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Diesel engine performance and emission analysis using biodiesel from various oil sources - Review

Gaurav Dwivedi [1], Siddharth Jain [2], M.P. Sharma [3]
[1,3]*Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand- 247667, India,*
[2]*Department of mechanical engineering, National institute of Technology Singapore, Singapore*

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* Corresponding Author: E-mail: gdiitr2005@gmail.com.: Tel+91 1332 285836 , Fax: +91 1332 273517

Abstract
As a renewable, sustainable and alternative fuel for compression ignition engine, biodiesel instead of diesel has been increasingly fuelled to study its effects on engine performances and emissions in the recent 15 years. Biodiesel, derived from the transesterification of vegetable oils or animal fats, is composed of saturated and unsaturated long-chain fatty acid alkyl esters. In spite of having some application problems, recently it is being considered as one of the most promising alternative fuels in internal combustion engine. The aim of the present paper is to do a comprehensive review of engine performance and emissions using biodiesel from different feedstocks and to compare that with the diesel. From the review it is found that the use of biodiesel leads to the substantial reduction in PM, HC and CO emissions accompanying with the imperceptible power loss, the increase in fuel consumption and the increase in NO_x emission on conventional diesel engine with no or fewer modification. However, many further researches about modification on engine, low temperature performance of engine, new instrumentation and methodology for measurements, etc., are recommended while using biodiesel as a substitute of diesel.

Keywords: Diesel, Engine, Biodiesel, Brake specific fuel consumption, Brake thermal efficiency

1. Introduction
The availability of energy resource plays a critical role in the progress of a nation. A almost all the human energy needs are currently met from the fast depleting fossil fuels associated with serious environmental consequences. Over the last century, there has been more than 20 fold increase in the consumption of energy worldwide and all major sources excepting hydropower and nuclear electricity are the finite sources and therefore are likely to be exhausted in near future [1].The rapid increase in the consumption of fossil fuels is resulting into climate change which is considered as the most important environmental problem of the present century and the recent studies hence indicates that the emission of green house gases to the atmosphere have contributed to the increase in the global mean temperature by approximately 0.8 °C during the past century. The impact of climate change on the ecosystem and human societies has prompted to develop ecofriendly and infinite renewable sources like solar, wind, small hydro, biomass, etc .Renewable energy sources in general and biomass energy in particular is capable of reducing our dependency on foreign import there by increasing the security of energy supply. The ethanol and biodiesel are the two liquid bio fuels that can replace/substitute gasoline /diesel respectively. Production and utilisation of the bio fuel would generate the of new economic opportunities in term of creation of job opportunities in rural areas in addition to the protection of the environment [4].Biodiesel and ethanol derived from biomass feed stocks can provide alternative substitute of petro diesel and gasoline respectively. The present paper will be restricted only to the biodiesel diesel substitute. Biodiesel can be obtained from a number of edible and non edible oil resources and major thrust is given for the utilisation of non edible seed plant. The oil from these plants can be transesterified by suitable method depending on its FFA content for the production of biodiesel that can be used to operate an CI engine. The present paper attempts to review the work on the performance of diesel engine using biodiesel-diesel blends as well as blend of diesel with various oils.

2. India's Energy Scenario

As per 2009/10, estimates, the crude oil production in India stood at 33.67 MT which is approximately the same as compared to the previous year's production of 33.51 MT (2008-09). Since the Indian economy is growing at the rate of 6% or more and the energy demand is therefore, expected to rise to 166MT by 2019 and 622MT by 2047. [1] The demand of crude oil in the country is met through indigenous supplies as well as through imports. The dependency on imported crude oil has been about 79% of the total demand in 2009/10 valued at Rupees 3753 billion which is 9% higher than the 2008-09,Fig I shows that the demand of crude has reached to 159.3MT during 2009-10which is about three times more than 57.8MT during1979-2000.

