International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 6 (2020), pp. 1076-1094
 https://dx.doi.org/10.37624/IJERT/13.6.2020.1076-1094

Effect of Biodiesel on the Performance and Emission Characteristics of Diesel Engines

Gaurav Vohra[1], Vineet Kumar[2], Harmeet Singh[3], Radhey Sham[4]

[1]*Research Scholar, I.K.G. Punjab Technical University, Jalandhar, India.*
[2]*Professor, Automobile Engineering, University Institute of Engineering, Chandigarh University, Mohali, India.*

[3]*Professor, Department of Mechanical Engineering, Guru Nanak Dev Engineering College, Ludhiana, India.*

[4]*Assistant Professor, Department of Mechanical Engineering, Chandigarh College of Engineering and Technology, Chandigarh, India.*

Abstract

Biodiesel has become one of the main sources of renewable energy. Their positive impact on the environment has earned a lot of attention in past few decades. Biodiesel has several effects on emission and performance attributes of a CI engine. This paper deals with those effects of biodiesels derived from various sources like Jatropha, Mahua, Karanja, soybean, palm, waste cooking oil (WCO) and many other edible and non-edible oils. It has been noticed that excessive use of biodiesel will lead to food shortage and therefore blending of biodiesel with conventional diesel has been suggested by various researchers. In blending, biodiesel and petro-diesel is mixed in a proper ratio to give a mixture of diesel-biodiesel. It has been stated that, blending up to 20% has no effect on properties and is same as that of diesel and provides better results. The emissions like CO, UHC and PM, reduced and was significantly lesser than that of diesel but NO_x emission was found to have much higher value when compared with diesel. When BSFC and BTE of diesel and biodiesel were compared, it was found that, BTE reduced but BSFC increased with blending. By considering all these factors and from this review, it can be said that biodiesel and its blend with diesel can be used in CI engine without any major tempering when blending is done up to a certain limit.

Keywords: Jatropha biodiesel, Thermal efficiency, Brake specific fuel consumption, NOx emissions, HC emissions.

I. INTRODUCTION

Energy is required in almost every field of research & development. It plays a vital role in development of a nation. Fossil fuels are becoming the main origin of energy. But because of the excessive use of fossil fuels and growing pollutant level in environment, search for alternative fuels have become a necessity [1-3]. Fuel consumption is estimated to increase from 8.61 million barrels per day to approximately 110.6 million barrels per day in 2035 [4]. We have limited reservoirs or stocks of petroleum and now we need a replacement for fossil fuels which can work in more efficient way than them. Some other problems like increased of fossil oil have also increased the requirement to have some better alternatives.

Biodiesel has become one of the best alternatives of fossil fuels. Biodiesel was firstly used by Rudolf Diesel. In 1900, He used peanut oil to run his diesel engine [5]. He used neat biodiesel but biodiesel can be mixed with biodiesel in a definite proportion. This mixing of biodiesel with diesel is called blending. If blending of biodiesel is done properly, its properties become similar to that of diesel fuel. It has been found that if the blending ratio of diesel to biodiesel is 80:20, it does not cause any harm to the engine and can perform very well [5-6]. Blending is also done to decrease the high viscosity of biodiesel. Viscosity of biodiesel is very high [4, 14, 16, 19, 22, 23, 25, 26, 33, 35, 43, 53, 54, 79-86, 87, 88]. So, diesel engine cannot be directly used with used biodiesel. This problem can be overcome by the process of blending.

Transesterification, of vegetable oils animal fats, is used to produce biodiesel. Figure 1 shows the transesterification reaction. In transesterification, the oil is converted chemically into its corresponding fatty ester [7]. E Duffy and J. Patrick conducted this test in 1853 and since then, lots of studies have been done on biodiesel till now using different oils like soybean oil [9,10], cotton seed [11-14], waste cooking oil[40], rapseed oil [14,16], Sunflower oil [14,17], Tyre pyrolysis oil [TPO] [18], Jatropha [7,10,19-27] and many others. A study tells that there are around 300 different kinds of oil seeds, amongst which “Oleander”, “Bitter Groundnut” and Kusune are the only vegetable oils which are considered to be a potential alternatives fuel for CI Engines [27].

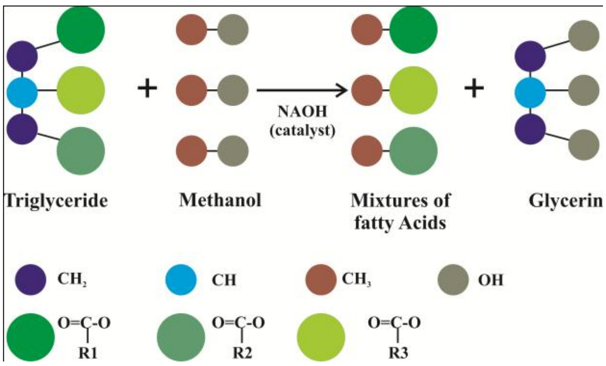

Figure 1. Transesterification Reaction

Biodiesel obtained from waste cooking oil (WCO) is much more economic source than any other source [15]. So many researchers have observed that WCO biodiesel decreases harmful exhaust emissions than diesel [28,29], Kulkarni et al. [30] stated that WCO gives much better engine performance than that of diesel fuel and produces less emissions than diesel except NO_X.

It is widely agreed that biodiesel is much more useful than diesel. It is inexhaustible and can be produced again and again, non-toxic and is less harmful to environment and biodegradable which prevents soil pollution [10]. It produces NO_X but is completely free of SO_X. It produces less amount of hydrocarbons (HC), CO, PM and CO_2 [5, 16, 17, 19-25, 31-42].Wang et al [32] concluded that with increase in blending, NO_X emissions also increases. Same Conclusion was given by Leila et al [13].On the other hand, a study tells that other emissions like total Hydrocarbon, Smoke Opacity and PM decreases with blending [43]. Another study [19] observed that NO_X emission increase in Jatropha biodiesel when blending is done but other emission decreases. A research found that when compared with diesel, HC, CO emission increase when brake power is increased in biodiesels [20]. Some researchers also concluded that NOx emissions decreases along with CO and UHC when blending is increased [22]. The high emission of NOx could be due to the high temperature inside the cylinder when the combustion of biodiesel is done [44].

Brake specific fuel consumption (BSFC) got mixed results from various authors. Some studies reported that it increases [27] with blending while other reported that it decreases [45] with blending. In Brazil, around 80% of all the biodiesel produced is obtained from soybean [46] whereas in Argentina, soybean gives 100% of it. In US, around Soybean contribution is 74% and in European nations it is around 16% [47, 48].

II. PROPERTIES OF BIODIESEL AND ITS BLEND

Performance and emission characteristics depend on fuel properties like viscosity, density, calorific value, cetane number etc. Table 1 lists the fuel properties of various biodiesels with their blends.

II.1 Viscosity

For better performance of engine, the viscosity of biodiesel should be low, because if viscosity is high than that would lead to poor spray and atomization of the fuel [49-51]. It is also the cause of higher fuel consumption [52]. Ghosh et al. [31] observed that viscosity of biodiesel varies from 3.5 to 5.5(cSt). Similar results were obtained by Ocatvio and Gomej [17] for sunflower oil. They got results by testing various blends of sunflower oil. For B30, B70 and B100 kinematic viscosity was 2.8502, 3.8502 and 4.3991 cSt respectively. Monirul et al. [23] found that the viscosity of Palm oil B10, B20, B100 was 3.3624, 3.4589, 4.3847 cSt., respectively. He also added that the viscosity of Jatropha oil B10, B20 and B100 was 3.7638, 8.8972 and 4.7128 cSt., respectively. Further information on the viscosity of biodiesel and various blends are given in the table 1.

II.II Density

Density is the distribution of mass on a given volume. Greater density means greater viscosity which causes poor atomization and combustions which affects the performance and emission properties of engine. Table 1 gives the detailed data on the density of different biodiesels. Monirul et al. [23] noticed that the densities of Palm and Jatopha oil varies from 832 – 857.6 and 835.8 – 840.5 respectively for different blends (B10, B20, B100). Nabi et al. [54] reported that, at low load densities of B20, B40 and B60 are 845, 852 and 858 respectively. They found that blend up to 20% with diesel gives density very much similar to that of pure diesel (840). Hence 20% blending of biodiesel with diesel is found to be much better. Similar outcomes have been stated by Masjuki et al. [136] who said that 20% blending doesn't require and kind of modification in the engine.

II.III Cetane Number

Cetane number is directly associated with the ignition delay. This has been agreed by several researchers that cetane number of conventional diesel is less than that of biodiesel [19, 35, 43]. Hence, when concentration of biodiesel in the blend is increased, CN also increases [56, 57]. Further data on CN of biodiesel is given in the table 1.

II.IV Calorific Value

Performance and emission of engine is very much influenced by calorific value of the fuel used. Benjamin M. Wood [14] stated that diesel has a calorific value of 42.70 MJ/Kg. Whereas Soybean, Rapeseed and Sunflower oil has a value of 38.38, 38.33, 38.54 MJ/Kg respectively. This is lower than that of diesel. Same kind of results were achieved by Thapa et al. [19] who stated that diesel - biodiesel blends have slightly less value of calorific value than that of petro-diesel. The experiment was done by taking Karanja, Polanga, Mahua, Rubber seed oil, Cotton seed, Tobacco oil, Neem, Linseed oil, Palm oil, and Jatropha as biodiesel. The different calorific values have been mentioned in the table 1.

III. EFFECT OF BIODIESEL ON PERFORMANCE OF AN ENGINE

Performance parameters are one of the most important factors that indicate whether the engine and fuel is good enough to use. These parameters are Brake Specific Fuel Consumption (BSFC), Brake Specific Energy Consumption (BSEC), Brake Thermal Efficiency (BTE) and Brake Power etc. Brief discussion on some of these parameters is given below and comparison between different biodiesels and diesel-biodiesel blends has been shown in table 2.

