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Mini Review Article

A review on combustion, performance, and emission characteristics of fuels derived from oil seed crops (biodiesels)

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Abstract

The present work is a literature review on combustion, performance, and emission characteristics of biodiesel fuels derived from different origins. Substitute for fossil fuels with renewable biofuels has been set as a target across world to reduce greenhouse effect and energy dependence as well as to improve rural economy. Biodiesel can be considered as one of the potential renewable energy sources for diesel engines. Biodiesel can be used directly or in blended form of diesel. In the present review, the results of combustion, performance, and emission characteristics of biodiesels obtained from different feedstocks which are reported in various research studies are discussed. From the review, it is observed that the combustion characteristics of biodiesel are almost similar to that of diesel. Biodiesel fuels show a slightly inferior performance when compared to diesel. The reported values of oxides of nitrogen emissions from biodiesels were higher as compared to diesel, whereas the carbon monoxide, hydrocarbon, and smoke emissions of biodiesel fuels are comparable to diesel. From the present review, biodiesel fuels can be recommended as a prospective alternative fuel for conventional petro-diesel fuel.

Keywords: Biodiesel; combustion; emissions; performance.
Abbreviation: CA_crank angle; CO_carbon monoxide; CO_2_carbon dioxide; CP_cloud point; DI_direct injection; FAME_fatty acid methyl esters; HC_hydrocarbons: NO_X_oxides of nitrogen; PP_pour point; PM_ particulate matter; TDC_top dead center.

Introduction

Ever increasing environmental concern, diminishing petroleum reserves and agriculture-based economy are the driving forces to promote biodiesel as an alternate renewable diesel fuel. Emissions from transportation engines are considered to greatly contribute to greenhouse gases (Sarin et al., 2007). Replacement of fossil fuels with renewable biofuels has been set as a target worldwide to reduce greenhouse effect and energy dependence as well as to improve agricultural economy. Renewable biofuel fuel is obtained by catalytic hydro-processing of the triglyceride feedstocks (Kalnes et al., 2007; Mikkonen, 2008). Biodiesels are renewable, biodegradable, and nontoxic fuels with the potential to reduce emissions of carbon dioxide (CO_2) (Perkinns et al., 1991). Also biodiesel combustion results in a decrease in hydrocarbon (HC), carbon monoxide (CO), and particulate emissions as compared to conventional petrodiesel, whereas an increase in oxides of nitrogen (NO_X) from biodiesel combustion compared to diesel has been reported in several researches (Choi and Reitz, 1999; Graboski and McCormick, 1998; Hess et al., 2005; Song et al., 2002). The advantages of biodiesel as fuels are their minimal sulphur and aromatic content, higher flash point, better lubricity, and higher cetane number (Korbitz, 1999; Ralph, 2001; Beer et al., 2002). Biodiesels have good ignition characteristics due to their long chain hydrocarbon structure (Wagner et al., 1984). On the other hand, their disadvantages include higher viscosity, higher pour point, lower calorific value, and poor volatility. The longer hydrocarbon chain of biodiesels can result in higher viscosity (Shu et al., 2007). In addition, oxidative stability and the poor low temperature properties of biodiesel has also been the subject of considerable research. Oxidative stability affects biodiesel primarily during extended storage. Biodiesels, which contain larger amounts of unsaturated fatty acids exhibit poor oxidative stability On the other hand, poor low temperature properties indicated by relatively high cloud points (CP) and pour points (PP) are higher for saturated fatty compounds compared to unsaturated ones (Knothe and Dunn, 2003; Knothe, 2005). Numerous efforts have already been made to analyse the usage of biodiesel derived from jatropha, mahua, karanja, rubber seed, and rice bran oils in diesel engines (Raheman and Phadatare, 2004; Ramadhas et al., 2005; Senthil et al., 2003; Sinha and Agarwal, 2005; Puhan et al., 2005; Saravanan et al., 2007).

Biodiesel combustion, performance, and emission characteristics

Biodiesel structure and transesterification

Biodiesel fuels are gaining more and more importance as an attractive alternative fuel in recent years. They are generally classified as fatty acid methyl esters (FAME), which are derived from transesterification of vegetable oils with methanol, although other alcohols can be used (Allen et al., 1999). Biodiesel is obtained from transesterification process when a vegetable oil is chemically reacted with an alcohol to produce mono alkyl esters i.e. biodiesel (Ejim et al., 2007). Vegetable oils can be considered as a triglyceride which consists of three fatty acids with glycerol molecule. The diagrammatic representation of a triglyceride is shown in Figure 1. Transesterification is a process in which the

Table 1. Fatty acid methyl ester composition of different biodiesel fuels.

