A COMPARATIVE EXPERIMENTAL STUDY BETWEEN THE BIODIESELS OF KARANJA, JATROPHA AND PALM OILS BASED ON THEIR PERFORMANCE AND EMISSIONS IN A FOUR STROKE DIESEL ENGINE

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ABSTRACT

The depletion of supply of fossil fuels and their increased cost has driven the search for alternative sources of energy. One of the best alternatives is mainly biodiesels obtained from different vegetable oils. The present study focuses on comparison of performance and emissions of a 4-stroke diesel engine run on three different biodiesels viz. Karanja, Jatropha and Palm separately. Short-term engine performance tests are conducted on a single-cylinder, four-stroke, direct-injection, variable compression ratio, compression ignition engine using the three biodiesels mentioned above at torques of 0, 5, 10, 15, 20 Nm, compression ratios of 14, 15, 16, 17, 17.5, 18 and injection pressures of 150, 200, 250 bar. The performance of the three biodiesels is compared on the basis of brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature and the emissions compared are hydrocarbons and oxides of nitrogen. It is found from the results that biodiesels differ very little from diesel in performance and are better than diesel with regard to hydrocarbon emissions. However oxides of nitrogen are found to be higher for biodiesels but not significantly higher when compared with diesel.

Keywords: biodiesels, Karanja, Jatropha, Palm, hydrocarbon, oxides of nitrogen, injection pressure, compression ratio.

INTRODUCTION

The search for alternative fuels which are eco-friendly and can be used as a substitute to conventional hydrocarbon based fuels is in demand due to concerns about depletion of fossil fuel reserves and also growing awareness against global warming [1]. One of the major alternative fuels which have been found to be eco-friendly is biodiesel. There are varieties of species from which biodiesels can be made available. Biodiesels produce carbon dioxide (CO_2) during combustion but through the process of photosynthesis they recycle CO_2. Hence they are called as carbon neutral. They are renewable and contain no sulphur. This characteristic of biodiesels can greatly reduce the existing environmental damage caused by acid rain [2]. If these biodiesels can successfully substitute conventional hydrocarbon based fuels in power generation sector they can be used as an emergency energy source. They will also play an eminent role in improving the financial status of the countries which are facing problems due to shortage of conventional fuel.

Biodiesel is defined as the mono alkyl esters of long chain fatty acids derived from renewable lipid sources [3]. Biodiesel is typically produced through the reaction of a vegetable oil or animal fat with methanol in the presence of a catalyst to yield glycerine and methyl esters [4, 5]. The methyl esters produced in this process are called biodiesels. This process of production of biodiesels is called transesterification [6, 7, 8, 9, 10, 11, 12]. In the last years, many researchers have conducted studies on various compression ignition engines using biodiesels.

Anand and Kannan [5] conducted an analysis of performance and emissions of a variable compression ratio diesel engine running at constant speed using cotton seed oil based biodiesel (COME) in blend proportion of 5% to 20% with diesel. Experimental investigation revealed that higher brake thermal efficiency and lower brake specific fuel consumption were observed when biodiesel proportions were less and compression ratios were 15 and 17. At 15:1 compression ratio, the brake specific fuel consumption was higher by 2.5% and 4.92% for the B5 and B20 blends respectively as compared to pure diesel. At 17:1 compression ratio, it was higher by 3.5% for both the B5 and B10 blends compared to diesel, whereas at 19:1 compression ratio, the B20 blend showed slightly better fuel economy. The maximum brake thermal efficiency values varied between 27.37-29.28% for COME-diesel blends and 26.65-27.92% for diesel fuel. Higher the blend proportion, a higher compression ratio was required to give similar performance hence the researchers concluded that bio-diesel running needs a higher compression ratio. NO_x emissions were found higher at higher compression ratio. The maximum NO_x emissions were found at compression ratio of 17 and the value was 205 ppm. The emissions of CO and CO_2 were slightly higher for lower blends. The emission of unburned hydrocarbons for all fuels was as low as 15-80 ppm, showing slightly milder values for COME-diesel blends compared to diesel fuel. All biodiesel blends tests revealed that biodiesels can be safely used in the engine requiring no hardware modifications.

