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CI engine performance and emission analysis using Karanja Oil Methyl Ester with Exhaust Gas Recirculation

B. Pattanayak[1], S. K. Acharya[2], S. S. Mohapatra[3]

ABSTRACT: Biodiesels are alkyl esters of different vegetable oils. Many researchers have concluded that use of biodiesel as alternate fuel in CI engine reduces CO, HC and smoke emissions but increases NOx emission due to higher oxygen content of biodiesel as compared to diesel. Exhaust Gas Recirculation (EGR) is a suitable technique to reduce NOx emission from the engine. In this paper experimental analysis on effect of EGR with Karanja Oil Methyl Ester (KOME) is represented. The experiment showed that B20 of KOME with 10% EGR is the best fuel taking into account the performance parameters brake specific fuel consumption (BSFC), brake thermal efficiency (BTE) and emission parameters CO and HC, whereas NOx emission increases to a great extent.

Key words: KOME, BSFC, BTE, EGR.

1. Introduction

Diesel engines are hugely used worldwide in transportation, agriculture and power generation sector. The increased popularity of diesel engines as compared to gasoline engines is because of its greater thermal efficiency and better fuel economy. But higher NOx and particulate matter (PM) emission from diesel engine causes heavy environmental impact. Another major problem faced by mankind in this context is reduced availability or non availability of fossil fuel for future use. For reducing the emissions of diesel engine various technologies like turbo-charging, advanced high pressure injection, split injection, exhaust gas recirculation, injection timing reduction and water injection are used. Out of all the above techniques exhaust gas recirculation is a proper technique to reduce NOx emission. The unavailability of fossil fuel for combustion can be tackled by use of alternate fuel. Vegetable oils are preferred to be used as alternate fuels as they are renewable and many of their properties are similar to that of diesel fuel. Under Indian climatic conditions only non-edible vegetable oils can be used as alternate fuel which are produced in appreciable quantity and can be grown in large scale on non-cropped marginal lands and waste lands. India has more than 300 species of trees, which produce oil bearing seeds out of which non-edibles like Jatropha, Karanja and Mahua contains 30% or more oils in their seed, fruit or nut [1]. As per statistics available Karanja oil has got a potential of 135000 million tonnes per annum and only 6% is being utilized [2]. Hence Karanja vegetable oil is selected for this study.

1.1 Characteristics of Karanja (Pongamia Pinnata)

Karanja is a drought resistant, semi-deducious, nitrogen fixing leguminous tree. It grows about 15-20 meters in height. Cropping of pods and single almond size seed can occure by 4-6 years and yields 9-90 kg of seed. The yield potential per hectare is 900 to 9000 kg/hectare [2]. Karanja oil is derived from kernel of Karanja tree. The oil content of the kernel is 30-40%. Karanja oil contains oleic acid (44.5-71.3%) as major fatty acid followed by lenoleic (10.8-18.3%), palmitic (3.7-7.9%) and stearic (2.4-8.9%) acids [3].

1.2 Biodiesel from Karanja vegetable oil as alternate fuel

The direct use of Karanja vegetable oil can lead to problems like injector nozzle choking, improper combustion and high smoke emission due to its high density and viscosity. The density and viscosity of Karanja vegetable oil can be reduced in a certain method called transesterification to produce alternate fuel called biodiesel. Biodiesel is the monoalkyl esters of long chain fatty acids derived from renewable feed stocks such as vegetable oil. Although the heat of combustion is slightly lower than that of petro-diesel, there is no engine adjustment necessary and there is no loss in efficiency [4].

