Performance Characteristics of Four Stroke Single Cylinder Diesel Engine With 10% Iso Butanol at Different Injection Pressures

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ABSTRACT: *Biodiesel with additives is attracting increased attention for performance and emission improvement of diesel engines. Higher fuel injection pressure is an effective way to improve the performance and reduce Particulate Matter (PM) emissions. In this present work, Isobutanol as an additive to the diesel and biodiesel blends was investigated experimentally in a direct injection diesel engine to evaluate performance, combustion and emissions at different injection pressures such as 200,225,250 and 275 bars respectively. Isobutanol was added as 10% by volume to diesel-biodiesel blends. From experimental results it was found that injection pressure could be increased up to 250 bar when the engine operates with biodiesel-diesel blends with isobutanol as an additive. At this increased pressure, brake thermal efficiency and fuel economy were improved with increasing blend percentage. Carbon Monoxide (CO) emissions and smoke opacity were reduced significantly while Nitrogen Oxides (NO_x) emissions increased marginally.*

Keywords: *Biodiesel; Brake thermal efficiency; Emissions; Injection pressure; Isobutanol*

I. INTRODUCTION

Fuel injection pressure in diesel engine plays an important role in engine performance. Higher injection pressure decreases fuel particle diameter which aids in better formation of mixing of fuel to air during ignition period, as a result of which engine performance will increase. High-pressure injection in combination with small orifice can achieve lean combustion which allows better fuel atomization, evaporation and improved emissions [1]. High injection pressure also reduces soot emissions [2]. The effect of injection pressure on performance of Direct Injection (DI) diesel engine shows the best performance at 220 bar and better fuel economy at 200 bar respectively [3]. In turbocharged diesel engines, high injection pressures for O_2, SO_2, and CO_2, while low injection pressure for NO_x and smoke level are preferred for decreasing emissions [4]. The problem of higher NO_x emissions at high injection pressures can be addressed by the addition of Carbon dioxide (CO_2) as diluents to the diesel [5]. Injection pressure variation is also investigated on various diesel-biodiesel blends by researchers. Higher injection pressures are preferred for biodiesel for effective atomization and mixing, since the viscosity of biodiesel is higher than diesel which causes problems in atomization and mixing. Optimum fuel injection pressure for linseed methyl ester was found to be 240 bar, based on comparable thermal efficiency, reduction in carbon monoxide, unburned hydrocarbons and smoke emissions. However oxides of nitrogen increase at higher injection pressures [6]. Diesel-Karajan biodiesel blends at fuel injection pressure of 210 bar demonstrate that the Hydro Carbon (HC) emissions decrease by 25 % and NO_x emissions decrease by 30 to 39 % respectively [7]. Hone oil can be blended with diesel up to 30% when the engine is operated at increased injection pressures [8]. Biodiesel-diesel blends in a turbocharged, high-pressure common rail diesel engines increase thermal efficiency and NO_x emission while Hydrocarbon, CO and CO2 emissions reduce significantly [9]. Bio-Ethanol at higher injection pressures reduces emissions without comprising the performance [10]. Hone oil-diesel blends show the better injector opening pressure of 240 bar for improving the brake thermal efficiency and emissions [11]. Diesel-methanol blends with the increased injection pressure from 180 bar to 220 bar reduce smoke, unburned hydrocarbon, and carbon monoxide emissions, while combustion efficiency, nitrogen oxides and carbon dioxide emissions increase [12]. Recent studies show that additives have become indispensable tools for performance and emission improvement. Oxygenates are the candidates for reducing particulate matter. Oxygenates like ethanol, I-propanol, I-butanol and I-pentanol improve performance parameters and reduce exhaust emissions [13, 14]. Gasoline-ethanol blends with additives such as cyclooctanol, cycloheptanol increase brake thermal efficiency when compared to gasoline with reduction in CO, CO_2 and NO_x while HC and O_2 increase moderately [15]. Gasoline with additives like ethanol and ethanol-isobutanol increase the brake power, volumetric and brake thermal efficiencies and fuel consumption. The CO and HC decreased while the NO_x concentration increased [16]. Bio-additives (matter extracted from palm oil) as gasoline additives showed improvement in fuel economy and exhaust emissions of SI engine [17]. Methyl-ester of Jatropha oil diesel blends with Multi-DM-32 diesel additive showed comparable efficiencies, lower smoke, CO_2 and CO [18]. The addition of Di Methyl Carbonate (DMC) to diesel fuel increases efficiency marginally with reduction in NO_x emissions while PM and soot emissions decrease considerably [19, 20]. Ethanol addition to diesel-biodiesel blends increases brake thermal efficiency with reduction in carbon monoxide and smoke emissions and at the same time hydrocarbons, oxides of nitrogen and carbon dioxide emissions increase[21].Some researchers have used cetane improvers and some others have used additives in coated engines. Addition of di-tertiary-butyl peroxide and the conventional cetane improver, ethyl hexyls' nitrate additives to diesel fuel reduced all regulated and unregulated emissions including NO_x emissions [22]. Additives with coated engines improved efficiency, in addition to the increase in cylinder pressure, reduction in NO_x and maximum heat release rate. Thermal Barrier Coated (TBC) DI diesel engine with fuel additives reduced the smoke density and NO_x emission of the engine exhaust [23]. 1-4 dioxins, as an additive to the diesel fuel showed the potential to reduce smoke density with slight increase in NO_x and drop in fuel economy for a normal engine.