III.I Effects of biodiesel on Brake Specific Fuel Consumption of an engine

According to most of the researchers [55, 63, 64, 112, 123-132], BSFC of biodiesel increases when biodiesel blend is increased in biodiesel – diesel blends.

A study at Southwest Research Institute (USA) experimented with pure soybean and stated that around 13%- 19% fuel consumption increases with respect to diesel fuel [112]. It was reported that when pure biodiesel is used, BSFC increases from 0.4209 (Kg/KWh) to 0.60 (Kg/KWh) at low load and at high load it increases from 0.3229 (Kg/KWh) for diesel to 0.73 (Kg/KWh). RizwanaulFattah et al. [55] Stated that catalyst increases the value of BSFC for same amount of blending. They used KOH, 2, b-di-tert-butyl-4-methylphenol (BHA) and 2(3)-tert-butyl-4-methoxy phenol (BHT) as a catalyst in PME B20 (Palm oil) to study the effects. It was observed that when using biodiesel only, the BSFC has a value of 267.4 g/KWh. While this value for B20 + BHA and B20 + BHT are 278.2 g/KWh and 279.5 g/KWh respectively at the engine speed of 2500 rpm. Same kind of observation was reported by Singh and Singla [113] who used 4 stroke, single cylinder, direct injection diesel engine with rated power 3.67 KW and injection timing 24.5° BTDC. Karanja was used as a biodiesel. BSFC was observed to have slightly higher value than that of pure biodiesel. Gosh et. Al. [31] observed that biodiesel of jatorpha, karanja and putranjiva shows higher value of BSFC than that of diesel fuel. But Jatopha showed much better results for BSFC than any other fuel. This could be because the calorific value of jatropha (38.5-42 MJ/Kg) is higher than that if other two biodiesels(for karanja-37 MJ/Kg) and viscosity is lower [19]. For putranjiva, karanja and jatropha the values of BSFC are 268 g/KWh, 311 g/ KWh and 382 g/KWh respectively for B10. Thapa et.al. [19] observed that when engine speed is changed, change in the value of BSFC also observed. They experimented with different engine speed. They observed that when engine speed is increased, the value of BSFC is decreased but when blending is increased BSFC also increased.

Most of the researchers agree with the fact that when engine speed and load increase then BSFC decreases. Paval et al. [21] observed that for jatopha oil, at low load, the value of BSFC is 0.60 Kg/ KWh and at high load it decreases to 0.4529 Kg/KWh. Same kind of results were obtained by Praveen et.al. [59] who stated that BSFC decreases with increase in load. But when blending is increased BSFC also increases. Chiatti et.al. [33] observed that when blending is increased, BSFC also increased. For B20 (Jatropha) BSFC increased by 3.9% while with B40 (Jatropha) it increased by 7.1% compared to that of pure petro-diesel.

This is due to that fact that calorific value of biodiesel is less than that of pure diesel, which has been mentioned in the earlier sections, and hence justifies the above statements [21].

In conclusion, most of the authors agreed that biodiesel has higher value of BSFC than that of diesel and it increases when blending in increased in diesel-biodiesel blends.

Further data on BSFC of different biodiesel has been stated in the table 2.

III.II Effect of biodiesel on Brake Thermal Efficiency (BTE)

Efficiency is the ratio of the output of a system to its input. BTE, in case of IC engines, can be stated as the ratio of brake power output to heat input. Most of the researchers [20, 21, 33, 35, 37, 60, 71, 72, 118-122] agreed with the fact that as the concentration of biodiesel in the blend increases, BTE decreases. But some of them also observed that BTE increases with increase of biodiesel in the blend [22, 23, 37, 41, 45]. Chiatti et al. [33] did experiments for performance of engine with ULSD (ultralow sulphur Diesel) as biodiesel. It was observed that, at full load, BTE decreases by 1% when blending is increased from B20 to B40 (diesel is taken as reference). Agarwal et al. [134] investigated for performance of engine for different percentage of biodiesel (B20, B50 and B75). The experiment was done on a 4 stroke- single cylinder engine. It was found that when biodiesel blending is increased, BTE got decreased. Paval et al. [21] Observed similar kind of results where they observed that, for jatropha, BTE decreased with increase in blending. For B0 and B100, BTE was found to be 29.6% and 21.1% respectively. Preveen et al. [59] found that BTE, for a diesel engine and CalophyllumInophyllum biodiesel blends with TiO2 nanoadditives and EGR, is decreased by 1.8%. Agrawal et al.[67] observed that, for Karanja(B50) in a single cylinder agricultural diesel engine, BTE was found to be 30%.

These results could be due to the properties of biodiesel such as higher viscosity [4,17], low cetane number [33], lower heating value [21] etc.

But some researchers observed that with the increase in diesel-biodiesel blending, BTE increases. Nalgundwaret al.[36] did experiments on a CI engine using two biodiesel blends, jatropha(JB) and palm(PB). For D90JB5PB5, D80PB10JB10 and D70JB15PB15, BTE was found to be increased by 3.2%, 2.1% and 27.83% respectively. Similar outcomes were obtained by Jayashri et al.[37] who analysed performance and emission of Neem biodiesel on a CI engine. They observed that BTE of Neem biodiesel increased by 34% when compared to diesel. Thangaraj el at.[41] found that at no load and at full load, BTE increases by 2.61% and 21.67% respectively for Karanja oil methyl ester biodiesel blend enriched with HHO gas when compared to diesel. Krishna et al. [45] stated that, at a speed of 1800 rpm, BTE of EGR coupled semi adiabatic diesel engine fuelled with blended rubber seed biodiesel is increased by 7% when diesel is taken as reference. Mosarok et al. [69] did experiments with palm biodiesel at 1500 rpm speed. BTE of B25 was found to be 30.895%.

This could be due the fact that biodiesel contains more oxygen than that of pure diesel which ultimately results in good combustion of the fuel and hence BTE increases [36, 37, 41].

Further data on Brake Thermal Efficiency is given in the table 2.

IV. EFFECTS OF BIODIESEL ON EMISSION OF AN ENGINE

Emissions in a CI engine are unburnt hydrocarbon (UHC), carbon monoxide(CO), NO_x, carbon dioxide(CO_2), and particulate matter (PM) etc. Diesel-biodiesel blend has been resulted in low emissions of PM, CO, UHC and CO_2, however, NO_x increases with blending [4,13,17,58,] compared with diesel. In this section, a review is given on emission characteristics of an engine when operated with neat biodiesel or diesel-biodiesel blend and the results have been compared in the table 3.

IV.I Effect of biodiesel on NO_x emission

Most researchers agree with the fact that NO_x emission increases with increase in diesel-biodiesel blend and has a value higher than that of neat diesel [4,13,17,19-21,23,25,33,34,36,41,49,58,59,60,61]. Octavia et al. [17]

performed experiment on a baseline engine operated with different injection system and EGR with sunflower oil (B30, B70) as biodiesel. It was recorded that NO_x emissions increased when blending is increased. Leila et al. [13] reported that, for soybean oil, NO_x emissions was 5% higher than diesel. Similar conclusions were obtained by Kathimelu et al. [20], he stated that NO_x emission increased when blending was increased. The experiment was done by taking jatropha and fish oil as biodiesels. It had a value of 7.3 – 11.2 g/KWh. Monirul el al. [23] stated that NO_x emission escalated by 22.13% comapered to diesel when operated with jatropha oil at 800 rpm engine speed. Pi-qiang et al. [25] experimented on a light-duty petro-diesel engine with jatropha biodiesel fuel. He found that for B5, B10, B20, B50 and B100, NO_x increased by 1.2%, 2.06%, 4.74%, 5.71% and 13.9%. Thangaraj et al. [41] found that, for a diesel engine operated with karanja oil methyl ester biodiesel blends, NO_x emission increased by 5.43% for B10 and 13.70% for B20 at full load when diesel is taken as a reference. Shahir et al. [68] experimented on a common rail, direct injection engine using animal fat biodiesel blends. They observed that NO_x emission increased upto 56 ppm to 313 ppm when blending is increased. Jayaprabakar et al. [7] experimented on a CI engine with rice bran and algae biodiesel and its blends. They operated their engine on different loading conditions. At a load of 25%, 50%, 75% and 100%, it was found that NO_x had a value of 80ppm, 195ppm, 250ppm and 430ppm respectively.

This could be due to the difference in the flame temperature and ignition delay caused by higher oxygen content [33].

But some studies also reported that, NO_x emission decreases when blending is increased. Ahmed et al. [22] reported that when additives like grapheme nanoplatelet are added in biodiesel NO_x emission decreases. For jatropha oil, it got decreased by 15%. Similar result was obtained by Jayashri et al. [37] who reported that, for neem biodiesel, NO_x emission got decreased by 21.875%, 8.375% and 18.875% for B10 B20 and B30 respectively. Krishna et al. [45] experimented on an EGR coupled semi adiabatic diesel engine fuelled by DEE blended rubber seed biodiesel. They observed that NO_x emission decreased by 19.5% when operated at an engine speed of 1800 rpm. Pryor et al. [62] stated that, for a small diesel engine operated with soybean oil, NO_x emission decreased by 5%.

The decrease in NO_xemission could be due to the low calorific value of blends and less exhaust temperature of gases [31].

Further details on NO_x emission is given in the table 3.

IV.II Effect of biodiesel on Unburnt Hydrocarbon (UHC) emission

The use of biodiesel and its blends with diesel reduces the HC emission and this has been agreed by most of the researchers [7, 19, 22, 23, 25, 31, 33, 37-39, 63-65]. Octavia et al. [17] reported that, for a baseline engine and sunflower biodiesel having EGR, HC emission decreases and it was found to be less than 50 ppm. HC emission decreased by 25% when biodiesel is used. Similar conclusion was obtained by Cercrle et al. [4] who stated that HC emission decreases when blending is done. Buenu et al. [34] experiment on a single cylinder diesel engine with Caster oil biodiesel. It was found that HC emission decreased by 18% and 21% for B10 and B20 respectively.

