World Applied Sciences Journal 30 (12): 1852-1858, 2014
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2014.30.12.338

Effect of Variable Compression Ratio on the Combustion, Performance and Emission Parameters of a Diesel Engine Fuelled with Diesel and Soybean Biodiesel Blending

Mohamed F. Al-Dawody and S.K. Bhatti

Department of Mechanical Engineering, Andhra University, India

Abstract: This work investigates the effect of variable compression ratio on the combustion, performance and emission characteristics of a single cylinder, direct injection diesel engine powered by soybean methyl ester (SME) blend with diesel fuel. Experiments were conducted with different compression ratios of 15, 16, 17.5 and 19 at various load conditions in terms of brake power at a constant speed of 1500 rpm. Three blends of soybean biodiesel (B20, B40 and B100) on volume basis have been tested and compared with respect to diesel fuel. Results of combustion analysis indicate that start of combustion for biodiesel blends was earlier than that of diesel. The heat release rate decreased with increasing the biodiesel percentage. Brake thermal efficiency was slightly lower with respect to diesel fuel. It was observed that increasing the compression ratio from 15 to 19 produces lower smoke opacity, hydro carbon (HC) and carbon monoxide (CO) respectively. Oxides of nitrogen (NOx) were found to be higher with higher compression ratio and higher substitution of SME. The best blend of SME was B20% SME which has less increase in the NOx emissions as compared with B40% & B100% SME biodiesel. The experimental results were verified with the results obtained by the simulation software Diesel-rk at the same working conditions.

Key words: Biodiesel · Combustion · Performance · Pollutant Emission · NOx · Diesel-rk software

INTRODUCTION

In recent years, the fossil fuels have suffered from a sudden rise in prices because of the limitations of deposit, supply and considerable increases in demand for petroleum fuels resulting from the industrialization. Furthermore, the regulations for particulate matter (PM) and NOx emissions from diesel engines have strengthened and reductions in carbon dioxide (CO_2), which is a greenhouse gas, emissions also raised important issues on environmental problems [1, 2]. For these reasons, biodiesel has been subject to intensive research work all over the world because they are extraordinarily attractive alternative fuels. In addition, since biodiesel does not contain carcinogens such as polyaromatic hydrocarbons and nitrous polyaromatic hydrocarbons, it produces pollutants that are less detrimental to human health [3]. In general, if the fuel properties of biodiesel are compared to petroleum diesel fuel, it can be seen that biodiesel has a higher viscosity, density and cetane number, but the energy content or net calorific value of biodiesel is about 10 to 12% less than that of conventional diesel fuel [4]. Soybean is a very versatile grain that gives rise to products widely used by agro-chemical industry and food industry. Besides, is a raw material for extraction of oil for biofuel production. Soybean has about 25% of oil content in grain. The largest producers of soybean are: United States, Brazil, Argentina, China and India [5]. Many researchers have found that although biodiesel fuels could reduce PM, CO and smoke exhaust emissions, NOx emissions are increased as compared to diesel fuel in diesel engines [6-16]. In the present study experiments and computational investigations are conducted on a diesel engine fueled with diesel, SME and their blends under constant speed with variable load and compression ratio without any modifications on the engine. The objective is to study the effect of blending by varying the compression ratio.

Corresponding Author: Mohamed F. AL_Dawody, Department of Mechanical Engineering, Andhra University, Visakhapatnam, 530003, A.P. India.