2.5% improvement of brake thermal efficiency and smoke reduction of 19% were observed when compared to neat diesel for TBC engines [24]. P-series glycol ethers were effective in reducing hydrocarbon, carbon monoxide, and particulate matter emissions [25]. Isobutanol–diesel fuel blends containing 5, 10, 15 and 20% isobutanol show marginal decrease in brake power and increase BSFC in proportion to the isobutanol content in the blends. It was also observed that slight improvement in BTE with the blend containing 10% isobutanol. CO emissions decrease with the use of the blends, while HC emissions increase compared to diesel fuel [26].

Present work attempts to investigate performance, combustion and emission characteristics of diesel engine with isobutanol as an additive to the diesel-biodiesel blends at different injection pressures from 200 bar to 275 bar. Since isobutanol has higher energy density and lower Reid Vapor Pressure (RVP) it can be used as a potential fuel additive to petroleum fuels.

II. Experimental Set-Up and Procedure

2.1 Experimental Set-up

The engine shown in Fig.1 for investigation on fish oil biodiesel-diesel blends to evaluate the performance and emission characteristics was a computerized single cylinder four stroke, naturally aspirated direct injection and water cooled diesel engine. The specifications of the test engine are given in Table 1. It was directly coupled to an eddy current dynamometer. The engine and the dynamometer were interfaced to a control panel which was connected to a computer. Engine Soft version 2.4 was used for recording the test parameters such as fuel flow rate, temperatures, air flow rate, load etc, and for calculating the engine performance characteristics such as brake thermal efficiency, brake specific fuel consumption.

Table1. Specifications of the test engine

Particulars	Specifications
Make	Kirloskar
Rated power	3.7 k(5hp)
Bore	80 mm
Stroke length	110 mm
Swept volume	562 cc
Compression ratio	16.5:1
Rated speed	1500 rpm

2.2 Test Fuels

For experimental investigation, biodiesel derived from fish oil was mixed with diesel in varying proportions such as 20%, 30% and 40% by volume and isobutanol as an additive was added as 10% by volume to all the blends designated as B20, B30 and B40 (i.e. B20 indicates biodiesel 20%, isobutanol 10% and remaining proportion diesel by volume respectively). Table.2 shows the properties of isobutanol.

Table 2. Properties of Isobutanol

Property	Range
Flash point, open cup, °C	37.7
Specific gravity, 20/20°C	0.8030
Viscosity at 20°C (Centipoises)	3.95
Auto ignition temperature, °C	440
Surface tension at 20°C, ((dynes/cm)	22.94
Heat of combustion, kJ/kg	36162

