Thus, looking for alternative sources of energy is of vital importance.

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 [5,6].

The advantages of bio-diesels as diesel fuel are the minimal sulfur and aromatic content, and higher flash point, lubricity, Cetane number, biodegradability and nontoxicity. On the other hand, their disadvantages which includethe 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 in References. [7,8].

A recent work by the authors [7] studied andcompared an extended variety of vegetable oils and biodieselsof various origins tested in blends with the normaldiesel fuel, ranging from the palm oil associated withwarm climates to soybean and rapeseed oil associatedwith temperate climates,incorporating in-betweenvegetable oils grown in temperate to warm climates(e.g.in theMediterranean area), such as cottonseed oil,sunflower oil, corn oil, olive kernel oil and their methylesters. Thus, a clearer picture was produced showing therelative performance and emissionscharacteristics ofthese fuels.

In the present study, rice-bran oil wasconsidered as a potential alternative fuel for anunmodified diesel engine because it has high oil content(around 40%) for biodiesel production. Main aim of thisstudy is to investigate the engine performance, emissionand combustion characteristics of a diesel engine fuelledwith methyl esters of rice-bran oil and its diesel blends compared tothose of standard diesel.

## II. PRODUCTION OF BIODIESEL AND ITS CHARACTERIZATION

### *A. Procedure for Production of Biodiesel*

In this study,the biodiesel fuel used was producedfrom the trans-esterification of raw rice-bran oil withmethanol ($CH_3OH$) catalyzed by Potassium Hydroxide(KOH). Theamount of KOH needed to neutralize the free fatty acidsin raw rice-bran oil was determined by performing a titration. The amount of KOH needed ascatalyst for every liter of rice-bran oil wasdetermined as 18 g. For trans-esterification, 240 mL$CH_3OH$ plus the required amount of KOH were added forevery liter of rice-bran oil, and the reactions werecarried out at 450°C. The water wash process wasperformed by using a sprinkler which slowly sprinkledwater into the biodiesel container until there was an equalamount of water and biodiesel in the container. The waterbiodiesel mixture was then agitated gently for 20 min,allowing the water to settle out of the biodiesel. After themixture had settled, the water was drained out.

### *B. Properties of Biodiesel*

To characterize thecompositions and properties of the produced biodiesel, a series of tests were performed.The properties of biodiesel as fuel and its blends with dieselfuel are shown in Table 1. It is shown that the viscosity ofbiodiesel is evidently higher than that of diesel fuel. Thedensity of the biodiesel is approximately 6.02% higherthan that of diesel fuel. The lower heating value isapproximately 9.08% lower than that of diesel fuel.Therefore, it is necessary to increase the fuel amount tobe injected into the combustion chamber to produce sameamount of power. Fuels with flash point above 520°C areregarded as safe. Thus, biodiesel is an extremely safe fuelto handle compared to diesel fuel. Even 25% biodieselblend has a flash point much above that of diesel fuel;making biodiesel a preferable choice as far as safety isconcerned. The analysis results of cold filter clogging temperature, a criterion used for low temperatureperformance of the fuels, suggest that the performance ofbiodiesel 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 diesel fuel and biodiesel blends (Source: Laboratory evaluation at Etalab –Chennai)*

| **Properties** | **Diesel** | **B50** | **B100** |
|---|---|---|---|
| Density @ 15°C in gm/cc | 0.8344 | 0.8576 | 0.8908 |
| Specific Gravity @ 15/15°C | 0.8360 | 0.8583 | 0.8916 |
| Kinematic Viscosity @ 40°C in CST | 3.07 | 4.10 | 6.46 |
| Acidity as mg of KOH/gm | - | 0.16 | 0.22 |
| Flash point by PMC (°C) | 60 | 56 | 150 |
| Fire point (°C) | 69 | 67 | 162 |
| Gross Calorific Value in Kcal/kg | 44125 | 10,472 | 10,402 |
| Sulphur | 0.05% | 0.043% | 0.052% |
| Cetane No. | 51 | 52.5 | 52 |

## **III.** EXPERIMENT

### *A. Equipment and method*

The engine Kirloskar TV1 was used; its mainparameters are shown in Table 2.

