Performance and Emission Characteristics of Combined Biodiesel Blend of Non-Edible Oil in Diesel Engine

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Abstract

Nowadays every country is facing energy crisis. Continuous extraction of crude oil resulting in depletion of fossil fuels reserves. It is motivating researchers to develop alternative source of energy. Biodiesel is promising alternative for petro-diesel. Lot of work has been done on single biodiesel blend of edible and non-edible source of energy. Very few works has been found on dual biodiesel blend. In the present study, combined blend of second-generation fuel (Jatropha and Karanja) was studied on single cylinder four-stroke multi fuel diesel engine test rig. Performance and emission analysis has been examined at different load and constant speed (1500 rpm). Result showed that break thermal efficiency of diesel is higher than all blends of biodiesel. Break specific fuel consumption of combined blend (JK15KB15) was significantly higher than diesel and marginally lower than single blend of Jatropha (JB30) or Karanja (KB30). Combined blend of JB15KB15 showed lower HC, CO emission but higher NOx emission than diesel. Moreover JK15KB15 showed better emission characteristics than single biodiesel blend with diesel.

Keywords: Biodiesel, Non-edible oil, Combined Blend, Performance, Emission

1. Introduction

Human beings are intending to use more and more facility for making their life easy thereby resulting in growth of industrialization and motorization. Besides it population growth demanding more energy day by day. It is reported that 1.1 % energy consumption is increasing only in transportation sector every year [5]. Mainly fossil fuels are being used to fulfil the demand of energy in industry and automobile field. This is also a well-known fact that in future, world cannot remain dependent on fossil fuels. Although these fossil fuels are limited and available in a small part of the globe. Researchers expected that the reserves of fossil fuels would be depleted in next 40 years. Moreover price of petroleum fuels are also increasing every year. Developing country like India is importing 80 % of crude oil of its total consumption petroleum products and paying huge amount of money in return of it.

Continuous use of petroleum products as a fuel of IC engines is also posing a threat to our environment. Carbon emission from these engines plays a major role in contribution of green house
gases. A study reveals that 22 % of total green house gas emission comes from the transportation sectors which is the main cause of global warming [5]. It is estimated that earth temperature will increase 2°C by 2050. This may result in deaths of millions of people around the world and disturb the ecological balance. To overcome these environmental imbalance many country have signed a UN agreement to reduce their carbon emission. Besides carbon emission, IC engines are also the source of other harmful emissions such as sulphur dioxide, particulate matter etc. This is degrading air quality and causing many health diseases such as Asthma, Lung cancer etc.

Depletion of fossil fuels, vehicular population growth and environmental concern are emphasizing to develop alternative and renewable. Compressed natural gas, alcohol, bio ethanol, bio methanol, bio fuel, solar cells and electrical cells are available as an alternatives source of energy. Among these alternatives, bio fuel is an emerging trend as a source of fuel for IC engines. It includes biodiesel, biomass and bio alcohol etc. Biodiesel is a carbon neutral fuel because plants absorb carbon dioxide through photosynthesis that is released in the exhaust gas emission. Many by-products formed during transesterification process are also useful. More than 300 crops for are identified for the vegetable oil as source of biodiesel [12]. Soybean, palm, mustard and coconut etc. are the edible vegetable source of biodiesel. Producing biodiesel from the vegetable source raise another issue of food vs. fuel concern. Therefore, most of the researchers are working on non-edible source of oil for the production of biodiesel. Jathropha, Karanja, Mahua, Neem, Rapeseed and Castor etc. are various non-edible source of oil used for the production of biodiesel.