Table 1: Properties of diesel and soybean methyl ester blends [17]

Property	Diesel	B20% SME	B40% SME	SME
Chemical formula	$C_{13.77}H_{23.44}$	$C_{14.97}H_{26.33}O_{0..34}$	$C_{16.07}H_{28.94}O_{0.68}$	$C_{19}H_{35}O_2$
Density at 15°C(kg/m^3)	830	841	852	876
Viscosity at 40°C (cst)	3.0	3.34	3.68	4.25
Calorific value (MJlkg)	42.5	41.18	39.89	36.22
Flash point (°C)	76	86.8	97.6	130
Cetane number	48	48.69	49.37	51.3

Table 2: Specifications of engine

Engine Make	Kirloskar TAF-1
Engine Type.	4-Stroke, Diesel Engine
Number of Cylinder	1
Bore × stroke	87.5×110 mm
Cylinder capacity	0.66 L
Compression ratio	Variable (15, 16, 17.5, 19)
Rated power	4.4 kW, 1500 rpm
Maximum torque	28 N.m,1500 rpm
Orifice diameter	0.15 mm
Injection timing	20°BTDC
Injection pressure	220 bar

Table 3: The accuracies of the measurements in the calculated values

Emission	Range	Accuracy
CO	0-10% vol	± 0.2%
CO_2	0-20% vol	± 1%
HC	0-20000 ppm	±10 ppm
O_2	0-22% vol	± 0.2%
NOx	0-5000 ppm	±10 ppm
Opacity	0-100%	± 1%

The Biodiesel Preparation and Specifications: The biodiesel used in this study was provided from Intech energy systems Pvt. Ltd. It uses a transesterification process together with methanol, which was catalyzed by potassium hydroxide. The properties of the diesel and biodiesel are summarized in Table 1.

Experimental Setup and Procedure: The engine used in the present study was a Kirloskar TAF-1, single cylinder, air cooled, vertical and direct injection variable compression ratio diesel engine with the specification given in Table 2. The schematic diagram of the experimental setup was shown in Fig. (1). The engine was coupled to an eddy current dynamometer. The inlet side of the engine consists of anti pulsating drum and air temperature measuring device. The exhaust side of the engine consists of exhaust gas temperature indicator, exhaust gas analyzer (AVL 437 DiGas 444) and smoke meter (AVL 415). The operating ranges with accuracy for gas analyzer and smoke meter were given in Table 3. A 64 bit DAQ system was also provided with the test rig to acquire crank angle and cylinder pressure data. The test rig was installed with AVL software for obtaining various curves and results during operation. The standarded compression ratio of the engine was 17.5. The engine was run at four different compression ratio (15, 16, 17.5 and 19). All tested fuels were conducted at five different engine loads in terms of brake power (0, 1.1, 2.2, 3.3 and 4.4 kW) at constant engine speed of 1500 rpm. Three test samples were prepared, namely B20% SME, B40% SME and B100% SME blends on a volume basis and the experiments were conducted over the same range of load

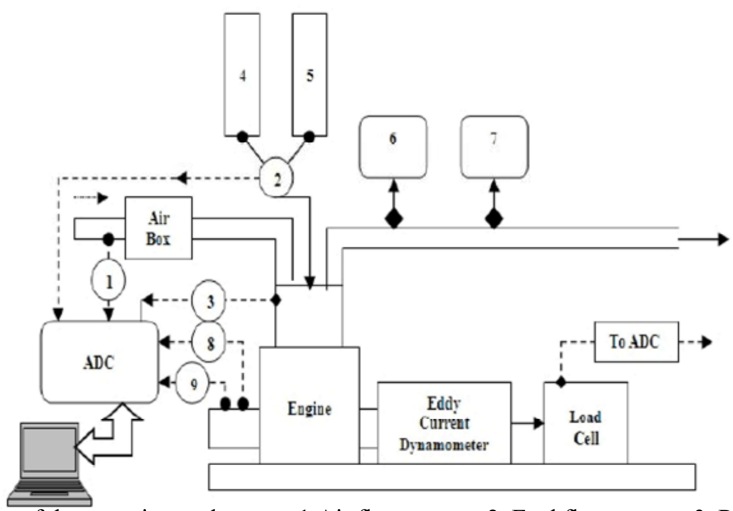

Fig. 1: Schematic diagram of the experimental set-up: 1.Air flow sensor; 2. Fuel flow sensor; 3. Pressure sensor; 4. Diesel tank; 5. Biodiesel tank ; 6. Five gas analyzer; 7. Smoke meter; 8. Speed meter; 9.Crank angle encoder