The engine bench is shown in Figure 1. An eddycurrentdynamometer was connected with the engine andused to measure the engine power. An exhaust gasanalyzer (AVL Di-gas analyzer) was employed tomeasure NOx, HC, CO, $O_2$ and $CO_2$ emission on line. Toinsure that the accuracy of the measured values was high,the gas analyzer was calibrated before each measurementusing reference gases. The AVL smoke meter wasused to measure the smoke density. The smoke meter was alsoallowed to adjust its zero point before each measurement.The AVL combustion analyzer is used to measure thecombustion 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$^2$ |

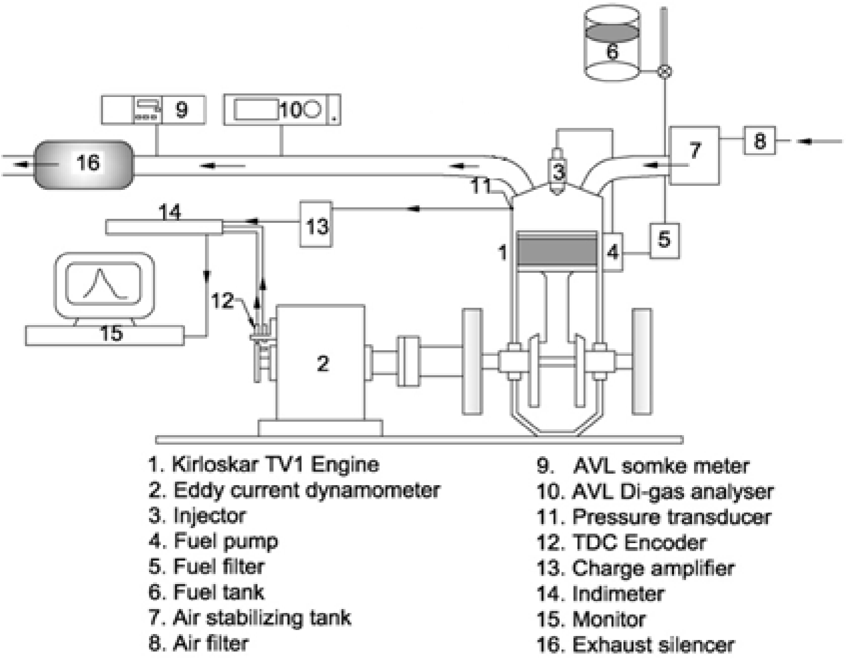

*Figure 1.Thelayoutof the engine test bench*

### *B. Engine Test Procedure*

The experiments were carried out by using diesel fuel as the base line data (B0), the various biodiesel blends; 20% biodiesel+ 80% diesel (B20), 40% biodiesel + 60% diesel (B40), 60% biodiesel + 40% diesel (B60), 80% biodiesel + 20% diesel (B80) and 100% neat biodiesel (B100) at different engine loads from 0% to 100% ratedengine load in approximate steps of 20%. Before runningthe engine to a new fuel, it was allowed to run forsufficient time to consume the remaining fuel from theprevious experiment. To evaluate the performanceparameters, important operating parameters such asengine speed, power output, fuel consumption, exhaustemissions and cylinder pressure were measured.Significant engine performance parameters such asspecific fuel consumption (SFC), and brake thermalefficiency (BTE) for biodiesel and its blends werecalculated.

## IV. RESULT AND DISCUSSION

### *4.1 Performance and emission characteristics*

The addition of biodiesel as an oxygenated fuel wasmost effective in rich combustion at high engine loads. Atlow engine loads, the amount of fuel supplied to theengine was decreased, and the overall mixture was furtherleaned out. Therefore, the biodiesel addition resulted indifferent effects on the performance and the emissions atdifferent engine loads.