1.3 Exhaust Gas Recirculation (EGR)

Exhaust Gas Recirculation is a proper technique to reduce NOx emission of CI engine. In EGR method a part of exhaust gas is mixed with fresh air and recirculated back into the combustion chamber. The effect of EGR on NOx reduction can be attributed to the following three theories: (1) increased ignition delay (2) increased heat capacity and (3) dilution of the intake charge with inert gases [5]. Increased ignition delay reduces rate of heat release (ROHR) premixed peak reducing NOx emission. The increased heat capacity due to higher specific heat of CO2 and H2O compared to O2 and N2 results in lower flame temperature and hence lower NOx emission [6]. Due to dilution effect there is a decrease in inlet O2 concentration, whose principal consequence is deceleration of mixing between O2 and fuel resulting in lower flame temperature and lower NOx [7]. Tsolakis et al. [8] conducted experiments to study the combined effects of Rapeseed oil methyl ester (RME) biodiesel combustion with the incorporation of exhaust gas recirculation. He found that the use of EGR in the case of biodiesel fuelled engine resulted in the increase of the ignition delay and shifted the start and end of combustion to later stages in the compression and expansion stroke. Agarwal et al. [9] conducted experiments on the effects of performance, emission, deposits & durability of a CI engine on EGR & non-EGR mode. At low load the thermal efficiency in increased & BSFC is decreased by EGR use but

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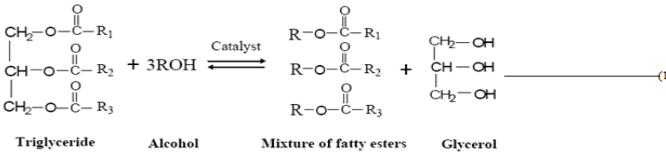
at high load they remain indifferent. The NOx emission decreases with EGR whereas HC, CO & soot emission increases. The carbon deposits on various engine parts is more with EGR so engine wear is more with EGR. At low load the thermal efficiency in increased & BSFC is decreased by EGR use but at high load they remain indifferent. The NOx emission decreases with EGR whereas HC, CO & soot emission increases. The carbon deposits on various engine parts is more with EGR so engine wear is more with EGR. H E Saleh [10] compared the performance and emission characteristic of jojoba methyl ester and diesel at constant speed with the use of EGR. Also the effect of cooled EGR at full of the engine was studied. He found that with the increase in EGR rate the exhaust gas temperature considerably reduced due to the reduction in flame temperature. NOx formation decreases but CO and HC emission increases with increase in EGR rate for Jojoba oil methyl ester. This is due to the reduction of flame temperature and low oxygen availability with exhaust gas recirculation.

2. Experimental method and materials

2.1 Biodiesel preparation and characterization

To prepare KOME, raw Karanja vegetable oil was purchased from market. The vegetable oil was filtered using a hand filter. To prepare KOME from the oil the acid value of the oil was measured using titration technique. The acid value of the oil was found to be 10.2 mgKOH/g. Acid value of Karanja oil generally comes near about 5.91 mgKOH/g [11]. The oil purchased from the market was prepared long back. This could be the reason behind the increased acid value of Karanja oil. The acid value of the oil is decreased and complete triglyceride is prepared by Esterification method. In esterification method acid catalyzed reaction of the oil with alcohol is done. To one lit of oil required amount of alcohol mixed with 5 to 10 mg of conc. H2SO4 is added. The reaction is carried out in biodiesel reactor. Samples are taken from the products of reaction in every half an hour and acid value is measured. The reaction is stopped when acid value of the oil comes below 5 mgKOH/g. The products of reaction are then allowed to be settled in a separating funnel. After 24 hours of settling triglyceride comes to the bottom of the funnel and unreacted alcohol comes to the top. The triglyceride of Karanja oil is then collected from the bottom of the separating funnel. The triglyceride of the oil is transesterified to produce biodiesel or Karanja oil methyl ester on the same reactor. In transesterification reaction 8 to 10mg of KOH alkali is mixed with required amount of methyl alcohol. This mixture is added to one lit of Karanja oil in the reactor. Then reaction is carried out at 600C with continuous stirring. The transesterification is represented as below in equation (1).



(1)

The products of the reaction is kept in the separating funnel and allowed to settle down. Glycerol is settled at the bottom of the separating funnel and collected. The top part of the funnel contains Karanja oil methyl ester or Karanja biodiesel. It is then water washed and heated to get pure Karanja biodiesel. Different properties of Karanja biodiesel is given in table 1.