| Nomenclature   | Description                  |
|----------------|------------------------------|
| B0             | 100 % Petro-diesel           |
| JB5KB5         | 5% Jatropha methyl ester+5 % Karanja methyl ester+90 % petro-diesel |
| JB10KB10       | 10% Jatropha methyl ester+10 % Karanja methyl ester+80 % petro-diesel |
| JB15KB15       | 15 % Jatropha methyl ester+ 15 % Karanja methyl ester+70 % petro-diesel |
| JB20KB20       | 20% Jatropha methyl ester+20 % Karanja methyl ester+60 % petro-diesel |
| JB30           | 30% Jatropha methyl ester+70 % petro-diesel |
| KB30           | 30 % Karanja methyl ester+70 % petro-diesel |
| CO             | Carbon monoxide              |
| CO₂            | Carbon dioxide               |
| HC             | Hydrocarbon                  |
| NOₓ            | Nitrogen oxides              |
| BTE            | Break thermal efficiency     |
| BSFC           | Break specific fuel consumption |
| KOH            | Potassium hydroxide          |

2. Literature Survey

Gaurav et. al.[8] investigated the performance behaviour of single cylinder diesel engine generating set of 2 KVA using Jathropha and Karanja biodiesel separately. It is reported that physical and chemical properties of biodiesel blend (B10 and B20) are very similar to diesel. BSFC of 100 % Karanja was 30.4% higher than diesel at full load. B20 and B30 biodiesel blend of Karanja showed efficiency near to diesel engine while exhaust emission was less than diesel engine.

Srirath et. al.[1] study the effect of hybrid biodiesel blend on single cylinder diesel engine. They prepared blend of mustard biodiesel and Pongamia biodiesel in different proportion and tested on diesel engine. Experimental result indicated that the blend PB5MB5 (5% Pongamia biodiesel+ 5% mustard biodiesel+90% diesel) had slightly higher thermal and mechanical efficiency than the blend PB10MB10 (10% Pongamia biodiesel+ 10% mustard biodiesel+80% diesel). Specific fuel consumption of both the biodiesel blend was also slightly higher than diesel. While CO and CO₂
emission was reported slightly lower than diesel. It was concluded that dual biodiesel blend up to 40% can be used as an alternative fuel in place of diesel. Further they suggested testing of other dual biodiesel blend on CI engine.

Datta and Mandal [2] analyzed the numerical simulation result of Diesel RK software on single cylinder CI engine. They studied the performance, combustion and emission behaviours of palm sterain biodiesel-alcohol (methanol or alcohol) blend in different proportion. It was reported that break specific fuel consumption, break thermal efficiency increases with the addition of alcohol to biodiesel. No significant difference in exhaust gas temperature occurs while the cylinder wall temperature decreases with the addition of alcohol. 15% addition of alcohol (ethanol and methanol) decreases NO\textsubscript{x} emission by 30% and 19% respectively. CO\textsubscript{2} does not affect while particulate matter (PM) and smoke emission increases significantly with addition of ethanol.

Mofijur et. al. [5] study the green house emission scenario in Australia and reported that performance and emission in diesel engine depends on many factors such as feedstock’s, properties, operating condition and use of instruments etc. It was concluded that binary and ternary blend reduces CO emission due to oxygenated biodiesel fuel. NO\textsubscript{x} emission increases and HC emission reduces. There was non-consensus report on CO\textsubscript{2} emission by using biodiesel.

Habibullah et. al.[10] study the engine performance and emission behaviour on single cylinder four stroke direct-injection diesel engine using combined blend of palm and coconut biodiesel. Low break power and high break specific fuel consumption was reported for PB15CB15, PB30 and CB30 biodiesel. Break thermal efficiency was much lower ((3.84-5.03%) than diesel while all emissions except NO\textsubscript{x} was reduced. Overall performance of PB15CB15 was better than CB30 and PB30.

Aydin et. al.[3] investigated the performance characteristics of diesel engine by using blend of biodiesel obtained from Safflower oil, bio ethanol and diesel in different proportions (D100, B2.5M2.5D95, B5M5D90, B5M2.5D92.5 and B2.5M5D92.5). It is reported that D100 is better in terms of performance while B2.5M5D92.5 is better in respect of emission characteristics.

Sanjid et.al. [6] presented experimental investigation of combined biodiesel blend of palm and Jathropha oil in respect of performance and emission characteristics on single cylinder diesel engine at different speed. It was shown that fuel properties of combined blend were as per ASTM standards of biodiesel specification. Break specific fuel consumption and NO\textsubscript{x} emission of combined blend was found slightly higher than diesel. CO emission was reduced 9.53 % for PJB5 and by 20.49 % for PJB10 in comparison to diesel. There was slight reduction in HC emission for the combined blend of biodiesel.