Biodiesel	Fatty acid methyl ester composition (wt %)							
	Lauric	Myristic	Palmitic	Stearic	Oleic	Linoleic	Linolenic	Others
Coconut	45.6	22.1	10.2	3.6	8.2	2.7	0	7.6
Cottonseed	0.1	1	20.1	2.6	19.2	55.2	0.6	1.2
Jatropha	0	0.1	15.6	10.5	42.1	30.9	0.2	0.6
Karanja	0	0.1	9.9	7.8	53.2	19.1	0	9.9
Mahua	0	0.2	20.8	25.2	36.4	15.8	0.3	1.3
Neem	0.8	0.5	18.2	20.1	41.3	16.4	0.3	2.4
Palm	0.2	0.8	39.5	5.1	43.1	10.4	0.1	0.8
Rapeseed	0	1	3.5	0.9	64.1	22.5	8	0
Rubber seed	0	0.2	12.5	8.3	27.8	37.7	13.4	0.1
Soybean	0.1	0.1	10.2	3.7	22.8	53.7	8.6	0.8
Sunflower	0.2	0.8	38.6	4.6	44	10.7	0.1	1

Note: The table values adapted from Gopinath et al. (2009)

reaction between triglyceride and alcohol occurs to produce alkyl ester and glycerol. Alkali (potassium hydroxide or sodium hydroxide) or acids (hydrochloric acid or sulphuric acid) are used to catalyze reaction (Agarwal, 2007; Hass, 2005). Alkali catalyzed transesterification is faster than acid catalyzed transesterification and is most used commercially (Puhan et al., 2005). The primary objective of the transesterification process is to reduce the viscosity of vegetable oil. The simple diagrammatic representation of a transesterification process is given in Figure 2. The reported values of fatty acid methyl ester composition of various biodiesels are listed in Table 1 (Gopinath et al., 2009).

Combustion characteristics

A number of researchers have experimentally investigated the combustion, performance, and emission characteristics of vegetable oils and their esters in diesel engines. Kinoshita et al., (2003) have investigated the combustion and emission characteristics of palm and rapeseed oil methyl esters and compared with gas oil in naturally aspirated water-cooled small direct injection (DI) diesel engine and swirl-chamber diesel engine. They found that the ignition delay of palm oil methyl ester was found to be lower when compared to gas oil. Similarly rapeseed methyl ester showed a longer ignition delay as compared to gas oil. The authors have also reported that the distillation temperatures of palm oil methyl ester at 5 to 90% recovery are lower than rapeseed oil methyl ester and stated that the former has a better volatility as compared to the later. Soybean oil methyl ester and its blends were analysed in a four cylinder DI diesel engine (Zhang and Van Gerpen, 1996). It was found that the blends exhibit a shorter ignition delay and similar combustion characteristics as compared to diesel. Senatore et al., (2000) have tested a DI turbocharged diesel engine with rapeseed oil methyl ester and found that heat release always takes place in advance with respect to TDC (between 3 and 5 deg. CA) compared to diesel fuel. It was stated that the mean combustion temperature attained peak value at the same crank angle. From the combustion study on blend of diesel and methyl tallowate, it was found that the peak rate of heat release for blend had found to be lower than the petrodiesel (Yu et al., 2002). Sinha and Agarwal (2005) have investigated and stated that the peak pressure and rate of pressure rise are higher for B20 fuel (blend of 80% diesel and 20% rice bran biodiesel by volume) at low engine loads (up to 10% load) but becomes lower when the engine load is increased. Pradeep and Sharma (2005) have investigated the use of blends of rubberseed biodiesel and diesel in a single cylinder-four stroke-water cooled-DI diesel engine. The cylinder pressure data obtained at full load condition indicated slightly higher values for B20, and B60 compared to diesel. However, peak pressure of B100 was comparable with diesel. The authors have stated that the higher peak pressures are probably due to dynamic injection advance, which can also vary for various blends due to changes in their properties. As unsaturated composition in biodiesel increases, the density and bulk modulus also increases which in turn advance the injection timing (Tat and Van Gerpen, 2003). Szybist et al., (2007) have reported that the injection and ignition process can be altered significantly by biodiesels and their blends. An increase in the ignition delay period and combustion duration with both jatropha oil and its esters with lower heat release rates were noticed compared to diesel fuel (Forson et al., 2004).

Performance and emission characteristics

Klopfenstein and Walker (1983) have tested a single cylinder DI diesel engine with saturated methyl esters from carbon number 12 to 18 and unsaturated esters of carbon number 18. The authors observed the following; among the saturated series, the heat of combustion per kg increased with chain length, reflecting their higher proportion of reduced carbon. For the same reason, esters of unsaturated acids had somewhat lower heats of combustion than the corresponding saturates. For the series of saturated esters, the volumetric fuel consumption is seen to increase with chain length. This might be expected in view of the inverse relationship, which exists between density and chain length for the fatty acid esters at near room temperature. Similarly the decreased volumetric consumption observed for methyl oleate and linoleate are partially accounted for the increase in density with increased unsaturation. Although the energy content of the esters increases with chain length, the increased specific fuel consumption with increasing chain length produces a marked linear decrease in thermal efficiency. Bettis et al., (1982) have investigated the use of safflower, rapeseed, and sunflower as fuels and found that engine power output to be equivalent to that of diesel fuel. Reductions in engine torque and power output were found with biodiesels containing 10 to 12% oxygen on weight basis due to their lower heating values (Altin et al., 2001; Antolin et al., 2002; Bari et al., 1982; Nwafor et al., 2000). Some investigators have reported that slight increase in engine power than diesel fuel was found with biodiesels and the increase may be attributed to the complete combustion with the fuel borne oxygen in the case of biodiesel fuels (Agarwal and Das, 2001; Kalam et al., 2003). The power output for palm oil and diesel blend was similar to that of diesel (Nwafor and Rice, 1996). Blends of jatropha oil and diesel, produces higher thermal efficiency without affecting NO_X emissions (Kalligeros et al., 2003). Higher exhaust temperatures were found with biodiesel as compared to conventional diesel fuel (Edwin Geo et al.,