Table-1: Different physical and thermal properties of Karanja biodiesel blend

Fuel blend	Sp.gravity	Kinematic viscosity(cSt) at 40ºC	Flash point (ºC)	Calorific value(MJ/kg)
100% diesel	0.832	1.9	64	42.21
B100	0.885	4.5249	187	36.12
B10	0.837	2.1831	72	41.582
B20	0.843	2.4164	79	40.911
B30	0.848	2.7149	80	40.298

2.2 EGR system

Appropriate plumbing is done for exhaust gas recirculation. Exhaust gases were tapped from exhaust pipe by means of a T-joint. One EGR valve is used to control the flow rate of exhaust gases. Then the gases pass through a diesel particulate filter which removes particulate matter from the exhaust gas. The filterized gas is passed through a surge tank which regulates its fluctuating flow. Then the gas pipe is connected with inlet flow passage where mixing of exhaust gases with fresh air occurs. Sufficient distance for through mixing of fresh air and exhaust gas were ensured. EGR amount was determined using the following expression.

The layout diagram of the engine with EGR system is given in fig. 1.

$$EGR = \frac{Mass\ of\ air\ admitted\ without\ EGR - Mass\ of\ air\ admitted\ with\ EGR}{Mass\ of\ air\ admitted\ without\ EGR} \times 100$$

The layout diagram of the engine with EGR system is given in fig. 1.

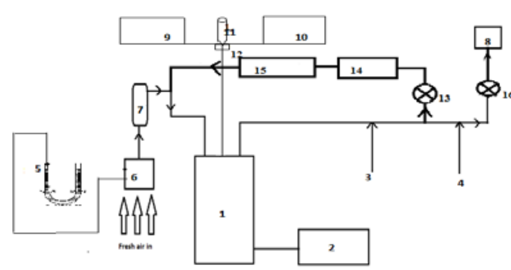


Fig. 1. Engine layout diagram with EGR system

1. Engine	7. Air filter	12. Controlling valve of fuel
2. Dynamometer	8. Muffler	13. EGR control valve
3. Exhaust gas pipe	9. Diesel fuel tank	14. Exhaust gas particulate valve
4. Exhaust gas analyser	10. Biodiesel fuel tank	15. Surge tank
5. U-tube manometer	11. Burette	
6. Air box		

2.3 Experimental engine Set-up and Methodology

To carry out the present study, a 5 hp diesel engine coupled with a hydraulic dynamometer was selected. The engine was a single cylinder, direct injection and water cooled diesel engine with a rated speed of 1500 rpm. Engine specification is given in table 2.

Table-2: General Specification of Engine test rig

Make	Kirloskar
Engine Type	Single cylinder, Vertical, Direct injection, Water Cooled
Bore	80 mm
Stroke Length	110 mm
Cubic Capacity	553 cc
RPM	1500
BHP	5hp
Compression Ratio	16.5 : 1
No.of strokes	4 strokes

In the present experimental set up, an air box of suitable volume (500 to 600 times the swept volume of the single cylinder engine) was used. The water head difference (hw) of U-tube manometer was calculated during engine running. From the head difference in the manometer, air flow rate was calculated. The fuel consumption of an engine is measured by determining the time required for consumption of a given volume of fuel. The mass flow rate of fuel consumption can be determined by the multiplication of volumetric fuel consumption and density. In the present set up, volumetric fuel consumption was measured by using a glass burette and stop watch. Engine exhaust emissions of HC, CO and NOx during experimentation were measured by Multi gas analyzer of AVL (digas 444) made. HC, CO are measured by NDIR method whereas NOx is measured by electro chemical method in the gas analyzer used. The reading of CO is measured in % by volume where as NOx and HC were measured in ppm using gas analyzer.