The reason stated for this was the high content of oxygen in biodiesel and better combustion of it compared to diesel. When the percentage of biodiesel is increased in diesel-biodiesel blend, it shortens ignition delay and hence decreases the UHC [64].

It has been reported in various studies that change in engine speed also affects HC emission. Jayashri et al [37] observed that HC emission got decreased when engine speed was increased. At 1500 rpm and 2000 rpm, HC emission was reduced by 22% and 26% respectively. Neem biodiesel was used on a compression ignition engine. Similarly, Monirul el al. found that, for palm oil, HC emission was reduced by 14.29% when operated at engine speed of 800 rpm. However, HC emission decreases steadily when engine speed is increased above 1500 rpm.

This could be due to the increased inlet air flow speed, which ultimately intensifies atomization of the fuel and hence makes the blend more homogenous and as a result decreases HC emission [64].

Change in load on engine also affects emissions. Pi-qiang [25] experimented on a light duty diesel engine with jatropha biodiesel fuel. It was observed that HC emission increases when load is increased. For load of 0.10 MPa, 0.26 MPa, 0.57 MPA and 0.77 MPa, HC emission was found to be reduced by 26.5%, 27.6%, 30.9% and 46.7% respectively. Similar results were obtained by Suja et al. [41] who observed that, for a diesel engine with karanja biodiesel oil, HC emission was reduced by 12.25% and 24.54 % at no load and full load respectively for B10. For B20, it got decreased by 16.47% and 30.71% at no load and full load respectively.

The reason of this effect, given by various authors [25,41], are that, at lower loads, the amount of fuel injection is low, cylinder temperature is low, large amount of air and poor fuel distribution HC emission is high and is low when the engine load is high.

It has been observed that additives to biodiesel also changes HC emission. Jayaprabakar et al. [7] experimented on a CI engine and observed that, when load increases, HC emission decreases. It was found that, for algae biodiesel, HC emissions were reduced by 33%, 35%, 35.2% and 45% at 25%, 50%, 75% and 100% load respectively. Reddy et al. [66] observed that, for CI engine and jatropha biodiesel oil, HC emission got decreased by 33.3% at full loading condition. For example, Tewari et al. [133] found that when carbon nanotubes are added to biodiesel blends, HC emission got decreased by 50% compared to diesel. This may be due to the higher oxygen content of biodiesel than that of diesel which results in better fuel combustion and hence emission becomes low.

Further data on HC emissions are given in table 3.

IV.III Effect of biodiesel on CO emissions: Many researchers concluded that CO emission decreases when biodiesel or diesel-biodiesel blend is used in place of diesel [17, 19, 31, 33, 37, 39, 43, 50, 58, 59, 68, 69, 100, 103, 112, 118, 146]. Zhang et. Al. [12] experimented for emission characteristics of pure diesel and diesel – biodiesel blends. It was found that CO emissions were low when biodiesel is used instead of diesel and it decreases further more when blending of diesel with biodiesel is increased. For Puranjiva(B90), Karanja(B90) and Jatropha(B90), CO emissions were 0.31%, 0.014% and 0.011% respectively. Maryam et al. [16], on their researcher, found that CO emissions were lower than that of diesel. The tests were executed on a single cylinder, 4 stroke engine with animal fat biodiesel. Rounce et al. [43] compared diesel and biodiesel emissions with DMC (Dimethyl Carbonate) as biodiesel. They experimented at an engine speed 1500 rpm. It was found that CO emission reduced when biodiesel is used. Similar observation has been obtained by Kathimelu et al.[20], who found that, for a single cylinder and 4 stroke city car engine, CO emission reduces when diesel is replaced by biodiesel. Gumus et al. [129] experimented on a single-cylinder, four-stroke, direct-injection diesel engine with diesel-biodiesel blend with different percentages of biodiesel. The experimented was done at a constant engine speed of 2200 rpm under various loading conditions. They observed that CO emission got reduced significantly when diesel-biodiesel blend is used instead of diesel.

Lower CO emission when using biodiesel could be due to the high combustion rate of the biodiesel and this has been stated by many researchers [17, 43, 58].

Some of the researchers also found that CO emission increases when biodiesel is used. For example, Seesy et al.[22] observed that, CO emission increased when biodiesel is used. They used FOME (Fish oil methyl esters) and JOME (Jatropha oil methyl ester) biodiesel on a CI engine. It was found that, CO emission increases when brake power is increased. They also concluded that JOME had more CO emission than FOME.

The authors stated that poor combustion of the biodiesel fuel could be the reason of high CO emission.

Fuel additives to the biodiesel also affect CO emissions. Ahmed et al. [27] studied the effects of graphenenano-platelet addition to jatropha biodiesel on performance and emission characteristics of a diesel engine. It was observed that for B20, CO emission reduced by 60%. Similar observations were observed by two other studies [131, 132] that found that CO emissions were reduced by 40% and 51% when zinc oxide and cerium oxide is used as additives to biodiesel respectively.

CO emission also depends on loading conditions and it has been observed by many authors. Qiang et al. [32] observed that CO emissions were different at different loads. They experimented on a light-duty diesel engine with jatropha biodiesel fuel. At low load of (0.10-0.26) MPa, CO emission reduced by 17.6% to 23.8% and at high load of (0.57-0.77) MPa, it was 15% to 23.1%. Most of the researchers agree on a fact that, CO emission decreases when load is increased and it increases when engine speed is increased.

Most of the researchers [100,103,130] found that properties of biodiesel like high cetane number, high oxygen content etc. are the reasons for low CO emission from biodiesel fuel.

From the above observations, it can be concluded that, when load increases, CO emission decreases and when engine speed increases, emission also increases. Similarly, CO emission decreases when biodiesel percentage is increased in diesel-biodiesel blend.

Further details on CO emissions are given in the table 3.

IV.IV Effect of biodiesel on PM and Smoke opacity

A number of researches have been done on PM emissions and smoke opacity from diesel engine using biodiesel or diesel-biodiesel blended fuels. Many authors found that, use of diesel-biodiesel blend reduces PM emissions and Smoke opacity when compared with diesel [4,7,10,17,19,23,27,31,32,33,37,43,45,58,63,64,71,73,122]. For example, Octavia et al. [17] experimented on a baseline, common-rail injection system with split injection engine with exhaust gas recirculation. For smoke opacity, as the biodiesel percentage is increased in diesel-biodiesel mixture, smoke opacity was observed to be reduced. PM emissions were also found to be reduced. Similar observation was observed by Maryam et al. [58], who stated that, for second generation biofuels on a CARB diesel engine, PM emissions got reduced when biodiesel is used instead of diesel.Monirul et al. [23] studies emissions characteristics of palm, jatropha and calophylluminophyllum biodiesel. At full load and a constant speed of 1000 rpm, smoke opacity reduced by 31.09% for B10 (Jatopha) when compared with diesel.(further information, about other biodiesels, has been given in the table). Similar trend was observed by Vamsi et al.[45], who studied the emission characteristics of EGR coupled semi adiabatic diesel engine with rubber seed biodiesel. At a constant speed of 1800 rpm, PM emissions reduced by 48.5% at full load. Ozsezen et al. [77] found that smoke opacity for palm oil got reduced by 67.65% compared to that of diesel fuel.

There are so many reasons for reduction of these emissions that researchers [16, 17, 21, 43, 63, 64] have found such as high oxygen content, low carbon content, almost no sulphur content compared to that of diesel.

Additives in biodiesel also affect these emissions and this has been observed by many studies. Rounce et al. [43] used Dimethyl Carbonate (DMC) as oxygenated additives to ultra-low sulfur diesel (ULSD). They observed that, at a constant speed of 1500 rpm, PM emissions got decreased by about 50% when B4 is used. This could be due to higher oxygen content of additive. Similar results were found by et al. [78]. They stated that when cerium oxide nanoparticles and CNT are added to jatropha biodiesel then it resulted in better emission characteristics. Smoke opacity reduced by 25%.

It has been stated by many studies that loading conditions also change emission characteristics of an engine. Jayaprabakar et al. [7] analyzed a diesel engine with algae biodiesel for emissions characteristics at different loads and they noted that, smoke opacity decreased when blending of diesel-biodiesel is increased. At a load of 25%, 50%, 75% and 100%, smoke opacity was found to be reduced by 20%, 25%, 38% and 52% when compared to diesel fuel. He stated that, the above phenomenon occurs due to the high fuel rate because of high engine load which increases smoke opacity.

Hence, it can be concluded that, smoke opacity decreases when blending is increased.

V. Conclusion

A wide number of results have been found by several studies and researchers on influence of biodiesel on performance and emission of diesel engine. Almost all the results have same trends but some results also contradicted others. There could be several reasons of this trend. One is the presence of large number of different engine technologies, fuel types, additives and environmental conditions. Used under different instrument, different methodology and by different researchers.

However, we can conclude some following results:

- Break specific fuel consumption is observed to be increased by 2% to up to 35% than that of diesel, while operating on different blending.
- Average BTE of the diesel engine was found to be decreased with increase in blending percentage. Although, some biodiesels, like neem, showed a different trend, i.e., BTE was found to be increased rather than decreased.
- Most of the results agree on the fact that, NO_xincreaseswith increase in blend percentage.This could be due to the difference in the flame temperature and ignition delay caused by higher oxygen content. Some researchers also came up with a different trend of results. Due to the use of different additives, $NO_x$was found to get decreased by upto 22%.
- Use of biodiesel with diesel reduces the HC emission which has been agreed by almost all the researchers. Change in load, change in engine speed and use of additives played different roles in minimizing the value of hydrocarbons.
- After many researches, it has been found that CO emissions decrease when blending of biodiesel is increased in diesel-biodiesel mixture. Lower CO, as stated by many authors, could be due to the high oxygen content which leads to the higher combustion rate of fuel.
- For smoke opacity and PM, results had mixed trends. For some biodiesels (like Pinus oil) smoke opacity was found to be decreased and for some biodiesels(like waste cooking oil and soybean oil), it was found to be increased.

