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# A Comprehensive Review on Influence of Biodiesel and Additives on Performance and Emission of Diesel Engine

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The depleting natural energy resources and emissions from diesel engine caused by petroleum fuels attract a need for alternative fuels such as biodiesel which will be renewable and demotes the emission. Biodiesels are world's future energy needs which expected to deflate the dependence on imported petroleum and revitalize the economy by increasing demand and prices for agricultural products. The recent research has been made in biofuels to extract biodiesel from vegetable oil and animal oil at an economical cost. In this present review, the need of biodiesel in present scenario and the influence of biodiesel and additives from different feedstock based on properties, combustion, performance, and emission characteristics fuelled in CI engine under different operating conditions are illustrated. It is reported that the oxygenating properties of biodiesel increase brake specific fuel consumption (BSFC) and consequently brake thermal efficiency (BTE) and considerably reduce hydrocarbons (HC), carbon monoxide (CO) emission. In biodiesel blends, BSFC increases with a decrease in BTE. Biodiesel shows slightly subservient performance than diesel. However, biodiesels are endowed with some disadvantages like lower calorific value, cold flow problems and higher density. To overcome these problems different additives are blended in biodiesels. It enhances the properties of biodiesels, improves the diesel engine performance, reduces the emissions and ultimately suits international fuel and emission standards. It is reported that all emissions except oxide of nitrogen ($NO_x$) are reduced with the addition of additives. This paper proposes certain biodiesel fuels with additives to replace petroleum fuels in comparison of performance and emission.

## 1. Introduction

The diesel engines are widely used in industries and transportation sectors. The subsequent augmentation in industrialization and an escalating graph of transportation biased increase in demand for diesel. Hence, diesel has owned its concern in every country's industrial economy. Since 1885 many fuels were tried but diesel finds felicitous one for ignition. However widespread use of diesel criticizes fossil fuel depletion and global warming with increased unbalanced demand. The petroleum products have a bad impact on the environment too; they degrade the air quality through exhaust gas emissions, which leads to the alternative fuel for diesel (Sinha et al., 2008). Rudolph Diesel had used peanut oil as the engine fuel for its demonstration at the 1900 world exhibition in Paris and said, "The use of biodiesels may seem insignificant today, such oils may become, in course of time, as important as petroleum products of the present time".
Biofuel is solely agriculture product, which helps in reducing smoke and particulate matter from engines, besides it will boost farming, agriculture-based industries (Tuccar et al., 2014). Among the biofuels a biodiesel; a vegetable or animal oil fats-based fuel is mostly suitable for diesel engines due to their high cetane number. Vegetable oils cannot be used in diesel engine directly because oils are heavily viscous, denser, having low heating value. The prolonged usage of vegetable oils may indicate coking and trumpet formation on the injector which increases carbon deposits, gelling of lubricating oils and oil ring sticking. Different techniques have been established to avoid these troubles of vegetable oils such as transesterification process, preheating oils, blending or dilution with other fuels and thermal cracking/pyrolysis (Alcantara et al., 2000). The different biodiesels and additives have been tried by the researchers to investigate the performance and emission of a diesel engine. The paper presents the comprehensive review of these researchers. The transesterification is a

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most appropriate process to produce biodiesel from vegetable oil (Rodriguez et al., 2017). Once the biodiesel is prepared by standard transesterification process, the additives are added according to requirement and nature of oil to enhance properties of biodiesel (Alarcon et al., 2017). The additives selected may be antioxidant, cold flow properties improver, lubricity improver, and cetane number improver etc. Biodiesel cannot be used directly in the engine they are blended with diesel in different percentage.