USA and some European country instructed to use 1-5 % bio fuel in vehicular consumption. Small proportion of addition of bio fuel would result in significant reduction of petro diesel. Most researchers investigated the effects of single and hybrid blend of biodiesel from plants source in diesel engine. Little work has been done in the field of combined biodiesel blend of non-edible oil. Therefore in the present work combined blend of Jathropha and Karanja have been prepared in different proportion and tested for performance and emission analysis of CI engine.

Jathropha curcas is a small tree of 5-8 m height. Its life is 40-50 years and seeds can be obtained after one year of plantation. America, Brazil, Argentina, Africa and India are the native land of Jathropha tree. It is water resistant and grows in arid or semi arid region. Near the railway line and wasteland is suitable place for the plantation of Jathropha tree. Its seeds contain 20-50 wt % oil [7]. Production of biodiesel from Jathropha plants is simple and economic. On the other hand, Karanja is medium size tree of height 15-20 meter. It is specially found in south-east Asia. It is generally grown in humid region. Their seeds contains 20-40 wt. percentage oil. Production of oil from Karanja seed is economic.
3. Experimental Methodology

3.1. Biodiesel Production

In the present study alkali transesterification process was used to convert Jathropha and Karanja vegetable oil into its biodiesel (Figure 1).

In this process first methanol (25% v/v) and potassium hydroxide KOH (1% wt/wt.)[6, 10] as a catalyst were mixed in a beaker and stirred for half an hour until all KOH were dissolved. This methoxide solution was then poured into a 10 litre capacity of biodiesel reactor which is already filled with vegetable oil. Combined mixture was run at 55°C and stirred at a speed of 200 rpm. During transesterification process fatty acid of vegetable oil reacted with methoxide solution and formed fatty acid methyl ester and glycerol. After 2 hour of transesterification reactions both the products were collected in a jar through bottom pipe. These products were kept for one day for settling the liquid. Dark grey lower layer was crude glycerine and upper yellowish transparent layer was fatty acid methyl ester (FAME). A clear visible line in a transparent jar separated both layers. After removing crude glycerol, upper layer of crude biodiesel was taken out in a jar. For washing of biodiesel, water washing was used to remove impurities from the biodiesel. In this process, one-third amount of hot distilled water (60°C) was mixed gently in the biodiesel and placed vertically on its base. Distilled water collected impurities from the biodiesel and settle down in the bottom. This process was repeated three to four times until water was observed without murky at the end of washing. After washing biodiesel was placed in an evaporator to remove water content and methanol. Thereafter final product was collected as a clean biodiesel. Biodiesel production from non-edible oil is given in flow chart (Figure 2). Details fatty acid composition and oil content of Jathropha and Karanja biodiesel is given in table 1.

Figure 1 Transesterification Reaction [13].

Figure 2 Flow Chart of Biodiesel Production from Non-Edible Oil
Table 1: Fatty Acid Composition of Jathropha and Karanja Biodiesel (wt. %) [7].

| Fatty Acid       | Structure | Jathropha (wt %) | Karanja (wt %) |
|------------------|-----------|------------------|----------------|
| Myristic acid    | C14:0     | 1.4              | ..             |
| Palmitic acid    | C16:0     | 13.6-15.1        | 3.7-7.9        |
| Palmitoleic acid | C16:1     | ..               | ..             |
| Stearic acid     | C18:0     | 7.1-7.4          | 2.4-8.9        |
| Oleic acid       | C18:1     | 34.3-44.7        | 44.5-71.3      |
| Linoleic acid    | C18:2     | 31.4-43.2        | 10.8-18.3      |
| α-Linolenic acid | C18:3     | ..               | ..             |
| Arachidic acid   | C20:0     | 0.2-0.3          | 2.2-4.1        |
| Behenic acid     | C22:0     | ..               | 4.2-5.3        |
| Total Saturation |           | 24.4             | 32             |
| Total Unsaturation|          | 75.6             | 68             |
| Oil content      |           | 20-60            | 25-40          |

