Effects of Biodiesel and its Blends with Diesel on the Performance and Emission Characteristics of A Di-Diesel Engine

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Abstract

In this study high speed diesel (HSD),biodiesel blend (B20),acrylic acid blend (E18A2) and biodiesel-acrylic acid ternary blend(B20+E18A2) were tested on a single cylinder four stroke naturally aspirated direct injection diesel engine. Experiments were conducted under four loading conditions at a rated speed of 1500 rpm. The performance and emission analysis were carried out for the full range of loading at standard conditions. The results revealed that the addition of biodiesel leads to increase in brake specific fuel consumption whereas the acid blend and ternary blends shows reduced BSFC at all loading conditions. On the other hand the brake thermal efficiency increased while adding oxygenated additives separately to base fuel and with biodiesel as ternary blend when compared to biodiesel blend. Biodiesel (B20) blend showed lower carbon monoxide and hydrocarbon emissions compared to other test fuels. All test fuels showed higher NOx emission when compared to the base fuel (HSD).

Keywords: *Acrylic acid, Ethanol, Emission, thermal efficiency, Brake specific fuel consumption, Cetane Number, additive.*

I. Introduction

Due to depletion in fossil fuel reserves and stringent emission norms the transportation sectors faces serious fuel crisis in recent times. The best solution for this current scenario is to search for alternate sources of energy. Biodiesel is one of the most promising alternate energy source, which is renewable, non-toxic and bio degradable methyl esters of edible oils, non edible oils and tallow fat. Vegetable oils and animal fats are not suitable for direct replacement of fuel due to their high viscosity, longer molecular chain, higher flash points, and lower vapour pressures. However these fundamental problems can be reduced and physical features of fuel can be improved through esterification [1].Some of the commonly used vegetable oils for biodiesel production are rapeseed oil [2], soya bean

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oil [3],cottonseed oil [4],coconut oil [5] ,waste cooking oil [6], Jatropha Curcus [7],rice bran oil [8], etc.

Due to high cetane number and oxygen content, usage of biodiesel reduces hydrocarbons and particulate matters compared to neat diesel. On the other hand adding oxygenated additives like ethanol in the fuel blend results in increase of brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE) gradually when compared with neat diesel. With addition of ethanol in poultry fat methyl ester blend improves the cold flow operability due to the reduction in viscosity of the blend [9]. The high oxygen content of biodiesel leads to high combustion temperature which in turn increases the NOx emissions. Some of the techniques like using additives and adopting exhaust gas recirculation pave way to reduce NOx emissions when using biodiesel [10]. Also the addition of nano aluminium particles to ethanol fuel increases the amount heat released linearly with nano aluminum concentration [11].

Effective blending of 20 % ethanol with neem oil increases BTE and reduces smoke intensity. As well as a slight reduction in NOx emission was also observed in neem oil-alcohol blends [12].Likewise several researches have been carried out with different biodiesel and alcohol blends in various blending ratios. But there were little works carried out on biodiesel prepared with calophyllum Inophyllum oil .Also less works were spotted with testing acid blends with biodiesel in a direct injection diesel engine. In the present work a brief comparison is made on the effect of alcohol-acid additives on the performance and emission characteristics of a direct injection diesel engine fuelled with biodiesel-diesel blends.

II. Materials and Methods

A. *Test fuels*

Calophyllum Inophyllum is an evergreen tree belongs to family clusiaceae.It is native to tropical areas of Asia, Africa and America [1,13].Calophyllum oil contains nearly 19.58 % free fatty acids (FFA).The crude calophyllum oil is extracted from kernels and biodiesel is produced by the methods specified by Ramesh et al [1] and Chavan et al [13]. The physio chemical properties of the prepared biodiesel are given in Table 1.

The two additives used in this study are ethanol and acrylic acid. They are purchased from Precision Equipments Pvt Ltd, Coimbatore.These additives were added directly to diesel as well as biodiesel-diesel blends. In this study, blends of Calophyllum Inophyllum based biodiesel and diesel fuel were evaluated. Ethanol (18%) and acrylic acid (2%) by volume was added to HSD separately and made it as a blend (E18A2).Low amount of acrylic acid was used do to its miscibility problems at higher ratios. The same ratio of ethanol and acrylic acid (Ethanol 18% and acrylic acid 2%) was added to 20% biodiesel (B20) and it was made as separate blend (B20+E18A2).