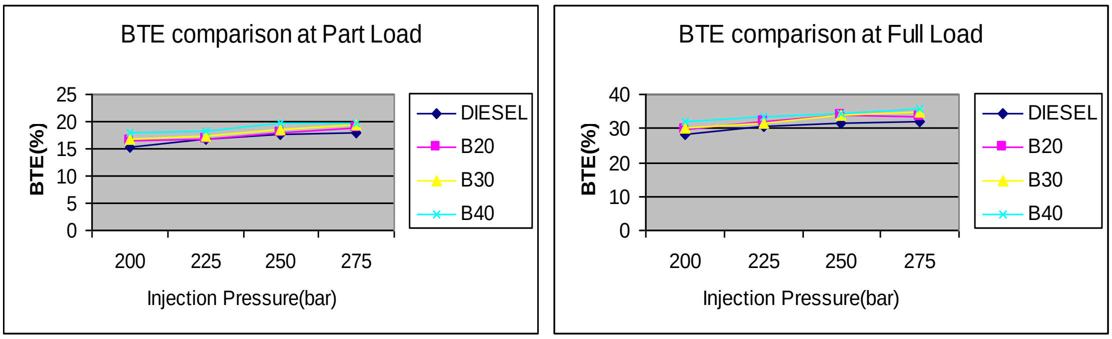
2.3 Experimental Procedure

The entire engine experiments were conducted at a rated speed of 1500 rpm with an injection timing of 27^0 before Top Dead Center (TDC). The engine was allowed to run till the steady state is reached. Then the engine was loaded in terms of 0%, 25%, 50%, 75% and 100% load. At each load, the experiments are conducted by varying the injection pressure from 200 to 275 bars. The first stage of experiments was performed with pure diesel at different loads from no-load to full load (20 N-m) by varying injection pressure form 200 bar to 275 bars with an interval of 25 bars. The engine loads were adjusted by an eddy current dynamometer. The second stage of experiments was conducted using various blends of diesel-biodiesel with isobutanol as an additive with same injection pressures and same operating conditions. All the performance and combustion characteristics readings were recorded online while exhaust emissions CO, and NO_x were recorded by the flue gas analyzer (FGA533) and smoke opacity was measured with Hart ridge smoke meter (OMS103).

III. Results and Discussion

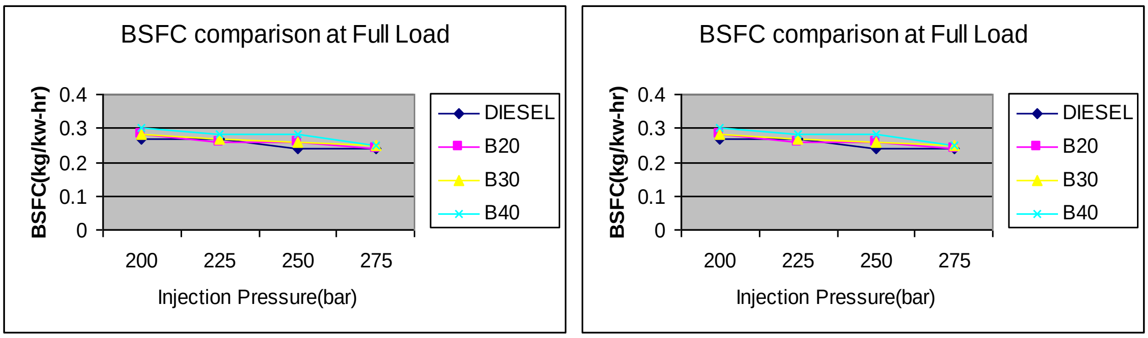
3.1 Performance analysis

Performance parameters such as BTE and BSFC results of diesel and blends are shown in figures 2 and 3. Figure 2(a) and (b) shows the variation of BTE with injection pressure for different fuels at part load and at full load respectively. Figure 2(a) shows that at part load BTE increases considerably from 200 to 250 bars, and thereafter the increase is insignificant. This may be attributed to the improved spray characteristics, better atomization and better fuel and air mixing as a result of increased injection pressure. This will lead to improved combustion process and in turn improved efficiency. However higher injection pressures (i.e. more than 250bar) lead to smallest diameter of fuel droplet and affect the spray pattern and penetration which lowers the performance [27]. Figure 2(b) shows that at full load only marginal improvement in BTE was observed. Blends with isobutanol maintain better BTE than diesel. Figure 3(a) and (b) shows the variation of Brake Specific Fuel Consumption (BSFC) with injection pressure for different fuels. Figure 3(a) shows that at part load operation, BSFC of the blends was considerably higher than diesel and Figure 3(b) shows that at full load it was slightly more when compared to diesel. The reason for this tendency is slight decrease in energy content of the blended fuel when isobutanol was added. It can also be observed that the BSFC of all the blends including diesel decreases with increase in injection pressure. The reason for decrease in BSFC with increase in injection pressure is due to complete combustion of fuel. Higher injection pressures assist in better mixing of fuel with air [28]