SFC is the ratio between mass flow of the tested fueland effective power. Figure 2 shows the SFC variation ofthe biodiesel and its blends with respect to brake power ofthe engine. In general, the SFC values of the biodieseland its blends are slightly higher than those of diesel fuelunder all range of engine loads. The lowest SFCs are0.274, 0.291, 0.293, 0.306, and 0.321 kg/kW h for B0,B20, B40, B60 and for both B80 &B100 respectively. The SFC of dieselengine depends on the relationship among volumetric fuelinjection system, fuel density, viscosity and lower heatingvalue. More biodiesel and its blends are needed toproduce the same amount of energy due to its lowerheating value in comparison with diesel fuel.

The SFC ingeneral, was found to increase with increasing proportion of B100in the fuel blends with diesel, whereas it decreases sharply withincrease in load for all fuels. The main reason for this could be thatpercent increase in fuel required to operate the engine is less thanthe percent increase in brake power due to relatively less portion ofthe heat losses at higher loads.As the SFC was calculated on weight basis obviously higherdensities resulted in higher values for SFC. As density of biodieselwas higher than that of diesel, which means, the same fuelconsumption on volume basis resulted in higher SFC in case of100% biodiesel. The higher densities of biodiesel blends causedhigher mass injection for the same volume at the same injectionpressure. The calorific value of biodiesel is less than diesel.

Due tothese reasons, the SFC for other blends was higher than that ofdiesel. Similar trends of SFC with increasing load in differentbiodiesel blends were also reported by other researchers [9,10,11,12]while testing biodiesel obtained from Karanja, Mahua and Hongeoils.As found byEkremBuyukkaya [4] the SFC was increased with theincreasing proportion of biodiesel in the blends.

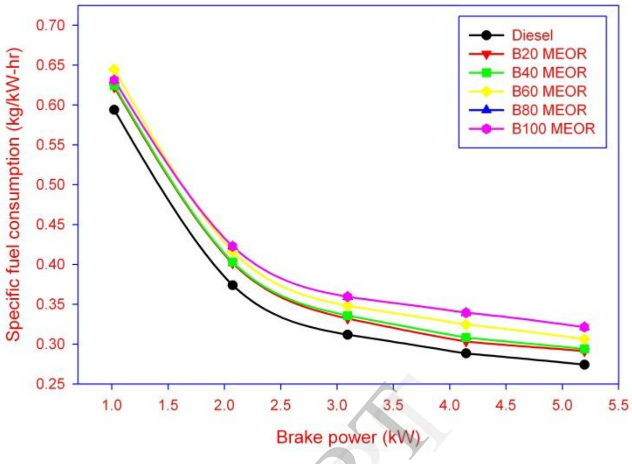

*Figure 2.Comparison of SFC with brake power for diesel, methyl esters of rice-bran and its blends*

Brake thermal efficiency (BTE) is the ratio betweenthe power output and the energy introduced through fuelinjection, the latter being the product of the injected fuelmass flow rate and the lower heating value. BTEcalculated for biodiesel and its blends with diesel fuel areshown in Figure 3. The brake thermal efficiency of theB20 blend was better than that of other blends. Thereduction in viscosity leads to improved atomization, fuelvaporization and combustion. It may also be due to betterutilization of heat energy, and better air entrainment. Inaddition, the ignition delay time of the above blend iscloser to that of diesel.

