Performance and Emission Characteristics of Biodiesel Fuelled Diesel Engines

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Received: 09.12.2014 Accepted: 05.02.2015

Abstract- Rapid industrialisation and growth in population has resulted in the rapid increase in energy demand. Indiscriminate use of fossil fuels has led to extinction of petroleum sources. Pollutant emissions from diesel engines has caused major impacts in disturbing the ecological system. To overcome these problems, focus is towards alternative sources. Biodiesel, derived from vegetable oils, animal fats and algae is the future prospect. The paper reviews the research on impact of biodiesel on performance and emission characteristics of diesel engine. Higher viscosity is found as the major problem in use of vegetable oil directly in engine that is removed by converting it into biodiesel by transesterification reaction. Fuel properties like calorific value, flash point and cetane value of biodiesel and biodiesel–diesel blends were found comparable petroleum diesel. Performance results reveal that most of the biodiesel, give higher brake thermal efficiency and lower brake-specific fuel consumption. Emission results showed that in most cases, NOx is increased, and HC, CO, and PM emissions are decreased. B_{20} blend of biodiesel with diesel was found the best suitable blend for engine. Biodiesel is an appropriate inherent source for alternative fuel, with environmental benefits.

Keywords—Biodiesel, Transesterification, BSFC, BTE, Emission, Vegetable Oils.

1. Introduction

Almost all countries are dependent on petroleum fuel to fulfil their energy requirements. Increase in energy demand due to growth in population has affected the underground fossil fuel resources. In order to counter this problem, researchers are looking for alternative sources of energy. Biodiesel is one of the potential alternatives to petroleum diesel, as its properties are very comparable to diesel. Moreover, biodiesel is mainly derived from renewable feedstocks like edible, non-edible oils or animal fats [1]. In recent decade, the main focus it to prepare biodiesel from edible oils like cottonseed oil, sunflower oil, coconut oil. Producing biodiesel from edible oils may leave negative effect on agriculture in terms of scarcity of food crops so non-edible oils are preferred for production of biodiesel. The main advantages of using biodiesel are it's portability, being readily availabile, better combustion efficiency, lower sulphur content, higher cetane number, higher biodegradability, domestic origin, higher flash point and improved lubrication property [2,3]. Researchers have found that with use of biodiesel nitrogen oxides (NO_X) emission increases whereas hydrocarbon (HC), carbon monoxide (CO), and particulate matter emissions (PM) decrease in comparison to diesel fuel [4,5]. The present paper, therefore, focuses on the emissions from biodiesel fuelled diesel engine operation.

2. Diesel Engine Emissions

With continuous utility of diesel engines in vehicle operations and power generators, emissions have increased at a higher rate. Pollution of atmospheric air is required to be reduced. Diesel engines emit lower carbon monoxide (CO) and hydrocarbon (HC) emissions but emit higher NOx and particulate matter [6]. Moreover the use of diesel engines with conventional fuels has led to the concern over saving fossil fuels and there is danger of extinction of petroleum in near future. Thereby necessity is to use cleaner fuels to protect environment from harmful gases. Alongside increasingly strict regulations in emission standards, there is still considerable concern that unregulated pollutants have deleterious effect on human health and the environment and the emissions of engine should be checked to ensure the emissions standards. [7].

Table 1. Typical diesel exhaust emissions [8]

	Component	Concentration
Components naturally occurring in air	N_2	70–75 vol%
	O_2	5–15 vol%
	CO_2	2–12 vol%
	H_2O	2–10 vol%
Regulated harmful components	CO	100–10000ppm
	HC	50–500ppm
	NOx	30–600ppm
	SOx	Proportional to fuel S content
	PM	20–200mg/m^3
Unregulated harmful components	Ammonia	1.25 mg/km
	Cyanides	0.625 mg/km
	Benzene	3.75 mg/km
	Toluene	1.25 mg/km
	Aldehydes	0.0 mg/km

Increasing numbers of transportation vehicles is causing an increase in global emissions, with N_2O being the main pollutant from diesel exhaust. Inside the engine, generation of CO_2 and H_2O indicates complete combustion of fuels consisting of hydrocarbons. Incomplete combustion of hydrocarbons may lead to wide range of harmful components as given in table 1 [8]. Table 2 provides emission standards according to Indian (Bharat Stage) standards. Across the country, Bharat stage III norms are being used as standards for emission since October 2010. In addition to this, more strict standars that is Bharat stage IV are being used since April 2010 in 13 major cities of India. As shown in table 2, maximum level of various exhaust emissions is trimmed down in Bharat Stage-IV as compared to Bharat Stage-III which helped in bringing down pollution levels and invariably resulted in inflated vehicle cost due to usage of new echnology & higher fuel prices. However, this increase in cost is compensated by savings in health related costs, because of lesser diseases due to particulate matter and pollution in the air. Human body experiences respiratory and cardiovasuclare ailments when it is exposed to air pollution. It is estimated that there are almost 620,000 deaths in 2010 due to air pollution.

