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Investigations on Performance and Emission Characteristics of Mix Oil Biodiesel Blends

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A B S T R A C T

An experimental investigation was carried out to analyze the performance and emission characteristics of a diesel engine fuelled with biodiesel blends (10, 20 and 30%) obtained by mixing karanja and linseed oil and diesel. Brake thermal efficiencies of biodiesel blends were found to be comparable with diesel with a slight reduction. BSEC increased with the proportions of biodiesel in biodiesel blends. B30 was found to cause the lowest HC emissions and the lowest CO emissions and diesel was found to deliver the lowest NOx emissions among the fuels used at all loads. Considerable reduction up to 37.32 % was found in smoke opacity of biodiesel blends. The study revealed that 10% biodiesel blend can be effectively used in an unmodified diesel engine.

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NOMENCLATURE

BTE	Brake thermal efficiency
BSEC	Brake specific energy consumption
CO	Carbon monoxide
HC	Hydrocarbons
NOx	Nitrogen oxides
ASTM	American Society for Testing and Materials
EN	European Standards
KOH	Potassium Hydroxide
FFA	Free Fatty Acid

INTRODUCTION

Monoalkyl esters of fatty acids derived from vegetable oils or animal fats are called biodiesel. If biodiesel is used with diesel in blends, it will reduce the use of diesel to large extent resulting in reduction of imports. India import about 46% of the total edible oil needs for catering domestic requirements [1]. Biodiesel is a renewable, environmentally friendly, biodegradable fuel. The use of biodiesel will solve the problem of environmental degradation [2]. Soybean, palm, rapeseed, peanut and sunflower oils are considered as a potential source for biodiesel production. However, non-edible oils such as Jatropha, Cottonseed, Mahua, Karanja etc. are more advantageous in compare to edible oils. Availability and cost are the main factors for the choice of feedstock for biodiesel production [3,4,5]. Developing countries like India can produce renewable energy from non- edible oils such as Karanja, Jatropha and Linseed oil in an effective and economical manner [6]. Biodiesel and ethanol are renewable biofuels and more attention is given to the feasibility of these fuels in India due to energy self-sufficiency, environmental concerns and increase in the rural economy. Indian diesel has 17^0C lower flash point than average diesel flash point of 52^0C in the world and also content higher sulfur and it may be blended with biodiesel to improve these parameters [7].

Biodiesel can be produced easily and it has a higher cetane number, good lubricating properties, higher density and lower sulfur emissions as compared to diesel. Biodiesel production has reached up to 2.2 billion

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gallons in the world. It is reported that more than 350 numbers of oil bearing crops are found to be used in the manufacture of biodiesel [7,8,9].

Biodiesel is generally produced by the method of transesterification in which, vegetable oils or animal fats is converted into fatty acid methyl esters [8,9]. Transesterification is one of the most popular methods to reduce viscosity of oils to produce biodiesel. For low FFA feedstock single step transesterification is sufficient to convert the whole oil into biodiesel. The reaction is reversible and therefore, excess alcohol is used to complete the reaction [10]. Most of the non-edible vegetable oils have high levels of free fatty acid and if the free fatty acid content in the oil is more than 3% then alkaline transesterification will not be feasible. If the free fatty acid content is below 2%, alkaline transesterification is preferred. It is reported that alkaline transesterification is 4000 times faster than acid transesterification [11]. Only Base catalyzed transesterification process is not useful if the FFA content of the feedstock is 3 wt% or greater [12, 13].

It is not possible to get the required quantity of particular oil in one place to produce biodiesel. It is therefore required to produce biodiesel with the mixtures of different oils to cater the fuel demand. Different lands and locations have different availability of plant species. It was reported that Castor oil of viscosity 225.8 cSt mixed with Soybean of viscosity 30.6 cSt or cottonseed oil of viscosity 34.6 cSt to produce biodiesel using base catalysed transesterification. Soybean oil, waste frying oil and pork lard were mixed to produce biodiesel by transesterification with a yield ranges from 81.7 to 88.8%. Base catalyzed transesterification was used to produce biodiesel from mixtures of canola oil and used cooking oil at different ratios by weight (80:20, 60:40, 40:60 and 20:80). In all these cases, FFA content was 1% and hence, base catalyzed transesterification can be used [14,15,16,17]. Oxidation of biodiesel is not desirable as it produces insoluble species leading to clogging fuel lines and pumps. High content of polyunsaturated fatty acid in biodiesel from fish oil results in its low oxidative stability. Antioxidants may be added to biodiesel or fish oil may be mixed with oils of high oxidative stability to produce biodiesel with improvement in its properties. Palm oil has high oxidative resistivity due to presence of ample amount of saturated fatty acid . It is concluded that palm oil should be mixed with fish oil before transesterification [18,19,20,21,22,23]. Yogish et al. reported that non-edible oil mixture of Jatropha and Karanja produced biodiesel by two step acid transesterification which would meet the requirement of fuel in near future [24].