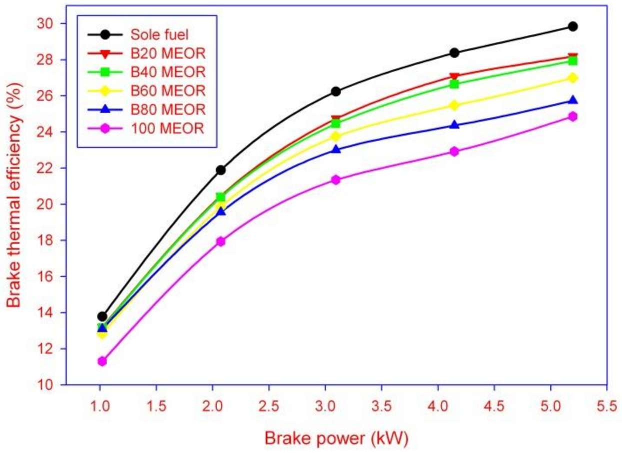

*Figure 3.Comparison of Brake thermal efficiency withbrake power for diesel, methyl esters of rice-bran oil and its blends*

Due to faster burning of biodieselin the blend, the thermal efficiency was improved. Thiswill be shown later in the heat release curves. Theefficiency of the B20 at full load is 28.185%.

The variations of Exhaust Gas Temperature (EGT) with respect to engine loading are presented in Figure4. In general, the EGT increased with increase inengine loading for all the fuel tested. The mean temperature increased linearly from 125°C at no load to 288°C at full loadcondition with an average increase of 15% with every 20% increasein load. This increase in exhaust gas temperature with load isobvious from the simple fact that more amount of fuelwas requiredin the engine to generate that extra power needed to take up theadditional loading. The exhaust gas temperature was found toincrease with the increasing concentration of biodiesel in theblends. The mean EGTs of the various blends were higher than the mean EGT of diesel. Thiscould be due to the increased heat loss of the higher blends, whichare also evident from, their lower brake thermal efficiencies ascompared to diesel.

Similar findings were obtained by other researchers [9,10,13,14,15]while testing different biodiesel.

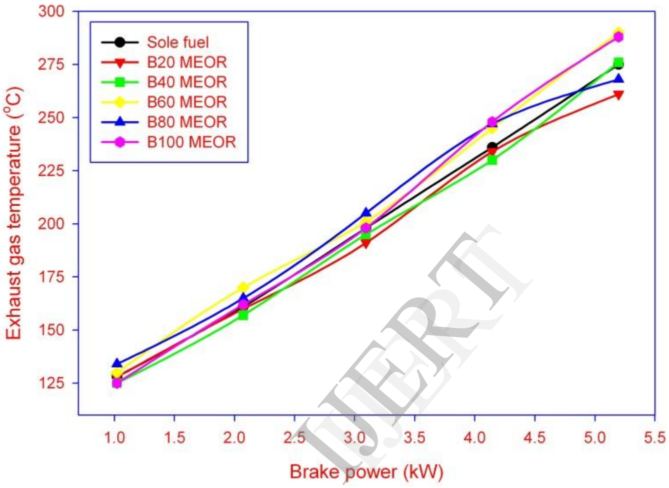

*Figure4. Comparison of exhaust gas temperature(EGT) with brake power for diesel, methyl ester of rice-bran oil and its blends.*

The variation of HC emission for rice-branbiodiesel blends under various engine loads is shownin figure 5. At a lower load, the blends containing higherpercentages of diesel will have higher HC emission. Itmay be due to the lower viscosity of higher percentagesof diesel in the blends, and a larger diesel dispersionregion in the combustion chamber. However, at full load,diesel had the highest HC emission. There was areduction of 25% HC emission for the B 100 blend.There is a reduction from 55 ppm to 44 ppm at the maximum power output of 5.2 kW. Thesereductions indicate that more complete combustion of the fuelsand thus, HC level decreases significantly.

Figure 6 shows the variations of NOx emissions withrespected to engine loads. There are mainly three factors,oxygen concentration, combustion temperature and time,affecting the NOx emissions. NOx emissions of biodieseland its blends are slightly higher than those of diesel fuel.The difference of NOx emission between diesel fuel andbiodiesel and its blends is no more than 60 ppm. Thehigher temperature of combustion and the presence ofoxygen with biodiesel cause higher NOx emissions,especially at high engine loads. In the same way, Nabi etal. [16] has reported NOx emissions were found toincrease due to the presence of extra oxygen in themolecules of biodieselblends. It has also been reported by Zheng et al.[17] that the biodiesel with a Cetane number similar to thedieselfuel produced higher NOx emissions than thediesel fuel. However, the biodiesel with a higherCetane number had comparable NOx emissions with the diesel fuel.