3.2. Experimental Strategy

Most of the study revealed that 20% biodiesel with diesel blend can be used successfully without engine modification. Therefore in the present study combined blend of biodiesel up to 40% are prepared for testing on diesel engines. Initially four combined blend of Jathropha and Karanja (JB5KB5, JB10KB10, JB15KB15 and JB20KB20) are prepared. Later on, best result of these blends are compared with single biodiesel blend and pure diesel. Physcio-chemical property of different blends such as density, viscosity, cetane number, calorific value, cloud point and pour point were measured as per ASTM standard (Table 2).

Table 2: Physical and chemical properties of different blends of biodiesel [5, 7].

| Properties                  | Diesel (J100) | Jatropha (K100) | Karanja (K100) | JB5 KB5 | JB10 KB10 | JB15 KB15 | JB20 KB20 | JB30 KB30 |
|-----------------------------|---------------|-----------------|----------------|---------|-----------|-----------|-----------|-----------|
| Density (kg/m³, at 40°C)    | 832           | 872             | 883            | 832     | 838       | 843       | 848       | 841       | 845       |
| Viscosity (mm²/s, at 40°C)  | 2.91          | 5.085           | 6.985          | 4.1     | 4.5       | 4.68      | 4.91      | 4.51      | 5.1       |
| Flash point (°C)            | 76            | 200             | 175            | 70      | 85        | 98        | 112       | 103       | 93        |
| Pour point (°C)             | -5.3          | 5               | 1.05           | -5      | -6        | -4.5      | -3.5      | -4.0      | -5.0      |
| Cloud point (°C)            | 6.5           | 2.7             | 14             | -10     | -9        | -6        | -4.2      | -8.0      | -5.5      |
| Cetane number (N)           | 48            | 50.5            | 55             | 45      | 47        | 47        | 48        | 47        | 48        |
| Calorific Value (MJ/kg)     | 46            | 40.5            | 37             | 44      | 43        | 44        | 43        | 45        | 44        |
3.3. Experimental Set Up

Kirloskar make single cylinder four-stroke multi fuel VCR diesel engine test rig was used for testing of biodiesel blend. Experimental set up of diesel engine test rig is shown in figure 3 and technical specifications are given in table 3. Experiments were conducted at rated speed (1500 rpm) and at varying load. Results were compared with the baseline data of diesel engine and single biodiesel blend. I C Engine soft version 9.0 was used to analyses break thermal efficiency (BTE) and break specific fuel consumption (BSFC). Exhaust gas analysis has been done on AVL DIGAS 4000 LIGHT (4 gas analyser). Technical specifications of AVL gas analyzer are given in table 4.

Initially engine test rig was run for 10 minutes on standard diesel. Then filter of diesel engine were disconnected and performance and emission results were recorded in respective instruments. Biodiesel blend was mixed thoroughly before using it on engine test rig. Thereafter required biodiesel blend was poured into fuel tank. For testing of each blend, engine is run for 5 minute to drain of all previously existing fuel from the fuel pipeline and injector pump. Performance and emission parameters were measured thrice on each time and average reading were recorded for the analysis.

Table 3: Technical Specifications of Experimental Test Rig

| Engine Type | Single cylinder, Four stroke , Multi Fuel(Petrol, Diesel , Ethanol and Biodiesel ) , VCR Engine |
|-------------|--------------------------------------------------------------------------------------------------|
| Cooling     | Water Cooled                                                                                     |
| Rated Power | 3.5 KW at 1500 rpm                                                                              |
| Stroke      | 110 mm                                                                                            |
| Bore        | 87.5 mm                                                                                            |
| Capacity    | 661 cc                                                                                            |
| Compression Ratio | 12:1-18:1                                                                                      |
| Injection Variation | 0-25° BTDC                                                                                     |
| Loading     | Eddy Current Dynamometer                                                                        |
| Fuel Gank   | 15 litre , Dual Compartment                                                                     |
| Piezo Sensor| Range 5000 psi, with low noise cable                                                            |
| Crank angle sensor | Resolution 1 Deg, Speed 5500 RPM with TDC pulse.                                                |
| Data Acquisition Device | NI USB-6210, 16-bit, 250kS/s.                                                               |
| Temperature Sensor | Type RTD, PT100 and Thermocouple, Type K                                                        |
| Load Sensor | Load cell, type strain gauge, range 0-50 Kg                                                     |
| Fuel Flow Transmitter | DP transmitter, Range 0-500 mm WC                                                              |
| Air Flow Transmitter | Pressure transmitter, Range (-) 250 mm WC                                                      |