In conclusion, these results show that, biodiesels can be used in blending the diesel fuel up to a certain limit (say 20%) in order to have better efficiency and better emissions.

REFERENCES

[1] Demirbas A. Progress and recent trends in biodiesel fuels. Energy conversion and management. 2009 Jan 1;50(1):14-34.

[2] Kumar N, Chauhan SR. Performance and emission characteristics of biodiesel from different origins: A review. Renewable and Sustainable Energy Reviews. 2013 May 1;21:633-58.

[3] No SY. Inedible vegetable oils and their derivatives for alternative diesel fuels in CI engines: A review. Renewable and Sustainable Energy Reviews. 2011 Jan 1;15(1):131-49.

[4] Cecrle E, Depcik C, Duncan A, Guo J, Mangus M, Peltier E, Stagg-Williams S, Zhong Y. Investigation of the effects of biodiesel feedstock on the performance and emissions of a single-cylinder diesel engine. Energy & Fuels. 2012 Apr 19;26(4):2331-41.

[5] Shahid EM, Jamal Y. A review of biodiesel as vehicular fuel. Renewable and sustainable energy reviews. 2008 Dec 1;12(9):2484-94.

[6] Dhar A, Agarwal AK. Experimental investigations of the effect of pilot injection on performance, emissions and combustion characteristics of Karanja biodiesel fuelled CRDI engine. Energy conversion and management. 2015 Mar 15;93:357-66.

[7] Jayaprabakar J, Karthikeyan A. Performance and emission characteristics of rice bran and alga biodiesel blends in a CI engine. Materials Today: Proceedings. 2016 Jan 1;3(6):2468-74.

[8] Royon D, Daz M, Ellenrieder G, Locatelli S. Enzymatic production of biodiesel from cotton seed oil using t-butanol as a solvent. Bioresource technology. 2007 Feb 1;98(3):648-53.

[9] Watanabe Y, Shimada Y, Sugihara A, Tominaga Y. Conversion of degummed soybean oil to biodiesel fuel with immobilized Candida antarctica lipase. Journal of Molecular Catalysis B: Enzymatic. 2002 Jun 7;17(3-5):151-5.

[10] Choudhary U, Yadav SK. Biodiesel Production from Karanj Crude Oil by Transesterification Process. International Journal on Emerging Technologies. 2013;4(2):31-41.

[11] Noureddini H, Zhu D. Kinetics of transesterification of soybean oil. Journal of the American Oil Chemists' Society. 1997 Nov 1;74(11):1457-63.

[12] Noureddini H, Zhu D. Kinetics of transesterification of soybean oil. Journal of the American Oil Chemists' Society. 1997 Nov 1;74(11):1457-63.

[13] Lackey LG, Paulson SE. Influence of feedstock: Airpollution and climate-related emissions from a diesel generator operating on soybean, canola, and yellow grease biodiesel. Energy & fuels. 2012 Jan 19;26(1):686-700.

[14] Wood BM, Kirwan K, Maggs S, Meredith J, Coles SR. Study of combustion performance of biodiesel for potential application in motorsport. Journal of Cleaner Production. 2015 Apr 15;93:167-73.

[15] Bhuiya M, Rasul M, Khan M, Ashwath N. Performance and emission characteristics of binary mixture of poppy and waste cooking biodiesel. Energy Procedia. 2017 Mar 1;110:523-8.

[16] Kilic G, Sungur B, Topaloglu B, Ozcan H. Experimental analysis on the performance and emissions of diesel/butanol/biodiesel blended fuels in a flame tube boiler. Applied Thermal Engineering. 2018 Feb 5;130:195-202.

[17] Armas O, Gómez A, Cárdenas MD. Biodiesel emissions from a baseline engine operated with different injection systems and exhaust gas recirculation (EGR) strategies during transient sequences. Energy & fuels. 2009 Dec 17;23(12):6168-80.

[18] Cetinkaya M, Karaosmanoğ lu F. A new application area for used cooking oil originated biodiesel: generators. Energy & fuels. 2005 Mar 16;19(2):645-52.

[19] Thapa S, Indrawan N, Bhoi PR. An overview on fuel properties and prospects of Jatropha biodiesel as fuel for engines. Environmental technology & innovation. 2018 Feb 1;9:210-9.

[20] Kathirvelu B, Subramanian S, Govindan N, Santhanam S. Emission characteristics of biodiesel obtained from jatropha seeds and fish wastes in a diesel engine. Sustainable Environment Research. 2017 Nov 1;27(6):283-90.

[21] Paul G, Datta A, Mandal BK. An experimental and numerical investigation of the performance, combustion and emission characteristics of a diesel engine fueled with jatropha biodiesel. Energy Procedia. 2014 Jan 1;54:455-67.

[22] El-Seesy AI, Hassan H, Ookawara S. Effects of graphene nanoplatelet addition to jatropha Biodiesel–Diesel mixture on the performance and emission characteristics of a diesel engine. Energy. 2018 Mar 15;147:1129-52.

[23] Monirul IM, Masjuki HH, Kalam MA, Mosarof MH, Zulkifli NW, Teoh YH, How HG. Assessment of performance, emission and combustion characteristics of palm, jatropha and Calophyllum inophyllum biodiesel blends. Fuel. 2016 Oct 1;181:985-95.

[24] Kaisan MU, Anafi FO, Nuszkowski J, Kulla DM, Umaru S. Exhaust emissions of biodiesel binary and multi-blends from Cotton, Jatropha and Neem oil from stationary multi cylinder CI engine. Transportation Research Part D: Transport and Environment. 2017 Jun 1;53:403-14.

[25] Tan PQ, Hu ZY, Lou DM, Li ZJ. Exhaust emissions from a light-duty diesel engine with Jatropha biodiesel fuel. Energy. 2012 Mar 1;39(1):356-62.

[26] Acharya N, Nanda P, Panda S, Acharya S. A comparative study of stability characteristics of mahua and jatropha biodiesel and their blends. Journal of King Saud University-Engineering Sciences. 2019 Apr 1;31(2):184-90.

[27] Yadav AK, Khan ME, Dubey AM, Pal A. Performance and emission characteristics of a transportation diesel engine operated with non-edible vegetable oils biodiesel. Case Studies in Thermal Engineering. 2016 Sep 1;8:236-44.

[28] Valente OS, Pasa VM, Belchior CR, Sodré JR. Exhaust emissions from a diesel power generator fuelled by waste cooking oil biodiesel. Science of the total environment. 2012 Aug 1;431:57-61.

[29] Ozsezen AN, Canakci M, Sayin C. Effects of biodiesel from used frying palm oil on the performance, injection, and combustion characteristics of an indirect injection diesel engine. Energy & Fuels. 2008 Mar 19;22(2):1297-305.

[30] Kulkarni MG, Dalai AK. Waste cooking oil an economical source for biodiesel: a review. Industrial & engineering chemistry research. 2006 Apr 26;45(9):2901-13.

[31] Yadav RK, Sinha SL. Performance and Emission Characteristics of a Direct Injection Diesel Engine using Biodiesel Produced from Karanja Oil. International Journal of Enhanced Research in Science Technology & Engineering. 2015;4(2):151-8.

[32] Wang WG, Lyons DW, Clark NN, Gautam M, Norton PM. Emissions from nine heavy trucks fueled by diesel and biodiesel blend without engine modification. Environmental science & technology. 2000 Mar 15;34(6):933-9.

[33] Chiatti G, Chiavola O, Palmieri F, Albertini S. Combustion and emissions characterization of biodiesel blends in a city-car engine. Energy & Fuels. 2014 Aug 21;28(8):5076-85.

[34] Pandey A, Parwani A. Experimental Analysis on Biodiesel Prepared from Non edible Oil Resource to use in small Agricultural Diesel Engine. International Journal on Emerging Technologies. 2014 Jan 1;5(1):135.

[35] Hasan MM, Rahman MM. Performance and emission characteristics of biodiesel–diesel blend and environmental and economic impacts of biodiesel production: A review. Renewable and Sustainable Energy Reviews. 2017 Jul 1;74:938-48.

[36] Nalgundwar A, Paul B, Sharma SK. Comparison of performance and emissions characteristics of DI CI engine fueled with dual biodiesel blends of palm and jatropha. Fuel. 2016 Jun 1;173:172-9.

[37] Nair JN, Kaviti AK, Daram AK. Analysis of performance and emission on compression ignition engine fuelled with blends of neem biodiesel. Egyptian Journal of Petroleum. 2017 Dec 1;26(4):927-31.

[38] Liu H, Ma X, Li B, Chen L, Wang Z, Wang J. Combustion and emission characteristics of a direct injection diesel engine fueled with biodiesel and PODE/biodiesel fuel blends. Fuel. 2017 Dec 1;209:62-8.

[39] Choudhary U, Yadav DS. Performance Characteristics of Diesel Engine Using Biodiesel and their Esters as Fuel. International Journal on Emerging Technologies. 2013 Nov.

[40] Serin H, Yıldızhan Ş. Hydrogen addition to tea seed oil biodiesel: performance and emission characteristics.

International Journal of Hydrogen Energy. 2018 Sep 20;43(38):18020-7.

[41] Thangaraj S, Govindan N. Evaluating combustion, performance and emission characteristics of diesel engine using karanja oil methyl ester biodiesel blends enriched with HHO gas. International Journal of Hydrogen Energy. 2018 Mar 22;43(12):6443-55.

[42] Knothe G. Biodiesel and renewable diesel: a comparison. Progress in energy and combustion science. 2010 Jun 1;36(3):364-73.

