Effects of Different Additives on Performance and Emission of Biodiesel Fuelled Compression Ignition Engine

Atul G. Londhekar[1], S. C. Kongre[2]

[1]Rajiv Gandhi Institute of Technology, Mumbai, India

[2]ASP Pipri, Wardha, India

Abstract: ***Due to the growing concern over greenhouse gases, Biodiesel is widely accepted as comparable fuel to diesel in diesel engines, as it is renewable, sustainable and alternative fuel for compression ignition engines. Biodiesel provides several factors like decreasing the dependence on imported petroleum, reducing global warming, increasing lubricity, and reducing substantially the exhaust emissions from diesel engine. However, there are some disadvantages in the use of biodiesel as it has lower heating value, higher density and higher viscosity, higher fuel consumption and higher NOX emission which limits its application. Here additives become essential tools not only to minimize these drawbacks but also promote use of biodiesel to meet the regional and international standards. Additives can contribute towards fuel economy and emission reduction either directly or indirectly without engine modification. A variety of additives are used in biodiesel fuel to meet specification limits and to enhance quality. For example, alcohol based ethanol, methanol, diethyl ether,gas based hydrogen, oxygen, metal based magnesium, aluminium, ferric chloride, butanol, manganese, cerium oxide and nano fuels etc used to meet specifications and quality. In this article variety of research papers reviewed to understand effects of various proportion of additives on different conditions of engine performance and exhaust emissions. The review concludes that the use of additives in biodiesel is need of hour to get better engine performance and emission characteristics for CI engine.***

Keywords: BP brake power BSFC brake specific fuel consumption BTE brake thermal efficiency CO2 carbon dioxide CO carbon monoxide

1. Introduction

In view of the fast depletion of fossil fuel, the search for alternative fuels has become inevitable, looking at huge demand of diesel for transportation sector, captive power generation and agricultural sector, the biodiesel is being a natural substitute of diesel [1]. The present energy situation has demanded active research interest in non-petroleum, renewable and nonpolluting fuels [2]. Biodiesel has excremental effect on HC and CO emissions. On the contrary, major problems associated with the use of biodiesel are lower engine power, higher BSFC due to their lower calorific values, higher densities and viscosities. NOx emission also increases with the use of biodiesel for higher fuel bound oxygen. To overcome some of these difficulties use of ethanol, *n*-butanol or diethyl ether in small proportion as additive has come out with great potential recently[3].The most promising bio-fuels as fossil liquid fuels supplements are vegetable oils, bio-diesels, bio-ethanol ,bio-butanoland bio-diethyl ether mixed in small proportions with diesel fuel for diesel engines [4]. India has the potential to be a leading world producer of biodiesel, as biodiesel can be harvested and sourced from non-edible oils like Jatropha curcas, karanja, Neem, Mahua etc. India is focusing on karanja which can grow in arid and wastelands as oil contents in their seeds is 30-40% [5]. Utilization of locally produced and processed fuel strengthens economy and energy security [6]. Non-edible oil can be used as alternate fuel in present diesel engine without any kind of modification, just by improving the properties of the fuel by the addition of base catalyzed transesterification with alcohol. Performance can also be improved by increasing the compression ratio from 16:1 to 20:1[7]. There are several reasons for applying hydrogen as an additional fuel to accompany diesel fuel in compression ignition (CI) engine. Firstly, it increases the H/C ratio of the entire fuel. Secondly, injecting small amounts of hydrogen to a diesel engine could decrease heterogeneity of a diesel fuel spray due to the high diffusivity of hydrogen which makes the combustible mixture better premixed with air and more uniform. It could also reduce the combustion duration due to hydrogen's high speed of flame propagation in relation to other fuels [8]. It was observed that the use of additives significantly reduced the emission of particulates and carbonaceous particle [9]. Potassium hydroxide(KOH) and sodium hydroxide (NaOH) are the most commonly used alkali additives but higher yield has been reported with KOH. Methanol and ethanol are the alcohols generally used in transesterification process. However methanol was preferred for the biodiesel production due to its low cost and higher reactivity compared to ethanol[10].