Raheman and Ghadge [13] conducted performance tests on diesel engine with compression ratios varied in the range from 18 to 20 and injection timings of 35° to 40° before top dead centre. The brake specific fuel consumption increased, the exhaust gas temperature increased and the brake thermal efficiency decreased slightly with increase in bio-diesel proportion in the blend at lower compression ratios and injection timings considered, where as these factors showed a opposite trend at higher compression ratios and advanced injection timings. It was noticed that brake specific fuel consumption for B20 was 4.7% less than that of pure diesel. The mean brake thermal efficiency of B20 was 0.9 % higher than that of pure diesel. Based on the results of this study the performance of bio-diesel was found to be similar to diesel at higher compression ratios and advanced injection timings.

Radu and Mircea [14] investigated sunflower oil diesel blend in a three cylinder, 33 kW direct injection diesel engine. When blended with diesel, biodiesel gave better power development with reduced injection timing. The short term tests conducted showed no signs of adverse combustion chamber wear or increase in carbon deposits or contamination of lubricating oil. Blends upto B20 showed acceptable thermal efficiency and specific fuel consumption with carbon deposits for longer runs.

Mc Donnel [15] investigated the use of semi-refined rapeseed oil on a diesel engine. It was reported in this study that engine performance was better with 25% blend. The use of rapeseed oil over a longer period of time was found to shorten the injector life due to carbon build up even though there was no wear on the engine components or contamination of lubricating oil.

Pradeep and Sharma [16] conducted tests on a single cylinder diesel engine running on rubber seed oil and its blends with diesel. The brake thermal efficiency was found to be less for biodiesel blends compared to diesel. Higher combustion duration and lower heat release rate were recorded for biodiesel.

Yoshimoto [17] conducted an experiment on single cylinder diesel engine to investigate the spray characteristics, engine performance, emissions and combustion characteristics of water emulsions of the blended fuel with equal proportions of rapeseed oil and diesel. They found that the performance was improved with slightly increased emissions of CO and NO_x with knock free combustion.

The readings are recorded at various torques, compression ratios and injection pressures. The torque is varied between 0Nm to 20Nm in the steps of 5Nm, the compression ratio is varied between 14 to 18 in the steps of 1 and also a compression ratio of 17.5 is considered as it is the default compression ratio of the engine without the tilting cylinder block arrangement, the injection pressure is varied between 150 to 250 bar in the steps of 50 bar.

KARANJA, JATROPHA AND PALM BIODIESELS

Karanja is a tree which needs no pesticides for growing plantations and average rainfall required is 500-2500mm. The plant life is 80-100 years and seeds start yielding at 5th/6th year onwards and around 8/10 years onwards gives income up to about $450 per acre, per year. Karanja trees can be normally planted along the highways, roads and canals to stop soil erosion and they also have potential to grow in wastelands. If the seeds fallen along the road sides are collected and oil is extracted at village level expellers thousands of tons of oil will be available.

Jatropha is a large shrub which can be grown in low and high rainfall areas either in the farms as a commercial crop or on the boundaries of fields as a hedge. It can be cultivated successfully with an average rainfall of 500-1200mm. The plant life is around 50 years and the plant starts fruiting after 2 years. The expected seed yield from 6th year onwards is 2500-4000 kg per hectare per year.

Palm is suitable for tropical regions, with hot and humid climate, high precipitation and is well distributed throughout the year. In a year it is able to produce about three to six tons of oil per hectare. Moreover, it has the advantage of being a perennial culture, which means that there is no interval between harvests. The palm produces fruits during the entire year. Palm produces two types of oils: palm oil and palm oil kernel. The first one is extracted from the fleshy part of fruit and the latter is derived from the fruit kernel. The oil used in this study is the one obtained from fleshy part.

The properties of Karanja, Jatropha and Palm biodiesels used for the present study are shown in Table-1. These properties conform to the standards specified in ASTM-D-6751.

Table-1. Properties of karanja, jatropha and palm biodiesels.