2. Production of Biodiesel

Biodiesel can be obtained from vegetable oils by tranesterification is the process which is favoured due to its simplicity and less time consuming nature. In this process a triglyceride such as vegetable oil is reacted with an alcohol like methanol or ethanol in the presence of an acidic or basic catalyst to produce fatty-acid esters which is called biodiesel and glycerol as a by-product. Among the alcohols, methanol and ethanol are used as these are easily available and are of cheaper cost. Physical and chemical properties like solubility and reactibility with triglycerides are also aid to their uses. Figure 3 shows the transesterification reaction where triglyceride is reacted with alcohol in presence of catalyst. It substitutes the glycerol of the glycerides with three molecules of mono alcohols producing methyl ester of vegetable oil and termed as biodiesel [10,11].

Table 2. Various emission standards in India [9]

Emission Standard	Category	Class	CO (g/km)	HC (g/km)	NOx (g/km)	HC+NOx (g/km)	PM (g/km)
Bharat Stage-III	Gross Vehicle Weight <= 2500 kg		0.64	-	0.50	0.56	0.05
	Gross Vehicle Weight >= 2500 kg	I	0.64		0.50	0.56	0.05
		II	0.80		0.65	0.72	0.07
		III	0.95		0.78	0.86	0.10
Bharat Stage-IV	Gross Vehicle Weight <= 2500 kg		0.50		0.25	0.30	0.025
	Gross Vehicle Weight >= 2500 kg	I	0.50		0.25	0.30	0.025
		II	0.63		0.33	0.39	0.04
		III	0.74		0.39	0.46	0.06

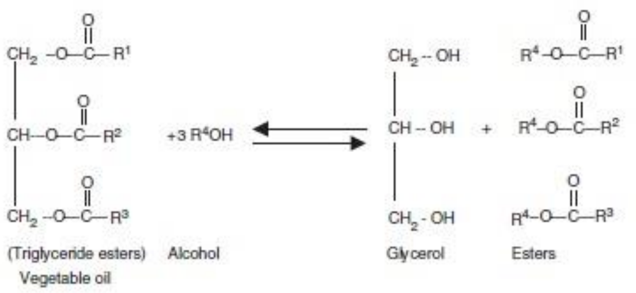

Fig. 1. Schematic of Transesterification reaction [31]

As shown in figure 1, triglyceride is reacted with alcohol, methanol or ethanol in presence of acid or basic catalyst. Selection of catalyst depends upon presence of free fatty acid (FFA) in oil. If FFA is less than 1% then base catalyst is used, otherwise acidic catalyst is used.

3. Results and Discussion

4.1 Performance Characteristics

The following performance characteristics are briefly discussed as below:

4.1.1. Brake Specific Fuel Consumption

For different biodiesel fuels, there is general trend followed by decrease in Brake Specific Fuel Consumption (BSFC) with the increase in engine speed and Brake Power. It indicates a minimised role of fuel oxygen at higher engine speed and hence low Air-Fuel (A/F) ratio allowing residual air borne oxygen to be available at the final stage of combustion [16]. The high fuel consumption is due to low heating values of the biodiesels than diesel fuel. The average BSFC values for B_{100}, B_{50}, B_{20} and B_{10} blends were found as 9%, 7%, 4%, 2% higher than diesel fuel [30].

4.1.2 Brake Thermal Efficiency:

With comparison to petroleum diesel, there is decrease in Brake Thermal Efficiency (BTE) for Waste Edible Oil biodiesel. BTE of used cooking oil biodiesel is found 2.5% lower than that of petroleum diesel at rated load of engine. The overall BTE reductions for 30% blend of Palm Biodiesel (PB_{30}), 30% blend of Coconut Biodiesel (CB_{30}) and 15% blend each of Palm and Coconut Biodiesel ($PB_{15}CB_{15}$) were respectively found to be 5.03%, 3.84%, and 3.97% lower than diesel fuel. The primary cause of lower BTE is higher viscosity, density than diesel [28]. Higher viscosity decreases atomization and fuel vaporization, which results in a more uneven combustion than that of diesel fuel [23]. 20% blend of jatropha and palm biodiesel had improved BTE. The highest BTE is found at 2200 rpm for all the fuels except 20% blend of Palm biodiesel (P20), which produced the maximum BTE at 2000 rpm. Blend of palm biodiesel and Diethyl ether had 4.4% higher BTE than B_{20} blend of palm biodiesel [29]

4.2 Emission Characteristics

The emission characteristics consists of CO, HC, NOx, Smoke opacity. Authors have reported that with use of biodiesel, CO and HC emissions are reduced whereas N_2O emissions increases with increase in biodiesel content. Smoke opacity improves with use of biodiesel as reported where Hartridge Smoke Unit (HSU) was found to be 50.44% less for B100 blend of cotton seed biodiesel as compared to diesel [2] and similar results are found for eucalyptus oil [12]. The emissions of various biofuels are discussed below:

4.2.1 Carbon Monoxide:

CO emission is due to improper combustion of fuel and it mainly depends on many engine temperature, and A/F ratio [13]. Figure 2 explains variation of CO exhaust emissions for various fuels which shows that biodiesel fuelled engine emits less emissions.