## 2. Biodiesel properties

Biodiesel can be differentiated by properties like density, calorific value, viscosity, cloud, pour and flash point. Density is significant property which impacts on fuel mass flow rate. The penetration of fuel in combustion chamber and atomization of fuel is depends upon the density and it kept as low as possible. The Neem oil methyl ester has the lowest density of 810 kg/m$^3$ (Khandelwal et al., 2015). The cloud point of fuel should be low because it affects the fuel volatility, fuel flow and its usability in cold region. Jatropha oil methyl ester reported lowest cloud point of 3 ℃. Fuel having lower pour point limits the use in the cold region. Palm oil methyl ester has a high pour point of 11 ℃ and rice bran oil methyl ester reported lowest of -2 ℃. Normally, flash point of biodiesel is 2 to 3 times of diesel. Jatropha oil methyl ester shows highest of 184.5 ℃ flash point (Rashed et al., 2016). The biodiesel have a higher viscosity than diesel. Karanja oil methyl ester reports higher viscosity of 5.6 cSt and cottonseed oil reports the lowest viscosity of 4.2 cSt. Table 1 shows the comparative analysis of properties of different biodiesels. The calorific value of fuel has its own importance on combustion; it impacts on thermal efficiency, fuel consumption, and exhaust emissions. Biodiesel shows the tendency of lower heating value. Rice bran has 42.2 MJ/kg of calorific value which is nearest to diesel (Sinha et al., 2008).

*Table 1: Comparative analysis of properties of different biodiesels (@ Viscosity measured at 40 ℃)*

| Property | Density (kg/m$^3$) | Viscosity @ (cSt) | Calorific value (MJ/kg) | Flash point (℃) | Cloud point (℃) | Cetane Number | Pour point (℃) | Carbon residue (% by weight) | Source |
|---|---|---|---|---|---|---|---|---|---|
| Cottonseed oil methyl ester | 874 | 4.2 | 40.6 | 142 | 4 | 51.2 | 0 | 0.24 | (Aydin and Bayindir, 2010, Rakopoulos, 2013) |
| Palm oil methyl ester | 859.9 | 4.63 | 40.91 | 182.5 | 10 | 59 | 11 | 0.02 | (Nagaraja et al., 2015, Rashed et al., 2016) |
| Rice bran oil methyl ester | 877 | 5.29 | 42.2 | 183 | 9 | 63.8 | - 2 | 0.35 | (Ashok et al., 2013, Subbaiah and Gopal, 2011) |
| Rapeseed oil methyl ester | 882 | 4.83 | 37.2 | 178.5 | - 4.1 | 53 | - 10 | 0.25 | (Hazar et al., 2010, Labecki et al., 2012) |
| Jatropha oil methyl ester | 865.7 | 4.73 | 39.83 | 184.5 | 4 | 51 | 3 | 0.3 | (Sivaganesan et al., 2017, Singh et al., 2012) |
| Karanja oil methyl ester | 890 | 5.6 | 36.6 | 168 | 8 | 52.5 | 6 | 0.05 | (Rath et al., 2011, Khandelwal et al., 2015) |
| Soya oil methyl ester | 876 | 4.25 | 36.22 | 160 | 1 | 51.3 | - | 0.25 | (Mohammed et al., 2014, Hira and Das 2016) |
| Neem oil methyl ester | 910 | 4.9 | 39.4 | 250 | 11 | 46 | -7 | - | (Khandelwal et al., 2015, Sivalakshmi et al., 2012) |

## 3. Performance and emission of biodiesel

The researchers have investigated the significant effect of blending of biodiesel with different proportion on performance and emission of CI engine at various operating conditions. Aydin and Bayindir (2010) have shown that the use of the lower blends (B5) of cottonseed oil slightly increases the engine torque at medium and higher speeds in CI engine. The BSFC of B20 was observed lower than other blends including diesel fuel; it is due to oxygen content and higher cetane number, which leads to complete combustion. Nagaraja et al. (2015) observed that BTE of palm oil biodiesel at 20 % blends is higher than diesel fuel. The oxygen contain in palm oil is higher so it promises clean burning but it shows high BSFC and low BTE as compared to neat diesel. Sivalakshmi and Balusamy (2012) observed the neem oil ester decrease heat release by 4 to 8% which ultimately reduces BTE by 5% and increases BSFC by 11 to 13%. Mohammed et al., (2014) have reported that soya methyl ester has 12.4% less heating value than neat diesel, which decreases BTE by 2.5 to 5% and increases BSFC by 4 to 8%. Figure 1a shows a comparative analysis of performance characteristics of different B20 biodiesel blends for BTE and BSFC (Rath et al., 2011, Singh et al., 2012, Ashok et al., 2013, Naik and Balakrishna, 2017, Nayak et al., 2017).