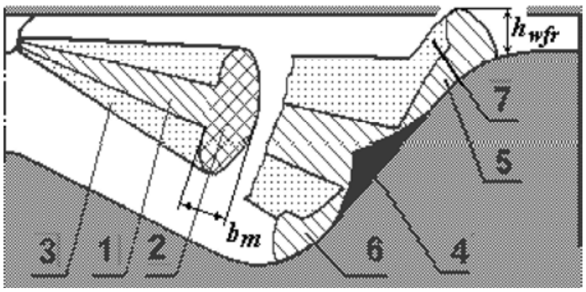

Fig. 2: Characteristic zones of the diesel spray

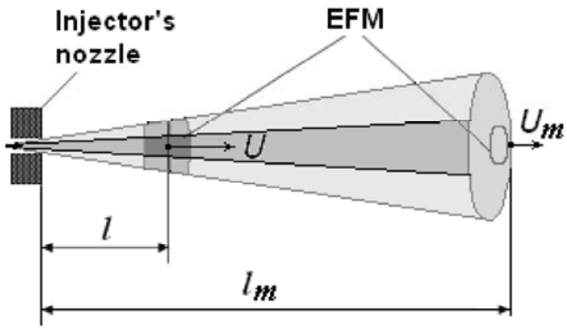

Fig. 3: Variation of spray evolution with time

and compression ratio. Engine was run with each biodiesel for 2 hours continuously and then the test results were obtained and compared with the baseline data of diesel fuel. Three sets of observations were taken and the average value was considered for this study.

Diesel-rk Simulation Software: The software Diesel-rk is intended for the calculation and optimization of internal combustion engines. It has advanced RK-model of mixture formation and combustion in a diesel engine and also it is the tool for multiparameter optimization [18]. In the multizone combustion model which is implemented in this work, the spray is split into seven characteristic zones, as shown in Fig.(2). In each zone specific evaporation and burning conditions are specified in the model. The spray evolution passes through three stages: (1) Initial formation of dense axial flow (2) Main stage of cumulative spray evolution (3) Period of spray interaction with the combustion chamber walls and fuel distribution on the walls.

As shown in Fig. (2) b_m represents the thickness of the free spray and h_{wfr} height of zone 7. As the spray moves on, constant breakup of the spray forward part takes place and the front is renewed by new flying fuel portions. The delayed droplets move from the breaking front to the environment. The moving spray carries the surrounding gas with it. The gas velocity in the environment is low, but gas in the axial core is rapidly accelerated to the velocity close to that of droplets. The core diameter in the cross section is about 0.3 of the spray outside diameter. The current position and the velocity of an elementary fuel mass (EFM) injected during small time step and moving from the injector to the spray tip are related as:

$$\left(\frac{U}{U_o}\right)^{3/2} = 1 - \frac{l}{l_m} \tag{1}$$

U is the velocity of the fuel (m/s), U_o Initial velocity of the spray at the nozzle (m/s), U_m velocity of the spray front (m/s), l current length of the spray (m) and l_m penetration distance of the control portion of the fuel (m). As an illustration, Fig. (3) presents the variation of spray evolution parameters as functions of time. The general principles, like modeling of spray, evaporating equations, heat release and emissions are mentioned in [19-20]. Same operating conditions and fuel properties with engine specifications were used as input data to the software.