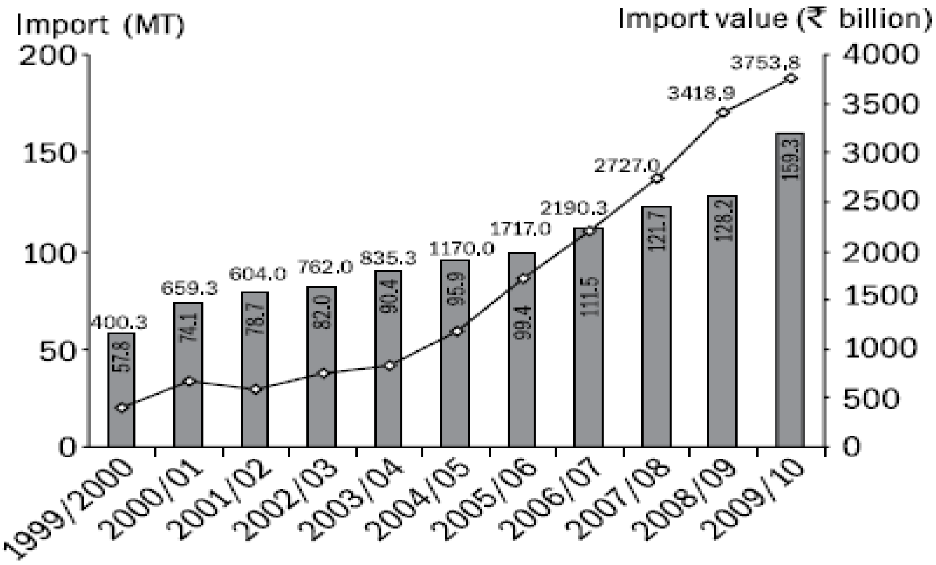

Fig 1. Annual imports and cost of crude oil imports [101]

The rapidly increasing demand of crude oil coupled with increase in fuel demand has forced the countries to look for alternative to conventional fuels As stated above, the biodiesel production from non edible seed plant like jatropha, pongamia, mahua etc are being considered as indigenous source of oil for biodiesel production. Once the oil resources starts to available in the country, the availability of biodiesel as substitute of diesel fuel will increase and dependency on oil import would reduce there by making the country self sufficient in fuel supplies.

3. National Biodiesel Mission

The demand of diesel is five times more than the gasoline in the country. The ethanol industry is well established while the biodiesel industry is still in the process of development. Indian Government has formulated an ambitious National Biodiesel mission in the year to substitute about 20% of the total diesel demand by biodiesel by 2011-2012.Accordingly *Jatropha curcas* has been accorded top priority to be used as non edible oil feed stocks for biodiesel production. The *Jatropha curcas* plant is being grown over 40000 ha of land from 2003 or so over to produce about3.75T of oil per hectare annually. Jatropha plant to biodiesel chain will include plantation, plant management oil extraction, oil refinement transtesterification, purification, stabilisation, blending and marketing when oil start to be available for conversion to biodiesel. This will allow to encourage the use of B_{20} blend with country and save the diesel fuel

4. Fuel Properties of Biodiesel

Biodiesel is mono-alkyl ester made from natural and renewable vegetable oil and animal fats based feedstock. The biodiesel is similar in fuel characteristics to conventional diesel as shown in table 1 which also compare the fuel characteristics specified by standard specification of different countries. The data indicates that the biodiesel is compatible with petroleum diesel and can be blended in any proportion with diesel to create suitable biodiesel blend. The blending of biodiesel with diesel is expressed as B_{xx} where xx indicates the percentage of biodiesel in the blend For example B20 blend is made by mixing 20% biodiesel with 80% diesel which can be used in CI engine with no modification with comparable power output. When higher blends including B100 is used the higher Brake Specific Fuel Consumption (BSFC) (gm/kWh) is reported to increase as reported in our

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earlier communication [24]. Countries like Germany, Italy, France, USA, India etc have developed their own biodiesel specification and are almost comparable. The flash point and acid value of DIN standard are slightly higher than ASTM standard and are normally followed all during the work.

Table 1: Comparison of fuel properties of Biodiesel of Different Standards [101]

S.No.	Fuel Properties	Austria (ONC-1191)	India (BIS-15607)	France (EU-15412)	Germany (DIN-EN-590)	Italy (UNI-10946)	USA (ASTM-424720)
1.	Density at 15^0C (g/cm^3)	0.85-.89	0.87-0.89	0.87-0.89	0.875-0.89	0.86-0.90	0.88
2.	Viscosity at 40^0C (mm^2/s)	3.5-5	1.9-6	3.5-5	3.5-5	3.5-5	1.96
3.	Flash point ^{0}C	100	130	100	110	100	130
4.	Cold Filter Plugging Point ^{0}C	0-5	0-5	N.A	0-10/-20	N.A	N.A
5.	Pour point ^{0}C	N.A	N.A	10	N.A	1-5	15-18
6.	Cetane number	≥49	≥40	≥49	≥49	N.A	≥47
7.	Neutralization number (mgKOH/g)	≤0.8	≤0.5	≤0.5	≤0.5	≤0.5	≤0.8
8.	Carbon residue (%)	≤0.05	≤0.05	N.A	≤0.05	N.A	≤0.05