Incessant use of diesel engine for power generation increases the emission at a higher rate, which pollutes the surrounding air. Aydin and Bayindir (2010) have observed the decrease in emissions with the increase in cottonseed biodiesel blends. The B100 blend had no $SO_2$ emission. Nagaraja et al., (2015) observed the palm oil biodiesel has lower HC and CO emissions and higher $NO_x$ emissions than neat diesel. Ashok et al., (2013) found a reduction in HC from 55 ppm to 44 ppm at maximum power for rice bran biodiesel. The oxygenating property enhances combustion leads to increase in $NO_x$ emission. It can be safely blended up to 20% with diesel for satisfactory engine performance and minimum exhaust emissions. Labecki et al., (2012) suggested that by using rapeseed oil HC and CO emissions are reduced but $NO_x$ emission shows increasing trend. After 150 hours it starts to affect lubricating oil which ages faster than neat diesel. Rath et al., (2015) observed 0.45% reduction in $CO_2$ for karanja biodiesel and also observed a significant reduction in smoke density from 50% to 38%. Mohammed et al. (2014) reported a reduction in CO emission by 11 to 41 % and increase in $NO_x$ by 7.5% for soya methyl ester shown in Figure 1b (Labecki et al., 2012, Rakopoulos, 2013; Nagaraja et al., 2015, Hira and Das 2016, Kumar et al., 2017, Naik and Balakrishna, 2017). The reduction in unburnt hydrocarbons was 15 to 38%. Due to lower carbon to hydrogen ratio (C/H) the smoke capacity gets reduced by 20 to 40%. Sivalakshmi and Balusamy (2012) have reported the reduction in CO, HC and $NO_x$ emission by 16%, 15% and 3% than neat diesel respectively for neem oil ester.

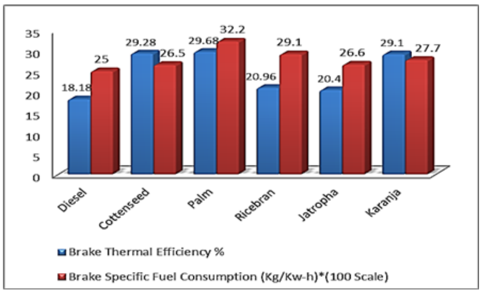


Figure 1a: Comparison of performance characteristics of different B20 biodiesel blends

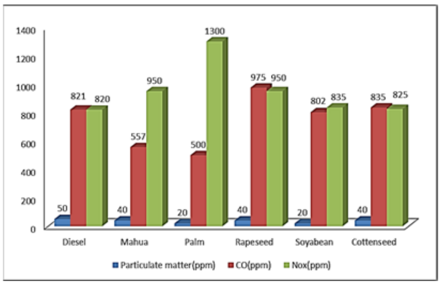


Figure 1b: Comparison of emission characteristics different biodiesel with their B20 blends

## 4. Properties of biodiesel blended with additives

The certain types of additives need to be blended in biodiesels to meet the international fuel standards. Additives are blended in certain proportion considering the nature of feedstock oil and properties like flash point, fire point, viscosity, density, calorific value and solubility etc. (Najafi 2018). The flame propagation speed of methanol is high since it is an oxygenating additive which increases the rate of the combustion process. It contains high latent heat and high-octane number. The properties such as kinematic viscosity, density, calorific value, cetane number and flashpoint of different additives are represented in Table 2.

*Table 2: Properties of different biodiesel additives*

| Additives | Kinematic viscosity at 40ºC (cSt) | Density (kg/m$^3$) | Calorific value (MJ/kg) | Cetane number | Flashpoint (ºC) | Source |
|---|---|---|---|---|---|---|
| Methanol | 1.04 | 796.6 | 23.80 | 4 | 12 | (Dinesha et al., 2015) |
| n-butanol | 3.6 | 810 | 33.10 | 25 | 36 | (Rakopoulos et al., 2014) |
| Ethanol | 1.4 | 790 | 26.95 | 8 | 13 | (Madiwale et al., 2017, Sivalakshmi et al., 2012) |
| Diethyl ether | 0.23 | 713 | 33.90 | ≥125 | - 40 | (Rakopoulos et al., 2014,) |
| Propanol | 2.41 | 803 | 29.82 | 12 | 53 | (Yilmaz et al., 2016) |
| Pentanol | 2.89 | 815 | 34.94 | 20 | 91 | (Yilmaz et al., 2016) |