Table 1: Physio chemical of prepared biodiesel

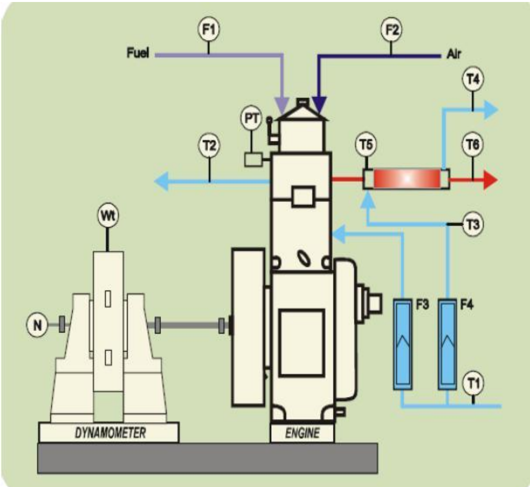
Property	Unit	Value
Density at 40^0C	kg/m^3	875.4
Kinematic Viscosity at 40^0C	mm^2/s	5.65
Cloud point	^{o}C	13
Pour point	^{o}C	4.5
Flash point	^{o}C	145
Fire point	^{o}C	158
Calorific Value	MJ/kg	38.54

B. *Engine test apparatus and method*

The experimental study was conducted on a single cylinder four stroke naturally aspirated DI-diesel engine. The general specifications of the test engine are shown in Table 1. A Kirloskar AV1 type standard engine test bed with eddy current dynamometer was used. The engine load was measure with a strain gauge load cell sensor .Engine speed was measured with rotary encoder made by Kubler-Germany. Inlet air, lubricating oil, exhaust gas temperatures were measured with multi point electronic temperature indicator. The schematic view of the engine test rig is shown in Fig. 1.

Table 2: General specifications of the test engine

Item	Specification
Engine type	Four stroke, DI Diesel Engine
Number of Cylinders	1
Cylinder bore×stroke (mm)	80×110
Cooling	Water Cooled
Rated Speed	1500 rpm
Rated Power	3.5 kW @ 1500 Rpm
Type of Loading	Eddy Current Dynamometer
Compression Ratio	16.5:1



T1-Cooling water inlet temperature

T2-Cooling water outlet temperature

T3-Calorimeter water inlet temperature

T4-Calorimeter water outlet temperature

T5-Exhaust gas temperature at calorimeter inlet

T6- Exhaust gas temperature at calorimeter outlet

Figure 1: Schematic view of the engine test rig

An I-SYS EDM 1601 five gas analyzer was used to measure NOx, CO, CO_2, HC and SOx emissions. In this study blends of biodiesel (B20),ethanol+acrylic acid+diesel (E18A2) and biodiesel+ethanol+acrylic acid+diesel (B20+E18A2) were evaluated separately. Then the performance and emission characteristics of the different test fuels were found and compared. Experiments were conducted at all loading conditions with constant engine speed of 1500 rpm. Before running the engine to a new fuel blend, it was allowed to run in no load condition for sufficient time to consume the residue fuel of previous experiment.

III. Results and Discussion

A. *Brake Specific Fuel Consumption*

For each test fuel and testing modes, the volumetric flow rates were measured and mass consumption of fuel were calculated. The variation of brake specific fuel consumption (BSFC) is shown in Fig. 2 for various test blends.

From Fig.2, it was clearly observed that the biodiesel blend (B20) shows highest BSFC at all loading conditions. Biodiesel blend (B20) shows nearly same BSFC as HSD at mid range loading conditions but BSFC increases at high loads. It was due to the lower heating value and higher density [18] of biodiesel which leads to consumption of more fuel to produce the same power output [15]. On the other hand ethanol and acrylic acid blend shows slightly reduced BSFC at mid range loads when compared to all other test fuels. The reduction in viscosity due to addition of ethanol and acrylic acid to the diesel enhances the spray characteristics. This in turn reduces the fuel consumption to produce same power output.