RESULTS AND DISCUSSIONS

A series of exhaustive engine tests were carried out at variable load with various percentage substitution of SME and different compression ratios. The combustion, performance and emission parameters obtained for biodiesel blends were compared with respect to diesel fuel. The range of operating conditions were constant engine speed 1500 rpm, injection pressure 220 bar, 20°CA before top dead centre injection timing and variable compression ratio of 15, 16, 17.5 and 19 respectively. The experimental results were compared with the results obtained from the simulation software Diesel-rk. The variable load condintion was considered from 0% to 100% of full load at various compression ratios. However, they are plotted only for 100% load to study the effect of blending by varying the compression ratio. This condition was chosen because it is the point of minimum air/fuel ratio and maximum smoke. This provides the best conditions for discerning any differences between the fuels.

Cylinder Pressure: In a diesel engine the cylinder pressure depends on the fuel burning rate during the premixed burning phase. The higher cylinder pressure ensures better combustion and heat release. Fig. (4) presents the cylinder pressure versus crank angle at varaible compression ratio for B20 SME. The combustion pressure with B20% SME increases steeply as a result of

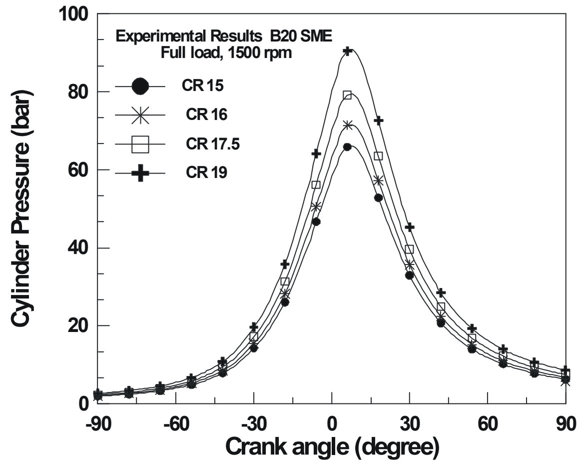

Fig. 4: Pressure-crank angle diagram at 20% SME

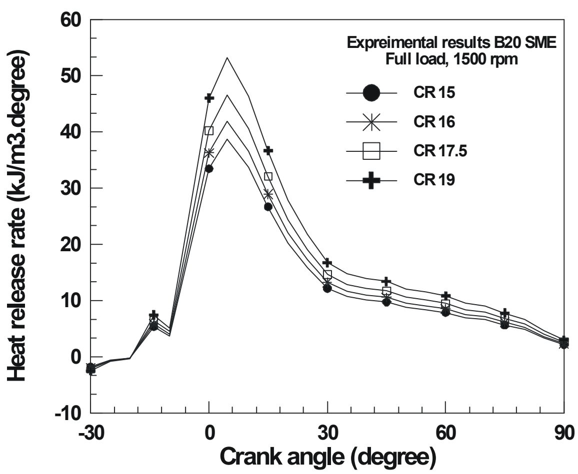

Fig. 5: Heat release rate at 20% SME

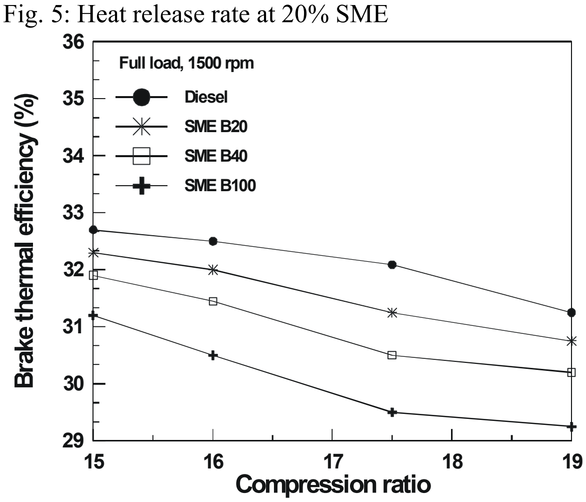

Fig. 6: Effect of compression ratio on the BTE

increasing in the compression ratio from 15 to 19 recording 37.45%. Increasing the compression ratio results in closer contact between the molecules of fuel and oxygen which reduces the time of reaction and releases more heat. The increase in compression temperature as well as the decrease auto ignition temperature decrease the delay period.