Disadvantages of Oxidative property of Linseed oil and high FFA of Karanja oil may be overcome by mixing. However, production and performance evaluation of biodiesel from mixtures of oils such as Karanja and Linseed having a high and a low FFA respectively have not been reported yet. In India, these oils are available in ample quantities and can be produced in large scale due to suitable climatic conditions for these crops. Hence, it is required to study the fuel properties, performance and emission characteristics of this biodiesel.

Karanja oil for biodiesel

Karanja is assumed to be originated from western ghats and is found on the sides of rivers, sea and in tidal forests [25]. Its botanical name is Pongamia Pinnata. It belongs to Fabaceae family. It is an Indo-Malaysian species. It is used for medicinal activities to prevent plasmodial, inflammatory, hyperammonic, ulcer, lice, lipidperoxidative, hyperglycaemic [26]. Karanja is non-edible oil because it contain furanoflavones, furanoflavonols, chromenoflavones, flavones and furano-dikeones [27]. Karanja has a production capacity of 1,35,000 metric tons per year in India. The Karanja seeds contain 40% oil. It belongs to nitrogen fixing trees [28]. Karanja oil contains (50% by weight) oleic acid. The advantage of nitrogen fixing trees is that it can restore and maintain soil fertility and also improve soil quality [29]. Karanja leaves belong to lactagogue fodder in arid regions. Karanja is intercropped with pasture grasses so that it can be grown well in shade of grasses [30]. Karanja tree can be grown in humid and subtropical regions of rainfall range of 500mm to 2500mm annually [31]. Karanja can sustain its survival in severe climatic conditions like drought, frost, heat, salinity etc. [32]. 9 to 90 kg of seeds can be yielded by a single tree. It is a fast growing plant. Direct sowing, root cutting and transplanting can be used to regenerate it. It is matured after 4-7 years. 3 x3 m^2 spacing is required for its plantation. Karanja plants and its oil are used as a source of traditional medicines, manure, timber, pesticide, leather tanning and fuel. Karanja oil was also used to a smaller extent for soap preparation, but its color, odor and its ineffectiveness in the improvement of oil quality by refining, bleaching and deodorization put an obstacle to its use in soap making [33, 34].

As compared to diesel, Karanja Biodiesel has a higher flash point, higher cetane number and lower sulfur content [35]. Karanja biodiesel has good low temperature operability as comparable to Jatropha biodiesel due to the presence of higher amount of oleic acid [36]. Mofijur et al. [37] reported that the use of biodiesel in diesel engine slightly lowered brake thermal efficiency. Dhingra et al. [35] reported that the fuel properties of Karanja biodiesel were similar to ASTM standard of biodiesel. It was therefore concluded to use blends of Karanja biodiesel as a fuel with diesel. It was reported that Karanja biodiesel can be used as an alternative fuel for diesel. It was investigated that the compression ratio of 17.9, 10% biodiesel blend and 3.81 kW power were the optimum parameter while using different biodiesel blends of 10, 20, 30 and 50% [38]. It was reported that the BTE improved and BSFC decreased by 10% at full load while using 100% biodiesel in a four stroke diesel. A test was conducted with B20 and B100 biodiesel blends. It was also found that emission of CO and HC for pure biodiesel were decreased by 30 and 23%, respectively [39].

Linseed oil for biodiesel

Usitatissimum is the botanical name of Linseed and it is also known as flax seed oil. Linseed oil can be obtained by different processes such as alkali refined, sun bleached, cold pressing and solvent extraction. It is also called drying oil because it hardens when expose to air. It is used in wood varnish, as a hardener and a plasticizer agent in putty. It is also used in oil paints as a pigment binder. It is used to prepare Linoleum. 500 tons of Linseed are produced in India per annum [34]. Linseed seeds yield 33-40% oil. Climatic and soil conditions of India favor the production of Linseed crops [6]. Linseed oil contains 60% linolenic acid, the most unsaturated acids [40].