3. Result and Discussion

3.1 Engine performance analysis

3.1.1 Brake Specific Fuel Consumption (BSFC)

The variation of BSFC of diesel and different blends of KOME i.e. B10, B20 & B30 are represented in fig. 2. The BSFC is found to be maximum in case of diesel whereas it reduces in case of biodiesel. The higher density and viscosity is said to be the reason behind this. Minimum BSFC is found in case of B20. With increase in the percentage of biodiesel in the fuel again BSFC increases due to low calorific value of biodiesel. The comparison of BSFC for B20 blend with different EGR percentage is shown in fig. 3. BSFC mainly increases with the increase in EGR percentage. The reason behind this is with increase in EGR percentage availability of oxygen for combustion reduces. This reduction in oxygen availability causes incomplete combustion of fuel. So more amount of fuel burns to produce same amount of power.

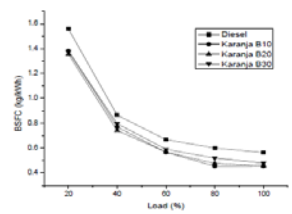


Fig. 2. Variation of BSFC with load for different fuels tested.

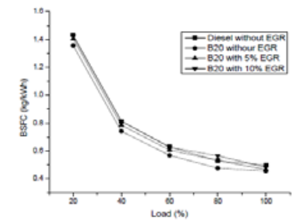


Fig. 3. Variation of BSFC for B20 with different EGR percentage

3.1.2 Brake Thermal Efficiency (BTE)

The fig. 4 represents the variation of BTE of diesel fuel and various blends of KOME with different loads. Brake thermal efficiency is found to be minimum for diesel fuel. Use of KOME blend as fuel increases the brake thermal efficiency of diesel engine due to the oxygen content of biodiesel which enhances proper combustion. BTE is found to be maximum for B20 blend at various loading conditions. But with further increase in percentage of biodiesel in the fuel the BTE value decrease due to the lower calorific value of Karanja biodiesel than diesel fuel. The comparison of BTE for B20 blend of biodiesel with different EGR percentage is represented in fig. 5. With increase in EGR percentage the BTE is found to be reducing as exhaust gas recirculation reduces oxygen availability for combustion which leads to incomplete combustion. So more amount fuel burns to produce the same amount power. BTE is found to be minimum for diesel with 10% exhaust gas recirculation.

3.2 Engine emission analysis

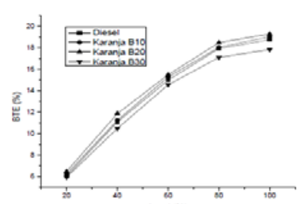


Fig. 4. Variation of BTE with load for different fuels tested.

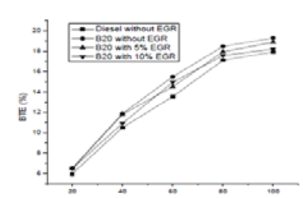


Fig. 5. Variation of BTE for B20 with different EGR percentage

3.2.1 CO emission

The variation of CO emission with different load is shown in the fig. 6. Maximum amount of CO emission is found with diesel fuel. With the use of KOME, CO emission is found to be reduced. The oxygen content of biodiesel helps in proper combustion which coverts Carbon Mono-oxide to Carbon Dioxide. Therefore use of different blends of biodiesel reduces CO emission. The comparison of CO emission for B20 blend with and without EGR is represented in fig. 7. With increase in EGR percentage CO emission is found to be increasing. With increasing the percentage of re-circulated exhaust gas the availability of oxygen for combustion reduces. Since proper combustion of the fuel does not occur, CO emission increases.

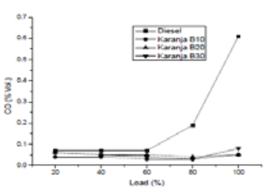


Fig. 6. Variation of CO with load for different fuels tested.