2. A) BTE at Part Load 2. b) BTE at Full Load

Figure2. Variation of Brake Thermal Efficiency with Injection Pressure for different fuel blends

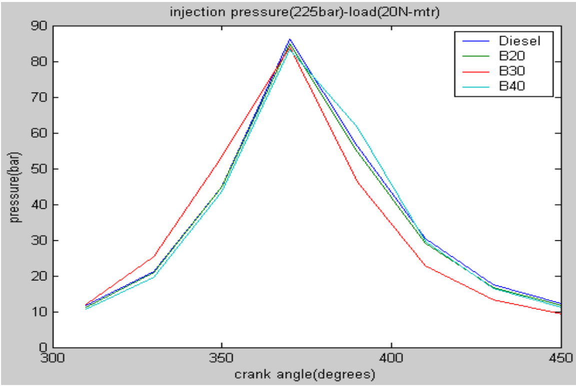


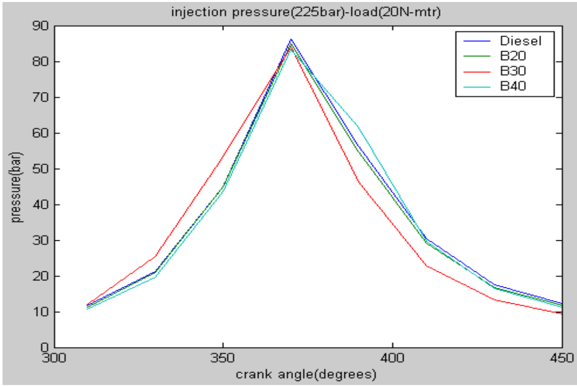
3. A) BSFC at Part Load 3. b) BSFC at Full Load

Figure 3. Variation of Brake Specific Fuel Consumption with Injection Pressure for different fuel blends

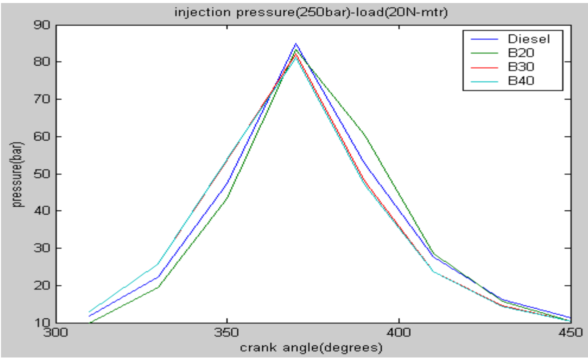
3.2 Combustion analysis

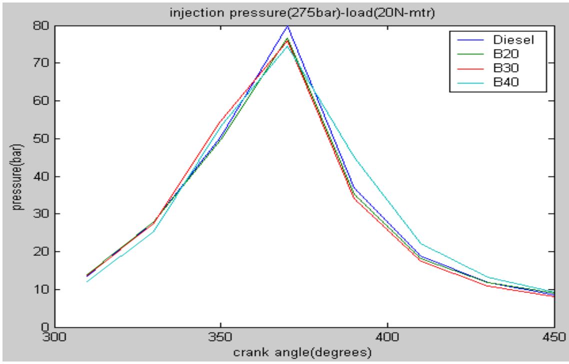
Combustion analysis such as cylinder pressure versus crank angle is shown in figure 4. Figure 4(a), (b), (c) and (d) shows the variation of cylinder pressure with crank angle at 200 bar, 225 bar, 250 bar and 275 bar injection pressures respectively for different fuels at 20N-m load. It can be seen from these figures that the cylinder pressure of the blends was lower than diesel at all injection pressures. The reason for decrease in cylinder pressure with the blends was due to the fact that the isobutanol has lower cetane number and heating value which lowers the combustion the pressure, these results are also identical with the literature [29]. And also cylinder pressure of the blends including diesel increases with increase in injection pressure up to 250 bar after that it decreases slightly at 275bar.