2. Biodiesel and Additives

Biodiesel has cold flow property which is a barrier to use it in cold or chilled weather [19].To improve the property of biodiesel fuel, various types of metal based additives are added with biodiesel for reaching more complete combustion and reducing exhaust emissions. The principle of such additives action consists of a catalytic effect on the combustion of hydrocarbons. These metal based additives include platinum (Pt), platinum–cerium (Pt–Ce), cerium (Ce), cerium–iron (Ce–Fe), iron (Fe), barium, calcium, manganese (Mn) and copper [11].Mg and Ni based additives

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reduced the flash point, pour point and viscosity of biodiesel fuel produced by animal fat, depending on the amount of additive [15].The effect of synthetic Mg additive with 10% chicken fat biodiesel of a single-cylinder, direct injection (DI) diesel engine was studied and obtained CO emission decreased by 13% compared with diesel fuel [16].It was observed that the NOX emission was reduced with the addition of cerium oxide nano additive to biodiesel due to its oxidation additive effect [17]. Brake thermal efficiency increased for biodiesel compared to diesel. A few researchers investigated the effect of additives on brake thermal efficiency[13].Studied the effect of platinum (Pt) based additive on a diesel engine and found that the use of platinum (Pt) based additive improved BTE compared to diesel fuel and biodiesel without additive [22].The effect of antioxidants to biodiesel on engine performance and emission was evaluated and observed that the density, kinematic viscosity and flash point of the blend increased as compared to the pure biodiesel. The addition of antioxidant also increased oxidation stability but calorific value was reduced [24]. Several researchers have published their different research to improve the fuel properties of biodiesel by the usage of various additives for their usage of different conditions and convenient handling. In general, metal based additives improved pour point, flash point and viscosity of biodiesel fuel[25].Biodiesel, the promising alternative fuel to fossil fuel, is produced from renewable biological resources such as vegetable oils and animal fats. Biodiesel production is modern and technological for researchers. It is non-toxic, biodegradable, environmental friendly, has high flash point and can be blended with diesel since the characteristics are similar[27].

Nomenclature

BP brake power
BSFC brake specific fuel consumption
BTE brake thermal efficiency
CO2 carbon dioxide
CO carbon monoxide
DEE diethyl ether
FBC fuel born additive
HC hydro carbon
NO2 nitrogen dioxides
NO nitric oxide
NOX oxides of nitrogen
SO2 oxide of sulfur
PM particulate matter
PPM parts per million
LPM litres per minute
UTO used transformer oil
WPO-MEK wood pyrolysis oil blended with methyl ester of karanja oil
FeCl3ferric chloride
BUT butanol
DGDE diethylene glycol dimethyl ester
EHN ethyl hexyl nitrate
DW distilled water

3. Effects of Additives on Engine Performance and Emission

The use of additives on the performance and emission characteristics of diesel engine have already been studied by several researchers and found promising results. But the types of additives which would be used in the engine should be selective. Many researchers have used different additives such as ethanol, methanol, diethyl ether, magnesium, aluminium, ferric chloride, butanol, manganese, cerium oxide nano fuels etc in biodiesel blend to improve the engine performance. In this article, the literature illustrating the effect of using different additives with biodiesel on engine performance and emission are surveyed.

3.1. Performance

3.1.1. Brake specific fuel consumption

It was reported that the fuel consumption of a CI engine fueled with biodiesel was higher than diesel fuel due to the loss of heating value and BSFC increases with the increase in the biodiesel content[6]. A few researchers investigated the effect of additives on BSFC in a CI engine fueled with biodiesel and found that BSFC was reduced with the use of additives[3,10,11,12]. It was observed that BSFC was reduced with the use of hydrogen along with biodiesel. The value of BSFC at 2lpm H2 was found as 10.75 and at 4lpm H2 the value of BSFC was 9.35 and that of baseline diesel was 13.23[1].