It is reported that Linseed Biodiesel may polymerise and oxidize due to presence of two double bonds in the reactive methylene groups at a temperature of around 900^{0}C during diesel engine performance. Linseed biodiesel has 45-47% Methyl linolenate content. Methyl Linolenate is susceptible to oxidation if its amount exceeds beyond 12% in biodiesel. Therefore, Methyl Linolenate content is restricted up to 12% in biodiesel, according to European Standards EN 14214 [41]. Linseed oil is easily available in abundant quantity. It is reported that Linseed biodiesel blend LB 10 is preferred over LB15 and LB20 to achieve better efficiency [42]. High BTE, high power output and low BSFC were reported when Linseed biodiesel was used in diesel engines. Low emissions of CO, HC, NOx and smoke were also reported [43]. The comparison of fatty acid compositions of Karanja and Linseed oil is shown in Table 1 [44,45,46].

MATERIALS AND METHODS

Materials

Methyl ester was produced by alkaline transesterification in the mixture of equal quantities of Karanja and Linseed oil with methanol in 6:1 molar ratio in the presence of a catalyst 2%wt KOH. The reaction time was 60 minutes and 78.2% yield of methyl ester was achieved [47].

Engine tests

Biodiesel was tested on a four stroke, single cylinder, water cooled, Kirloskar diesel engine (Compression ratio 18:1 and rated Power 3.5kW at 1500 rpm). Engine tests were performed with B10, B20 and B30 at different loads (brake powers). B10, B20 and B30 were biodiesel blends of 10, 20 and 30% by volume respectively with diesel. A set of readings was obtained by running the engine with fuel at a compression ratio of 18 and varying the load from 0.5 kW to rated load of 3.5 kW in steps of 0.5 kW with constant speed of 1500 rpm. The engine performance characteristics were recorded by using the software ‘Engine Soft’. The CO, NOx, HC and smoke opacity were measured with AVL DIX, (Emission Diagnostic System). Various performance and emission parameters were obtained and the results of this experiment are discussed with bar charts as given below:

TABLE 1. Comparison of fatty acid composition of Karanja and Linseed oil

S.N	Compound	Linseed Oil (% wt)	Karanja Oil (% wt)
1	Myristic	0.045	-
2	Palmitic	6.21	12.3
3	Oleic	18.5 - 20.17	50
4	Stearic	5.63	7
5	Linoleic	14.4 - 14.93	15.21
6	Linolenic	51.12 - 59.8	1.98

TABLE 2. Physical Properties of Karanja oil, Linseed Oil, Mix oil Biodiesel Blends

S.N	Name of Property	Karanja Oil	Linseed Oil	B10	B20	B30	ASTM D6751 Biodiesel standards	Diesel
1	Density kg/m^3	912.4	926.3	854.2	858.5	862.7	880	850
2	Viscosity cSt	27.8	29.2	3.1	3.4	3.6	1.9 to 6.0	2.8
3	Calorific value MJ/kg	34	30.6	43.1	42.5	41.9	-	43.7
4	Pour Point ^{0}C	4	-4	-13	-11	-10	-15 to 10	-15
5	Cloud Point ^{0}C	13	1	-8	-7	-5	-3 to -12	- 10
6	Flash Point ^{0}C	205	239	85	94	103	130 min.	76

RESULTS AND DISCUSSION

Properties of biodiesel

The physical properties of Karanja Oil, Linseed oil, Mix oil Biodiesel blends and Diesel were tested. These properties are compared with Biodiesel standards, ASTM D 6751 and are found satisfactory. These are shown in Table. 2.

Engine performance characteristics

BTE of diesel was found to be 29.72% maximum followed by 28.76% for B10 and minimum 27.92% for B30 at 3.5 kW brake power. In all cases, maximum decreases in BTE with respect to diesel up to 6.05% were observed between diesel and B30 at 3.5kW brake power. Brake thermal efficiency is defined as the ratio of brake power to the product of calorific value and flow of fuel. Therefore, brake thermal efficiency depends on rate of fuel flow and calorific value of fuel at a particular brake power. Biodiesel blends were found to have lower calorific value as compared to diesel and it decreased with an increase in the proportion of biodiesel in the blend. It was stated that the rate of fuel flow rate increased was more comparable to the rate of decrease in the calorific value of the blends with increasing percent of biodiesel in the blends. Therefore, brake thermal efficiencies for biodiesel blends were lower than that for diesel. This agrees with [48]. BTE of different fuels is shown in the bar chart (Figure 1)