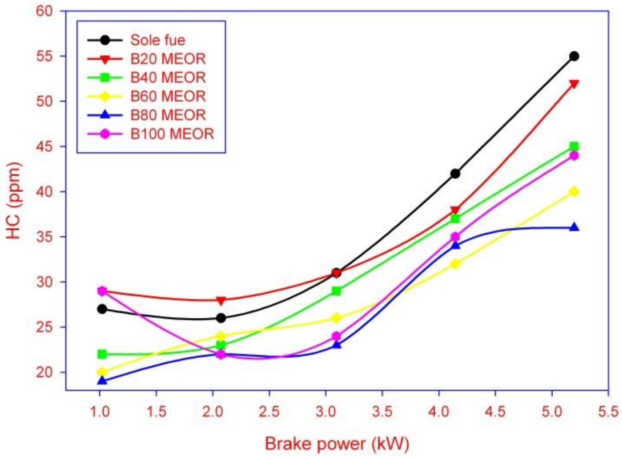

*Figure 5. Variation of Hydrocarbon with brake power for diesel, methyl esters of rice-bran oil and its blends*

A higher Cetane number would result in a shortenedignition delay period thereby allowing less time for theair/fuel mixing before the premixed burning phase.Consequently, a weaker mixture would be generated andburnt during the premixed burning phase resulting inrelatively reduced NOx formation. Reduction of NOxwith biodiesel may be possible with the properadjustment of injection timing and introducing to exhaustgas recirculation (EGR) or Selective catalytic reductiontechnology (SCR).

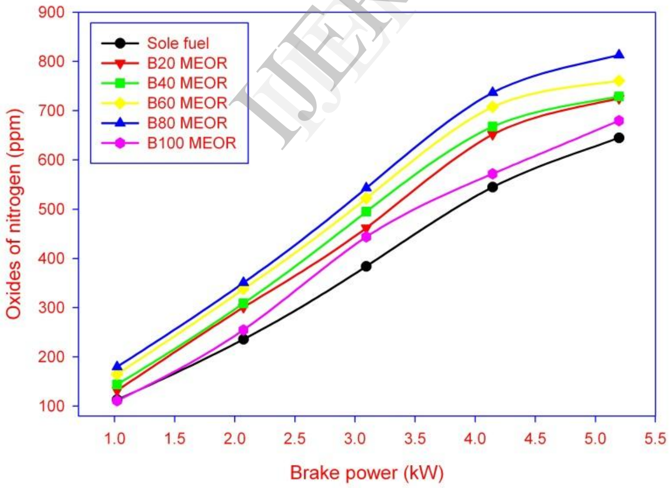

*Figure 6. Variation of Oxides of nitrogen with Brake Power for diesel, methyl ester of rice-bran oil and its blends.*

The variation of smoke emission at different loadsfor biodiesel blends is shown in figure 7. The significantincrease in smoke emission may be due to theoxygenated blends. Smoke is mainly produced in thediffusive combustion phase; the oxygenated fuel blendslead to an improvement in diffusive combustion. Another reasonof smoke emission when using biodiesel is lower C/Hratio and absence of aromatic compounds as comparedwith diesel fuel. The carbon content in biodiesel is lowerthan diesel fuel. The more carbon a fuel moleculecontains, the more likely it is to produce soot.Conversely, oxygen within a fuel decreases the tendencyof a fuel to produce soot [18].