Table 1: Effects of additives on engine performance

Sr No.	Biodiesel used	Additives	H2	BTE		BSFC		Refs
				BX	BO	BX	BO	
1)	Karanja oil	Methanol	-	↑4.2%	-	-	-	27
2)	Karanja oil	-	-	-	-	↑	-	27
3)	Karanja oil	-	-	↓	-	↑slightly	-	27
4)	Karanja oil	-	-	↑25%	-	↑50%	-	27
5)	Karanja oil	-	-	↑	-	↓7.4%	-	27
6)	Karanja oil	-	-	↓ slightly	-	↑	-	27
7)	Karanja oil	-	-	No change	-	-	-	27
8)	Karanja oil B10	-	-	26	40	0.321	0.21	6
9)	Karanja oil B20	-	-	22	40	0.39	0.21	6
10)	Karanja oil B50	-	-	20	40	0.42	0.21	6
11)	Karanja oil B100	-	-	18	40	0.46	0.21	6
12)	Waste cooking Palm oil	FeCl3	-	↑ slightly	-	↓ slightly	-	10
13)	Palm oil B20	-	-	19	18.8	432	428	3
14)	Palm oil B15	Ethanol	-	19	18.8	440	428	3
15)	Palm oil B15	n-butanol	-	19.6	18.8	422	428	3

16)	Palm oil B15	Diethyl Ether	-	19.8	18.8	418	428	3
17)	Palm oil	FeCl3	-	↑3.1%	↑1.8%	↓18.4%	↑8.6%	11
18)	Palm oil B20	Methanol, Ethanol, DW, DEE	-	-	↑	-	↓	21
19)	Mahua oil B100	-	-	26.63	30.09	0.556	0.387	7
20)	Mahua oil B95	-	-	28.01	30.09	0.503	0.387	7
21)	Mahua oil B90	-	-	29.74	30.09	0.4993	0.387	7
22)	Mahua oil B85	-	-	29.97	30.09	0.4104	0.387	7
23)	Mahua oil B100	DEE	-	↓ slightly	↑	↑slightly	↑	17
24)	Cottonseed oil	Ethanol	-	-	↑26.5%	-	↓	22
25)	Cottonseed oil	-	-	0.32	0.324	310	260	4
26)	Cottonseed oil	DEE	-	0.342	0.324	280	260	4
27)	Cottonseed oil	BUT 20	-	0.338	0.324	290	260	4
28)	Methyl Ester	DEE	-	0.356	0.324	270	260	4
29)	Methyl Ester	BUT	-	0.352	0.324	280	260	4
30)	Methyl Ester	-	-	0.325	0.324	295	260	4
31)	UTO 40	-	-	32.01	28.64	-	-	2
		-	4 lpm	42.14	28.64	-	-	
32)	UTO 100	-	-	31.72	-	-	-	2
		-	4lpm	38.91	-	-	-	
33)	Pongamia Methyl Ester	DGDE 0.2	-	31	30	1.5	1.55	5
34)	Pongamia Methyl Ester	DGDE 0.4	-	32	30	1.5	1.55	5
35)	Pongamia Methyl Ester	DGDE 0.6	-	33	30	1.4	1.55	5
36)	WPO-MEK	-	-	32.02	28.64	13.57	13.23	1
		-	2lpm	36.7	28.64	10.75	13.23	
		-	4lpm	38.5	28.64	9.35	13.23	
37)	Jatropha oil	Al-Mg	-	↑1%	↓17%	↓3%	↑15%	12
38)	Jatropha oil	-	7%	↑2%	↑1.7%	-	-	8
39)	Jatropha oil B15	Cerium oxide Nano fuel	-	-	↑1.7%	-	↑2%	13
40	Neem oil	DEE	-	↑6%	↑4%	↓25%	↓1.92%	18
41	Neem oil	DEE	-	↑5%	-	-	-	19
42)	Neem oil	Ethanol	-	-	↑ slightly	-	-	23
43)	Tall oil B60	Manganese	-	-	-	↓10%	↑	14
44)	Tall oil B60	Magnesium	-	-	-	↓	-	15
45)	Waste chicken fat	Magnesium	-	-	-	↑5.2%	-	9,10
46)	Chicken fat	Magnesium	-	-	↓4 .8 %	-	↑5.2%	25
47)	Rice Bran oil B25	-	-	-	↑	-	↓	20
48)	Rice Bran oil	Ethanol	-	↑ slightly	↑ 27.82%	↑ 3.93%	↑ 6.98%	26
49)	Fish oil	DEE	-	-	↑ 16%	-	↑ slightly	16
50)	Canola oil B20	EHN	-	-	-	↓4.12%	-	24