In case of fuel blends with different calorific values, BSFC is not a significant parameter, instead BSEC is a more reliable parameter because it considers calorific value of different fuels into account. Brake specific energy consumption may be defined as product of calorific value and brake specific fuel consumption. Therefore, BSEC was considered in this study. It was observed that the BSEC decreased with increase in load. This may be attributed to decrease in brake specific fuel consumption at higher loads for operating the engine. BSEC increased with the proportions of biodiesel in biodiesel blends due to its higher brake specific fuel consumption comparatively. The BSEC of all biodiesel blends was slightly higher than that of diesel. This may be attributed due to lower heating value, lower volatility and higher density of biodiesel. In all cases, the maximum increase up to 11.49 % with respect to diesel was observed for B30. This agrees with [48,49]. BSEC of different fuels is shown in the bar chart (Figure 2)

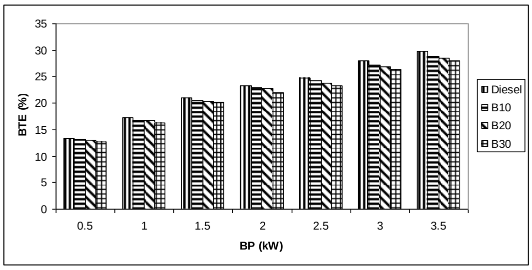

Figure 1. Variation of brake thermal efficiency with brake power

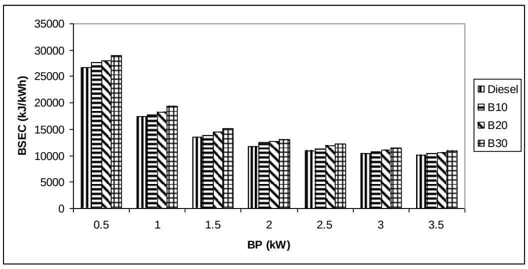

Figure 2. Variation of brake specific energy consumption

Engine emissions

It was observed that smoke opacity decreased with increase in compositions of biodiesel blends which implies that biodiesel tends to reduce smoke emissions. Smoke opacity decreased with increase in compositions of biodiesel blends with a maximum decrease up to 37.32 % observed between diesel and B30 biodiesel blend. This may be attributed due to the oxygen content in biodiesel and absence of aromatic and sulfur compounds and lower boiling point of biodiesel. This agrees with literature [50,51]. Smoke opacity of different fuels is shown in the bar chart (Figure.3)

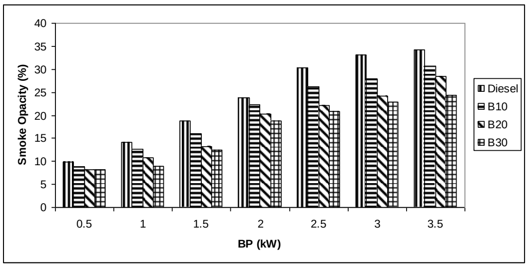

Figure 3. Variation of smoke opacity with brake power

It was observed that HC emissions increased with loads for all fuels. This may be attributed due to less availability of oxygen at higher loads. Biodiesel blends showed 20.68 to 70 % lower HC emissions than diesel. Maximum reduction of HC emissions in biodiesel blends was observed at minimum load. Reduction in HC emissions increased with the proportion of biodiesel in blended fuel. B30 showed lower HC emissions than other fuels at all loads. It was found that HC emissions for biodiesel blends were lower than that of diesel. This may be attributed due to the higher oxygen content in biodiesel, which facilitates smooth and complete combustion inside the engine cylinder. This agrees with reported data [52]. Variation of hydrocarbon emissions with brake power is shown in Figure 4.