[43] Rounce P, Tsolakis A, Leung P, York AP. A comparison of diesel and biodiesel emissions using dimethyl carbonate as an oxygenated additive. Energy & Fuels. 2010 Sep 16;24(9):4812-9.

[44] Mustapić Z, Krička T, Stanić Z. Biodiesel as alternative engine fuel. Energija. 2006 Dec 31;55(6):634-57..

[45] Krishna KV, Sastry GR, Krishna MM, Barma JD. Investigation on performance and emission characteristics of EGR coupled semi adiabatic diesel engine fuelled by DEE blended rubber seed biodiesel. Engineering science and technology, an international journal. 2018 Feb 1;21(1):122-9.

[46] Pandey A, Parwani A. A Review Performance and Economic Analysis Biodiesel. International Journal on Emerging Technologies. 2014 Jan 1;5(1):121.

[47] Balat M. Potential alternatives to edible oils for biodiesel production–A review of current work. Energy conversion and management. 2011 Feb 1;52(2):1479-92.

[48] Trostle R. Global agricultural supply and demand: factors contributing to the recent increase in food commodity prices (rev. Diane Publishing; 2010.

[49] Alptekin E, Canakci M. Characterization of the key fuel properties of methyl ester–diesel fuel blends. Fuel. 2009 Jan 1;88(1):75-80.

[50] Kuti OA, Zhu J, Nishida K, Wang X, Huang Z. Characterization of spray and combustion processes of biodiesel fuel injected by diesel engine common rail system. Fuel. 2013 Feb 1;104:838-46.

[51] Ramírez-Verduzco LF, García-Flores BE, Rodríguez-Rodríguez JE, del Rayo Jaramillo-Jacob A. Prediction of the density and viscosity in biodiesel blends at various temperatures. Fuel. 2011 May 1;90(5):1751-61.

[52] Ramírez-Verduzco, L. F., García-Flores, B. E., Rodríguez-Rodríguez, J. E., & del Rayo Jaramillo-Jacob, A. (2011). Prediction of the density and viscosity in biodiesel blends at various temperatures. *Fuel*, *90*(5), 1751-1761.

[53] Shang Q, Jiang W, Lu H, Liang B. Properties of Tung oil biodiesel and its blends with 0# diesel. Bioresource technology. 2010 Jan 1;101(2):826-8.

[54] Devarajan Y, Munuswamy DB, Nagappan B, Pandian AK. Performance, combustion and emission analysis of mustard oil biodiesel and octanol blends in diesel engine. Heat and Mass Transfer. 2018 Jun 1;54(6):1803-11.

[55] Fattah IR, Masjuki HH, Kalam MA, Mofijur M, Abedin MJ. Effect of antioxidant on the performance and emission characteristics of a diesel engine fueled with palm biodiesel blends. Energy Conversion and Management. 2014 Mar 1;79:265-72.

[56] Sithta A, Kumar A, Mahla SK. Utilization of Argemone oil biodiesel in commercial Di-CI engine. International journal on Emerging Technologies. 2012 Sep;3(2):19-23.

[57] Knothe G, Van Gerpen JH, Krahl J, editors. The biodiesel handbook. Champaign, IL: AOCS press; 2005 Jan 30.

[58] Hajbabaei M, Johnson KC, Okamoto RA, Mitchell A, Pullman M, Durbin TD. Evaluation of the impacts of biodiesel and second generation biofuels on NOx emissions for CARB diesel fuels. Environmental science & technology. 2012 Aug 21;46(16):9163-73.

[59] Praveen A, Rao GL, Balakrishna B. Performance and emission characteristics of a diesel engine using Calophyllum inophyllum biodiesel blends with TiO2 nanoadditives and EGR. Egyptian journal of petroleum. 2018 Dec 1;27(4):731-8.

[60] Ghobadian B, Rahimi H, Nikbakht AM, Najafi G, Yusaf TF. Diesel engine performance and exhaust emission analysis using waste cooking biodiesel fuel with an artificial neural network. Renewable energy. 2009 Apr 1;34(4):976-82.

[61] Marshall W, Schumacher LG, Howell S. Engine exhaust emissions evaluation of a Cummins L10E when fueled with a biodiesel blend. SAE Technical Paper; 1995 Oct 1.

[62] Bhardwaj V, Singla V, Gaikwad P, Sharma G. Study of performance characteristics of compression ignition engine fuelled with blends of biodiesel from used cottonseed oil. International Review of Applied Engineering Research. ISSN.:2248-9967.

[63] Manu J, Mahla SK. Experimental investigations on the utilization of waste cooking oil based biodiesel & n-butanol in CI Engine (Doctoral dissertation).2014.

[64] Canakci M, Ozsezen AN, Arcaklioglu E, Erdil A. Prediction of performance and exhaust emissions of a diesel engine fueled with biodiesel produced from waste frying palm oil. Expert systems with Applications. 2009 Jul 1;36(5):9268-80.

[65] John B. Heywood, Internal combustion engine fundamentals. Pub: McGraw Hill International Editions. 1988.

[66] Reddy JN, Ramesh A. Parametric studies for improving the performance of a Jatropha oil-fuelled compression ignition engine. Renewable Energy. 2006 Oct 1;31(12):1994-2016.

[67] Agarwal AK, Rajamanoharan K. Experimental investigations of performance and emissions of Karanja oil and its blends in a single cylinder agricultural diesel engine. Applied Energy. 2009 Jan 1;86(1):106-12.

[68] Shahir VK, Jawahar CP, Suresh PR, Vinod V. Experimental Investigation on Performance and Emission Characteristics of a Common Rail Direct InjectionEngine Using Animal Fat Biodiesel Blends. Energy Procedia. 2017 Jun 1;117:283-90.

[69] Mosarof MH, Kalam MA, Masjuki HH, Ashraful AM, Rashed MM, Imdadul HK, Monirul IM. Implementation of palm biodiesel based on economic aspects, performance, emission, and wear characteristics. Energy conversion and Management. 2015 Nov 15;105:617-29.

[70] Bhuiya MM, Rasul MG, Khan MM, Ashwath N, Azad AK. Prospects of 2nd generation biodiesel as a sustainable fuel—Part: 1 selection of feedstocks, oil extraction techniques and conversion technologies. Renewable and Sustainable Energy Reviews. 2016 Mar 1;55:1109-28.

[71] Rakopoulos CD, Antonopoulos KA, Rakopoulos DC, Hountalas DT, Giakoumis EG. Comparative performance and emissions study of a direct injection diesel engine using blends of diesel fuel with vegetable oils or bio-diesels of various origins. Energy conversion and management. 2006;47(18-19):3272-87.

[72] Hoque N, Mourshed M, Das BK. Performance and emission comparison of Karanja (pongamia pinnata), Pithraj (aphanamixis polystachya), Neem (azadira chtaindica) and Mahua (madhuca longofolia) seed oil as a potential feedstock for biodiesel production in Bangladesh. International Journal of Automotive & Mechanical Engineering. 2015 Jul 1;12.

[73] Gumus M, Kasifoglu S. 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. 2010 Jan 1;34(1):134-9.

[74] Nanthagopal K, Ashok B, Tamilarasu A, Johny A, Mohan A. Influence on the effect of zinc oxide and titanium dioxide nanoparticles as an additive with Calophyllum inophyllum methyl ester in a CI engine. Energy Conversion and Management. 2017 Aug 15;146:8-19.

[75] Khalife E, Tabatabaei M, Najafi B, Mirsalim SM, Gharehghani A, Mohammadi P, Aghbashlo M, Ghaffari A, Khounani Z, Shojaei TR, Salleh MA. A novel emulsion fuel containing aqueous nano cerium oxide additive in diesel–biodiesel blends to improve diesel engines performance and reduce exhaust emissions: Part I–Experimental analysis. Fuel. 2017 Nov 1;207:741-50.

[76] Wu F, Wang J, Chen W, Shuai S. A study on emission performance of a diesel engine fueled with five typical methyl ester biodiesels. Atmospheric Environment. 2009 Mar 1;43(7):1481-5.

[77] Ozsezen AN, Canakci M. Determination of performance and combustion characteristics of a diesel engine fueled with canola and waste palm oil methyl esters. Energy Conversion and Management. 2011 Jan 1;52(1):108-16.

[78] Selvan VA, Anand RB, Udayakumar M. Effect of Cerium Oxide Nanoparticles and Carbon Nanotubes as fuel-borne additives in Diesterol blends on the performance, combustion and emission characteristics of a variable compression ratio engine. Fuel. 2014 Aug 15;130:160-7.

[79] Amini-Niaki SR, Ghazanfari A. Comparison of fuel and emission properties of petro diesel and sunflower biodiesel prepared by optimized production variables. Fuel. 2013 Jul 1;109:384-8.

[80] Srivastava A, Prasad R. Triglycerides-based diesel fuels. Renewable and sustainable energy reviews. 2000 Jun 1;4(2):111-33.

[81] Vatambe A. Effect of injection pressure on performance and emission characteristics of single diesel engine with methyl-ester of Mahua oil as fuel. International Journal on Emerging Technologies. 2015 Jul 1;6(2):298.

[82] Saluja RK. Assessment of Effect of Load and Injection Timing on the Performance of Diesel Engine Running on Diesel-Biodiesel Blends. International Journal of Renewable Energy Research (IJRER). 2017 Mar 22;7(1):200-13.

[83] Mamualiya A, Lal H. Effect on Performance and Emission Characteristics of Direct Injection using Biodiesel Produced from Kranja oil. International Journal on Emerging Technologies. 2015 Jan 1;6(1):130.

[84] Tat ME, Van Gerpen JH. The kinematic viscosity of biodiesel and its blends with diesel fuel. Journal of the American Oil Chemists' Society. 1999 Dec;76(12):1511-3.

[85] Al-Hamamre Z, Al-Salaymeh A. Physical properties of (jojoba oil+ biodiesel),(jojoba oil+ diesel) and (biodiesel+ diesel) blends. Fuel. 2014 May 1;123:175-88.