Properties	Karanja biodiesel	Palm biodiesel	Jatropha biodiesel	Diesel	ASTM D 6751-09
Density (kg/m^3)	874	850	862	830	Not mentioned
Calorific value (kJ/kg)	39292	37800	39230	43000	Not mentioned
Viscosity @40 ^{0}C (cSt)	5.21	4.32	4.8	2.75	1.9-6.0
Cetane number	51	55	51	45	Not mentioned
Flash point (^{0}C)	160	167	135	74	130 min

Present study

In the present study, constant speed runs are conducted on a variable compression ratio, four stroke, direct injection, diesel engine using three different biodiesels as fuels. The three biodiesels used for the study are Karanja (KME), Jatropha (JME) and Palm (PME) biodiesels. The data obtained by using these three biodiesels is compared with each other and with the baseline data obtained using conventional diesel (DO).

EXPERIMENTAL TEST RIG

The specifications of the engine on which the present investigations were carried out are given in Table-2 and the experimental set-up is shown in Figure-1. The engine is coupled to an eddy current dynamometer. The output from the dynamometer is fed to the load cell which is strain gauge type for measuring the torque applied to the engine. The make and model of load cell, pressure sensors and exhaust gas analyzer is shown in Table-3.

Table-2. Specifications of the engine.

Engine	Make Kirloskar, type 1 cylinder, 4 stroke diesel, water cooled, power 3.5 kW at 1500 rpm, stroke 110 mm, bore 87.5 mm. 661 cc, CR 17.5, modified to VCR engine CR range 12 to 18
Stroke and bore	87.5mm x 110mm
Rated power	3.5 kW at 1500 rpm
Load/torque at rated power	12 kg/20Nm
Injection pressure	210 bar
Compression ratio range	14-18

Table-3. Make and model of other components of test rig.

Load cell	Make : Sensotronics, model 60001
Cylinder pressure sensor	Make: PCB piezotronics Inc, Model - SM108A02
Fuel pressure sensor	Make: PCB piezotronics Inc, Model - SM111A22
Exhaust gas analyzer	Make: INDUS Scientific private limited; Model - PEA 205

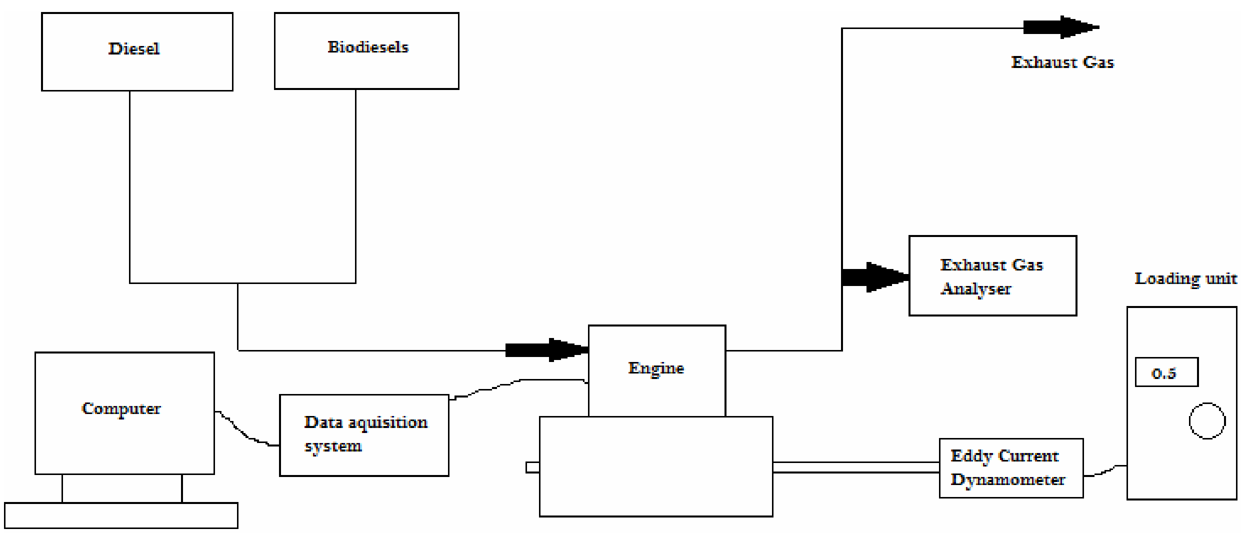

Figure-1. Experimental test rig.