BX, X% biodiesel, BO pure diesel; ↑ Increase/High; ↓ Decrease/Low

3.1.2. Brake thermal efficiency

The Brake thermal efficiency obtained from biodiesel fuel in a CI engine was lower compared with diesel fuel[7,6,17,27]. A few authors found no significant change in BTE between biodiesel and diesel fuel[5,4,27,4]. A few researchers found the effect of additives on BTE and they observed that BTE was higher for biodiesel with the addition of additives as compared with pure diesel[26,3,10].It was observed that with the addition of hydrogen the BTE was increased[1,2]. The value of BTE for WPO-MEK with 2 lpm H2 was found as 36.7% and with 4 lpm H2 it was 38.5% and that of baseline diesel is 28.64%[1].The brake thermal efficiency for UTO 40 is 32.01% at full load, and that is increased after supplying 4 lpm hydrogen to 42.14%,whereas that of baseline diesel is 28.64%. UTO 100 exhibits the brake thermal efficiency of 31.72% at full load, and that is increased after supplying 4 lpm hydrogen to 38.91% .The maximum thermal efficiency was recorded for UTO 40 with 4lpm hydrogen enrichment [2]. Table 1 depicts the effects of additives on engine performance parameters, such as: brake specific fuel consumption, brake thermal efficiency.

3.2 Emission

3.2.1. NOX emission

Oxides of nitrogen which occur in the engine exhaust are a combination of nitric oxide (NO) and nitrogen dioxide (NO2). Some authors reported that NOX emissions increased with the use of biodiesel in CI engine[1,2,6,27].It was observed that with the addition of additives along with biodiesel the NOX emission were reduced[3,4,5,7,10].The additives like ethanol and *n*-butanol have showed lower NOx emission when added along with biodiesel which can be explained by their lower calorific value and higher heat of evaporation which resulted in lower in-cylinder temperature[23].The NOx emission of UTO 100 and UTO 40 with hydrogen is found to be higher compared to UTO 100 and UTO 40 without hydrogen and also baseline diesel[2].

3.2.2. CO2 emission

It was reported that with the increase in the biodiesel content the CO2 emission increased [6]. Some authors investigated the effect of additives on CO2 emission and observed that with the addition of additives along with biodiesel the CO2 emission were reduced as compared with baseline diesel[5,10].It was observed that with the addition of hydrogen along with biodiesel the CO2 emission were reduced. At full load the carbon dioxide emission is 1.3% for UTO 40 with hydrogen and 1.4% for UTO 100 with hydrogen while that of UTO 40 and UTO 100 without hydrogen shows 2% and 1.8% CO emission respectively and that of diesel is 1.7%[2].

3.2.3. CO emission

CO emission is highest for pure biodiesel because of poor spray characterization that results in improper combustion which gives rise to CO formation[7]. It was observed that for some biodiesel the CO emission were reduced as compared with baseline diesel[3,4,6,7,27]. A few authors investigated the effect of additives on CO emission and observed that with the addition of additives along with biodiesel the CO emission were reduced as compared with pure diesel[3,4,7,9,10,12,16,26].It is found that the carbon monoxide was decreased with increase in hydrogen addition. The carbon monoxide emission of UTO 40 was 0.008% and that was reduced after supplying 4lpm H2 to 0.003%. The CO emission of UTO 100 was 0.012% and that was reduced after supplying 4lpm H2 to 0.005% whereas that of baseline diesel was 0.01%[2,8].

3.2.4. HC emission

The HC emission of biodiesel is lower compared to diesel[1,3,4,6,7,27].HC emissions were lowest for K20 and K50 at all engine operating conditions [6]. With the addition of hydrogen along with biodiesel the HC emission were reduced. The HC emission is lower for UTO 40 and UTO 100 with hydrogen compared with the other fuels without hydrogen and baseline diesel. The HC emission of UTO 40 with hydrogen is about 3ppm at full load compared to diesel 5.6 ppm while UTO100 with hydrogen exhibits 4.8 ppm at full load [1,2,8].

Table 2: Effects of additives on exhaust emissions.