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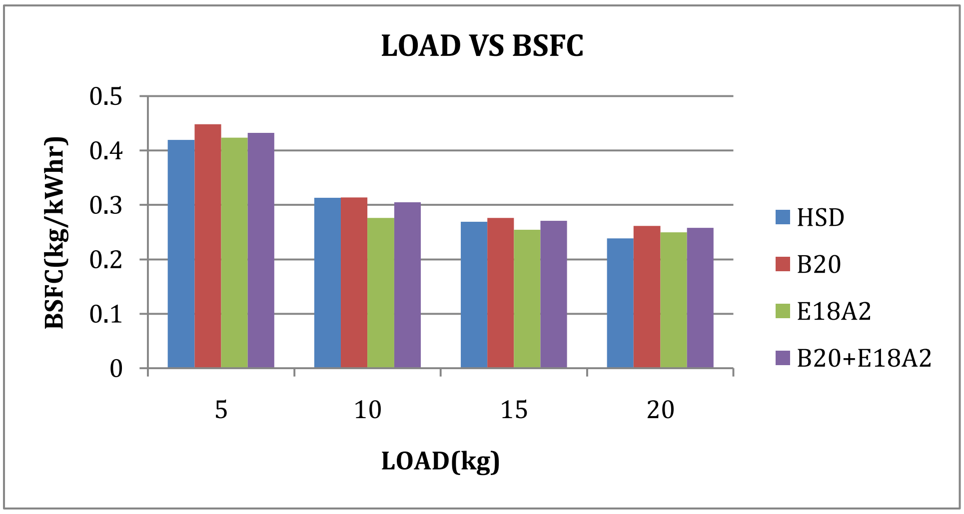

Figure 2: Variations of BSFC for fuel blends

B. *Brake Thermal Efficiency*

Engine thermal efficiency varies inversely with BSFC and heating value of the fuel used. Fig. 3 shows the variation of the brake thermal efficiency of all test fuels at various loading conditions.

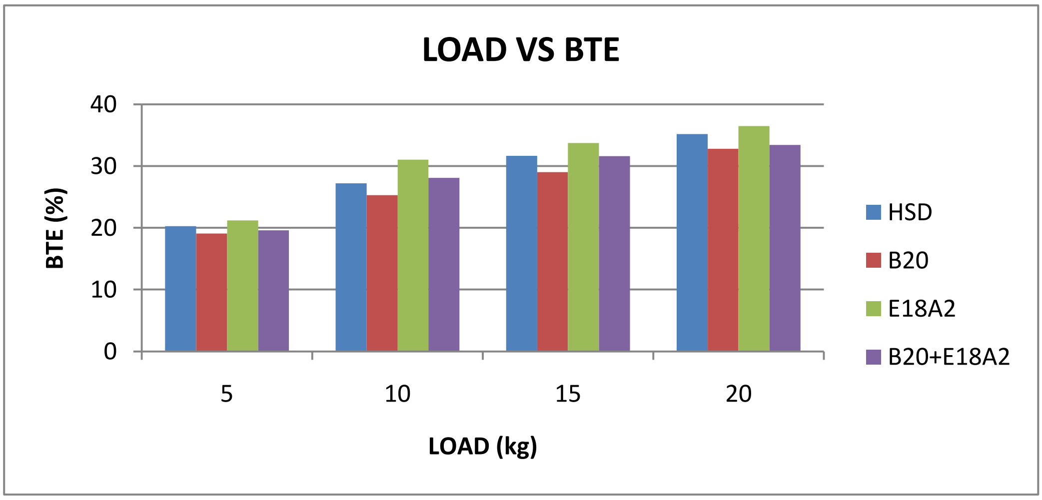

Figure 3: Variations of BTE for fuel blends

As shown in Fig.3, the E18A2 blend shows peak BTE all loading conditions when compared to all fuel blends. E18A2 blend shows an average of 1.78% increase in BTE at all loading condition when compared to the base fuel HSD. The reduced viscosity of E18A2 additive improves the atomization of fuel which increases the in-cylinder temperature and enhances the combustion. It was clearly seen that the addition of E18A2 additive to biodiesel (B20+E18A2) also improved the BTE at all loads when compared to normal biodiesel blend (B20). The reduction in BTE of biodiesel blends was imposed to high viscosity, poor spray characteristics, high volatility and lower calorific value.