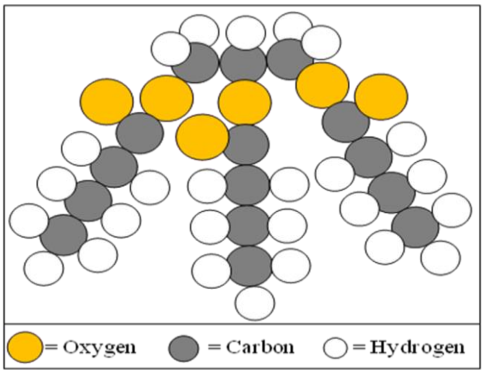

Fig 1. Diagrammatic representation of a triglyceride that consists of three fatty acids with glycerol molecule. (Adapted from: http://justindunham.net/wp-content/uploads/2010/06/triglyceride.jpg)

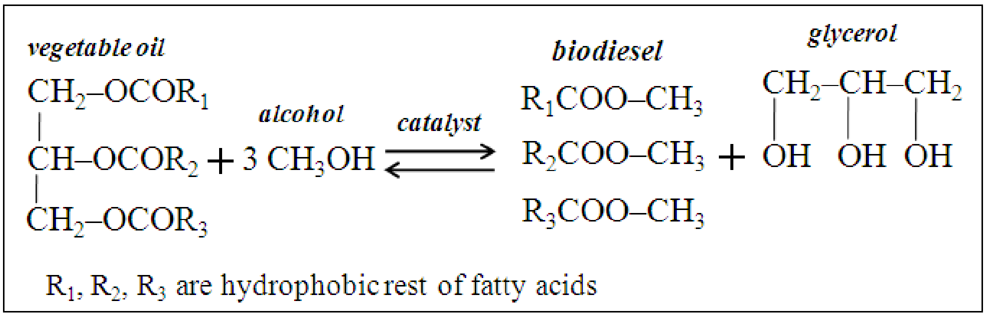

Fig 2. Diagrammatic representation of a typical transesterification process shows the reaction between vegetable oil and alcohol through catalyst to produce biodiesel and glycerol as by product.
(Adapted from: http://kfch.upce.cz/images/Ved_cin/bionafta_reakce1_EN.gif)

2008; Nwafor, 2004; Ramadhas et al., 2005; Senthil et al., 2003). Biodiesel exhibits lower thermal efficiency due to lower heating value compared to diesel fuel (Canakci and Van Gerpen, 2003; Rantanen et al., 1993). Graboski et al., (2003) have conducted experiments in diesel engine using methyl ester of soybean soapstock and found that 20% addition of biodiesel decreased particulate matters (PM) emission by 30% and increased NO_X by 2.8% as compared to diesel. Biodiesel containing higher methyl oleic ester produced significantly lower NO_X (Yamane et al., 2001). The NO_X, CO, and smoke emissions were slightly lower for soybean ester as compared to diesel, whereas a reduction of about 50% in HC emission was found with soybean ester as compared to diesel (Scholl and Sorenson, 1993). The complete combustion due to fuel borne oxygen in biodiesel reduces CO, HC, and smoke emissions (Chang and Van Gerpen, 1997; Ergeneman et al., 1997; Kalam et al., 2003; Kalligeroset al., 2003; Monyem et al., 2001; Ozaktas et al., 1997). The NO_X, CO, and CO_2 emissions decreased by 32%, 59%, and 8.6% respectively with the olive oil methyl ester as compared to diesel (Dorado et al., 2003). When compared to diesel, HC and CO had decreased; while NO_X emission increased for methyl ester of rapeseed and its blends with diesel (Labeckas and Slavinskas, 2006).

Conclusions

From the present review, it is observed that the combustion characteristics of biodiesel are almost similar to that of diesel. However, biodiesel fuels show a slightly inferior performance when compared to diesel. Biodiesel exhibits higher oxides of nitrogen as compared to diesel, whereas the carbon monoxide, hydrocarbon, and smoke emissions are comparable to diesel fuel. Most of the research studies reviewed in the present review is based on short term engine tests in which the biodiesel fuels seem to be very promising. Hence review of long term issues such as engine deposits, injector coking, and contamination of the engine due to the usage of biodiesel fuels are necessary.

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