Heat Release Rate: Fig. (5) shows the heat release rate analysis per degree crank angle for B20 SME with various compression ratios. It can be observed that the value of heat release rate increases with increase in the compression ratio recording maximum values for 19 compression ratio due to the increase in the cylinder pressure and combustion temperature. It is evident from this figure, that B20 SME biodiesel has an earlier start of combustion. The early start of combustion is caused by earlier start of injection and shorter ignition delay. The SME has higher density (Table 1), which affects the fuel compression process in the volumetric injection pump. Hence, the needle nozzle lifted more rapid when using biodiesel. This case leads to advance in start of injection timing [21]. As well as the higher bulk modulus (lower compressibility) of vegetable oils and their methyl esters lead to advanced injection timing [22].

It is known that the fuels with high cetane number makes auto-ignition easily and gives short ignition delay. So, primary reason for the decrease in the ignition delay is cetane number of the biodiesel which is higher than that of diesel fuel. At the same time, the ignition delay increases with increasing aromatic compounds of the fuel [23]. Therefore, using biodiesel reduces the ignition delay compared to the diesel fuel, since it contains a small amount of aromatic compounds.

Brake Thermal Efficiency: Brake thermal efficiency (BTE) is one of the main important performance parameters which indicates the percentage of energy present in the fuel that is converted into useful work [24]. Fig.(6) explains the variation of brake thermal efficiency with compression ratio for diesel and SME blends. The decreasing trend in efficiency with increasing the concentration of SME in diesel may be due to the lower heating value of biodiesel compared to that of diesel. Also it may be due to poor atomization and high viscosity of biodiesel. A slight decrease is observed in the BTE for B20% of SME as compared to diesel fuel.

HC Emissions: Hydrocarbon emission is an important parameter for evaluating emission behavior of the engine. Fig.(7) shows the variation of HC emission with compression ratio for diesel fuel blended with SME biodiesel. It can be seen that diesel fuel has higher HC emission than all blends of SME. The HC value