5. Compare the fuel properties of different oil with diesel

The table 2 shows that cetane number of all the oils is slightly lower than the diesel indicating that straight vegetable oil SVO are the potential substitute of diesel but the viscosity ranging from 27.2 (linseed oil) to maximum of 51.15 mm^2/sec (tallow oil) is considerably higher than diesel which indicates that there is a need to bring the viscosity of oil near to the diesel either by physical or chemical modification producing the resulting product as perfect substitute of diesel in all respect. The cold flow properties of SVO are lower than diesel indicating that performance of oil as fuel is difficult at low temperature due to its solidification as compared to diesel

Table 2: Comparisons of Properties of Vegetable Oils and their Esters with Diesel Fuel

Type of vegetable oil	CN	HV (kJ/kg)	Viscosity (mm^2/s) Temp)	Cloud Point (°C)	Pour Point (°C)	Flash Point (° C)	Density (kg/m^3)
Castor oil	N.A	39500	297 (38°C)	N.A	-31.7	260	961
Coconut oil	N.A	N.A	N.A	N.A	N.A	N.A	924.27
Cottonseed oil	41.8	39468	33.5 (38 °C)	1.7	-15.0	234	925.87
Linseed oil	34.6	39307	27.2 (38°C)	1.7	-15.0	241	929.07
Olive oil	N.A	N.A	N.A	N.A	N.A	N.A	918
Palm oil	42	N.A	N.A	N.A	N.A	N.A	910.1
Peanut oil	41.8	39782	39.6 (38 °C)	12.8	-6.7	271	914
Rapeseed oil	37.6	39709	37.0 (38 °C)	-3.9	-31.7	246	920
Sesame oil	40.2	39349	35.5 (38 °C)	-3.9	-9.4	260	922
Soybean oil	37.9	39623	32.6 (38°C)	-3.9	-12.2	254	997.5
Sunflower oil	37.1	39575	37.1 (38 °C)	7.2	-15.0	274	920
Tallow oil	N.A	40054	51.15 (40°C)	N.A	N.A	201	820
Jatropha oil	51	39700	51 (30^0C)	16	N.A	242	932
Pongamia oil	51	46000	55.1(30^0C)	23	N.A	110	884
Diesel	47	45343	2.7 (38 °C)	-15.0	-33.0	52	870.20

Table 3 shows that the biodiesel is highly oxygenated fuel which result in better combustion performance and flame temperature compared to diesel and lesser emit lower gaseous emissions. Higher biodiesel flash point makes it storage less risky than diesel. All these properties indicate that the biodiesel is a suitable substitute of diesel. The following are the general feature of the engine and fuel performance.

Table 3: Compare the fuel Properties of Biodiesel with Diesel [101]

S.No.	Fuel properties	Diesel	Biodiesel
1	Fuel standard	ASTM D 975	ASTM D 6751
2	Fuel composition	C_{10-21} HC	C_{12-22} FAME
3	Lower heating value(MJ/kg)	42.52	37.12
4	Kinematic viscosity at 40^0C	1.3-4.1	1.9-6.0
5	Density at 15^0C(kg/m3)	848	878
6	Water, by wt.(ppm)	161	0.05% max.
7	Carbon, (wt %)	87	77
8	Hydrogen, (wt %)	13	12
9	Oxygen, (wt %)	0	11
10	Sulphur, (wt %)	0.05 max.	0
11	Boiling point,(^{0}C)	188 to 343	182 to 338
12	Flash point,(^{0}C)	60 to 80	100 to 170
13	Cloud point,(^{0}C)	-15 to 5	-3 to 12
14	Pour point,(^{0}C)	-35 to -15	-15 to 16
15	Cetane number	40 to 55	48 to 60
16	Auto ignition temperature, (^{0}C)	316	N.A
17	Stoichiometric air/ fuel ratio, (w/w)	15	13.8

5. Performance Parameter of Engine Operation Using Biodiesel

5.1 Engine Performance

Biodiesel produces about 3-5% less engine power and torque due to its lower energy compared to diesel. It is expressed in terms of kWh/litre of fuel or as Brake specific fuel consumption (BSFC) in gm/kWh.