The engine is installed with piezo-sensors for measurement of injection pressure (Fuel pressure sensor) and cylinder pressure (Cylinder pressure sensor). The fuel pressure sensor is mounted on the fuel line near the injector for measuring injection pressure and cylinder pressure sensor is mounted in the cylinder head for measurement of cylinder pressure. The signals from the pressure sensors are interfaced to the computer through a data acquisition system. Windows based software package “EnginesoftLV” is used for evaluation of performance. The compression ratio is changed online without altering the combustion chamber geometry by using a specially designed tilting cylinder block arrangement. The fuel is delivered by an in line fuel injection pump with the initial fuel delivery starting at 23^0 before top dead centre (BTDC). The setup also has transmitters for air and fuel flow measurements. Rotameters are provided for cooling water and calorimeter water flow measurement. The exhaust gas is analyzed using an exhaust gas analyzer. The analyzer uses the principle of Non-Dispersive Infra Red (NDIR) technique for measurement. The emissions measured are hydrocarbons and oxides of nitrogen in ppm.

RESULTS AND DISCUSSIONS

The thermal performance study on the diesel engine using DO, KME, JME, PME is carried out with respect to the effect of torque, compression ratio (CR), injection pressure (IP) on brake specific fuel consumption (BSFC), brake thermal efficiency (BTHE), exhaust gas temperature (EGT). Similarly, exhaust emissions such as unburned hydrocarbons (HC) and nitrogen oxide (NO_x) are experimentally analyzed.

PERFORMANCE CHARACTERISTICS

Brake specific fuel consumption (BSFC)

The comparison of the variation of BSFC in kg/kWh with the varying torque during engine operation using KME, JME, PME and DO is given in Figure-2. The graph shown is for a constant CR of 18 and IP of 200 bar. As expected, BSFC decreases gradually with increasing torque. At a torque of 5 Nm, BSFC for KME, JME and PME is higher by about 17%, 33% and 41%, respectively in comparison with that for DO. For torques of 10Nm and 15Nm, BSFC is found to be respectively higher by about 9% and 6% for KME, about 16% and 11% for JME and 13.7% and 20.8% for PME. However, BSFC is found to be of almost the same magnitude for all the fuels when the torque on the engine is 20 Nm. The main reason for lower BSFC with high torque could be that percent increase in fuel required to operate the engine is less than the percent increase in brake power due to relatively less portion of the heat losses at higher torques.

The higher BSFCs for KME, JME and PME can be related, reasonably, to the lower calorific value of the biodiesels. Due to lower calorific value of biodiesels, more biodiesel is consumed in order to meet the load demand.

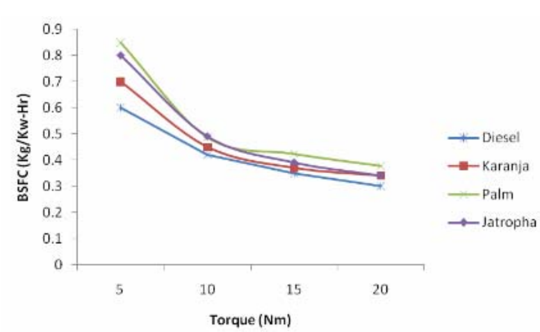

Figure-2. Variation of BSFC with torque for the tested fuels.

The variation of BSFC with CR at a constant torque of 20Nm and IP of 200bar for the engine operated with KME, JME and PME are compared with that when engine operated with DO in Figure-3. It is observed that BSFC for all the fuels have similar trends of variation with CR and is decreasing very sharply over the range of CR under consideration. The BSFC was found to be the least at CR of 18 for all the fuels tested. With the increase in CR from 14 to 18 the BSFC decreases by 14.7%, 17.5% and 2.6% for KME, JME and PME respectively. The BSFC is maximum for KME at 14CR.