Sr No	Biodiesel used	Additives	H2	NOx		CO2		CO		HC		Smoke		Refs
				BX	BO	BX	BO	BX	BO	BX	BO	BX	BO	
1)	Karanja oil	Methanol	-	-	-	-	-	↓ 46.5%	-	↑ slightly	-	↓	-	27
2)	Karanja oil	-	-	↑ slightly	-	-	-	↑ slightly	-	-	-	↓	-	27
3)	Karanja oil	-	-	-	-	-	-	↑	-	-	-	-	-	27
4)	Karanja oil	-	-	↑ 12%	-	-	-	↑	-	↑	-	-	-	27
5)	Karanja oil	-	-	↓ 26%	-	-	-	↓ 60%	-	-	-	↓ 80%	-	27
6)	Karanja oil	-	-	↓	-	-	-	↑	-	↓	-	-	-	27
7)	Karanja oil	-	-	↑ 15%	-	-	-	↓ 50%	-	-	-	↓ 43%	-	27
8)	Karanja oil B10	-	-	5	5	800	920	150	180	1.7	2.3	95	97	6
9)	Karanja oil B20	-	-	15	5	950	920	0	180	0.7	2.3	39	97	6
10)	Karanja oil B50	-	-	17	5	950	920	0	180	0.6	2.3	35	97	6
11)	Karanja oil B100	-	-	7	5	1000	920	300	180	2.6	2.3	94	97	6
12)	Waste cooking Palm oil	FeCl3	-	3.8	5	220	290	25	55	-	-	-	-	10
13)	Palm oil B20	-	-	360	350	-	-	1.5	2.7	88	128	-	-	3
14)	Palm oil B15	Ethanol	-	310	350	-	-	0.8	2.7	112	128	-	-	3
15)	Palm oil B15	n-butanol	-	305	350	-	-	1	2.7	126	128	-	-	3
16)	Palm oil B15	Diethyl Ether	-	300	350	-	-	1.2	2.7	128	128	-	-	3
17)	Palm oil	FeCl3	-	↑ 4.1%	↓ 11.3%	↑ 6.7%	↑ 2.1%	↑ 9.7%	↓ 22%	↓ 26.6%	↓ 50%	↓ 6.9%	↓ 21%	11
18)	Palm oil B20	Methanol, Ethanol, DW, DEE	-	-	↓ 2.7%	-	↓	-	↓	-	↓	-	-	21
19)	Mahua oil B100	-	-	1059	573	-	-	0.383	0.887	31	55.67	17.04	8.7	7
20)	Mahua oil B95	-	-	988	573	-	-	0.573	0.887	41	55.67	14.43	8.7	7
21)	Mahua oil B90	-	-	967	573	-	-	0.507	0.887	40	55.67	12.09	8.7	7
22)	Mahua oil B85	-	-	836	573	-	-	0.486	0.887	34.6	55.67	8.81	8.7	7
23)	Mahua oil B100	DEE	-	↓	-	-	-	-	↓ 67%	-	↓ 5%	-	↓ 15%	17
24)	Cottonseed oil	Ethanol	-	↓	↓	-	-	-	↓	-	↓ 18%	-	↑	22
25)	Cottonseed oil	-	-	960	1240	-	-	480	320	58	77	43	34	4
26)	Cottonseed oil	DEE	-	900	1240	-	-	335	320	78	77	23	34	4
27)	Cottonseed oil	BUT 20	-	920	1240	-	-	340	320	73	77	27	34	4