5.2 Deposit and Clogging

Deposits and clogging problems are widely reported and are generally attributed to sub standard quality of biodiesel or due to its less oxidation stability and therefore engine wear is relatively more when run on biodiesel.

5.3 Pollution from engine exhaust:

Biodiesel results in much less air pollution due to its higher oxygen content and absence of “aromatic compounds” and sulphur. The NOx tends to be slightly higher compared to biodiesel which can be minimized by proper engine timing.

5.4 Cold-weather performance

Diesel engines operated in cold weather experience the problems of clogging of the filters and/or choking of the injectors. The use of flow improving additives and “winter blends” of biodiesel and kerosene has proved effective in the operating range of climate temperatures B100 tends to operate well at temperatures down to about 5°C. Additives reduce the range by about 5-8°C, while the winter blends have proved effective at temperatures as low as -20°C or below.

6. Criteria for a fuel to be engine fuel

In IC engine, the thermal energy is released by burning the fuel in the engine cylinder. The combustion of fuel in IC engine is quite fast but the time needed to get a proper air/fuel mixture depends mainly on the nature of fuel and the method of its introduction into the combustion chamber. The fuel should therefore satisfy the following performance.

1. High energy density.
2. Good combustion characteristics.
3. High thermal stability.
4. Low deposit forming tendencies.
5. Compatibility with the engine hardware.
6. Good fire safety.
7. Low toxicity.

8. Less pollution.
9. Easy transferability and onboard vehicle storage.

The combustion process in the cylinder should take as little time as possible with the release of maximum heat energy during the period of operation. Longer operation results in the formation of deposits which in combination with other combustion products may cause excessive wear and corrosion of cylinder, piston and piston rings. The combustion product should not be toxic when exhausted to the atmosphere. These requirements can be satisfied using a number of liquid and gaseous fuels. The biodiesel from non edible sources like Jatropha, Pongamia, Mahua, Neem etc meets the above engine performance requirement and therefore can offer perfect viable alternative to diesel oil in India.

7. Performance of diesel engine with biodiesel fuel

Literature survey reveals that biodiesel perform satisfactorily during diesel engine operation. and B_{20} blend provides the fuel economy almost similar to the diesel. Due to its high lubricity, it causes less wear and tear to engine part. Numerous studies have are reported on the performance and emission of CI engines, fuelled by B_{100} biodiesel as well as its blends with diesel. It oxygenated nature leads to more complete combustion, resulting in lower emission due to higher combustion temperature. The biodiesel blends with diesel give performance similar to diesel as the fuel properties of biodiesel and diesel are almost similar as seen from data given in table 3 which shows that the cetane number, flash point and lubricity of biodiesel are higher while the calorific value is lower. The following parameters are used to evaluate the performance of diesel engine using biodiesel and its blends:

7.1 Brake Mean Effective Pressure (BMEP)

It is an important parameter for comparing the performance of different fuels and defined as the average pressure the engine can exert on the piston through one complete operating cycle. It is the average pressure of the gas in the fuel mixture inside the engine cylinder based on net power. BMEP is independent of the RPM and size of the engine.

If N is the number of revolutions per second, and n_c the number of revolutions per cycle, the number of cycles per second is just their ratio (W) which can be expressed by

$$W = \frac{P n_c}{N}$$

By definition:

$$W = p_{mep} * V_d$$

So that :

$$p_{mep} = \frac{P n_c}{V_d N}$$

7.2 Brake Horsepower (BHP)

It is the measure of an engine's horsepower before the loss in power caused by the gearbox, alternator, water pump, and other auxiliary components like power steering pump, muffled exhaust system, etc. Brake refers to a device used to load an engine and hold it at a desired RPM. During testing, the output torque and rotational speed can be measured to determine the brake horsepower which is the actual shaft horsepower and is measured by the dynamometer by :

$$BHP = IHP - FP$$

Where BHP is brake horse power and IHP is indicated horse power while FP is frictional power The indicated power is produced from the fuel inside the engine while some power is lost due to friction the remaining power available at the shaft of the engine is brake horse power.