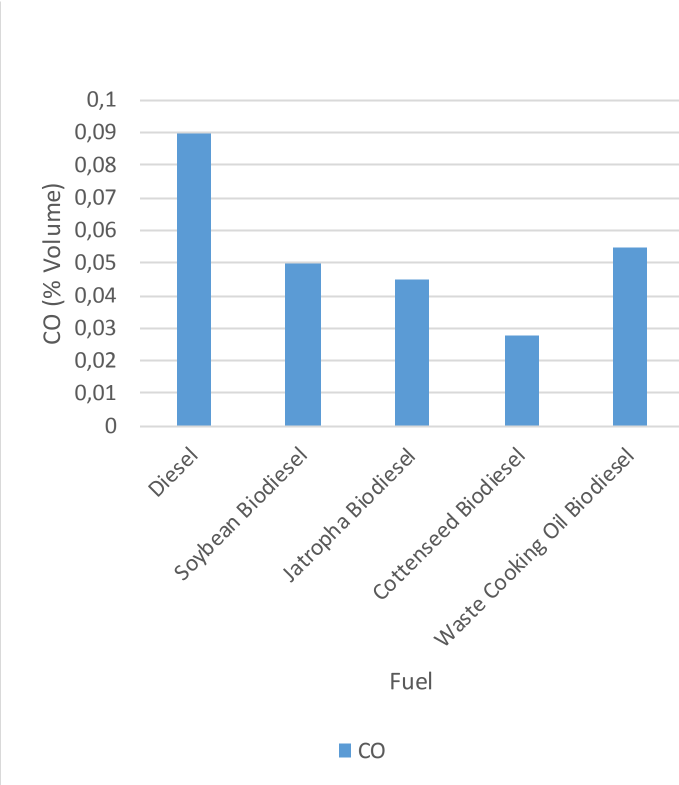

Fig. 2. CO Emissions for various fuels [13,18,19]

With use of biodiesel, reduction in CO emissions is found which may be due to oxygen enriched biodiesel, in which increase in the proportion of oxygen and promotes oxidation of CO during the engine exhaust process [14]. CO emissions from citrus sinensis biodiesel was found as 220 ppm at 1000 rpm and 410 ppm at 2400 rpm for B_{20} compared to diesel same was 550 ppm and 690 ppm respectively [15]. For Cotton seed biodiesel CO emissions were found as 540 ppm and for palm biodiesel about 620 ppm in comparison to 650 ppm from diesel at 1600 rpm [27]. For canola oil biodiesel at 1200 rpm, diesel produces the maximum CO (59.53 g/kW h), which decreases gradually with biodiesel–diesel blends and becomes the lowest (51.24 g/kW h) for B_{20} blend (approximately 14% lower) [17].

4.2.2 HC Emissions

There are two reasons for hydrocarbon emissions:

(1) The leaner fuel mixture than required during combustion in diesel engine [20].

(2) Under-mixing of fuels [20].

Karanja oil based biodiesel was tested on 1 cylinder, four stroke CI engine and reported that there was reduction of 2.85%-12.8% for 20% and 40% biodiesel blends used in diesel engine at Different loads (33.3%, 66.6% and 100%), different blends (20%, 40%, 60% and 80%) and constant speed 1500 rpm. There was 40.1% and 49.6% average reduction in HC emissions with use Cocos nucifera and Jatropha biodiesel respectively. It was due to higher oxygen in fuel than petroleum diesel. With use of antioxidants, emission characteristics improve further [21]. There was 21% reduction of HC for biodiesel obtained fish oil. HC emissions 9.8%, 19.7%, 21.6%, 23.4% and 26.2% for B_{20}, B_{40}, B_{60}, B_{80}, B_{100} are found to decreased. With the increase in the percentage of biodiesel in blends, HC emissions followed a trend of decreasing consequently [22]. The average HC emissions for diesel, PB_{30}, CB_{30}, in the entire engine speed range were 78.50, 64.17, 54.00 ppm respectively. Thus, the average reduction in HC emission was 18.26%, 31.21%, and 25.90% for PB_{30}, CB_{30} respectively and fuel [23]