C. *HC emission*

Hydrocarbon emission is the indication of the completeness of the combustion in an engine. As shown in the Fig. 4, it is clearly observed that HC emission decreases as the load increases for all test fuels.

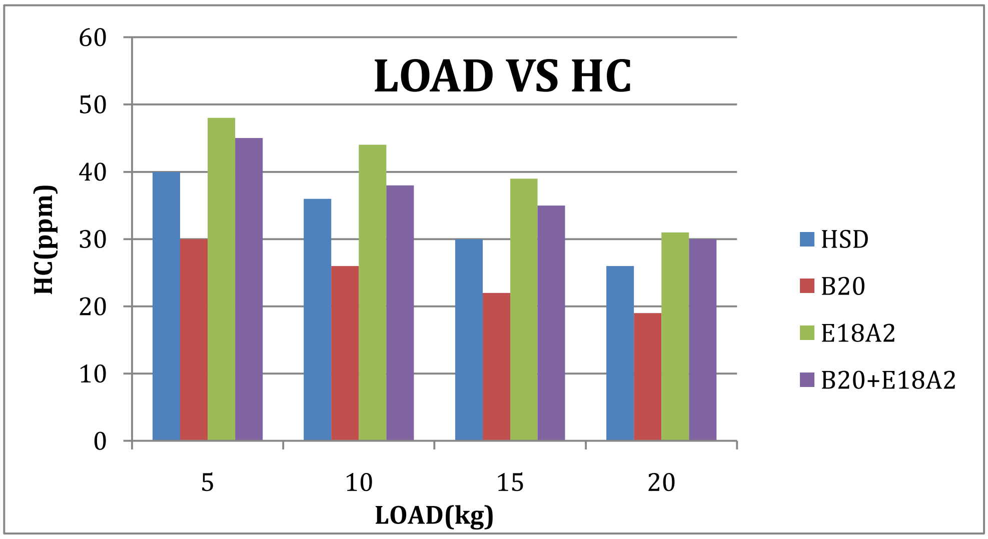

Figure 4: Variations of HC for fuel blends

Biodiesel blend (B20) shows less HC emission at all loading conditions where as the acid blend (E18A2) shows highest HC emission at all loading conditions .Approximately 16% increase in HC emission was observed for E18A2 blend when compared to HSD at all loading conditions. Also B20 shows nearly 25% decrease in HC emission when compared to HSD. Since biodiesel possess high cetane number, the combustion temperature will also be high, thus burning the fuel completely .So this high temperature combustion reduces HC emission whereas due to the low cetane number and cooling effect of acid blend [17] ,the increased HC emission was observed.

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D. *CO emission*

Carbon monoxide is one of the most toxic gases produced due to partial oxidation carbon compounds [18] .The variation of CO emissions for various fuel blends at full range of loading condition is shown in the Fig. 5.

As shown in Fig.5, the E18A2 blend shows that CO emission is 0.046 %, 0.039 %, 0.043 % and 0.029% higher than that for HSD for the loads of 5 kg, 10 kg, 15 kg and 20 kg respectively. The high cetane number of biodiesel reduces the ignition delay [15] and leads to high in-cylinder temperature due to complete combustion. So the CO emission of biodiesel shows the decreasing trend when compared to other test fuels. Meanwhile acid blend shows peak CO emission due to its lower cetane number and cooling effect.