4. a) Injection Pressure 200 bar 4.b) Injection Pressure 225 bar



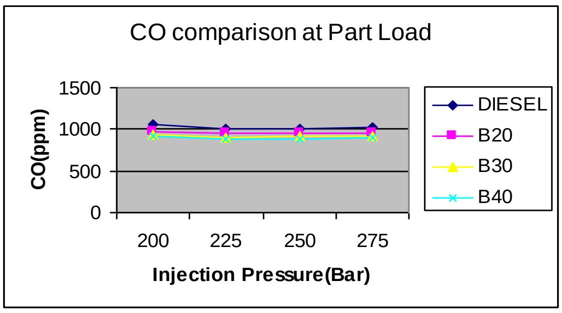


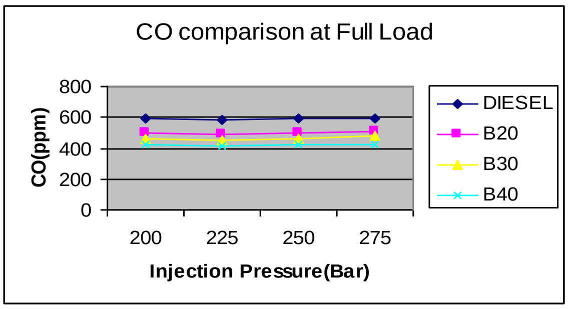
4. c) Injection Pressure 250 bar 4.d) Injection Pressure 275 bar

Fig.4 Variation of Cylinder Pressure with Crank Angle for different fuel blends

3.3 Emission Analysis

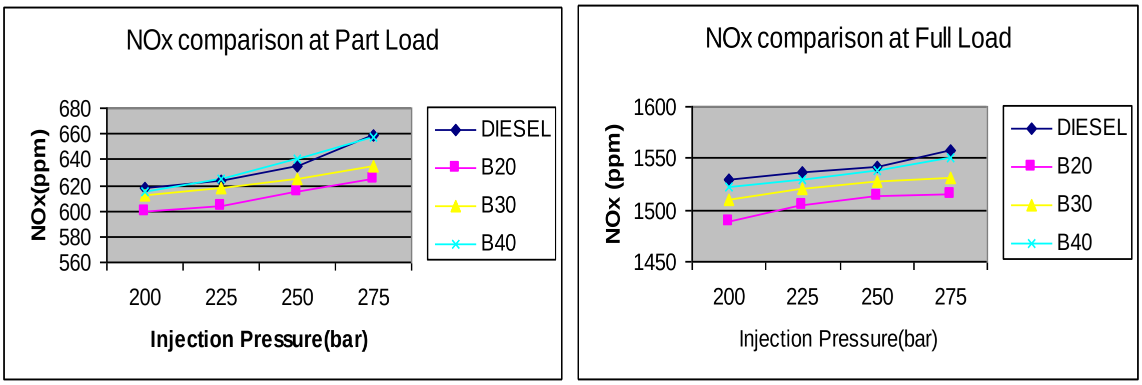
Exhaust emission results such as CO, NO_x and smoke are shown in figures 5 to 7. Figure 5(a) and (b) shows the variation of CO emissions with injection pressure for different fuels both at part load and full load respectively. Figure 5(a) shows that, CO emissions at part load decrease up to 225 bar and thereafter the variation was insignificant, while at full load as shown in Figure 5(b) significant reductions were observed with the blends than the diesel. The reasons for reduction in CO emissions were oxygen content of the blends enhances the fuel air mixing and isobutanol has lower C/H ratio and also it causes the leaning effect on the blends resulting in lower CO emissions. The effect of injection pressure at full load on CO emissions was significant than at part load operation. Figure 6(a) and (b) shows the variation of NO_x emissions with injection pressure for different fuels both at part load and full load respectively. NO_x emissions are lower for the blends when compared to diesel at all injection pressures. However they increase with increase in injection pressure. The rate of increase in NO_x is higher at higher injection pressures when compared to that of lower injection pressures. The formation of NO_x is a temperature dependent phenomenon, at higher injection pressures the increase in NOx level is due to faster combustion and higher temperatures reached in the cycle [30]. Isobutanol has lower heating value and oxygen content which results in lower combustion temperatures and consequently NO_x emissions decrease [31]. Figure 7(a) and (b) shows the variation of Smoke opacity with injection pressure for different fuels. Smoke density decreases significantly with the addition of isobutanol to the blends and it decreases further with increase in injection pressure. However slight variation was observed with the increase in blend percentage. The results of NO_x and smoke also compare with the results of [32].