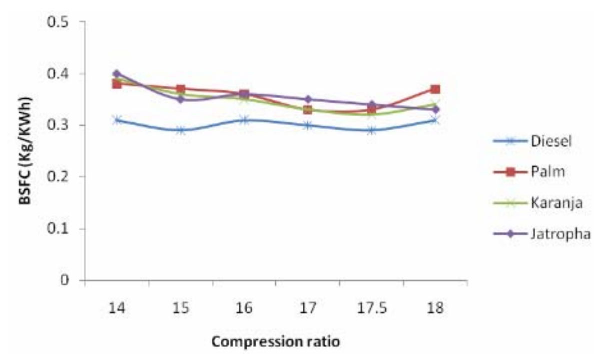

Figure-3. Variation of BSFC with CR for tested fuels.

Figure-4 represents the variation of BSFC with IP at torque of 20N-m and CR of 18. With the increase in IP, BSFC is found to decrease for all the fuels tested although the decrease is found to be marginal. The decrease in BSFC may be due to a reason that with increase in IP, fuel is atomized to a higher degree and hence the power demand is met with less amount of fuel due to better combustion. At tested maximum torque of 20Nm and CR of 18, BSFC for KME, JME and PME are found to be higher by 0.02 Kg/kW-Hr, 0.04 Kg/kW-Hr and 0.05 Kg/kW-Hr, respectively as compared to that of DO at an IP of 250 bar.

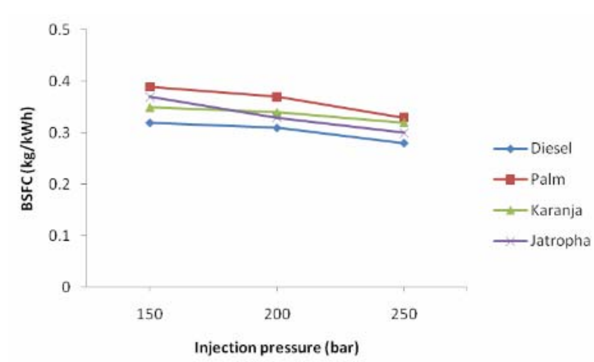

Figure-4. Variation of BSFC with IP for tested fuels.

Brake thermal efficiency (BTHE)

Figure-5 shows the effect of torque on brake thermal efficiency (BTHE) of the engine when fuelled with DO, KME, JME and PME separately. The graph shown is for a constant CR of 18 and IP of 200 bar. There

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is an improvement in BTHE with increasing torque. The highest value of BTHE is obtained for DO, KME, JME and PME at a full torque of 20Nm. The lower calorific value and higher viscosity of biodiesels compared to that of diesel are responsible for low BTHE of biodiesels. The higher viscosity of biodiesel is the cause for poorer mixture formation in the cylinder. The BTHE values for all the biodiesel tested are very close to each other. The highest value of BTHE for KME, JME and PME is less by only 2.6%, 5.94% and 2.58% than that for DO, respectively.

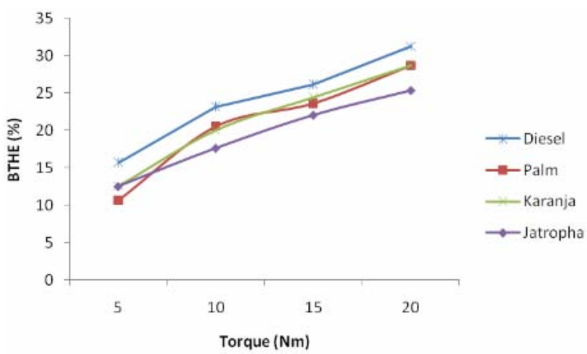

Figure-5. Variation of BTHE with torque for tested fuels.

Figure-6 shows BTHE values at full torque of 20Nm and IP of 200bar for different CRs for KME, JME, PME and DO. The BTHE at full load is found to be highest for the CR of 18 for all the fuels tested. This may be due to the high temperature of compressed air which leads to better combustion of fuel. At lower CR, there is large difference between the values of BTHE of all the biodiesels tested. As the CR increases the deviation between the fuels reduces and finally at highest CR (CR of 18) the values of BTHE for all the biodiesel are almost same. At CR of 14, the BTHE of KME, JME and PME are 6.45%, 3.46% and 4.33% lower compared to BTHE of DO. This may be the consequence of higher viscosity of biodiesels which leads to poorer mixture formation. However at CR of 18 all the biodiesels perform very close to diesel showing a deviation of only 0.5% to 1%.