7.3 Mechanical Efficiency

Part of the indicated work per cycle is used to expel exhaust gases, induct fresh air, and also overcome the friction of the bearings, pistons, and other mechanical parts of the engine. The mechanical efficiency is the measure of the ability of the engine to overcome the frictional power loss and can be defined as

$$\text{Mechanical Efficiency} = \frac{\text{Work output}}{\text{Work input}}$$

The work output is also defined as brake horse power and input is indicated horse power and the ratio of BHP to IHP is defined as mechanical efficiency.

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7.4 Brake Specific Fuel Consumption (BSFC)

The BSFC defined as the fuel flow rate per unit of power output is a measure of the efficiency of the engine in using the fuel supplied to produce work. It is desirable to obtain a lower value of BSFC meaning that the engine used less fuel to produce the same amount of work. It can be calculated by

BSFC (g/kWh) $=W_f/P_b$

Where, W_f = fuel consumed (g/h)

P_b = brake power (kW) which can be calculated by:

$P_b = P_g/\eta_g$

Where, P_g = load (kW) at generator end

η_g = efficiency of the generator

Numerous, authors [5, 15, 39, 42, 45, 46, 51, 53, 72, 76, 92, 95 and 96] have performed the experiment on the diesel engine to increase the BSFC using various blends of biodiesel from various resources including diesel. The table 4 reports the performance of CI engine using biodiesel from various oil sources. The finding of table 4 indicated that there is increase in the BSFC when using biodiesel as compared to diesel for the same power output. This is because that the heating value of biodiesel is less as compared to diesel

7.5 Brake Thermal Efficiency (BTE)

It is the ratio of the thermal energy in the fuel to the energy delivered by the engine at the crankshaft. It greatly depends on the manner in which the energy is converted as the efficiency is normalized respect to the fuel heating value. It can be expressed by:

BTE (η_b) = $P_b/(m_f \times NCV)$

Where, P_b = brake power (kW)

m_f = fuel consumption (kg/sec)

NCV = net calorific value (kJ/kg)

BTE has also been determined by various workers [18, 26, 39, 42, 45, 46, 53, 72, 77, 79, 80, 81, 82, 95 and 98] using biodiesel as fuel and it is found that there is no significant change in the thermal efficiency while using biodiesel up to B_{20} but there is a slight decrease in thermal efficiency when B_{100} was used which is due to the lower energy content of biodiesel.

Table 4: Effect of using biodiesel on engine performance

Biodiesel	**Efficiency**	**% B.S.F.C**	**Exhaust gas emission %**			**Reference**
			CO	HC	NO_x	
Biodiesel (SOB)	N.A	+13.8	-20	-21	+13	[1]
	N.A	+12.4	N.A	N.A	10%	[4]
	N.A	+15.1	N.A	-50	+15	[1]
	N.A	+13.8	-46	-54	-14.7	[33]
Biodiesel (COB)	+3	+15	-24	N.A	+10	[3]
	N.A	+8	+0.3% to	N.A	-1.1% to -	[5]
Ethylic biodiesel fuel	N.A	+9	-14	N.A	N.A	[4]
Rapeseed-oil biodiesel (ROB)	N.A	+3	N.A	N.A	+8	[4]
	N.A	+14	N.A	N.A	+3.7	[4]
	N.A	+8	-36.8–to-	-39.6–to-	N.A	[16]
Waste-oil and	N.A	+20	N.A	N.A	+20	[33]
Palm-oil biodiesel	N.A	+20	N.A	-22	N.A	[18]
(Recycled cooking fat	8.6 -18.3	N.A	N.A	N.A	+40	[5]
Ethanol–methyl ester	N.A	+10	N.A	-1.2	N.A	[4]
B20	+3	+20.13	-35	N.A	+9	[4]
80 % paraffinic	N.A	+12.3to+15.1	-40(at low	-16	N.A	[18]
Fatty acid methyl	+3	N.A	N.A	N.A	+1%	[27]
Biodiesel	N.A	+11.4	N.A	N.A	+11.2	[34]

***The increase or decrease in the value is compared with diesel as standard taken as zero**

Table 5 represent the result of the work done by various workers on the engine performance using biodiesel from different sources as the engine fuel. The main finding are also reported which gives a broader view of the type of the work done on existing engine and engine modification if any.