The additive n- butanol is having a less hydrophilic tendency, higher calorific value and high cetane number closer to conventional diesel fuel. It is highly miscible with diesel than ethanol. By using n-butanol the soot formation can be reduced significantly. It also has a higher percentage of $O_2$ which improves combustion. Ethyl alcohol or ethanol is neutral fuel (pH is 7) which contains 34 % more oxygen than conventional fuel. A small addition of ethanol shows an increase in BTE (Mofijur et al., 2016). Diethyl ether is also an oxygenating compound which shows lower auto-ignition temperature (Imtenan et al., 2014). Due to high flammability, it improves the calorific value of biodiesels and considerably reduces the engine emission.

The researchers have blended different additives in biodiesel to enhance engine performance and to meet emission control standards. Table 3 shows fuel additives and fuel properties of the different feedstock of biodiesel. Madiwale et al. (2017) observed the reduction in viscosity of cottonseed oil up to 2.8 to 2.6 cSt with the addition of 5 % of ethanol. The cloud point was reduced up to -22 to -24 ℃, with the appearance of wax. Besides, it lowers the calorific value by 3460 kJ/kg and flash point from 30 to 14 ℃. The use of ethanol also reduces the density by 6 to 8 kg/m$^3$. Malarmannan et al. (2016) have investigated the drop in kinematic viscosity and density and increase in cetane number from 45.9 to 49.8 with the addition of 5 % of diethyl ether (DEE) in cottonseed oil. It indicates enhanced combustion quality without change in calorific value.

*Table 3: Fuel additives and fuel properties of the different feedstock of biodiesel (@ measured at 40 ºC)*

| Feedstock of biodiesel | % of additives | Density (kg/m$^3$) | Viscosity $^@$ (cSt) | Flash point (ºC) | Calorific value (MJ/kg) | Cetane number | Source |
|---|---|---|---|---|---|---|---|
| Cottonseed oil (B20) | 5 % of ethanol | 842.9 | 2.6 | 14 | 39.76 | - | (Madiwale et al., 2017) |
| Cottonseed oil (B40) | 5 % of ethanol | 850.6 | 2.8 | 16 | 38.17 | - | (Madiwale et al., 2017) |
| Cottonseed oil (B10) | 5 % of DEE | 836 | 2.60 | - | 43 | 49.8 | (Rakopoulos 2013) |
| Cottonseed oil (B10) | 10 % of DEE | 830 | 2.5 | -. | 42 | 53.8 | (Malarmannan et al., 2016) |
| Cottonseed oil (B20) | 5 % of DEE | 840 | 2.8 | - | 43 | 50.70 | (Malarmannan et al., 2016) |
| Palm oil (B20) | 5 % of n- butanol | 833 | 3.39 | 85.5 | 43.43 | 47 | (Imtenan et al. 2014) |
| Palm oil (B20) | 2 % of methanol | 837 | 2.31 | 13 | 40.21 | - | (Vedaraman et al., 2011) |
| Cardanol oil (B20) | 10 % of methanol | 826 | 4.09 | 55 | 42.06 | - | (Dinesha et al., 2015) |
| Castor (B10) | 20 %Ethanol | 875 | 2.35 | 11 | 39.0 | 44.6 | (Singh and Shukla 2016) |
| Rice Bran oil | 5 % Ethanol | 780 | 1.35 | 22 | - | 10 | (Subbaiah and Gopal 2011) |
| Neem oil | 5 % Ethanol | | 4.2 | 153 | 40.4 | 49 | (Sivalakshmi et al., 2012) |
| Jatropha | 1 % Propylene glycol | 871 | 4.10 | 83 | 37.4 | - | (Prabu et al. 2014) |