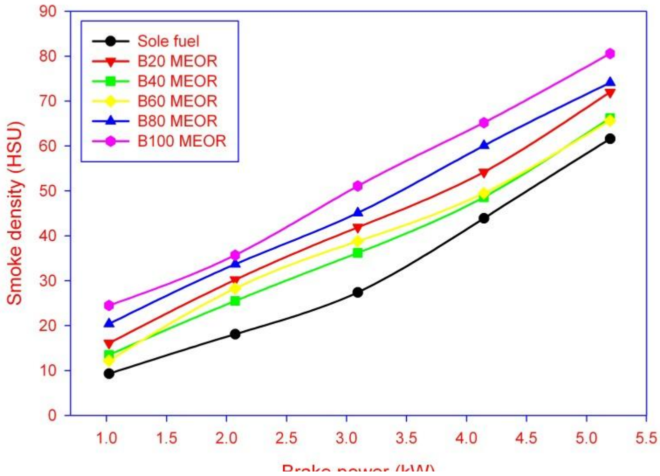

*Figure 7. Variation of Smoke density with brake power for diesel, methyl ester of rice-bran oil and its blends.*

### 4.2 Combustion characteristics

Figure 8 shows the variation of cylinder pressurewith crank angle for diesel, biodiesel and its blends at1500 rpm and full load conditions. From this figure, it isclear that the peak cylinder pressure is decreased with theincrease of biodiesel addition in the blends. However, thecombustion process of the test fuels is similar, consistingof a phase of premixed combustion following by a phaseof diffusion combustion. Premixed combustion phase iscontrolled by the ignition delay period and sprayenvelope of the injected fuel [19, 20]. Therefore, theviscosity and volatility of the fuel have very importantrole to increase atomization rate and to improve air fuelmixing formation. The cylinder peak pressure because ofthe high viscosity and low volatility of biodiesel and itsblends is slightly higher than that of standard diesel. It isobserved that the peak pressures of 67.847, 66.582, 65.106,64.802,65.634 and 66.714 bar were recorded for standard diesel,B20, B40, B60, B80 and B100, respectively. Similarconclusions were drawn by other authors in the literature[19, 21]. However, the cylinder peak pressure of biodieselfuels was close to diesel fuel due to the improvement inthe preparation of air fuel mixture as a result of low fuelviscosity [21, 22].

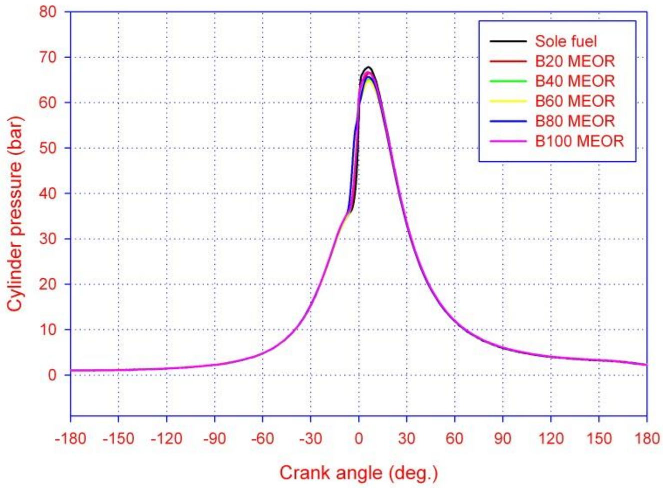

*Figure 8. Variation of Cylinder pressure with crank angle*

The heat release rate is used to identify the start ofcombustion, the fraction of fuel burned in the premixedmode, and differences in combustion rates of fuels [23].Analyses of cylinder pressure data to obtain the heatrelease rate for biodiesel and its blends were conducted.Figure 9 shows heat release rate indicating that theignition delay for B100 and its blends was shorter thanthat for diesel. The maximum heat release rate of standarddiesel, B20, B40, B60, B80 and B100 is 145.387, 109.253, 86.993,76.992, 70.227 and 104.252 respectively. The less intense premixed combustion phasewas due to the shorter ignition delay of biodieselcompared with that of diesel. This was probably the resultof the chemical reactions during the injection of vegetableoil at high temperature. The similar conclusions weredrawn by other authors in the literature, there were atdifferent conclusions. Ozsezen et al. [23] explained thatthe crude sunflower-oil exhibited, in average, 2.080longer ignition delay due to its lower cetane numberwhen compared with diesel fuel.