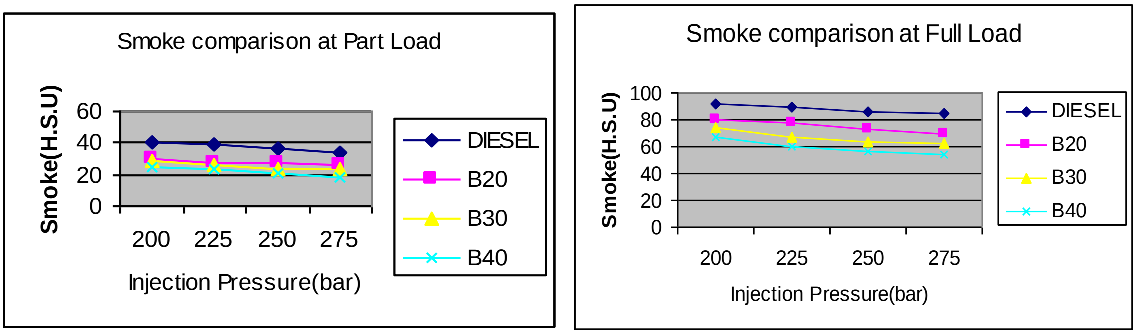
5. a) Part Load 5.b) Full Load

Fig.5 Variation of CO emissions with Injection Pressure for different fuel blends



6. a) Part Load 6.b) Full Load

Fig.6 Variation of NO_x emissions with Injection Pressure for different fuel blends



7. a) Part Load 7.b) Full Load

Fig.7 Variation of Smoke Density with Injection Pressure for different fuel blends

IV. CONCLUSION

The conclusions derived from present experimental investigation to evaluate performance, combustion and emission characteristics on four stroke single cylinder diesel engine fuelled with diesel-biodiesel blends with isobutanol as an additive at different injection pressures are summarized as follows:

1. Brake thermal efficiency increased with all blends when compared to the conventional diesel fuel. Maximum Brake thermal efficiency obtained was 33.5% with B40 blend with 10% isobutanol against 28% with conventional diesel.
2. Brake specific fuel consumption decreased with the blends with isobutanol when compared with diesel fuel.
3. Cylinder pressure of the blends increase with increase in injection pressure.
4. CO emissions and smoke density decrease significantly with the blends and isobutanol and further decrease with the increasing injection pressure when compared with diesel. NO_x emissions decrease marginally with the blends and isobutanol which however increase with injection pressure

REFERENCES

[1] Prashanth Karra. And Song Charng Kong. Diesel Emission Characteristics Using High Injection Pressure with Converging Nozzles in a Medium-Duty Engine. SAE Paper Number, 2008-01-1085.
[2] Sukumar Puhan. Jegan,R. Balasubbramanian,K. and Nagarajan,G. Effect of injection pressure on performance, emission and combustion characteristics of high linolenic linseed oil methyl ester in a DI diesel engine. Renewable Energy, 2009, 34, 1227–1233.
[3] Rosli Abu Bakar. Semin. and Abdul Rahim Ismail. Fuel Injection Pressure Effect on Performance of Direct Injection Diesel Engines. American Journal of Applied Sciences, 2008 5 (3): 197-202.
[4] Ismet Celýkten. An experimental investigation of the effect of the injection pressure on engine performance and exhaust emission in indirect injection diesel engines. Applied Thermal Engineering, 2003, 23, 2051–2060.
[5] Can Cinar, Tolga Topgul, Murat Ciniviz, and Can Hasimoglu. Effects of injection pressure and intake CO2 concentration on performance and emission parameters of an IDI turbocharged diesel engine. Applied Thermal Engineering, 2005, 25, 1854–1862.
[6] Nagarhalli,M.V. and Nandedkar,V.M. Effect of injection pressure on emission and performance characteristics of Karanja biodiesel and its blends in C.I. Engine. International Journal of Applied Engineering Research, 2011, Volume 1, no 4.
[7] Venkanna, B.K. Swati B.Wadawadagi, and Venkataramana Reddy,C. Effect of Injection Pressure on Performance, Emission and Combustion Characteristics of Direct Injection Diesel Engine Running on Blends of Pongamia Pinnata Linn Oil (Honge oil) and Diesel Fuel. The CIGR Ejournal, 2009, Manuscript number 1316. Vol. XI.
[8] Wang,X.G. Zheng,B. Huang,Z.H. Zhang,N. Zhang,Y.J. and Hu, E.J. Performance and emissions of a turbocharged, high-pressure common rail diesel engine operating on biodiesel/diesel blends. Proc. IMechE Part D: J. Automobile Engineering, 2010, Vol. 225.
[9] Paolo Sementa. Bianca Maria Vaglieco. And Francesco Catapano. Influence of the Injection Pressure on the Combustion Performance and Emissions of Small GDI Engine Fuelled with Bio-Ethanol. SAE Paper Number: 2011-37-0007.
[10] Won, H.W. and Peters,N. Optimizing the injection pressure for cluster nozzle concepts in a direct injection diesel engine. International Journal of Engine Research, 2010, 11: 163-175.