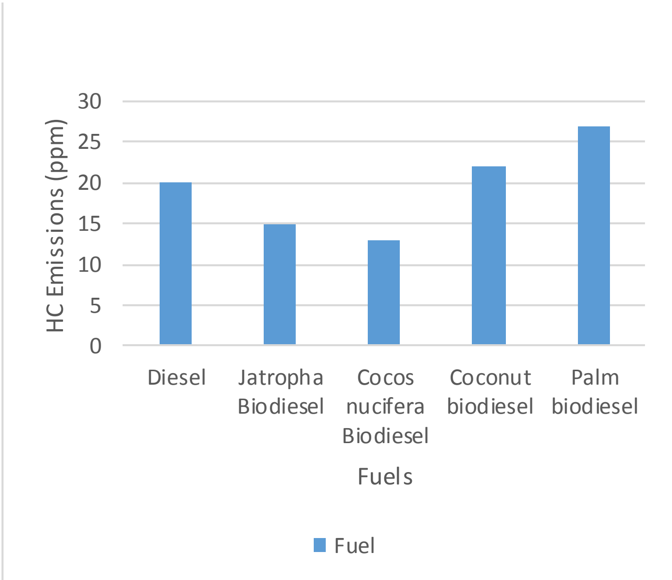

Fig. 3. Variation of HC emission with different fuel sources [20,23]

4.2.3 NOx Emissions

Main factors for NOx are equivalence ratio, oxygen concentration, combustion temperature and time. NOx are produced in cylinder areas where high temperature peaks appeared during the uncontrolled combustion. The NOx from biodiesel are found greater than petroleum diesel at all load conditions. This is mainly due to presence of oxygen and higher cetane number of biodiesel blends. Figure 4 explains variations of NOx emissions for various fuel sources. It is observed that the average NOx for diesel, B_{30} blend of palm biodiesel, B30 blend of coconut biodiesel and dual blend of palm and coconut blend together ($PB_{15}CB_{15}$) were 643.83, 664, 680.33 and 672.16 ppm, respectively. The average NOx emissions for PB_{30}, CB_{30}, and $PB_{15}CB_{15}$ were respectively 3.13, 5.67 and 4.40% higher than that of diesel fuel [22]. Experimental results of Karanja biodiesel reported that NO_x increases with increase in engine load, due to higher combustion temperature. At full load condition, NOx emission were found to be about 2000 ppm whereas same was 2240, 2400, 2650, 2840 and 3100 ppm approximately for KB_5, KB_{10}, KB_{20}, KB_{30} and KB_{100} respectively [24]. NOx were 580 ppm for citrus sinensis biodiesel as compared to 170 ppm when engine was run at 1600 rpm [13].

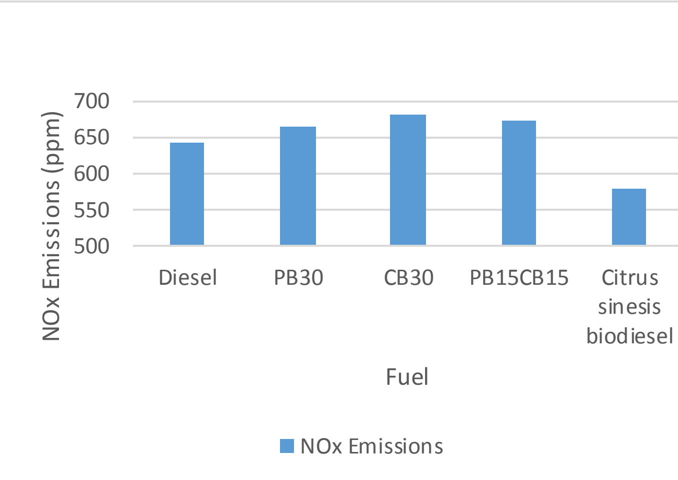

Fig. 4. Variation of NOx with various fuel sources [15,23,24]

There are some contradictory results also where use of biodiesel results in the reduction of NOx emissions. NOx emissions for diesel was about 485 ppm, Waste Frying Oil biodiesel gave approximately 465 ppm when engine was run at 3000 rpm [25]. At idling stage, there is slight reduction in NOx with increase in biodiesel proportion in blends as compared to diesel [26].

5. Conclusion

The review work shows that various feedstocks like edible oils, non-edible oils and algae are available for production of biodiesel. The main problem with direct usage of vegetable oil in engine is the higher oil viscosity which can be removed by preheating or converting it into biodiesel. Fuel properties of biodiesel are comparable to those of petroleum diesel. Analysis of performance parameters like BSFC, BTE shows that as the blend ratio increases, the performance reduces. Emission characteristics show that commendable reduction in HC and CO emissions increases in NOx emissions increase.

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