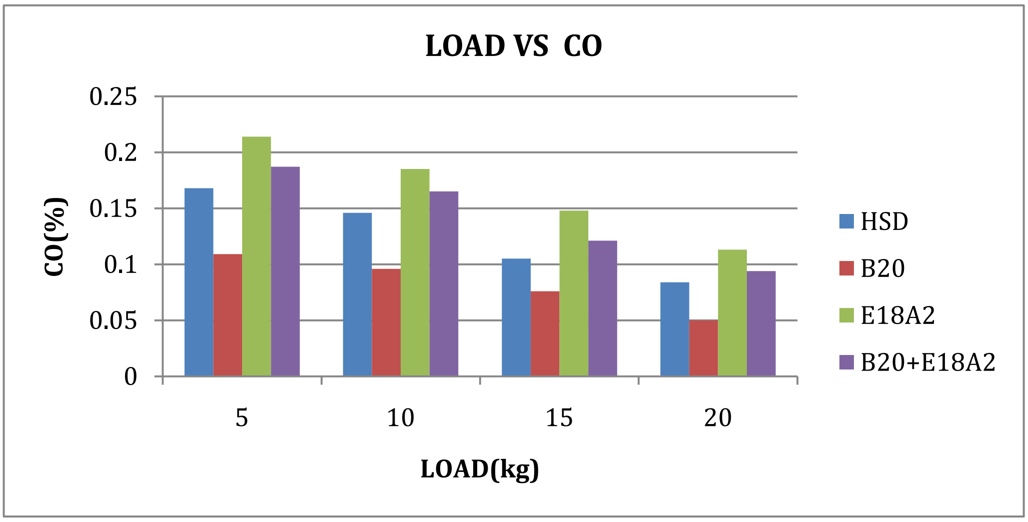

Figure 5: Variations of CO for fuel blends

E. *CO_2 emission*

The presence of CO_2 in the exhaust indicates the completeness of combustion. CO_2 emission for test fuels at various loading condition is shown in the Fig. 6.

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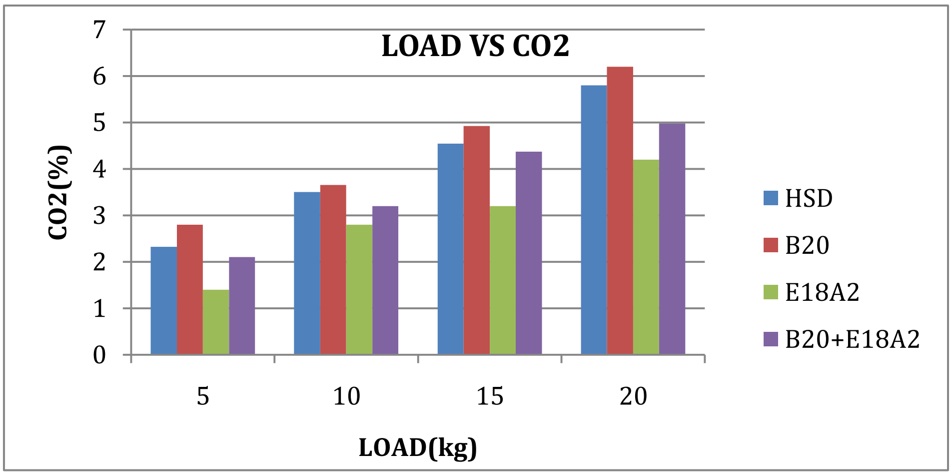

Figure 6: Variations of CO_2 for fuel blends

From the Fig.5 and Fig.6, it can be clearly seen that the biodiesel blends which showed low CO emission, shows high CO_2 emission due to the complete combustion. Also the acid blend shows low CO_2 due to the partial oxidation of the fuel mixture. The reasons were same as that of for CO and HC emission. An average increase of 0.35 % CO_2 emission has been observed in B20 blend when compared to HSD. Meanwhile B20+E18A2 shows moderate emission level when compared to B20 blend and E18A2 blend.

F. *NOx emission*

NOx emissions increases due to thermal formation mechanism [9,14] , temperature and pressure inside the cylinder[18].Despite its high cetane number, biodiesel results in NOx emissions which is one of the major setbacks in using it as primary fuel. The characteristics of NOx emission are shown in the Fig. 7.