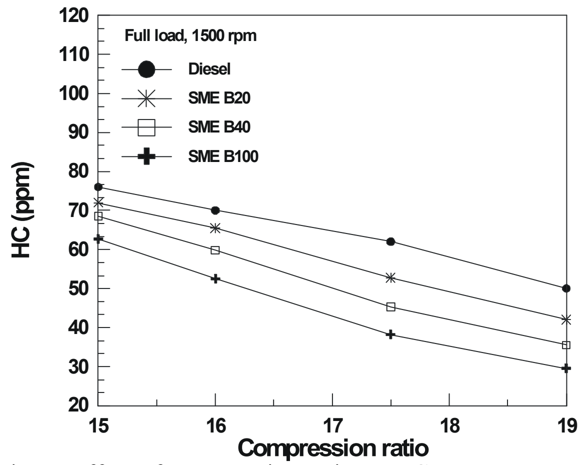

Fig. 7: Effect of compression ratio on HC

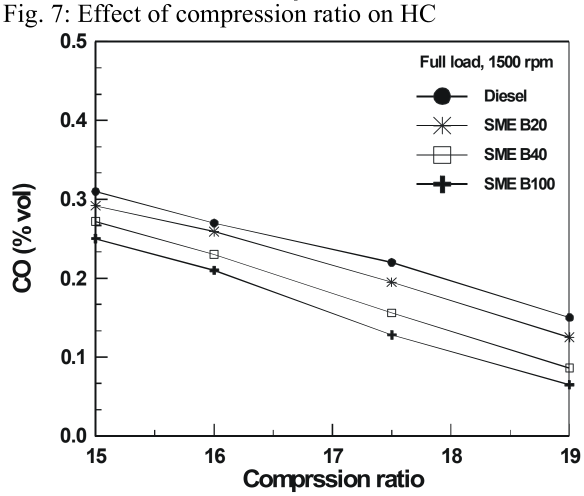

Fig. 8: Effect of compression ratio on CO

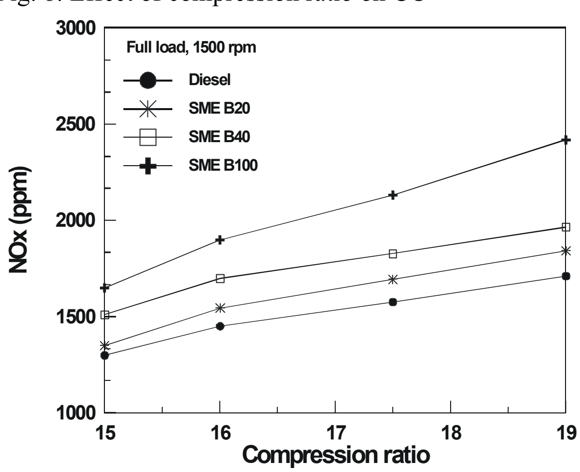

Fig. 9: Varaition of NOx with compression ratio

continuously decreases with the increase in the percentage of SME for all compression ratios. The obvious reason for that is the complete combustion and higher inside temperature due to the availability of excess content of oxygen as compared to pure diesel fuel. As the percentage of SME blends is varied from 0% to 100%, the value of HC is reduced by 41% for CR 19 and for CR 17.5 the percentage of reduction is 38.4% as compared to that of diesel fuel.

CO Emissions: It can be seen from Fig. (8) all blends of SME are found to emit significantly lower CO concentration compared to that of pure diesel over all compression ratios. When the percentage of blend of biodiesel increases, CO emission decreases. The excess amount of oxygen content of biodiesel results in complete combustion of the fuel and supplies the necessary oxygen to convert CO to CO_2. Both HC and CO emissions are low at higher percentage of SME. With B100% SME the percentage reduction in the CO value is 19.35%, 22.22%, 41.7% and 56.66% for 15, 16, 17.5 and 19 compression ratio as compared to diesel fuel.

Nox Emissions: Fig. (9) shows the variation of NOx emissions with compression ratio for diesel-SME blends. It is found to be higher with higher compression ratio and higher concentration of biodiesel. Many researchers reported that oxygenated fuel blend can cause an increase in the NOx emissions. It can be observed that at full load conditions, due to higher peak temperature, the NOx values are higher for biodiesel and diesel fuels. At standard compression ratio 17.5, the NOx emissions increased by 7.5%, 16% and 35% with B20% SME, B40% SME and B100% SME respectively. It can be seen that B20% SME has lower increase in the NOx compared to other blends of SME. the results of this study confirmed with the observations noticed by [22].

Smoke Opacity: Fig. (10) presents the variation of smoke opacity with compression ratio for diesel and SME blends. It is observed that smoke opacity of diesel and various blends of SME was lower at low loads, but increased at higher engine loads because more fuel is injected at higher load so less oxygen will be available for the reaction. Also it is noticed that smoke opacity for all SME percentages are lower than that of pure diesel. This is because smoke decreases with high oxygen content in the biodiesel that contributes to complete fuel oxidation even in locally rich zones, so the oxygen within the fuel decreases the tendency of a fuel to produce smoke [4]. Another reason for smoke reduction when using biodiesel is the lower C/H ratio as compared to pure diesel fuel. For compression ratio of 15, 16, 17.5 and 19, the smoke

