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Investigations on environmental emissions characteristics of CI engine fuelled with castor biodiesel blends

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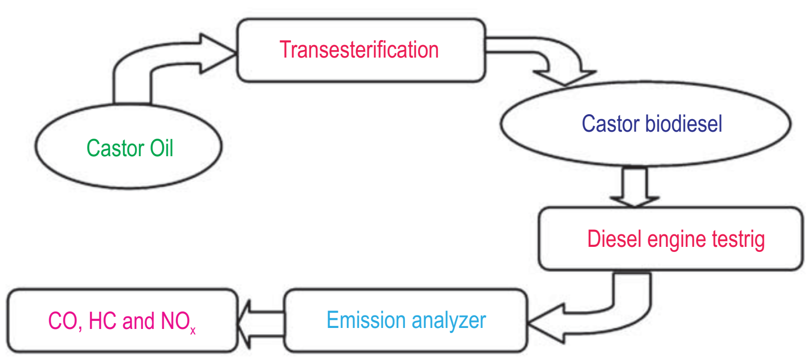
Abstract

Aim : Biodiesel is an attractive fuel option for diesel engines in view of issues related to fossil fuel crisis and environmental degradation. The present study aimed to prepare biodiesel from non-edible grade castor *Ricinus communis* oil and to evaluate the emission characteristics of castor biodiesel fuelled diesel engine at different engine operating loads.

Methodology : The biodiesel was prepared from non-edible grade castor oil by single step alkaline transesterification process at room temperature.The fuel properties like kinematic viscosity, density, calorific value, flash point, pour point, and cloud point were measured as per ASTM D-6751 specifications.The engine used for experimental work is a single cylinder, four stroke, constant speed, direct injection diesel engine. The engine testing was performed at different engine loads (0.9, 1.8 and 2.7 bmep) and at constant speed of 1500 rpm with different tested fuel blends *i.e.* B0, B20, B40 and B60. The emission parameters like nitrogen oxides, hydrocarbons and carbon monoxide were evaluated using flue gas analyzer.

Results : Production yield of 96.5% was obtained using biodiesel synthesis and castor oil based biodiesel was found to possess similar fuel properties when compared to fossil petro-diesel. At full engine load condition of 2.7 bmep, the hydrocarbon emission was lowered by 24.6, 39.6 and 42.1% for B20, B40 and B60 fuels, respectively, and the carbon monoxide emission was reduced by 12.9, 17.1 and 26.2% for tested fuel blends B20, B40 and B60, respectively, when compared to petro-diesel. At 2.7 bmep load condition, the NO_x emissions was higher by 28.2% for B60 fuel when compared to petro-diesel, while, at 0.9 bmep load condition, NO_x emissions increased by 11.8 and 15.1% for B20 and B40 blends, respectively, when compared with petro-diesel.

Interpretation : The non-edible grade of castor oil can be used as a raw material for biodiesel production and its blend with diesel is a suitable fuel candidate for use in diesel engine without modifications, which results in overall low emissions.



Introduction

Increasing uncertainty about global energy production and environmental pollution concerns promote stimulus to explore renewable alternative fuels for IC engines, which would have lesser detrimental influence on the environment. Although some significant step to improve ambient air quality have been taken by regulatory agencies but the situation is alarming in certain cases, which results in serious health implications (Monterio *et al*., 2009; Gui *et al*., 2008). Because of non-renewable nature of fossil fuels and deteriorating air quality, entire world is looking foralternative non-edible oils as a substitute for diesel. Biodiesel has many environmentally beneficial properties. Biodiesel combustion decreases emission of carbon monoxide and unburnt hydrocarbons (Pasupathy Raju *et al*., 2016). Biodiesel has gained attention as an alternative fuel because of its non-toxic, biodegradable and renewable characteristics. Furthermore, cold flow properties, NOx emissions and high costs are certain considerations that have to be vanquished (Young, 2011; Duraisamy *et al*., 2010). In the last few decades, there have been major thrust for use of these alternative environmental friendly fuels for transportation purpose (Ogunniyi, 2006). Although, several research studies have been carried out by using different non-edible sources like Mahua oil, Pongamia oil, Neem oil, Jatropha oil etc., and investigated their effect on engine performance and emission (Scholz *et al*., 2008).