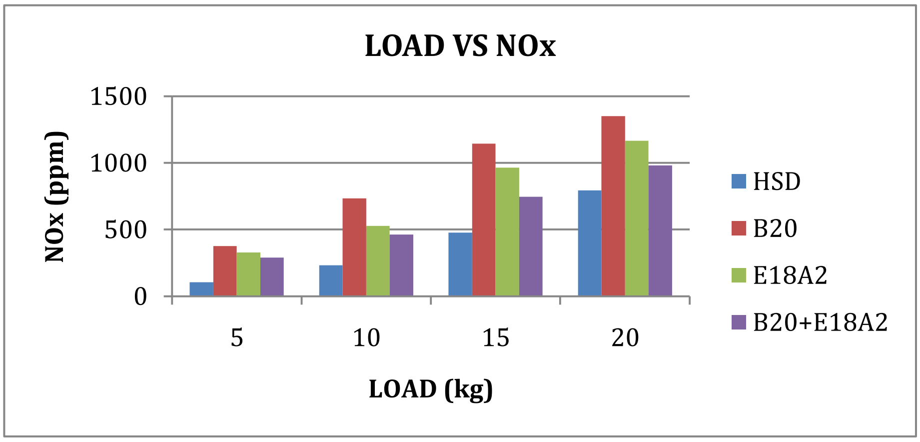

Figure 7: Variations of CO_2 for fuel blends

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The NOx emissions increase with increase in load for all fuel blends. It is clearly observed that biodiesel blend (B20) shows peak NOx emissions at all loading conditions. It was due to the high cetane number of biodiesel that shortens the ignition delay, which in turn increases the combustion temperature. Adding acid-alcohol additive to the biodiesel blend results in reduction of NOx emission by 27% at high load. This is because of addition of alcohol induces cooling effect in cylinder and reduces the in cylinder temperature [17].But none of the blend seems to be superior to HSD in terms of NOx emission.

Iv. Conclusion

Biodiesel (B20) blend, E18A2 blend and Biodiesel (20%)+Ethanol(18%)+Acrylic acid(2%) blend are used in a direct injection diesel engine and results are compared to neat diesel fuel. A number of conclusions can be made based on the performance and emission characteristics.

Biodiesel (B20) blend increases the brake specific fuel consumption and Biodiesel-Alcohol-Acid blend gives lower BSFC than B20 blend which is due to improved spray characteristics and higher heat of vaporization of acrylic acid and ethanol. Addition of alcohol-acid additive separately, as well as with biodiesel improves brake thermal efficiency when compared to biodiesel blend (B20). It is due to improved oxygen content of fuel and reduced viscosity leads to high temperature combustion which in turn enhances BTE.Addition of alcohol and acid to fuel increases CO and HC emissions at all loading conditions when compared to biodiesel blends and HSD. Despite the improved oxygen content in fuel ,the CO and HC emissions increases due to the dominance of cooling effect of alcohol-acid addition. The cooling effect reduces in-cylinder temperature which leads to partial oxidation of carbon in the fuel. Biodiesel blend (B20) shows increased NOx emission at all loading conditions when compared with all test fuels. The main reason behind NOx formation is the thermal mechanism. The high cetane number of biodiesel leads to shorter ignition delay which enhances the combustion at high temperature which results in higher NOx emission at exhaust. On the other hand addition of alcohol-acid reduces the in-cylinder temperature which reduces the NOx emissions when compared to biodiesel blend.

On the whole Biodiesel-ethanol-acrylic acid blend shows optimum performance and emission characteristics which lies in between the biodiesel blend and ethanol-acrylic acid blend. The increased emissions for the Biodiesel-ethanol-acrylic acid blend can be controlled by techniques like Exhaust gas recirculation [16], preheating intake air [17].