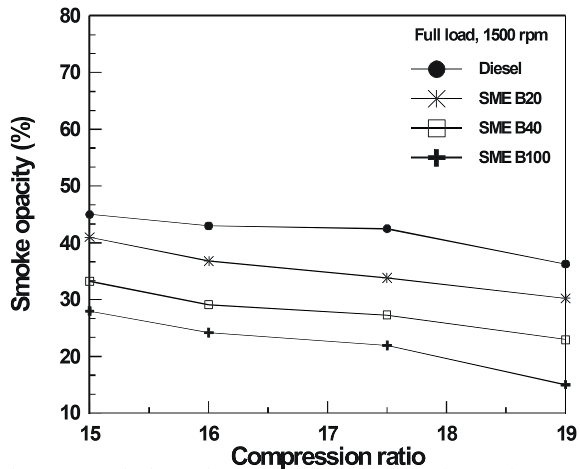

Fig. 10: Variation of smoke with compression ratio

Table 4: Comparison of experimental results with Diesel-rk software results

% change in parameter	Biodiesel blending (0-100)%	Experimental results	Diesel-rk software results	Δ%
Peak pressure	From 0% to 100%	2.98%	2.5%	0.59
BTE	From 0% to 100%	8.07%	7%	1.07
BSFC	From 0% to 100%	14.65%	17.31%	2.66
Smoke	From 0% to 100%	48.31%	52.96%	4.64
NOx	From 0% to 100%	35.3%	38.43%	3.33

level with B100% SME is reduced by 37.78%, 43.72%, 48.3% and 58.62% as compared to that of diesel fuel respectively.

Experimental Verfication: In this section the point of discussion is to compare some of the results obtained from experimental investigation with the simulation of Diesel-rk software. A slight difference between the two is recorded. In order to predict the values very near to the experimental results, a separate code has to be incorporated to put all the experimental constraints and loses by using the user defined functions in the software, then the predictions will be very near to the practical results. The results are compared at 4.4 kW full load, 17.5 CR and 1500 rpm. The difference between these results is reported and arranged in Table 4.

CONCLUSIONS

The following conclusions can be drawn from this study:

- The peak pressure is observed to be closer to TDC when blending of SME increased and it was higher with higher compression ratio reaching maximum value with CR 19.
- All blends of SME have earlier start of combustion as compared to base line diesel fuel.
- Increasing the percentage of SME is noticed to reduce the brake thermal efficiency slightly and increase the BSFC.
- Both HC and CO emissions decrease drastically with the increase in the blends of SME recorded maximum reduction with B100% SME for all compression ratios.
- The measured Nox for all blends of SME is higher than that of diesel. It is found to be higher with higher compression ratio and higher SME blends.
- Smoke opacity is reduced for all SME blends. It is observed to be lower with higher compression ratio and higher percentage of SME.
- The best fuel combination is B20% SME which has same combustion results with good reduction in the emissions as compared to base line diesel fuel, also less increase in the NOx emissions is noticed in B20% SME as compared with B40% & B100% SME biodiesel.

REFERENCES

1. Seung H.Y. and S. Chang, 2011. Experimental investigation on the combustion and exhaust emission characteristics of biogas–biodiesel dual-fuel combustion in a CI engine. Fuel Precessing Technology, 92(5): 992-1000.
2. Kim, M., S. Yoon, J. Hwang and C. Lee, 2008. Characteristics of particulate emissions of compression ignition engine fueled with biodiesel derived from soybean. Engineering for Gas Turbine and Power, 130(5): 1-7.
3. Graboski, M.S. and R.L. McCormick, 1998. Combustion of fat and vegetable-oil derived fuels in diesel engines. Prog. Energy Combust. Sci., 24(2): 125-164.
4. Cengiz, O. and A. Sehmus, 2009. Biodiesel production from inedible animal tallow and an experimental investigation of its use as alternative fuel in a direct injection diesel engine. Applied Energy, 86(10): 2114-2120.
5. Roberto, G., E. Oscar, D. Valdir, M. Dalni and T. Ednilton, 2011. Use of soybean oil in energy generation. Recent Trends for Enhancing the Diversity and Quality of Soybean Products, pp: 301-320.