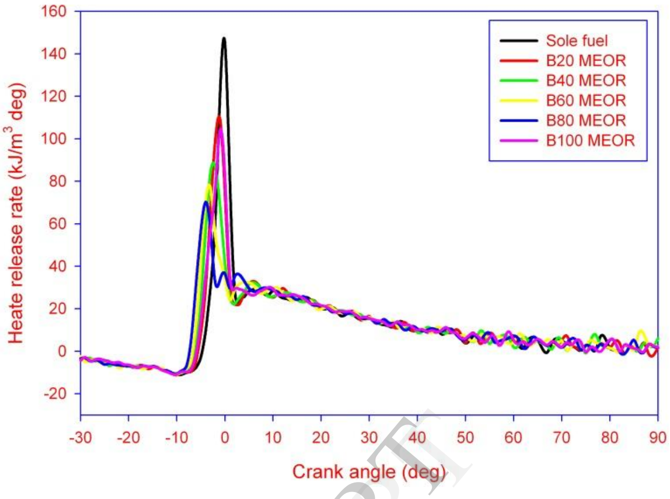

*Figure 9. Variation of Heat release with crank angle*

## V. **CONCLUSIONS**

The performance, emissions and combustioncharacteristics of a direct injection compression ignitionengine fueled with biodiesel and its blends have beenanalyzed, and compared with the diesel fuel. Thebiodiesel is produced from rice-bran oil by amethod of trans-esterification. The tests for properties ofbiodiesel demonstrate that almost all the importantproperties of biodiesel are in close agreement with thediesel fuel. This diesel engine can performsatisfactorily on biodiesel and its blends with diesel fuelwithout any engine modifications.

1. The SFC increases with increase in percentage ofbiodiesel in the blends due to the lower heating value ofbiodiesel. The BTE of biodiesel and its blends are slightlyhigher than that of diesel at high engine loads, and keepalmost same at lower engine loads.

2. The oxygen content in the biodiesel results in bettercombustion and increases the combustion chambertemperature, which leads to higher NOx emissions,especially at high engine loads.

3. HC emissions of biodiesel and its blends have littledifference from diesel fuel.

4. The combustion starts earlier for biodiesel and itsblends than for diesel. The peak cylinder pressure ofbiodiesel and its blends is lower than that of diesel fuel,and almost identical at high engine loads. The peakpressure rise rate and peak heat release rate of biodieselare lower than those of diesel fuel.

Based on the results of this study, the following specificconclusions were drawn:

1. The fuel properties of rice-bran biodiesel were within limitsexcept calorific value; all other fuel properties of rice-bran biodieselwere found to be similar as compared to diesel.

2. The brake specific fuel consumption increased and brakethermal efficiency decreased with increase in the proportion ofbiodiesel in the blends. A reverse trend was observed withincrease in engine load.

3. The amount of CO and HC in exhaust emission reduced,whereasNOx increased with increase in percentage ofrice-bran biodiesel in the blends. However, the level of emissionsincreased with increase in engine load for all fuelstested.

4. The performance and emission parameters for different blendswere better compared with diesel.

From these findings, it is concluded that rice-bran biodiesel couldbe safely blended with diesel up to 20% without significantlyaffecting the engine performance (SFC, EGT) and emissions(CO, HC and NOx) and thus could be a suitable alternative fuel fordiesel engines.

The study suggests that excess oxygencontents of biodiesel play a key role in engineperformance and biodiesel is proved to be a potential fuelfor complete or partially replacement of diesel fuel.