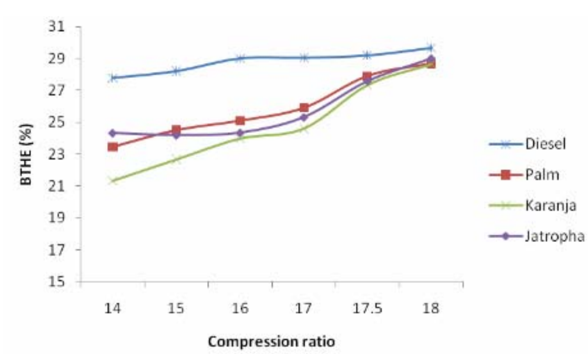

Figure-6. Variation of BTHE with CR for tested fuels.

The variation of BTHE with increasing IP at a constant torque of 20Nm and CR of 18 is as shown in Figure-7. At higher IPs the degree of complete combustion of fuel is more because of higher degree of atomisation. This results in higher BTHE at higher IP. When the IP increases from 150 bar to 250 bar the BTHE increases by 1.45 %, 0.66 %, 1.2 % and 0.95 % for DO, KME, JME and PME, respectively.

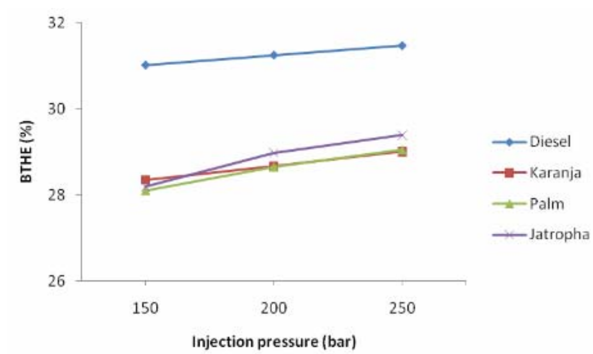

Figure-7. Variation of BTHE with IP for tested fuels.

Exhaust gas temperature (EGT)

The EGT varying with torque for the fuels tested at a CR of 18 and IP of 200 bar is shown in Figure-8. The high EGTs are observed when engine runs with DO as fuel and at higher torques. High EGTs are an indication of incomplete combustion of fuel inside the cylinder. Due to the presence of about 9-10% oxygen in biodiesels, the combustion of biodiesels is complete and hence EGTs for biodiesel are generally less as compared to that for DO which can be seen from Figure-8. The highest value of EGT for DO, KME, JME and PME are 350.75^{0}C, 343.77^{0}C, 319 ^{0}C and 329.91^{0}C respectively. Over the range of torques varied it is observed that the EGT values are almost same for all the biodiesels and the very less variation observed may be due to experimental perturbations.

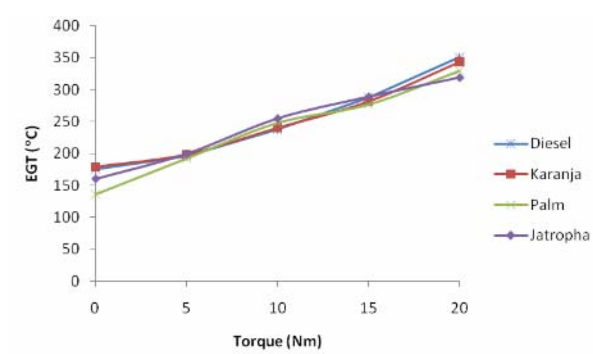

Figure-8. Variation of EGT with torque for tested fuels.

The effect of CR of the engine on EGT is as shown in Figure-9. As already discussed, higher CR leads to better combustion of fuel and hence it can be observed from the figure that EGT for all the tested fuels decreases

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with increasing CR. The lowest EGT value is observed at CR 18. With the increase in CR from 14 to 18, EGT reduces by 17.2%, 17.3%, 20.19% and 17.13% for DO, KME, JME and PME, respectively.