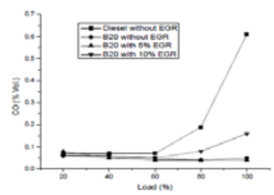


Fig. 7. Variation of CO for B20 with different EGR percentage

3.2.2 HC emission

The fig. 8 represents the variation of HC emission at different loading condition for diesel and various blends of KOME. With the increase in percentage of KOME in the fuel content HC emission decreases drastically due to the oxygen content of biodiesel which helps in proper combustion. HC emission is found to be maximum for diesel fuel whereas minimum for B30 at all loading condition. The comparison of HC emission for B20 blend with and without EGR is represented in fig. 9. It indicates that with increase in percentage of re-circulated exhaust gas HC emission increases due to improper combustion of the fuel which occurs due to unavailability of oxygen for combustion. With increase in exhaust gas less amount of fresh air is sucked into the engine. Minimum HC emission is found for B20 blend of KOME.

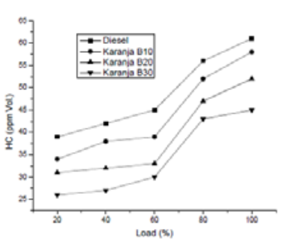


Fig. 8. Variation of HC with load for different fuels tested

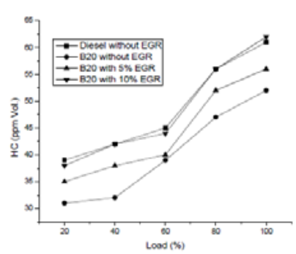


Fig. 9. Variation of HC for B20 with different EGR percentage

3.2.3 NOx emission

The fig. 10 represents the variation of NOx emission for diesel and different blends of KOME at various loading condition. NOx emission occurs if combustion occurs at high temperature in presence of excess oxygen. So increasing the percentage of biodiesel in the blend NOx emission increases as oxygen content of biodiesel is more than that of diesel. Use of B30 emits maximum NOx emission. The comparison of NOx emission for B20 blend of KOME is represented in fig. 11. With increasing the percentage of re-circulated exhaust gas NOx emission decreases. The specific heat of exhaust gas is more than that of atmospheric air. Due to this higher specific heat of exhaust gas the flame temperature reduces. This reduction in flame temperature reduces NOx emission as NOx emission occurs at higher temperature with availability of excess oxygen. Also recirculation of exhaust gas reduces the oxygen availability for combustion. Maximum reduction of NOx emission occurs in case of 10% EGR.

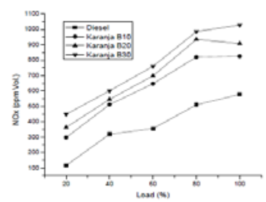


Fig. 10. Variation of NO_x with load for different fuels tested.

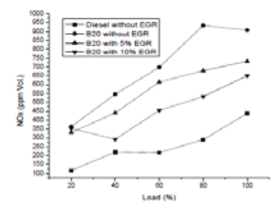


Fig. 11. Variation of NO_x for B20 with different EGR percentage.

4. Conclusion

The aim of our study was to reduce the emission level coming out of the engine and replace the conventional diesel fuel by some alternate fuel. From the experiment following points are concluded:

1. Alternate fuel can be produced from vegetable oil. Here biodiesel is used as alternate fuel. Karanja biodiesel is produced from Karanja vegetable oil by two stage transesterification process.
2. B20 of Karanja biodiesel shows the best performance characteristic among the blended fuels as with increase in percentage of blending the performance characteristic detoriates as calorific value of biodiesel is less than diesel fuel.
3. The use of biodiesel or blends of biodiesel reduces CO and HC emission from the engine as the oxygen content of biodiesel is more than that of diesel.
4. Use of Karanja biodiesel increases the NOx emission as combustion of biodiesel increases the flame temperature and also oxygen availability also more in case of biodiesel use.
5. Exhaust Gas Recirculation technique is used to reduce the NOx emission from engine.
6. Combined use of Karanja biodiesel and EGR technique reduces all the emission parameters from the engine.
7. Using EGR technique BSFC increases and BTE of the engine decreases.
8. Use of B20 of Karanja biodiesel with EGR may supplement the deficiencies of engine performance.

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