6. Zhang, X., G. Gao, L. Li and Z. Wu, 2008. Characteristics of combustion and emissions in a DI engine fueled with biodiesel blends from soybean oil. SAE, pp: 2008-01-1832.
7. Mustafa, C., 2005. Performance and emissions characteristics of biodiesel from soybean oil. Proc. IMechE, Part D: J. Automobile Engineering, 219(7): 915-922.
8. Scholl, K. and S. Sorenson, 1993. Combustion of soybean oil methyl ester in a direct injection diesel engine. SAE, pp: 1993-930934.
9. Gumus, M. and S. Kasifoglu, 2010. Performance and emission evaluation of a compression ignition engine using a biodiesel (apricot seed kernel oil methyl ester) and its blends with diesel fuel. Biomass and Bioenergy, 34(1): 134-139.
10. Ekrem, B., 2010. Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics. Fuel, 89(10): 3099-3105.
11. Masood, M., S.N. Mehdi and P. Ram Reddy, 2007. Experimental investigations on a hydrogen-diesel dual fuel engine at different compression ratios. ASME J. Gas Turbine and Power, 129(2): 572-578.
12. Mohamed F. Al-Dawody and S.K. Bhatti, 2013. Optimization strategies to reduce the biodiesel NOx effect in diesel engine with experimental verification, Energy Conversion and Management, 68(11): 96-104.
13. Agarwal, D., S. Sinha and A. Kumar, 2006. Experimental investigation of control of NO_x emissions in biodiesel-fueled compression ignition engine. Renewable Energy, 31(14): 2356-2369.
14. Mueller, J. and A. Boehman, 2009. An experimental investigation of the origin of increased NO_x emissions when fueling a heavy-duty compression-ignition engine with soy biodiesel. SAE, pp: 2009-01-1792.
15. Rakopoulos, C.D., D.T. Hountalas, E.G. Giakoumis and E.C. Andritsakis, 2008. Performance and emissions of bus engine using blends of diesel fuel with bio-diesel of sunflower or cottonseed oils derived from Greek feedstock. Fuel, 87(2): 147-157.
16. Gokalp B., E. Buyukkaya and H.S. Soyhan, 2011. Performance and emissions of a diesel tractor engine fueled with marine diesel and soybean methyl ester. Biomass and Bioenergy, 35(8): 3575-3583.
17. Mohamed F. Al-Dawody and S.K. Bhatti, 2011. Effect of soybean oil biofuel blending on the performance and emissions of diesel engine using diesel-rk software. Engineering Science and Technology, 3(6): 4539-4555.
18. DIESEL-RK as an engine simulation tool, available from http://diesel-rk.bmstu.ru/Eng/index.php, accessed 22 January (2013).
19. Kuleshov, A.S., 2005. Model for predicting air-fuel mixing, combustion and emissions in DI diesel engines over whole operating range, SAE, pp: 01-2119.
20. Kuleshov, A. and K. Mahkamov, 2008. Multi-zone diesel fuel spray combustion model for the simulation of a diesel engine running on biofuel. Proc. IMechE, Part A: J. Power and Energy, 222(3): 309-321.
21. Ahmet, N. and C. Mustafa, 2011. Determination of performance and combustion characteristics of a dieselengine fueled with canola and waste palm oil methyl esters. Energy Conversion and Management, 52(1): 108-116.
22. Boehman, A.L., D. Morris, J. Szybist and E. Esen, 2004. The impact of the bulk modulus of diesel fuels on fuel injection timing. Energy Fuel, 18(6): 1877-1882.
23. Stringer, F.W., A.E. Clarke and J.S. Clarke, 1970. The spontaneous ignition of hydrocarbon fuels in a flowing system. Proc Inst Mech Eng., 184: 212-25.
24. Heywood, J.B., 1988. Internal combustion engine fundamentals, 1988. (McGraw-Hill, New York).
25. Metin, G., S. Cenk and C. Mustafa, 2012. The impact of fuel injection pressure on the exhaust emissions of a direct injection diesel engine fueled with biodiesel-diesel fuel blends, Fuel, 95: 486-494.