[86] Chen LY, Chen YH, Hung YS, Chiang TH, Tsai CH. Fuel properties and combustion characteristics of jatropha oil biodiesel–diesel blends. Journal of the Taiwan Institute of Chemical Engineers. 2013 Mar 1;44(2):214-20.

[87] Sahoo PK, Das LM, Babu MK, Naik SN. Biodiesel development from high acid value polanga seed oil and performance evaluation in a CI engine. Fuel. 2007 Feb 1;86(3):448-54.

[88] Joshi RM, Pegg MJ. Flow properties of biodiesel fuel blends at low temperatures. Fuel. 2007 Jan 1;86(1-2):143-51.

[89] Turrio-Baldassarri L, Battistelli CL, Conti L, Crebelli R, De Berardis B, Iamiceli AL, Gambino M, Iannaccone S. Emission comparison of urban bus engine fueled with diesel oil and 'biodiesel'blend. Science of the Total Environment. 2004 Jul 5;327(1-3):147-62.

[90] Hansen KF, Jensen MG. Chemical and biological characteristics of exhaust emissions from a DI diesel engine fuelled with rapeseed oil methyl ester (RME). SAE Technical Paper; 1997 .

[91] da Silva FN, Prata AS, Teixeira JR. Technical feasibility assessment of oleic sunflower methyl ester utilisation in Diesel bus engines. Energy conversion and management. 2003;44(18):2857-78.

[92] Graboski MS, McCormick RL, Alleman TL, Herring AM. The effect of biodiesel composition on engine emissions from a DDC series 60 diesel engine. National Renewable Energy Laboratory (Report No: NREL/SR-510-31461). 2003.

[93] Hamasaki K, Kinoshita E, Tajima H, Takasaki K, Morita D. (3-09) Combustion Characteristics of Diesel Engines with Waste Vegetable Oil Methyl Ester ((AF-3) Alternative Fuels 3-Biomass Fuels and Fuel Design). InThe Proceedings of the International symposium on diagnostics and modeling of combustion in internal combustion engines 01.204 2001 Jul 1 (p. 55). The Japan Society of Mechanical Engineers.

[94] Ramadhas AS, Muraleedharan C, Jayaraj S. Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. Renewable energy. 2005 Oct 1;30(12):1789-800.

[95] de Marco Rodriguez I, Laresgoiti MF, Cabrero MA, Torres A, Chomon MJ, Caballero B. Pyrolysis of scrap tyres. Fuel processing technology. 2001 Aug 1;72(1):9-22.

[96] Murugan S, Ramaswamy MC, Nagarajan G. The use of tyre pyrolysis oil in diesel engines. Waste management. 2008;28(12):2743-9.

[97] Kidoguchi Y, Yang C, Kato R, Miwa K. Effects of fuel cetane number and aromatics on combustion process and emissions of a direct-injection diesel engine. JSAE review. 2000 Oct 1;21(4):469-75.

[98] Kumar MS, Ramesh A, Nagalingam B. Complete vegetable oil fueled dual fuel compression ignition engine. SAE Technical Paper; 2001.

[99] Valente OS, Da Silva MJ, Pasa VM, Belchior CR, Sodre JR. Fuel consumption and emissions from a diesel power generator fuelled with castor oil and soybean biodiesel. Fuel. 2010 Dec 1;89(12):3637-42.

[100] Özcanli M, Serin H, Saribiyik OY, Aydin K, Serin S. Performance and emission studies of castor bean (Ricinus Communis) oil biodiesel and its blends with diesel fuel. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2012 Jul 26;34(19):1808-14.

[101] Dhar A, Agarwal AK. Performance, emissions and combustion characteristics of Karanja biodiesel in a transportation engine. Fuel. 2014;119:70-80.

[102] Lin YC, Lee WJ, Hou HC. PAH emissions and energy efficiency of palm-biodiesel blends fueled on diesel generator. Atmospheric Environment. 2006 Jul 1;40(21):3930-40.

[103] Namliwan N, Wongwuttanasatian T. Performance of diesel engine using diesel B3 mixed with crude palm oil. The Scientific World Journal. 2014;2014.

[104] Schumacher LG, Borgelt SC, Hires WG, Fosseen D, Goetz W. Fueling diesel engines with blends of methyl ester soybean oil and diesel fuel. Agricultural Engineering Department, University of Missouri. Missouri, Columbia: biodiesel. org. 1994:1598-606.

[105] Serdari A, Fragioudakis K, Teas C, Zannikos F, Stournas S, Lois E. Effect of biodiesel addition to diesel fuel on engine performance and emissions. Journal of propulsion and power. 1999 Mar;15(2):224-31.

[106] Staat F, Gateau P. The effects of rapeseed oil methyl ester on diesel engine performance, exhaust emissions and Long-Term behavior-A summary of three years of experimentation. SAE transactions. 1995 :1-7.

[107] Last RJ, Krüger M, Dürnholz M. Emissions and performance characteristics of a 4-stroke, direct injected diesel engine fueled with blends of biodiesel and low sulfur diesel fuel. SAE Technical Paper; 1995.

[108] Murugan S, Ramaswamy MC, Nagarajan G. A comparative study on the performance, emission and combustion studies of a DI diesel engine using distilled tyre pyrolysis oil–diesel blends. Fuel. 2008;87(10-11):2111-21.

[109] Kegl B. Effects of biodiesel on emissions of a bus diesel engine. Bioresource technology. 2008; 99(4):863-73.

[110] Sudhir CV, Sharma NY, Mohanan P. Potential of waste cooking oils as biodiesel feedstock. Emirates journal for engineering research. 2007;12(3):69-75.

[111] Ozsezen AN, Canakci M, Turkcan A, Sayin C. Performance and combustion characteristics of a DI diesel engine fueled with waste palm oil and canola oil methyl esters. Fuel. 2009 ;88(4):629-36.

[112] Paul G, Datta A, Mandal BK. An experimental and numerical investigation of the performance, combustion and emission characteristics of a diesel engine fueled with jatropha biodiesel. Energy Procedia. 2014;54:455-67.

[113] Singh Y, Singla A. Comparative analysis of jatropha and karanja-based biodiesel properties, performance and exhaust emission characteristics in an unmodified diesel engine. Pollution. 2015;1(1):23-30.

[114] Yilmaz N, Morton B. Comparative characteristics of compression ignited engines operating on biodiesel produced from waste vegetable oil. Biomass and Bioenergy. 2011;35(5):2194-9.

[115] Sivakumar M, Sundaram NS, Thasthagir MH. Effect of aluminium oxide nanoparticles blended pongamia methyl ester on performance, combustion and emission characteristics of diesel engine. Renewable Energy. 2018;116:518-26.

[116] Basha JS, Anand RB. An experimental investigation in a diesel engine using carbon nanotubes blended water–diesel emulsion fuel. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy. 2011;225(3):279-88.

[117] Basha J, Anand RB. Effects of nanoparticle-blended water biodiesel emulsion fuel on working characteristics of a diesel engine. International Journal of Global Warming. 2010; 2(4):330-46.

[118] Stringer FW, Clarke AE, Clarke JS. The spontaneous ignition of hydrocarbon fuels in a flowing system. InProceedings of the institution of mechanical engineers, conference proceedings 1969 Sep (Vol. 184, No. 10, pp. 212-225). Sage UK: London, England: SAGE Publications.

[119] Lertsathapornsuk V, Pairintra R, Aryusuk K, Krisnangkura K. Microwave assisted in continuous biodiesel production from waste frying palm oil and its performance in a 100 kW diesel generator. Fuel Processing Technology. 2008 Dec 1;89(12):1330-6.

[120] Szybist JP, Boehman AL, Taylor JD, McCormick RL. Evaluation of formulation strategies to eliminate the biodiesel NOx effect. Fuel Processing Technology. 2005 Jun 25;86(10):1109-26.

[121] Chauhan BS, Kumar N, Cho HM. A study on the performance and emission of a diesel engine fueled with Jatropha biodiesel oil and its blends. Energy. 2012 Jan 1;37(1):616-22.

[122] Meng X, Chen G, Wang Y. Biodiesel production from waste cooking oil via alkali catalyst and its engine test. Fuel processing technology. 2008 ;89(9):851-7.

[123] Lapuerta M, Armas O, Rodriguez-Fernandez J. Effect of biodiesel fuels on diesel engine emissions. Progress in energy and combustion science. 2008 Apr 1;34(2):198-223.

[124] Sahoo PK, Das LM. Combustion analysis of Jatropha, Karanja and Polanga based biodiesel as fuel in a diesel engine. Fuel. 2009 Jun 1;88(6):994-9.

[125] Peterson CL, Thompson JC, Taberski JS. One-thousand-hour engine durability test with HySEE and using a 5X-EMA test cycle. Transactions of the ASAE. 1999;42(1):23.

[126] Liu Y. Used cooking oil promises to fuel China's rapidly expanding car fleet. World Watch Institute. 2006;10:12.

[127] Cheng CH, Cheung CS, Chan TL, Lee SC, Yao CD, Tsang KS. Comparison of emissions of a direct injection diesel engine operating on biodiesel with emulsified and fumigated methanol. Fuel. 2008;87(10-11):1870-9.

[128] Canakci M, Van Gerpen JH. Comparison of engine performance and emissions for petroleum diesel fuel, yellow grease biodiesel, and soybean oil biodiesel. Transactions of the ASAE. 2003;46(4):937.

[129] Cetinkaya M, Karaosmanoğ lu F. A new application area for used cooking oil originated biodiesel: generators. Energy & fuels. ;19(2):645-52.

[130] Lertsathapornsuk V, Pairintra R, Aryusuk K, Krisnangkura K. Microwave assisted in continuous biodiesel production from waste frying palm oil and its performance in a 100 kW diesel generator. Fuel Processing Technology. 2008;89(12):1330-6.