## REFERENCE

1. Tat, M.E. and Van Gerpen, J.H. The Kinematic Viscosity of Biodiesel and Its Blends with Diesel Fuel. Journal of American Oil Chemists Society, (1999), Vol. 76, no. 12, 1511-1513.
2. Tat, M.E. and Van Gerpen, J.H. The Specific Gravity of Biodiesel and Its Blends with Diesel Fuel. Journal of American Oil Chemists Society, (2000a),Vol. 77, no. 2, 115-119.
3. Tat, M.E., Van Gerpen, J.H., Soylu, S., Canakci, M., Monyem, A. and Wormley, S. The Speed of Sound and Isentropic Bulk Modulus of Biodiesel at 21 °C from Atmospheric Pressure to 35 MPa. Journal of American Oil Chemists Society, (2000b), Vol. 77, no. 3, 285-289.
4. EkremBuyukkaya, Effect of biodiesel on a DI diesel engine performance, emission and combustion characteristics. Fuel 89 (2010) 3009-3105.
5. Graboski MS, McCormick RL. Combustion of fat and vegetable oil derived fuels in Diesel engines. Prog Energy Combust Sci 1998;24:125–64.
6. 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.
7. 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 fuelwith vegetable oils or bio-diesels of various origins. Energy Convers Manage 2006; 47:3272–87.
8. 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.
9. Raheman H, Ghade SV. Performance of compression ignition engine withMahua (Madhucaindica) biodiesel. Fuel 2007;86:2568–73.
10. Raheman H. Diesel engine emissions and performance from blends ofKaranja methyl ester and diesel. Elsevier. Biomass Bioenerg 2004;27:393–7.
11. Hickman AJ, Graham MA. Performance related exhaust emissions from heavyduty diesel engines. Elsevier Science Publishers.Sci Total Environ1993;134:211–23.
12. MustufaCanakei, AhmetErdil, Erol, ArcaKlioghu. Performance and exhaustsemissions of a bio-diesel engine. ApplEnerg 2006;83:594–605.
13. AK Agarwal, S Garg. Characterization and utilization of biodiesel as an alternativefuels for diesel engines. Consultative workshop in scientific strategiesfor production of non-edible oils for use as bio-fuels. Organized by JagadguruSri Shivarathreeshwara Academy of Technical Education in Bangalore on 6–7September 2003.

14. Ramdas AS, Jayraj S, Muralidharan C. Use of vegetable oils as Internalcombustion engine fuels-A review. Renewable Energy 2004;29:729–42.
15. Agarwal AK. Biofuels (alcohols and biodiesel) applications as fuels for internalcombustion engines. Progress in energy and combustion science 2007;33:233–71.
16. Nabi N, Rahman M, Akhter S. Biodiesel from cotton seed oil andits effect on engine performance and exhaust emissions. Applherm Eng 2009;29:2265–70.
17. Zheng M, Mulenga MC, Reader GT, Wang M, Ting DSK, TjongJ. Biodiesel engine performance and emissions in low temperaturecombustion. Fuel 2008;87(6):714–22.
18. Tree DR, Svensson KI. Soot processes in compression ignitionengines. Prog Energy Combust Sci 2007;33:272–309.
19. Senthil KM, Kerihuel A, Bellettre J, Tazerout M. Experimentalinvestigations on the use of preheated animal fat as fuel in acompression ignition engine. Renew Energy 2005;30:2314–23.
20. Devan PK, Mahalakshmi NV. Study of the performance, emissionand combustion characteristics of a diesel engine using poon oilbasedfuels. Fuel Process Technology 2009;90:513–9.
21. Ozsezen AN, Canakci M, Turkcan A, Sayin C. Performance andcombustion characteristics of a DI diesel engine fueled with wastepalm oil and canola oil methyl esters. Fuel 2009;88:629–36.
22. Devan PK, Mahalakshmi NV. Performance, emission andcombustion characteristics of poon oil and its blends in a DI dieselengine. Fuel 2009;88:861–7.
23. Canakcı M, Ozsezen AN, Turkcan A. Combustion analysis ofpreheated crude sunflower oil in an IDI diesel engine. BiomassBioenergy 2009;33:760–7.