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References

1. Ramesh.K, Amirthagadeswaran.K.S, Geen Paul.V "Bio-diesel development process from Calophyllum Inophyllum Seeds" Proceedings of Advanced Mechanical Sciences (2012).
2. Warabi Y, Kusdiana D, Saka S. “Reactivity of triglycerides and fatty acids of rapeseed oil in supercritical alcohols” Bioresource Technology 2004;91:283–7.
3. D.H. Qi , H. Chen, L.M. Geng, Y.ZH. Bian, X.CH. Ren , “Performance and combustion characteristics of biodiesel–diesel–methanol blend fuelled engine” Applied Energy 87 (2010) 1679–1686.
4. J.K. Kim, E. S. Yim, C. H. Jeon, C.-S. Jung and B. H. Han , “cold performance of various biodiesel fuel blends at low temperature” International Journal of Automotive Technology, Vol. 13, No. 2, pp. 293−300 (2012).
5. H.G. How, H.H. Masjuki , M.A. Kalam , Y.H. Teoh, “An investigation of the engine performance, emissions and combustion characteristics of coconut biodiesel in a high-pressure common-rail diesel engine” Energy 69 (2014) 749-759.
6. G.R. Kannan , R. Karvembu , R. Anand, “Effect of metal based additive on performance emission and combustion characteristics of diesel engine fuelled with biodiesel” Applied Energy 88 (2011) 3694–3703.
7. Gaurav Dwivedi, Siddharth Jain, M.P. Sharma, “ Impact of Biodiesel and its Blends with Diesel and Methanol on Engine Performance” IJES Vol.1 No.2 2011 PP.105-109.
8. G. Venkata Subbaiah, K. Raja Gopal, Syed Altaf Hussain, B. Durga Prasad and K. Tirupathi Reddy “ Rice bran oil biodiesel as an additive in diesel- ethanol blends for diesel engines” IJRRAS 3 (3) June 2010 pp.334-342.
9. Hem Joshi, Bryan R. Moser, Joe Toler , William F. Smith, Terry Walker, “Effects of blending alcohols with poultry fat methyl esters on cold flow properties ” Renewable Energy 35 (2010) 2207-2210.
10. Donepudi Jagadish, Ravi Kumar Puli, K. Madhu Murthy, “Addition of Ester (Biodiesel) to Ethanol-Diesel Blend to Improve the Engine Performance and to Control the Emissions of Nitrous Oxides” Energy and Power: 2011; 1(1): 1-5.
11. Matthew Jones, Calvin H Li, Abdollah Afjeh, GP Peterson , “Experimental study of combustion characteristics of nanoscale metal and metal oxide additives in biofuel (ethanol)” Jones et al. Nanoscale Research Letters 2011, 6:246.
12. S. Sivalakshmi and T. Balusamy , “Performance and emission characteristics of a diesel engine fuelled by neem oil blended with alcohols” International Journal of Ambient Energy Vol. 32, No. 4, December 2011, 170–178.
13. Chavan S.B, Kumbhar R.R, Deshmukh R.B , “Callophyllum Inophyllum Linn (“honne”) Oil, A source for Biodiesel Production” Research Journal of Chemical Sciences, Vol. 3(11), 24-31, November (2013).

14. Lei Zhu , C.S. Cheung , W.G. Zhang , Zhen Huang, "Emissions characteristics of a diesel engine operating on biodiesel and biodiesel blended with ethanol and methanol" Science of the Total Environment 408 (2010) 914–921.
15. Su Han Park, Junepyo Cha, Chang Sik Lee, "Impact of biodiesel in bioethanol blended diesel on the engine performance and emissions characteristics in compression ignition engine" Applied Energy 99 (2012) 334–343.
16. K. Venkateswaralu, S. R. Murthy,V. Subbarao, K. Vijaya kumar , "Effect of exhaust gas recirculation and ethyl hexyl nitrate additive on biodiesel fuelled diesel engine for the reduction of NOx emissions" Front. Energy 2012, 6(3): 304–310.
17. Nadir Yilmaz, Tomas M. Sanchez, "Analysis of operating a diesel engine on biodiesel-ethanol and biodiesel-methanol blends" Energy 46 (2012) 126-129.
18. A.Sanjid et al, "Impact of palm, mustard, waste cooking oil and Calophyllum Inophyllum biofuels on performance and emission of CI engine" Renewable and sustainable energy reviews 27(2013) 664-682.