[131] Di Y, Cheung CS, Huang Z. Experimental investigation on regulated and unregulated emissions of a diesel engine fueled with ultra-low sulfur diesel fuel blended with biodiesel from waste cooking oil. Science of the total environment. 2009;407(2):835-46.

[132] Patil KR, Thipse SS. Characteristics of performance and emissions in a direct-injection diesel engine fuelled with kerosene/diesel blends. International Journal of Automotive and Mechanical Engineering. 2014 ;10:2102.

[133] Tewari P, Doijode E, Banapurmath NR, Yaliwal VS. Experimental investigations on a diesel engine fuelled with multiwalled carbon nanotubes blended biodiesel fuels. International Journal of Emerging Technology and Advanced Engineering. 2013;3(3):72-6.

[134] Agarwal D, Agarwal AK. Performance and emissions characteristics of Jatropha oil (preheated and blends) in a direct injection compression ignition engine. Applied thermal engineering. 2007;27(13):2314-23.

[135] Bertoli C, D'Alessio J, Giacomo ND, Lazzaro M, Massoli P, Moccia V. Running light-duty DI diesel engines with wood pyrolysis oil. SAE transactions. 2000:3090-6.

[136] Abedin MJ, Masjuki HH, Kalam MA, Sanjid A, Rahman SA, Fattah IR. Performance, emissions, and heat losses of palm and jatropha biodiesel blends in a diesel engine. Industrial crops and products. 2014;59:96-104.

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 6 (2020), pp. 1076-1094
 https://dx.doi.org/10.37624/IJERT/13.6.2020.1076-1094

Table 1: Properties of biodiesel as compared to diesel [14,15,19,20,21,24,25,27,28,32,39,43,70,83-93]

Specification	Unit	Diesel	Polanga	Mahua	Cotton seed	Jajoba oil	Linseed oil	Putranjiva	Karanja	Jatropha
Density(15°C)	Kg/m³	810-860	888.6-910	904-916	874-911	863-866	865-950		876-891	864-880
Viscosity(°40C)	cSt	2-5.7	4.5-5.34	3.98-5.8	4-4.9	19.2-25.4	16.2-36.6	5.18	4.37-9.60	3.7-5.8
Cetane No.		40-55	#REF!	51-52	41.2-59.5	63.5	28-35	40.2	35.6-58	41-55
Cloud Point	°C	-20-0	13.2-14	3.5	1.7	1.6	1.7		13-15	5
Pour Point	°C	-20-5	4.3	1-6	-10 to -15	-6-6	-4 to -18	2	-3-5.1	3-5.2
Lower Heating Value	MJ/Kg	39-44								30.5
Calorific Value	MJ/Kg		39.2-41.3	39.4-39.9	39.5-40.1	42.7-47.3	33.7-39.8	39.2	36.0-38.1	38.5-42.0
Specific Gravity (at 25°C)		0.834						0.883	0.899	0.878
Flash Point	°C	50-98	151-170	127-129	210-243	61-75	108	152	163-190	162-183.6
Fire Point	°C	85						155	192	175
Percent C(wt%)		64.8-87								76.6
Percent H(wt%)		12.6-13.6								12.1
Percent O(wt%)		4-21.6								11.3
Molecular weight		190								282

Table 2: Effect of biodiesel on Performance of the engine

S.No	Engine type and test condition	Biodiesel	Blend percentage	Brake Thermal Efficiency (BTE)	Brake Specific Fuel Consumption (BSFC)	Reference
1	6-cyliner, 7.81 engine	Rapeseed	B20	-	↑ 2.95% than diesel	89
2	6-cylinder engine, 170kW rated power, ECE R49 test cycle	Rapeseed	B100	-	↑14% than diesel	90
3	6-cylinder, 9.61engine	Sunflower	B5	-	No significant change	91
			B30	-	No significant change	
4	Heavy-duty engine. 11.11254kW	methyl esters	B100	No significant change	-	92
5	Single-cylinder, 11.77 kW at different load	waste oil	B100	No significant change	-	93
6	Single-cylinder, 5.5 kW	Indian rubber seed oil	B50	10%	-	94
			B100	20%	-	
7	4-stroke,DI diesel engine, 1500rpm, 4.4 kW rated power	Tyre pyrolysis oil (TPO)	B20	28.5% at full load	Slightly change	95
			B90	-	Slightly change	
8	4-stoke, Compression ignition engine, full load: 4.4 KW	Waste cooking oil	B100	26% less than diesel	0.351 kg/KWh	96
9	2-cylinder diesel engine 1500rpm	Jatropha oil	B0	14.6% at low load (2 kW)	0.531 kg/kWh at low load	135
			B100	10.3% at low load (2 kW)	0.73 kg/kWh at low load	
			B0	29.69% at high load	0.73 kg/kWh at high load	
			B100	27.45% at high load	0.49 kg/kWh at high load	
10	4-stroke, water cooled, 42 kW rated power, 4000 rpm rated speed, 2500 rpm current speed	Palm oil	B20	32.10%	0.267 kg/kWh	97
			B100	31.70%	0.307 kg/kWh	

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 6 (2020), pp. 1076-1094
© International Research Publication House. https://dx.doi.org/10.37624/IJERT/13.6.2020.1076-1094

11	4-stroke direct injection water cooled diesel engine, 3.67 kW rated power, 1500 rpm	Jatropha	B50	28.40%	slightly higher	65
12	Single cylinder 4-stroke engine, 1000-3000 rpm rated speed	Putranjiva	B10	31.70%	0.268 kg/kWh	98
			B30	27.50%	0.314 kg/kWh	
			B50	26.50%	0.332 kg/kWh	
			B70	25.90%	0.345 kg/kWh	
			B70	27.80%	0.328 kg/kWh	
		Jatropha	B10	30.20%	0.282 kg/kWh	
			B30	30.30%	0.286 kg/kWh	
			B50	29.90%	0.295 kg/kWh	
			B70	29.68%	0.302 kg/kWh	
13	Baseline engine with exhaust gas recirculation (EGR)	Sunflower	B30, B70	Less than diesel fuel	More than diesel fuel	17
14	City-car diesel engine at full load	Biodiesel	B20	↓ 1% compared to diesel	↑ 3.9% compared to diesel	33
			B40	↓ 1% compared to diesel	↑ 7.1% compared to diesel	
15	Single- cylinder, 4 stroke diesel engine	Jatropha	variable blends (B5,10,30,30,100)	Lower with the increase in fuel	Greater than diesel fuel and increased with the increase in fuel blends at	21
				Less than diesel fuel at 2200 rpm	Greater than diesel fuel at 2200 rpm	
				Greater than diesel fuel at 20-80 %	at 20% blend, it was lower than diesel fuel at 1500 rpm and different loads	
				No significant change at 3800 rpm	Greater than diesel fuel at 3800 rpm	
				less than diesel fuel at 3600 rpm	Greater than diesel fuel at 3600 rpm	
16	Single cylinder, 4 stroke, air cooled, direct injection, CI engine, rated speed: 1500 rpm, load: 4.4 kW	Jatropha and fish oil	B100	24.8-28.4 %	-	20
17	Diesel powered generator	Caster oil and soybean oil	B35	-	↑ 3.2-7.1%	99
18	4-stroke diesel engine at low load	Caster oil	B25	-	↑4.4%	100
19	4-stroke diesel engine, 1500 rpm rated speed, varing load condition	Jatropha	B100	10.3% which is lower than diesel at	0.13 kg/kWh which is higher than that of diesel fuel at low load (2kW)	21
				21% which is lower than diesel fuel at high load	0.491 kg/kWh which is higher than that of diesel fuel at high load	

20	Diesel engine with graphene nanoplatelets	Jatropha	B20	↑ 25%	↓ 20%	22
21	4-stroke diesel engine, rated speed : 1000-2400 rpm	Palm oil, Jatropha oil,	B10, B20 (for all oils)	-	Average increase : 10.15% (for all oils)	23
22	Diesel engine, rated speed : 800 , at full load	Waste palm oil methyl ester	B100	-	↑ 7.5%	77
23	DI CI diesel engine at constant engine speed and fixed load	Palm, jatopha and diesel oil	D90 JB5 PB5	↑ 3.2%	↓ 0.91%	36
			D80 JB10 PB10	↑ 2.2%	↑ 2.36%	
			D70 JB15 PB15	↓ 27.83%	↑ 16.52%	
24	Compression ignition engine, rated engine speed : 1500 rpm	Neem oil	B10, B20	Average increase : 34%	-	37
25	Diesel engine, rated engine speed : 1500 rpm, hydrogen additives	Tea seed oil	B10	-	↑ 4.37-6.5%	40
			B20	-	↑ 4.9-11.59%	
26	4-stroke Diesel engine with constant engine speed and varying load, additive : HHO gas	Karanja oil methyl ester	B10	↑ 2.03% at no load	↓ 0.28% at no load	36
				↑ 19.40% at full load	↓ 1.30% at full load	
			B20	↑ 4.33% at no load	↓ 4.01% at no load	
				↑ 26.64% at full load	↓ 10.16% at full load	
27	Common rail direct injection engine	Waste animal fat	B30	-	0.23 kg/kWh	68
28	Transportati-on engine, rated speed : 1700 rpm	Karanja	varies blends	Decrease-d with increase in blending at low load	Increased- with increase in blending	101
29	EGR coupled semi-adiabatic diesel engine rated engine speed : 1800 rpm	DEE blended Rubber seed	B100	↑7% compared to diesel	↓5.5% compared to diesel	45
30	DI diesel engine, rated engine speed : 1500 rpm	Methyl ester	B25	30.90%	↑ 2.59% compared to diesel	100
			B50	30.56%	↑ 8.93% compared to diesel	
			B75	29.22%	↑ 9.25% compared to diesel	
			B100	29.58%	-	
31	4-stroke diesel engine with exhaust gas recirculation (EGR) additive: TiO_2	CalophyllumIn ophyllum oil	B100	↓ 1.8%	-	59
32	Compression ignition engine, Rated engine speed : 2900 rpm	Oleander	B100	Higher than diesel, 20.20%	Lower diesel, 0.314 kg/kWh	27
		Kusum	B100	Lower than diesel, 19.7%	Higher than diesel, 0.34 kg/kWh	