Table 5: Engine Performance by different Workers

Configuration of Engine	**Type of Biodiesel**	**Findings**	**Reference**
4276T Turbo Charged	B_{20} blends	For the same efficiency the Bio diesel blends require more fuel consumption compared to diesel	[1]
High speed direct injection engine	B-100 and Diesel	At low temperature combustion CO and HC pollutant emission are found to reduce with the use of Bio diesel	[2]
Diesel Engine	Cotton seed oil bio diesel	Exhaust emission of CO and particulate matter and smoke were reduced but with slight increase in NO_X emission. Thermal efficiency with Bio diesel is reported longer (slightly) than diesel due to lower heating value of the later.	[3]
Marine craft engine	Bio diesel and Diesel	For the same efficiency the biodiesel consumption was found higher with lower CO emission at higher speed	[5]
Single-cylinder Horizontal type	Soyabean and yellow grease bio diesel and ultra low sulphur diesel fuel	NO_X emissions were higher for bio diesel. Lower Soot, CO, unburnt hydrocarbon emissions compared to diesel	[6]
Diesel Engine	Bio diesel/Diesel	Concludes that the Bio diesel can be used safely in Diesel engine at least in smaller blending ratio. Higher NO_X and lower CO and HC emission	[7].
Single cylinder stationery engine	Aviation fuel(JP-5) Bio Diesel/ Diesel	JP-5 reduces both NO_x and particulate emissions. Bio Diesel reduces the particulate emission Diesel yields large gaseous emissions compared to bio diesel and JP-5 fuel.	[8].
Diesel Engine	Diesel, B-20, B-80, BE-20(20% ethanol+80% Biodiesel)	Engine performance improved with the use of BE-20 and exhaust emission were fairly reduced.	[11]
Four Cylinder Direct injection at constant speed (1800 r.p.m) engine	Bio Diesel blended with 10% methanol, 10% Fumigation methanol/Diesel fuel	Reduction in CO_2, NO_X and particulate emission and in mean soot particle diameter. For the blends, slightly higher break thermal efficiency is achieved at low engine load while fumigation mode gives high BTE at medium and high temperature load.	[12]
Direct Injection water cooled two cylinder, naturally aspirated (RD-270) engine	Waste cooking Biodiesel /Diesel blend	Sulphur content of Bio Diesel fuel is reported as 180ppm which is 28 times less than diesel fuel. Maximum power and torque using Diesel are 18.2 kW and 64.2 Newton meter at 3200 and 2400 rpm respectively. Power is increased by 2.7% and torque by2.9% on biodiesel.	[13]
Diesel Engine	B-5 and B-20 blends of rapeseed oil biodiesel with diesel	The use of biodiesel results in 60% lower smoke capacity and higher BSFC up to 11% compared to diesel fuel	[16]
Diesel Engine	Soybean biodiesel	Increase in fuel consumption with higher blends of	[26]

	blends (B5,B20,B35,B50) Castor biodiesel blends (B5,B20,B35,B50)	biodiesel is observed Lesser amount of Soybean Biodiesel was used in comparison to castor oil biodiesel.	
Common rail engine	B10 blends	Particulate emissions were found to reduce. Marginal higher NO_X emission	[27]
Internal Combustion Engine	Anhydrous ethanol Diesel fuel Biodiesel (B-100) Natural gas used as fuel	The diesel was the most polluting fuel The ecological efficiency of engine are B-100 is 86.75% Natural gas 91.95 Ethanol 82.52% Diesel 77.34%	[28]
Single cylinder engine with exhaust gas recirculation	Diesel and B100	CO and smoke emission were reduced higher NO_X emission when using biodiesel and exhaust gas recirculation	[30]
Four cylinder turbocharged (1400 rpm)	Diesel and B100	Significant reduction in particulate matter, CO and unburnt HC NO_X emission increased by 11.2% 13.8% increase in BSFC was found with biodiesel	[33]
Diesel Engine	Diesel and B100	CO emission reduce by 12% NO_X emission increased by 20% Increase in BSFC by 11.4%	[34]

The above result indicate that almost all the unmodified engine yielded low CO and smoke emission, higher NO_x emission using B100 biodiesel compared to diesel. The performance of different blend in unmodified engine also indicated the same blend but with more BSFC and lower emission as the proportion of diesel in the blend is decreased from B10 to B50 or more.