Castor oil, extracted from seeds of *Ricinus communis*, belongs to the family of Euphorbiaceae, can be used as biodiesel feed stock. World's average total production of castor seed has been reported to be around 12.5 lakh tons and is available in more than 30 countries. India ranks among one of the top producers of castor and its derivatives contribute to almost 65% share (Deep *et al*., 2017). Different varieties of castor seeds generally contain on an average of about 46-55% oil by weight (Gunstone, 2004). Due to the presence of ricin, ricine and certain allergens, castor seeds are poisonous to humans and animals (Nangbes *et al*., 2013). It is hard non-drying, viscous, pale yellow and non-volatile oil (Aydin *et al*., 2010). Paradox to other vegetable oils, it is characterized for its indigestibility, high hygroscopicity, high viscosity (226 $m^{-2}s$ at 40 °C) and partial solubility in alcohol. These properties increase the viability of this oil for the industrial production of coating, plastic and cosmetics, but limit its application as a biofuel (Hasimoglu *et al*., 2008).

Literature study indicates limited work on the fuel characterization of castor oil based biodiesel and its utilization with emphasis on environmental implications. Keeping in view of this, utilization of castor oil for biodiesel production and its impact on emission characteristics in a light duty unmodified diesel engine was assessed. The engine behavior with respect to emission characteristics is compared against a fossil petro-diesel. The present study was carried out to evaluate the suitability of higher percentage blend of castor oil based biodiesel-diesel blends on the emission characteristics at different engine loads in order to create a self-sustained source of energy in India.

Materials and Methods

Biodiesel preparation process : Free fatty acid can cause saponification instead of biodiesel production, so it is important to know the free fatty acid content of oil. The free fatty acid of castor oil was found to be less than 1% (Table 1). Single step alkaline based trans-esterification process was employed for preparation of biodiesel from castor oil. The process of optimization was done on the basis of oil to methanol molar ratio, amount of catalyst, reaction temperature and residence time of reaction. As these variables has great influence on the yield of ester produced. The biodiesel reactor unit consists of glass flask, heating oil bath, reflux condenser, stirrer motor mechanism and temperature indicator. Under optimized conditions, a mixture of 130 ml methanol and 2.5 g of NaOH was prepared separately. This mixture was then added to 500ml of castor oil at ambient temperature and quickly stirred for 1 hr without heating. The final product was kept overnight in a separating funnel until two layers were formed, the lower layer of glycerol was removed. After washing with distilled water for 3-4 times, crude biodiesel was stirred and heated at 90˚C to remove moisture traces. After cooling, a light yellow crystal clear biodiesel was formed. The biodiesel yield of 96.5% was obtained under these optimized conditions at room temperature. The test fuel properties were determined in strict compliance with ASTM norms. The various properties of castor oil based biodiesel and diesel fuel are shown in Table 2.

Experimental setup and test procedure : The engine used for the study is a single cylinder, four stroke, water cooled naturally aspirated, constant speed diesel engine. It is a small utility diesel engine used in various commercial applications. The test bench comprises of diesel engine coupled to an eddy current dynamometer for measuring the power output of the engine (Fig. 1). The various fuel blends used in the study were B20, B40 and B60 containing 20%, 40% and 60% biodiesel, respectively. The engine tests were performed at three different engine loads (0.9, 1.8 and 2.7 bmep). All the experiments were carried out at constant speed of 1500 rpm. The emission parameters studied were carbon monoxide, unburned hydrocarbon and oxides of nitrogen (NO_x). The un-burnt hydrocarbon (UHC) and carbon

Table 1 : Fatty acid profile of castor oil

Fatty acid	Structure	wt % age
Ricinoleic acid	18:1	83.97
Palmitic	16:0	0.46
Stearic	18:0	0.52
Oleic	18:1	2.28
Linoleic	18:2	0.61
Linolenic	18:3	0.33
Dihydroxylstearic	18:0	0.24

monoxide (CO) emissions were measured using HG-540 emission gas analyzer and oxides of nitrogen (NO_x) by KM19106 flue gas analyzer. The castor oil based biodiesel was mixed withdiesel (diesel fuel was procured from the local retail outlet of Indian Oil Cooperation Limited) on the volume basis by simple mixing. To ensure higher level of accuracy, all the experiment performed were replicated thrice to get an average value.