		Bitter groundnut	B100	Lower than diesel	Higher than diesel, 0.331kg/kWh	
33	6-cylinder, 4 stroke, turbocharged , DI, CI engine. Constant load :	Waste cooking oil	B20	↓ 2%	↑ 75 g/kWh	102
34	6-cylinder, 4stroke, WC, DI, CI engine, constant engine speed :1800 rpm.	Waste fry oil	B100	↑ average 1.89%	↑average 8.64%	103

Table 3: Effect of biodiesel on Emissions of the engine

S. NO.	Engine type andtest conditions	Biodiesel	Blend percentage	NO_x	CO	UHC	PM & Smoke Opacity	Refe-rence
1	6-cylinder engine, constant engine	Soybean	B10, B20, B30, B40	↑ 15% for B40	-	-	-	104
2	L10E engine	Biodiesel	B20	↑ 3.7%	-	-	-	105
			B30	↑ 1.2%	-	-	-	
3	6-cylinder engine, ECE R49 test cycle	Biodiesel	B100	↑ 9.5%	-	-	-	106
4	Heavy-duty engine	Soybean	B10	-	-	↓ 28%	-	107
			B20	-	-	↓ 32%	-	
			B100	-	-	↓ 75%	-	
5	Single cylinder,4 stroke, air cooled, CI engine, constant engine speed : 1500 rpm, load: 4.4 kW	Tyre pyrolysis oil	B20	1740 ppm	↓ 0.05%	27 ppm	-	108
			B90	1820 ppm	↓ 0.06%	31 ppm	-	
6	6-cylinder, 4 stroke, water cooled, constant engine speed: 2200 rpm	Pinus	B100	↓ 50%	↓ 25%	↓ 30%	↓ 50% smoke	109
7	Single Cylinder, Rated speed:1500rpm Injection pressure: 200 bar	Waste cooking oil	B20	↑ 1-7%	↓ 59%	↓ 57%	-	110
			B40	-	↓ 23%	-	-	
			B80	-	↓ 35%	-	-	
			B100	↑ 30%	↓ 31%	-	↑ 24% smoke	
8	Navy Star Engine, 6 Cylinder engine,	Soybean	B20	↑ 3.7%	↓ 8%	-	-	112

	Rated speed: 2000 rpm		B40	↑ 15%	↓ 18%	-	-	
			B80	↑ 16%	-	-	-	
			B100	-	↓ 50%	↓ 75%	↑ 20%	
9	2-cylinder, 4 stroke CI engine, constant engine speed: 1500 rpm, engine load: 7.35 kW	Jatropha	B100	470 ppm	-	-	-	112
10	Single cylinder, 4 stroke, direct injection, water cooled, diesel engine, constant rated speed: 1500 rpm, rated power: 3.67 kW	Jatropha(JB)	JB50	935 ppm	0.42%	62 ppm	Smoke opacity	113
		Karanja(KB)	KB50	952 ppm	0.15%	54 ppm	-	
11	Single cylinder, 4 stroke CI engine, constant rated speed: 1000-3000 rpm	Putanjiva	B10	118 ppm	0.04%	111 ppm	8.1 Hsu & 17.8 mg/m^3	31
			B30	108 ppm	0.03%	102 ppm	7.3 Hsu & 17.1 mg/m3	
			B50	91 ppm	0.03%	89 ppm	6.7 Hsu & 14.4 mg/m3	
			B70	83 ppm	0.03%	78 ppm	5.9 Hsu & 12.5 mg/m3	
		Karanja	B10	99 ppm	0.02%	116 ppm	6.4 Hsu & 18.9 mg/m3	
			B30	86 ppm	0.02%	104 ppm	4.9 Hsu & 18.3 mg/m3	
			B50	78 ppm	0.02%	95 ppm	4.2 Hsu & 17.6 mg/m3	
			B70	72 ppm	0.02%	84 ppm	4.0 Hsu & 17.1 mg/m3	
		Jatropha	B10	76 ppm	0.01%	105 ppm	4.4 Hsu & 15.4 mg/m3	
			B30	71 ppm	0.02%	93 ppm	4.1 Hsu & 14.8 mg/m3	
			B50	59 ppm	0.02%	87 ppm	3.8 Hsu & 14.0 mg/m3	
			B70	56 ppm	0.01%	71 ppm	3.2 Hsu & 12.6 mg/m3	
12	Baseline Common-rail engine, split injection and lower EGR ratio & exhaust gas recirculation(ECR)	Biodiesel	B100	↑	↓	↓	↓ smoke opacity and PM	17
13	Diesel enigne	Soybean	B20	↑ 3.9%-6.9%	-	-	-	32

			B100	↑ 17.4%-47.4%	-	-	-	
		Animal fat	B20	↑ 1.5%-5.9%	-	-	-	
			B50	↑ 6.4%-16.3%	-	-	-	
			B100	↑ 14.1%-39.4%	-	-	-	
14	City car diesel engine	Biodiesel	B20 & B40	-	Decreases with increase	Decreases with increase	Decreases with	33
15	4 stroke diesel engine, constant engine speed: 1500 rpm	Jatropha	B100	↑ 25.97%	↓ 73%	↓ 67%	↓ 72.73% PM	
16	single cylinder, 4 stroke diesel engine	Jatropha	varies blends	↑ 5.58%-25.97%	↓ 50%-73%	↓ 45%-67%	↓ 50%-72.73%	19
17	Compression ignition engine operated at constant engine speed at fixed load	Caster bean oil	B10	-	-	↓ 18%	-	110
			B20	-	-	↓ 21%	-	
18	4 stroke direct injected diesel engine	Low sulphur diesel oil	B10	-	-	↓ 28%	-	114
			B20			↓ 32%		
19	4 stroke diesel engine, rated engine speed: 1500 rpm with varing loads	Jatropha	B100	470 ppm at low	-	-	-	21
				840 ppm at high	-	-	-	
20	Direct injection, Single cylinder, diesel engine, constant engine speed, additive: aluminium oxide	Pongamia methyl ester	B100	↑ 30%	↓ 40%	↓ 55%	25% smoke opacity	115
21	Single cylinder diesel engine, AVL Di-gas analyser, additive: carbon nano tubes	Water-diesel emulsion	B100	↓ 28%	↓ 50%	↓ 50%	-	116
22	Compression ignition diesel engine, additive: alumina	Jatropha	B100	↑ 22%	↓ 40%	↓ 45%	-	117
23	4 stroke Diesel engine, constant engine speed: 800 rpm	Palm oil mathyl ester	B100	↑ 22.13%	↓ 86.89%	↓ 14.29%	↓ 67.65%	77
24	DI CI diesel engine at constant engine speed and fixed load	Palm, jatopha and diesel oil	D90 JB5 PB5	↑ 5.3%	↓ 7.1%	-	-	36
			D80 JB10 PB10	↑ 9.2%	↓ 17.7%	-	-	
			D70 JB15 PB15	-	↓ 14.5%	-	-	
25	Compression ignition engine, rated engine speed : 1500 rpm	Neem oil	B10	↓ 21.875%	↓ 26%	↓ 17%	↑ 12%	37

			B20	↓ 8.375%	↓ 22%	↓ 10%	↑ 21%	
			B30	↓ 18.875%	↓ 5%	↓ 9%	↑ 21%	
26	Light-duty diesel engine, constant rated speed : 1500rpm	Jatropha	B5	↑ 1.02%	-	↓ 26.5%	↓ 4.54%	25
			B10	↑ 2.06%	-	↓ 27.6%	↓ 14.1%	
			B20	↑ 4.74%	-	↓ 3.9%	↓ 24.9%	
			B50	↑ 5.71%	-	↓ 46.7%	↓ 54%	
			B100	↑ 13.9%	↓17.6 % - 2.38% at low	-	↓ 80.5%	
27	4 stroke diesel engine with varying load, additive: HHO gas	Karanja	B10	↑ 5.43%	-	↓ 12.25%-24.54% from	-	41
			B20	↑ 13.7%	-	↓ 16.47%-30.71% from	-	
28	Common rail direct injection engine	Waste animal fat	B30	56-313 ppm	↓ 32%	-	-	
29	EGR coupled with semi adiabatic diesel engine, rated engine speed : 1800 rpm	DEE blended Rubber seed oil	B100	↓ 19.5%	-	-	↓ 48.5%	45
30	Diesel engine, constant rated engine speed: 1500 rpm	Palm	B100	↓ 3.3%	↓ 8.8%	↓ 2.2%	-	69
31	4 stroke diesel engine with exhaust gas recirculation (EGR)	Calophyllum Inophyllum oil	B20	↑ 63 ppm	↓ 23%	↓ 12%	↓ 16.23% smoke	59
32	Compression ignition engine, Rated engine speed : 2900 rpm	Kusum	B100	1887 ppm	0.14%	60 ppm	↓27.3% smoke	27
		Bitter Groundnut	B100	1923 ppm	0.13%	55 ppm	↓ 25.9% smoke	
		Oleander	B100	1750 ppm	0.15%	70 ppm	↓ 28.2% smoke	
33	6-cylinder, 4 stroke, turbocharged, DI, CI engine. Constant load :600Nm, constant speed:1800 rpm	Waste cooking oil	B20	↑ slightly	↓ slightly	10ppm at 4.6 kW	-	102
34	6-cylinder, 4stroke, WC, DI, CI engine, constant engine speed: 1800 rpm.	Waste fry oil	B10	↓ 1.68%	-	↑ 33.28%	↑ 78.84% smoke opacity	103