8. Comparison of emissions from biodiesel and diesel

Literature has further reveals that the engine operation on biodiesel blend with diesel emit lower gaseous emission than diesel fuel expect NO_X which increase to 2% with B_{20} and 10% with B_{100} use. Further, the use of biodiesel or its blend with diesel increases the NO_x emission and decreases the CO and HC emission [1, 3- 6, 12, 26, 30, 32, 36, 38- 48, 52- 55, 61, 64, 68- 72, 77- 89, 91, 95, 98, 100] The comparison of emission of B100, B20 and diesel is given in table 6.

Table 6: Emission Comparison of Biodiesel and Diesel [101]

S.No.	**Type of emission**	**B_{100}**	**B_{20}**
1	Hydrocarbon (HC)	-67%	-20%
2	CO	-48%	-12%
3	Particulate matter (PM)	-47%	-2%
4	NO_X	+10%	+2%
5	SO_2	-100%	-20%
6	PAH	-80%	-13%

The above table shows that all emissions with biodiesel are lower than diesel except NO_X. The higher of NO_X emission could be reduced either by slight retard of injection timing (1° top 5°) or by the use of catalytic converter. The life cycle analysis of biodiesel shows that the reduction in CO emission is about 16% with B_{20} and 72% with B_{100} use on per litre combustion basis [101].

The work reported by the and has in concern with modification in the engine and is compiled in the table 7 which indicates that most of the workers have proposed the advancement of combustion process is due to advanced injection derived based on the physical properties of biodiesel like viscosity, density, compressibility, sound velocity through the injection advance may contribute to slightly increased NO_x emissions when biodiesel is used. The oxygenated nature of biodiesel is found to enhance the complete combustion of the fuel, resulting in the reduction of CO and HC emissions. The higher cetane number also helps reduce the HC emissions.

Table 7: Work reported on the Engine modification of diesel engine by various researchers

S.No.	Fuel Used	Engine	Modification in Engine		Critical Observation	References
1.	Blends of palm oil and rapeseed oil biodiesel with diesel	Diesel engine	Compression ratio	16:1	1- Palm oil and rapeseed oil biodiesel gave Shorter ignition delay than diesel fuel due to their higher cetane number of biodiesel.	[102]
			Inlet valve opening	18°before TDC		
			Inlet valve closing	234° after TDC		
			Exhaust valve opening	120°after TDC		
			Exhaust valve closes	16°after TDC		
			Soot of Injection	22° before TDC		
2.	soy-biodiesel and diesel	Six cylinder diesel engine of 25 HP at 250 r.p.m	Compression ratio	17.3:1	1- Higher consumption of biodiesel and higher NOx is reported due to difference in calorific value and oxygen content of biodiesel compared to diesel.	[103]
			Intake valve opening/closing	20 BTDC/200 ATDC		
			Exhaust valve opening/closing	220 BTDC/20 ATDC		
			No. of cylinders	6		
			Turbocharger	Boost pressure with intercooler, No waste-gate		
3.	Karanj biodiesel and diesel	Four cylinder turbocharged direct injection diesel engine	Compression ratio	17.5:1	A significant reduction in NOx and smoke emissions were found observed with the use of biodiesel.	[104]
			Max. torque condition	285 N-m@23.33 s^{-1}		
			Max. power condition	70 kW @ 53.33 s^{-1}		
			Injection timing (static)	12 ° CA BTDC		
4.	Biodiesel and diesel	Four cylinder CI engine	Compression ratio	19:1	Similar pattern w.r.t load for neat diesel and biodiesel. Biodiesel use reduces the soot emission due to the absence of aromatics, the low sulphur, and higher oxygen content in biodiesel.	[105]
			Maximum power	46.0 kW at 4000 rpm		
			Maximum torque	63.67 Nm at 2000 rpm		
5.	Soya Biodiesel	Four stroke direct	Compression ratio	17.3:1	The increasing of exhaust gas recirculation rate,	[106]