## 5. Performances and emission of biodiesel blended with additives

A small percentage of addition of additives may have a huge impact on combustion properties of diesel. Madiwale et al., (2017) investigated that 5% addition of ethanol in B20 cottonseed oil increases the BTE by 7 to 12% but slightly drops brake power due to the lower calorific value of blend. The air consumption was increased by 60 to 70 % and the $NO_X$ emission was reduced than neat diesel. The CO emissions were higher than diesel but less than B20 blend. Malarmannan et al., (2016) investigated the performance and emission of cottonseed oil biodiesel with DEE; the BTE improves with increasing blending ratio with 5% constant DEE addition. Due to the low heating value of cottonseed oil, the BSFC increases. It is also reported that the $CO_2$ emission increase with an increase in load due to high oxygen content. The CO emission shows increasing behavior as blending ratio and DEE level increases due to the higher latent heat of vaporization. Imtenan et al., (2014) framed effect of different additives like ethanol, n-butanol, and DEE with palm and jatropha biodiesels on performance and emission of diesel engine shown in Figure 2a and 2b respectively.

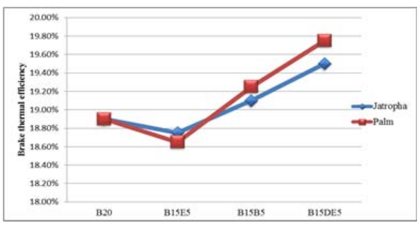


*Figure 2a: Brake Thermal Efficiency (%) at 2000 rpm of Jatropha and Palm blends with Ethanol, n-butanol, and DEE additives*

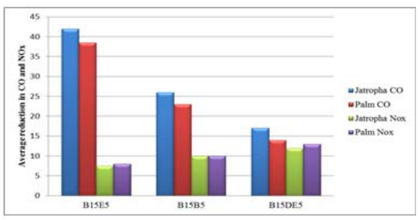


*Figure 2b: Average Reduction (%) in CO and $NO_x$ at B15 blends of Jatropha and Palm oil with Ethanol, n- butanol and DEE additive*

Dinesha et al., (2015) have found the highest BTE at 75 % load when the engine is fuelled with cardanol and methanol. Brake specific energy consumption (BSEC) shows decreasing trend with load, which reduced by 8.3%. The emissions such as CO, HC, SO and $NO_X$ were reduced by 8%, 2.1%, 1.89% and 23.2%

respectively. Prabu et al., (2014) observed improvement in BSEC and BTE due to the enrichment of oxygen molecule by addition of ethylene glycol and propylene glycol oxygenates in jatropha biodiesel and shows a diminution of smoke capacity (43.5%) as compared with neat diesel (39.5 %). Yilmaz et al., (2016) tested propanol, n-butanol, and 1-pentanol additives (10 %) in waste oil methyl ester, which shows 5.08 %, 6.7%, and 2.9% less CO emission and $NO_x$ emission was 27.58%, 31.14%, and 4.12% lower than diesel respectively. Prabu et al., (2014) blended propylene glycol and 2-butoxyethanol additives with biodiesel and found a dominant emission reduction in CO and smoke capacity and increase $NO_x$ emission. Also, increase in BTE was observed with slight increase in unburned HC emission.

## 6. Conclusion

The study framed the effect of biodiesels and additives on the engine performance, combustion, and emission. The renewable and oxygenated biodiesel produced from vegetable oil by transesterification is most suitable alternative fuel for petroleum-based diesel. The transesterification process is the best method to reduce the production cost of biodiesel. The transesterification reaction is mainly influenced by the reaction condition, catalyst used, and type of feedstock oil. The different researchers have shown the positive results of engine performance and emission characteristics when fuelled with the biodiesel blends such as cottonseed oil, rice bran oil, palm oil, rapeseed oil, jatropha oil and soybean oil, compared with diesel. Biodiesel blends shows the slightly inferior performance of CO, HC emissions as compared with diesel. $NO_x$ emission for the biodiesel blends is higher than diesel. The increase in specific fuel consumption and a decrease in BTE are due to lower calorific value and higher density of biodiesel compared with diesel.

Additives are blended with diesel to meet the international biodiesel standard specifications. The use of additives showed improvement in engine performance and reduction in BSFC. All the emissions except NOx can be reduced by addition of additives such as methanol, ethanol pentanol, n-butanol, propanol etc. The biodiesels with additives are promising an alternative to petroleum fuels. The broad research on the use of biodiesel and additives in multi-cylinder diesel engine with economical cost needs to be conducted to blend the biodiesel as an alternative fuel in a diesel engine without engine modification.

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