Table 4: Technical Specifications of Exhaust Gas Analyzer (AVL DIGAS 4000 LIGHT)

| Measurement data | Range         | Resolution |
|------------------|---------------|------------|
| CO               | 0-10 % Vol.   | 0.01 Vol.  |
| CO₂              | 0-20 % Vol    | 0.1 Vol.   |
| HC               | 0-20000 ppm Vol.| 1 ppm       |
| NOₓ              | 0-5000 ppm Vol.| 1 ppm       |
| O₂               | 0-25 % Vol.   | 0.01 % Vol.|
| Engine Speed     | 250-9990 rpm  | 10 rpm      |
4. Results and Discussion

4.1 Performance Analysis

4.1.1 Brake Thermal Efficiency. Break thermal efficiency (BTE) is the ratio of mechanical energy available at the output shaft to the chemical energy available in the fuel. Variation of break thermal efficiency with respect to load is shown in the figure 4. From the figure, it is clear that break thermal efficiency increases with increasing engine load [7, 9]. It is due to incomplete combustion and rich fuel air ratio at low load. At higher load break thermal efficiency increases due to shorter ignition delay and complete combustion of fuel. Break thermal efficiency of biodiesel blend decreases with increasing proportion. Maximum break thermal of JB20KB20 biodiesel was observed 30.05%, which is 2.6% lower than diesel. This is due to lower heat content and higher viscosity of fuel. Presence of unsaturated hydrocarbon may hinder the complete combustion of fuel and further decreases the break thermal efficiency. Break thermal efficiency of combined blend JB15KB15 was observed marginally higher than KB30 and JB30 blend at full load.

Figure 3. Schematic Diagram of Experimental Set up.

Figure 4. Break thermal efficiency vs Load

Figure 5. Break specific fuel consumption vs load.
4.1.2 Brake Specific Fuel Consumption. It is the rate of consumption of fuel per unit kilowatt-hour. Variation of break specific fuel consumption (BSFC) with respect to load is shown in figure 5. Higher BSFC was observed at low load. It is due to rich fuel air mixture and incomplete consumption. Low temperature of cylinder also causes heat loss and further increases fuel consumption [7]. At higher load, high cylinder temperature and smaller ignition delay resulting in complete combustion and reduced BSFC. However, biodiesel blend shows lower fuel consumption. It may be due to available oxygen content of biodiesel fuel that causes better combustion than diesel fuel at lower load. At higher load, BSFC increases with increasing blend proportion of biodiesel. It is due to lower heat content. Moreover higher viscosity cause difficulty in fuel atomization and result in increase in BSFC. JB15KB15 blend shows 16.67% higher BSFC than diesel in idle condition. While at full load JB15KB15 has 6.03% higher BSFC than diesel and it is 1.65% higher than JB30 and 1.23% higher than KB30. Possible reason is the difference of viscosity and percentage of unsaturated hydrocarbon.

4.2 Exhaust Gas Analysis

AVL DIGAS 4000 light gas analyzer is used to measure exhaust gas emission of experimental diesel engine test rig. Before testing, all reading of gas analyzer were set zero to the atmosphere.