Results and Discussion

Emission of nitrogen oxides (NO_x) is one of the toxic air pollutants and the foremost anthropogenic source of its formation is combustion. In the ambient air, automobile and other combustion generated sources account for more than 50% of NO_x emission emitted. NO_x is generally formed due to dissociation reaction of nitrogen and oxygen inside the combustion chamber during peak combustion process. Since it is a high temperature species, therefore, its formation is influenced by high combustion flame temperature, availability of oxygen and available time for combustion (Monyem *et al.*, 2001). Fig. 2 (a) shows variations in the NO_x emissions for B0, B20, B40 and B60 at different load condition. It is known that formation of NO_x is dependent upon residence time, and peak combustion temperature. At all load conditions, the NO_x emissions were found to increase by increasing the load for different blends. Moreover, the increase in emission of NO_x was proportional to the biodiesel concentration in fuel blend. At 2.7 bmep load condition, the NO_x emission was higher by 28.2% for B60 fuel when compared to petro-diesel, while at 0.9 bmep load condition NO_x emissions increased by 11.8 and 15.1% for B20 and B40 blends, respectively when compared to petro-diesel. It reveals that production of NO_x emissions was higher for biodiesel blends, because inherent oxygen molecules in biodiesel fuel may provide additional amount of oxygen that causes complete combustion, resulting in high combustion temperature (Jindal *et al.*, 2015). Moreover, higher density and viscosity of biodiesel blends may lead to advancement in injection of fuel, resulting in its early combustion and higher NO_x emissions (Singh *et al.*, 2015).

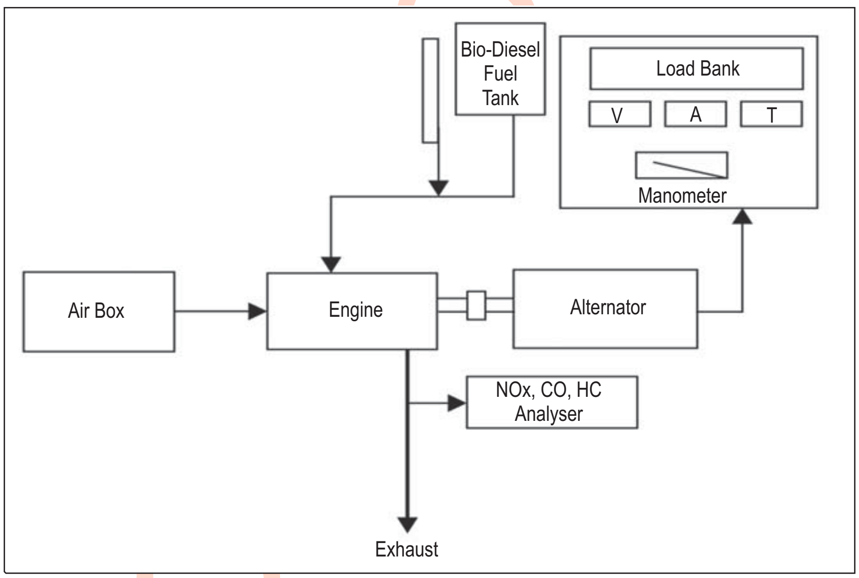


Fig. 1 : Layout of engine test rig used in experimental work

Table 2 : Physical properties of test fuel as per ASTM standard (2008)

Property	ASTM standard	ASTM limits	B0	B20	B40	B60
Kinematic viscosity at 40^0C (cSt)	D445	1.9-6	2.7	3.65	4.58	5.51
Density at 15 °C (kg m^{-3})	D1298	900	830	844	858	872
Calorific value ($MJkg^{-1}$)	D240	>33.00	43.4	42.7	42.0	41.3
Flash point (ºC)	D93	>130	58	78	108	132
Pour point (ºC)	D97	-15 to 10	-6	-1	4	8
Cloud point (ºC)	D97	-2 to -12	-8	-5	-2	1.8