[11] Venkanna. Krishnamurthy. Belagur, Vekataramana. and Reddy, Chittimini., Effect Of Injector Opening Pressures On The Performance, Emission And Combustion Characteristics Of DI Diesel Engine Running on Honne Oil and Diesel Fuel Blend. Thermal Science International Scientific Journal, 2010, Volume 14, Issue 4, Pages 1051 – 1061.
[12] Mustafa Canakci. Cenk Sayin. Ahmet Necati Ozsezen. and Ali Turkcan. Effect of Injection Pressure on the Combustion, Performance, and Emission Characteristics of a Diesel Engine Fueled with Methanol-blended Diesel Fuel. Energy Fuels, 2009, 23 (6), pp 2908–2920.
[13] Ryo,Michikawauchi. Shiro, Tanno. Yasushi,Ito. and Mutsumi,Kanda. Combustion Improvement of Diesel Engine by Alcohol Addition - Investigation of Port Injection Method and Blended Fuel Method. SAE International Journal of Fuels Lubricants, 2011, 4:48-57.
[14] Sivalakshmi,S. and Balusamy,T. Effects of oxygenated Organic Compounds-neem Oil Blends on the Performance and Exhaust Emissions of a DI Diesel Engine . SAE Paper Number: 2011-01-0331.
[15] Ananda Srinivasan,C. and Saravanan, C.G. Study of Combustion Characteristics of an SI Engine Fuelled with Ethanol and Oxygenated Fuel Additives. Journal of Sustainable Energy & Environment, 2010, 85-91.
[16] Balaji,D. Govindarajan,P and Venkatesan. 2010. Influence of isobutanol blend in spark ignition engine Performance and emissions operated with gasoline and Ethanol. International Journal of Engineering Science and Technology, 2010, Vol. 2(7), 2859-2868.
[17] YAO, ChunDe. ZHANG. ZhiHui, XU. YuanLi, and HUANG.Yu. Experimental investigation of effects of bio-additives on fuel economy of the gasoline engine. Science in China Series E: Technological Sciences.
[18] HanumanthaRao,Y.V.RamSudheer,Voleti. SitaramaRaju,A.V. and Nageswara Reddy,P.Experimental investigations on jatropha biodiesel and additive in diesel engine. Indian Journal of Science and Technology, 2009, Vol.2, No 4.
[19] Zhang, G.D. Liu,H. Xia,X.X. Zhang, W.G. and Fang. J.H. Effects of dimethyl carbonate fuel additive on diesel engine performances. Proc. IMechE Part D:J.Automobile Engineering,2005, D13904,Vol. 219.
[20] Nibin,T.Sathiyagnanam,A.P. Sivaprakasam,S.and Saravanan,C.G. Investigation on Emission Characteristics of a Diesel Engine using Oxygenated Fuel Additive. IE(I) Journal MC,2005, Vol 86.
[21] Venkata Subbaiah,G. Raja Gopal,K. Syed Altaf Hussain. Durga Prasad,B. and Tirupathi Reddy,K. RiceBran Oil Biodiesel As an dditive In Diesel-Ethanol Blends For Diesel Engines. Ijrras,2010, 3(3).
[22] Manish Nandi, K. The Performance of Ditertiary-Butyl Peroxide as Cetane Improver in Diesel Fuels. ARCO Chemical Company, Newtown Square, PA 19073.
[23] Sathiyagnanam,A.P. Saravanan,C.G. and Dhandapani,S. Effect of Thermal-Barrier Coating plus Fuel Additive for Reducing Emission from DI Diesel Engine. Proceedings of the World Congress on Engineering, 2010, Vol II WCE 2010, June 30 - July 2, 2010, London, U.K.
[24] SundarRaj,C. Sendilvelan,S. and Arul,S. Performance of a Thermally Insulated Constant Speed Diesel Engine with Dioxane Blended Fuels. Global Journal of Researches in Engineering, 2010, Vol. 10 Issue 2 (Ver 1.0).
[25] Karas,L.J. Kesling,H.S. Jr, Liotta,F.J. Jr. and Nandi,M.K. Low Emission Oxygenated Diesel Fuel. 3801 West Chester Pike Newtown Square,PA19073-2387. ARC0 Chemical Company Research and Development.
[26] Murat, Karabektas. and Murat, Hosoz. Performance and emission characteristics of a diesel engine using isobutanol–diesel fuel blends. Renewable Energy, 2009, Volume 34, Issue 6, Pages 1554-1559.
[27] Venkanna,B.K., Swati, B., Wadawadagi, Venkataramana Reddy,C., Effect of Injection Pressure on Performance, Emission and Combustion Characteristics of Direct Injection Diesel Engine Running on Blends of Pongamia Pinnata Linn Oil (Honge oil) and Diesel Fuel. Agricultural Engineering international: The CIGR Ejournal, 1316. Vol. XI. May, 2009.
[28] Sanjay Patil, Akarte.M.M., Effect of Injection Pressure on CI Engine Performance Fuelled with Biodiesel and its blends. International Journal of Scientific & Engineering Research, Volume 3, Issue 3, March 2012.
[29] K.Venkateswarlu, B.S.R Murthy, and V.V Subbarao., An Experimental Investigation on Performance,Combustion and Emission Characteristics of Diesel-Biodiesel Blends with Isobutanol as an Additive. SAE Technical Paper number: 2012-28-0011, DOI: 10.4271/2012-28-0011.
[30] Hariharan, V.S., Vijayakumar Reddy, K., Effect of injection pressure on diesel engine performance with Sea lemon oil. Indian Journal of Science and Technology, Vol. 4, No. 8, 2011.
[31] Xiaolei Gu, Guo Li, Xue Jiang, Zuohua Huang,and Chia-fon Lee., Experimental study on the performance of and emissions from a low-speed light-duty diesel engine fueled with *n*-butanol–diesel and isobutanol–diesel blends. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering 0954407012453231 first published on August 13, 2012.
[32] Yakup Icıngur, Duran Altiparmak., Effect of fuel cetane number and injection pressure on a DI Diesel engine performance and emissions. Energy Conversion and Management, Volume 44, Issue 3, February 2003, Pages 389–397.