	and diesel	injection diesel engine	Induction system	Variable geometry turbocharger	results in slight increase in BSFC and soot emission and decrease in (NOx) emission.	
			Fuel injection system	Common rail (up to 1.65 MPa)		
			Fuel injection type	Piezoelectric with six nozzles		
6.	Rapeseed oil biodiesel and diesel	Diesel engine (162 kW at 2200 r.p.m)	Compression ratio	17.5:1	The influence of biodiesel usage on the injection pressure, injection timing, ignition delay, in-cylinder gas pressure and temperature, heat release rate, exhaust gas temperatures, harmful emissions, specific fuel consumption, and on the engine power are analyzed. The relationships among fuel properties, injection and combustion characteristics, harmful emissions, and other engine performance parameter determined.	[107]
7.	Sunflower biodiesel and diesel	Single cylinder diesel engine	Compression ratio	17:1	Gave lower BTE, brake power (BP), brake mean effective pressure (BMEP), and higher BSFC due to lower heating value compared to diesel.	[108]
			Rated brake power, kW	5.775 At 1500 rpm		
			Fuel injection angle	45° BTDC		
8.	kernel oil biodiesel and diesel oil	Single cylinder diesel engine (Lombardini 6 LD 400)	Compression ratio	18:1	Increasing in the injection timing, compression ratio, and injection pressure significant improve combustion and heat release characteristics has been observed.	[109]
			Maximum engine moment	21 Nm at 2200 rpm		
			BMEP	0.64 MPa at 20 Nm		
			Fuel injection timing	20 °CA BTDC		
9.	Ethanol blending with biodiesel and diesel	Single cylinder diesel engine (Rainbow – 186) of 50 HP capacity	Compression ratio	18:1	Engine performance improved with biodiesel use compared to diesel	[110]
			Standard injection pressure	20 MPa		
			Maximum speed	7500 rpm		
			Maximum torque	250 N m		

			Number of cylinders	4 in line		
10.	Biodiesel and diesel	Four cylinder diesel engine	Compression ratio	17:1	Increase in BSFC observed at lower engines loads,32.4% reduction in BTE 27.7% reduction in CO emission	[111]
			Rated power	46.5 kW at 1800 rpm		
			Rated torque	285 N m at 1200 rpm		
11.	Biodiesel from nonedible animal tallow and diesel	Four stroke and direct injection (Rainbow – LA186)	Compression ratio	18:1	The reduction in exhaust emissions observed when using tallow methyl esters as alternative fuel for diesel	[112]
			Standard injection pressure	19.6 MPa		
12.	Biodiesel and diesel	Diesel engine (Mitsubishi-6D14)	Maximum power	118 kW at 3000 rpm	Wide usage of biodiesel blends as alternative fuels can protect the environment	[113]
			Maximum torque	534 Nm at 1600 rpm		
13.	Biodiesel and diesel	Medium-duty, direct injection, four-cylinder diesel engine	Peak power output	117 kW at 2300 rpm	The emissions of SPM decreased with lower sulphur content i.e blending with biodiesel,	[114]
			Peak torque output	580 Nmat 1400 rpm		
			Power outputs	42.5 kW, 85 kW, 25 kW and 75 kW		
14.	Soya Biodiesel and diesel	direct injection, turbocharged diesel engine	Compression ratio	16.8:1	Biodiesel, has lower specific reactivity	[115]
			Rated power	117 kW at 2300 r min^{-1}		
			Maximum torque	580 Nm at 1400 r.p.m		
15.	Sunflower biodiesel and diesel	In line turbocharged , intercooled, diesel engine (2.2 l Nissan)	Maximum torque	248 N m @ 2000 r.p.m	Biodiesel a very attractive alternative to conventional fuel	[116]
			Compression ratio	18:1		
			Maximum power	82 kW @ 4000 rpm		

Conclusions

The use of biodiesel will lead to loss in engine power mainly due to the reduction in heating value of biodiesel compared to diesel, and it result in the increase in biodiesel fuel consumption. From the review it can be concluded that the use of biodiesel favours to reduce carbon deposit and wear of the key engine parts, compared with diesel. It is attributed to the lower soot formation, which is consistent to the reduced PM emissions of biodiesel, and the inherent lubricity of biodiesel. The vast majority of literatures agree that NO_x emissions will increase when using biodiesel. This increase is mainly due to higher oxygen content for biodiesel. Moreover, the cetane number and different injection characteristics also have an impact on NO_x emissions for biodiesel. It is accepted commonly that CO emissions reduce when using biodiesel due to the higher oxygen content and the lower carbon to hydrogen ratio in biodiesel compared to diesel. It is predominant viewpoint that HC emissions reduce when biodiesel is fuelled instead of diesel. This reduction is mainly contributed to the higher oxygen content of biodiesel, but the advance in injection and combustion of biodiesel also favour the lower THC emissions. The further improvement in production of biodiesel should be performed in the future to promote biodiesel properties and quality. And the further development in additives which improve consumption of biodiesel should be needed to favour power recovery, economy and emissions especially for NO_x emissions.

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