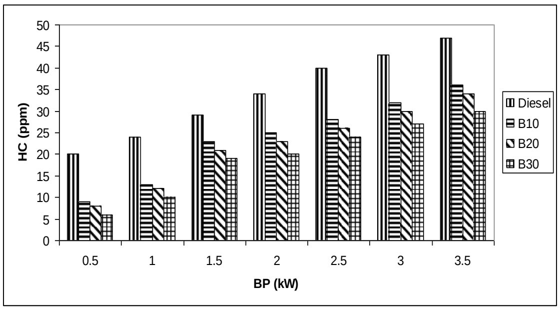

Figure 4. Variation of hydrocarbon emissions with brake power

The increase in CO emission was observed with the increase in loads for all fuels. This may be attributed due to induction of rich mixture at higher loads resulting in incomplete combustion. Biodiesel blends emitted lower CO emission. This may be attributed due to the presence of more oxygen in biodiesel than diesel, resulting in the conversion of CO into CO_2. This agrees with literature [53]. Biodiesel blends showed 21.83 to 66.66% lower CO emissions than diesel. Variation of carbon monoxide emissions with brake power is shown in Figure 5.

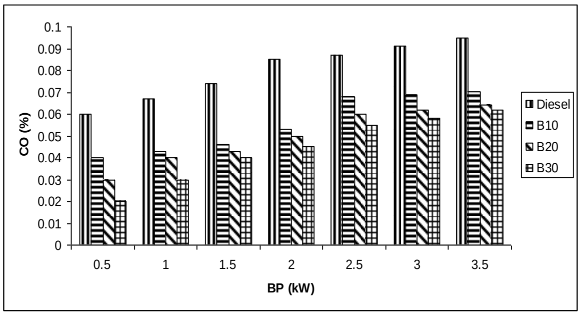

Figure 5. Variation of carbon monoxide emissions with brake power

It was found that NOx emissions increased with increase in loads. Biodiesel blends showed 2.32 to 19.7 % higher NOx emissions than diesel. Although biodiesel has 14% lower energy content than diesel, but the in-cylinder gas temperature of diesel is lower than that of biodiesel. In-cylinder gas temperature of biodiesel is higher due to the presence of double bond molecules (unsaturation) on it which reveal slightly higher flame temperature resulting in higher NO_x emissions. This agrees with reported data [54]. Variation of NOx emissions with brake power is shown in Figure 6.

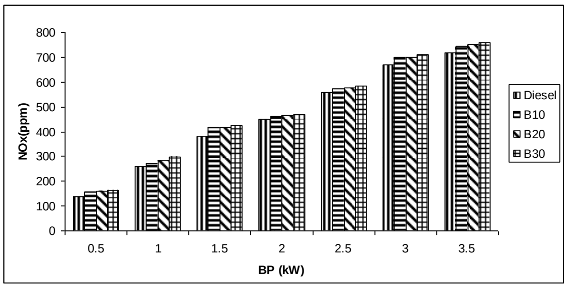

Figure 6. Variation of NOx emissions with brake power

CONCLUSIONS

The following conclusions have been made in this study:-
1. Brake thermal efficiencies of biodiesel blends were found to be decreased in the range of 0.9 to 6.05% than that of diesel.
2. BSEC also increased in the range of 1.13% 11.49% for biodiesel blends and it was found that it increases with the proportions of biodiesel in biodiesel blends.
3. B30 was found to have the lowest HC emissions up to 70% and CO emissions up to 66.66% with respect to diesel and diesel was found to have the lowest NOx emissions among the fuels used.
4. Considerable reduction in the range from 6.69 to 37.32% were observed in smoke opacity of biodiesel blends while compared with diesel.
Experimental investigation has revealed that optimum biodiesel blend is B10 which can be used in an unmodified diesel engine in an effective manner considering the above performance parameters.

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Persian Abstract

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چکیده

یک مطالعه تجربی برای تجزیه و تحلیل عملکرد و ویژگی های نشر (گاز) موتور دیزل که با بیودیزلی ترکیبی (۱۰، ۲۰ و ۳۰ درصد) که با مخلوط کردن روغن karanja و روغن بذر کتان و دیزل به دست آمده بود، پر شده بود، انجام شد. بازده حرارتی ترمز بیودیزل با دیزل با کاهش کمی قابل مقایسه بود. BSEC با افزایش نسبت بیودیزل در سوخت مخلوط افزایش یافته است. B30 کمترین انتشار HC و CO را موجب شد و مشخص شد که دیزل کمترین مقدار انتشار NO_x را در میان تمام سوخت های مورد استفاده داشته است. کاهش قابل توجه تا ۳۲/۳۷٪ در کدورت دود مخلوط بیودیزل پیدا شد. این مطالعه نشان داد که ۱۰٪ ترکیب بیودیزل می تواند به طور موثر در یک موتور دیزل اصلاح نشده استفاده شود.