4.2.1. Hydrocarbon (HC) Emission. HC emission is the result of incomplete combustion of hydrocarbon existing in the fuel. Many factors such as fuel properties, engine operating conditions, fuel air ratio and fuel atomization may affect the hydrocarbon emission. Figure 6 shows the variation of hydrocarbon emission with respect to load. At lower load, lower temperature of cylinder wall and high fuel air ratio result in incomplete combustion which causes higher HC emission. As load increases HC emission reduces due to higher cylinder wall temperature and shorter ignition delay, which result in complete combustion. At full load, rich fuel air mixture and less oxygen availability result in more HC emission. Biodiesel blend shows reduced hydrocarbon at zero load in comparison to pure diesel. Possible reason is oxygenated biodiesel fuel and higher cetane number of biodiesel blend. JB15KB15 showed 13.21 % reduced HC emission than pure diesel. At full load, JB15KB15 has 6.1% lower HC emission than Diesel. In comparison of JB30 and KB30, combined biodiesel blend shows 1.28% lower HC emission at full Load. It may be due to different unsaturated hydrocarbon and viscosity blend.

4.2.2. Carbon mono oxide (CO) Emission. CO emission is the result of incomplete oxidation of carbon. CO emission increases with increasing load (Figure 7). Rich fuel air mixture and less time availability for combustion causes higher CO emission at full load. Biodiesel fuel has higher oxygen content and higher cetane number which causes complete combustion of fuel and thereby resulting in less CO emission than the diesel. Combined biodiesel blend JB15KB15 has 20% lower carbon emission than the diesel. Combined biodiesel blend and single biodiesel blend shows similar hydrocarbon emission while at higher load CO emission is marginally lower than the single blend of biodiesel.

4.2.3. Carbon dioxide (CO₂) Emission. CO₂ emission depends on extent of combustion and oxygen content available in the fuel. CO₂ emission increases with increasing load. At higher load, more fuel burnt and higher cylinder wall temperature result in complete combustion. Figure 8 shows the variation of CO₂ emission vs. load. Oxygenated biodiesel blend increases the possibility of complete combustion and therefore it has higher CO₂ emission. Biodiesel blend JB15KB15, JB20KB20, JB30 and KB30 has 1.8 %, 1.6 %, 1.6% and 1.7 % CO₂ emission respectively at half load but at full load rich fuel air mixture, less oxygen content and poor fuel atomization result in marginally higher CO₂ emission than pure diesel.
4.2.4. Nitrogen oxides (NO\textsubscript{x}) Emission. Figure 9 shows the effect load on NO\textsubscript{x} emission. NO\textsubscript{x} emission is mainly attributed to higher temperature during combustion. Temperature of cylinder increases with increasing load therefore NO\textsubscript{x} emission is higher. For biodiesel blend natural oxygen content and inherent availability of nitrogen from air increases the formation of Nitrogen oxide and Nitric oxide. Therefore combined blend shows higher NO\textsubscript{x} emission. At full load, JB15KB15 shows 4.32\% higher NO\textsubscript{x} emissions than diesel.

5. Conclusion

Detailed experimental analysis has been performed on single and combined biodiesel blend of Jatropha and Karanja. Physical and chemical properties of different blend were evaluated using ASTM standard method. Performance and emission parameter were recorded and analyzed. Following observations are summarized:

Physico-chemical property of combined and single blend of Jatropha and Karanja such as density, viscosity, cetane number, cloud point and pour point are within the limit of ASTM standard. Experimental result showed that break thermal efficiency increases with load. Combined biodiesel blend JB15KB15 shows 2.6\% lower thermal efficiency than diesel and marginally higher than single biodiesel blend. Break specific fuel consumption of biodiesel blend is higher due to lower heat content.

Figure 6. HC emission vs load

Figure 7. CO emission vs load

Figure 8. CO\textsubscript{2} emission vs load

Figure 9. NO\textsubscript{x} emission vs load
than diesel. Blend JB15KB15 has 12.9% higher fuel consumption than diesel at full load. Hydrocarbon (HC) and carbon monoxide (CO) emissions are lower than the pure diesel while NOx and CO2 emission is higher than diesel.

It is concluded that combined blend can be used an alternative fuel to increase the proportion of biodiesel blend. JB15KB15 as an alternative fuel can be used in diesel engine without modification.

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