The effects of isobutanol- and n-butanol-enriched diesel fuel on the diesel engine performance and emissions are investigated. Neat diesel, 15% isobutanol–85% diesel, 30% isobutanol–70% diesel, 15% n-butanol–85% diesel, and 30% n-butanol–70% diesel blends are investigated in this study. The tests were carried out at light and medium loads and a fixed low engine speed, and by using various combinations of the exhaust gas recirculation rate and the injection timing to investigate the effect of the molecular structure difference on soot formation. The results show that n-butanol–diesel blends give a longer ignition delay than isobutanol–diesel blends do. Hence isobutanol has a higher peak cylinder pressure and a higher premixed heat release rate than n-butanol does. Adding butanol (isobutanol and/or n-butanol) to diesel fuel is able to decrease the soot emissions substantially, while the change in the nitrogen oxide emissions varies slightly. Soot emissions from n-butanol–diesel blends are lower than those from isobutanol–diesel blends. Introducing exhaust gas recirculation and retarding the injection timing are effective approaches to decrease the nitrogen oxide emissions. However, a high exhaust gas recirculation rate leads to a loss in the fuel efficiency. The combination of a low exhaust gas recirculation rate, later injection and butanol blends can achieve low-temperature combustion and simultaneously decrease the nitrogen oxide and soot emissions.