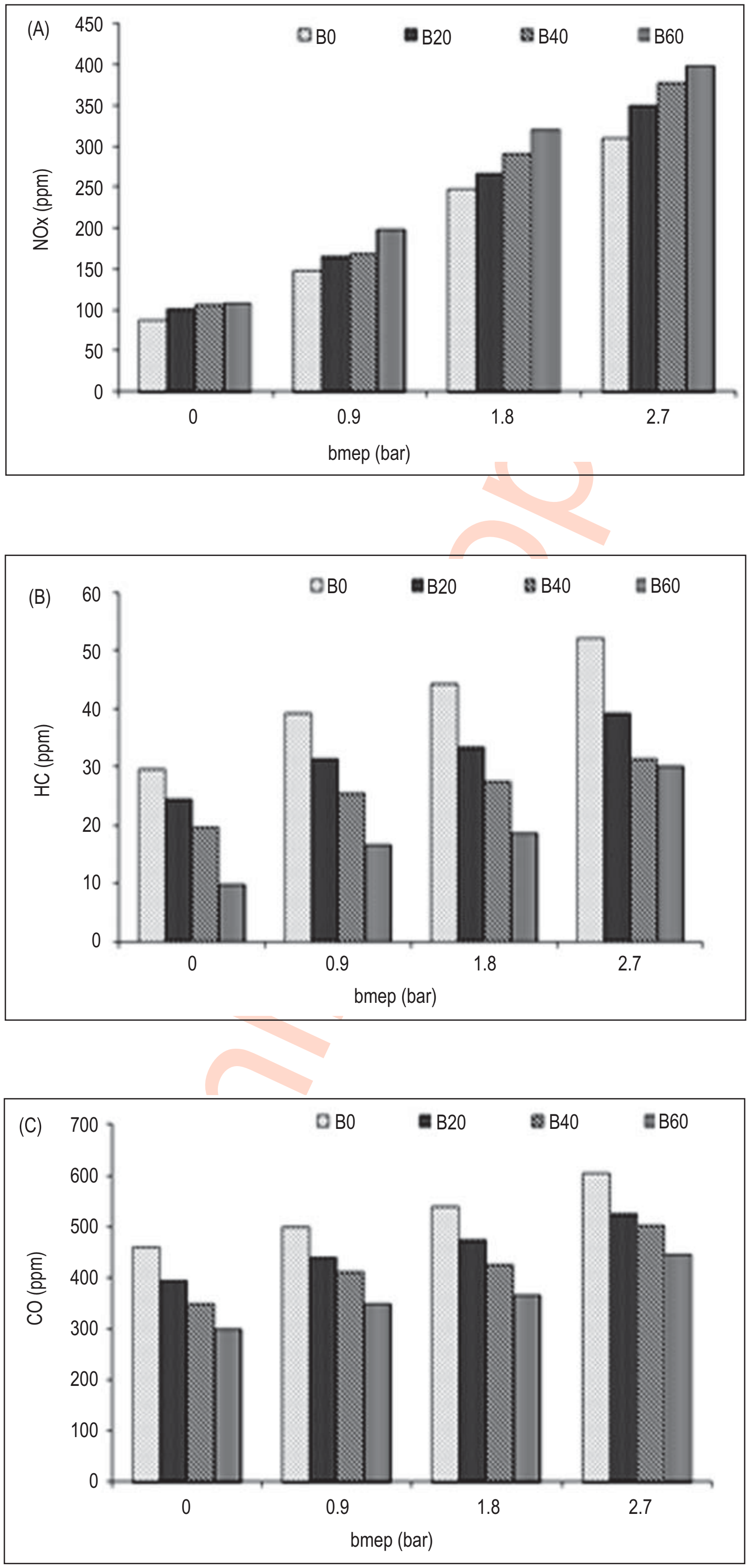


Fig. 2 : Variation in the values of (a) NOx, (b) HC and (c) CO with brake mean effective pressure (bmep)

On the other hand, Fig. 2(b) shows un-burnt HC emission traces for pure diesel and different biodiesel blends with conventional diesel. At full engine load condition of 2.7 bmep, the hydrocarbon emission was lowered by 24.6, 39.6 and 42.1% for B20, B40 and B60 fuels, respectively, when compared to petro-diesel. Thus, at all load conditions, HC emissions decreased with increasing proportion of biodiesel in the blends which may be attributed to the fact that oxygenated fuels improve the fuel oxidation process and reduces the tendency of unburned HC emission in exhaust tailpipe. These results are in close agreement with the previous findings, wherein HC emission reductions were higher with increasing biodiesel concentration (Qi *et al*., 2010; Sahoo *et al*., 2009). Moreover, high cetane number of biodiesel blends reduces the ignition delay period which is also responsible for reduction of HC emissions (E-Xue *et al*., 2011).

The formation of CO emission depends on the availability of oxygen, carbon content of fuel and combustion efficiency of the participating fuel (Karthikeyan *et al*., 2016). Variation in CO concentration with bmep for various tested fuels is plotted in Fig. 2 (c) The CO formation decreased with increase in biodiesel blend, however, CO emission increased with increase in load for all tested fuels. Moreover, at full engine load of 2.7 bmep, the carbon monoxide emission was reduced by 12.9, 17.1 and 26.2% for tested fuel blends B20, B40 and B60, respectively, when compared to B0 which may be attributed to the enhanced oxidation process favored by higher oxygen content in fuel molecules. In addition, high cetane number of biodiesel concentration improves combustion quality and decreases delay period of fuel, resulting in lower possibility of formation of rich fuel zone that subsequently reduces CO emissions (Ramesha *et al*., 2015).

It has been concluded that the fuel properties of biodiesel blends were closer to mineral diesel and are in strict compliance with ASTM D6751 specifications. There was a substantial reduction in HC and CO emissions at all engine loads with biodiesel blends when compared to neat diesel fuel. However, biodiesel blends resulted in higher Nox emissions when compared to diesel at all operating loads. Thus, castor biodiesel is a suitable fuel blend to be used in CI engines for reducing emissions and abatement of air pollution at source.

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