28)	Methyl Ester	DEE	-	1020	1240	-	-	230	320	70	77	17	34	4
29)	Methyl Ester	BUT	-	1080	1240	-	-	255	320	62	77	18	34	4
30)	Methyl Ester	-	-	1120	1240	-	-	270	320	50	77	26	34	4
31)	UTO 40	-	-	370	320	2	1.7	0.008	0.01	6.2	5	18.1	19.2	2
		-	4 lpm	450	320	1.25	1.7	0.003	0.01	3	5	15	19.2	
32)	UTO 100	-	-	420	320	1.8	-	0.012	-	6.6	-	25.5	-	2
		-	4 lpm	470	320	1.35	-	0.005	-	4.8	-	16	-	
33)	Pongamia Methyl Ester	DGDE 0.2	-	580	600	6.5	7	0.06	0.09	43	60	62	80	5
34)	Pongamia Methyl Ester	DGDE 0.4	-	550	600	6.5	7	0.06	0.09	38	60	62	80	5
35)	Pongamia Methyl Ester	DGDE 0.6	-	560	600	6.5	7	0.05	0.09	42	60	70	80	5
36)	WPO-MEK	-	-	481	318	-	-	-	-	↓	-	-	-	1
		-	2	523	318	-	-	↓	-	↓	-	-	-	
		-	4	550	318	-	-	↓	-	↓	-	-	-	
37)	Jatropha oil	Al-Mg	-	↓ 45%	↑	-	-	↓ 50%	↓ 66%	↓ 76%	↓ 85%	-	-	12
38)	Jatropha oil	-	7%	-	↑ 140 ppm	-	-	↓ 0.9%	-	↓ 30 ppm	-	↓ 20%	-	8
39)	Jatropha oil B15	Cerium oxide Nano fuel	-	-	↓ 23.5%	-	-	-	-	-	↓ 50%	-	↓ 14.5%	13
40)	Neem oil	DEE	-	-	-	-	↓	-	↓	-	↓	-	-	18
41)	Neem oil	DEE	-	↑	-	-	-	↓ 25%	-	↑	↑	↓	↓	19
42)	Neem oil	Ethanol	-	-	↑ slightly	-	-	-	↓	-	↓	-	↓	23
43)	Tall oil B60	Manganese	-	-	↓	-	↓	-	↓	-	-	-	↓	14
44)	Tall oil B60	Magnesium	-	-	↓	-	↓	-	↓	-	-	-	↓	15
45)	Waste chicken fat	Magnesium	-	↑ 5%	-	-	-	↓ 13%	-	-	-	↓ 9%	-	9,10
46)	Chicken fat	Magnesium	-	-	↑ 5%	-	-	-	↓ 13%	-	-	-	↓ 9%	25
47)	Rice Bran oil B25	-	-	-	↓	-	↓	-	↓	-	↓	-	-	20
48)	Rice Bran oil	Ethanol	-	-	↓	-	↑	↓	↓ slightly	-	↓	↓	-	26
49)	Fish oil	DEE	-	↓ 80%	↓ 85%	↓ 33%	↓ 60%	↓ 38%	↓ 80%	↓ 38%	↓ 80%	-	-	16
50)	Canola oil B20	EHN	-	↑ 5.8%	↑	-	-	↑ 9.84%	↓	-	-	-	-	24

BX, X% biodiesel, BO pure diesel; ↑ Increase/High; ↓ Decrease/Low

3.2.5. Smoke

It was reported that smoke opacity with biodiesel was higher than baseline diesel[4,7].Smoke opacity for K100 was higher than mineral diesel at lower engine loads. For lower Karanja oil blends, smoke opacity was lower than mineral diesel[6]. Smoke opacity was reduced with the addition of additives along with biodiesel as compared with baseline diesel [4,5,7,9,10,11,26].At full load the smoke emission for UTO 100 was found to be 25.5 BSU (Bosch Smoke Units) which is much higher than diesel 19.2 BSU. UTO40 shows 18.1 BSU. However smoke emission was reduced after supplying Hydrogen [2].

Table 2depicts the effect of additives on engine emission, such as: oxides of nitrogen, carbon dioxide, carbon monoxide, hydrocarbons and smoke.

4. Conclusion

a) The fuel consumption of a CI engine fueled with biodiesel was higher than diesel fuel due to the loss of heating value and BSFC increases with the increase in the biodiesel content.
b) Brake specific fuel consumption depends on the ethanol content present in the blend with the increase in ethanol content, the brake specific fuel consumption increases.
c) The addition of hydrogen along with biodiesel assists in increasing engine performance and emission reduction in CI engine due to hydrogen's high speed of flame propagation in relation to other fuels.
d) BTE was higher for biodiesel with the addition of additives and hydrogen along with biodiesel as compared with pure diesel.
e) The additives like ethanol and *n*-butanol have showed lower NOx emission because of water content, when added along with biodiesel.
f) With the addition of hydrogen along with biodiesel the CO2 emission were reduced.
g) Normally all exhaust emissions like CO, CO2, HC and smoke are reduced greatly with the addition of oxygenated additives to biodiesel fuels especially iso butanol, ethanol and diethyl ether.

h) Diethyl ether and ethanol are also useful to reduce smoke opacity.
i) The addition of additives along with biodiesel plays an extremely important role to increase engine performance and emission reduction in CI engine.
j) Oxidative additives reduces NOx emission drastically.
k) From this study, it is understood that with the use of biodiesel the performance and emission characteristics are not satisfactory, The addition of additives along with biodiesel plays an extremely important role to increase engine performance and emission reduction in CI engine.

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