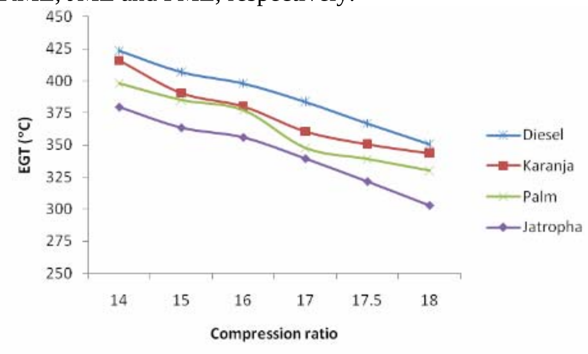

Figure-9. Variation of EGT with CR for tested fuels.

Figure-10 shows that EGT increases with increase in IP. This may be because of more heat being generated inside the engine cylinder due to complete combustion of fuel. Since the calorific value of biodiesel is less the heat generated inside the cylinder is also less and hence EGT is less for biodiesel. Also the combustion of biodiesels is more complete due to the presence of indigenous oxygen in them which results in less EGT. EGT is found to decrease by almost 50 ^{0}C for all fuels when IP is increased from 150 to 250 bar. Further, the lowest values of EGT for KME, JME and PME are found to be 5.67%, 10.66% and 6.77% less, respectively than DO.

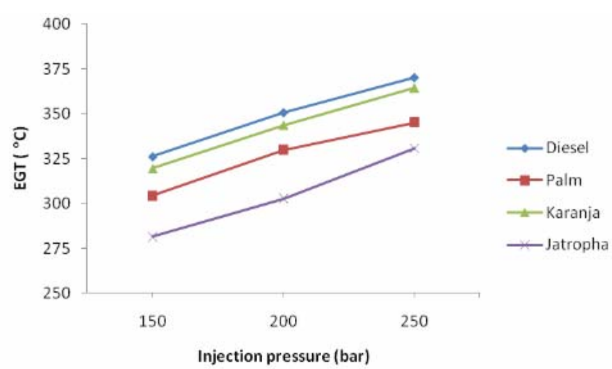

Figure-10. Variation of EGT with IP for tested fuels.

EMISSION CHARACTERISTICS

Oxides of nitrogen (NO_x)

The comparison of the variations of NO_x emissions with respect to torque, CR and IP for KME, JME, PME and DO are shown in Figures 11, 12 and 13, respectively. NO_x emissions increase with increase in torque for all the fuels at a constant CR of 18 and IP of 200bar. KME, JME and PME are fuels with higher oxygen content than DO. Hence, when more oxygen is available during combustion of fuel, the nitrogen from air readily gets combined with oxygen and forms compounds like nitrogen oxide and nitric oxide. NO_x emissions are almost same for KME, JME and PME as compared to that of DO for the entire range of torque under consideration. At a torque of 20Nm, the NO_x levels measured in ppm for KME, JME and PME are 179, 170 and 176ppm, respectively whereas it is 160ppm for DO.

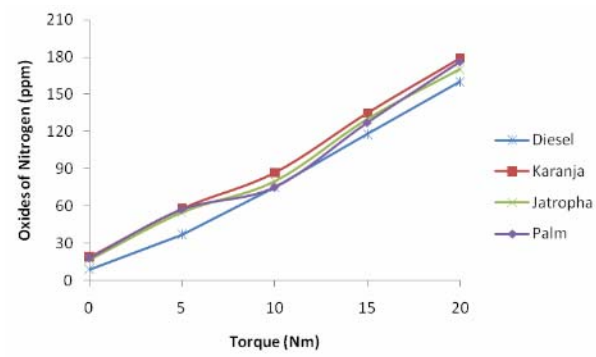

Figure-11. Variation of oxides of nitrogen with torque for tested fuels.

Opposite trend of variation of NO_x emissions with CR between biodiesels and DO can be seen in Figure-12. The figure shown is for torque of 20Nm and IP of 200bar. The trend of increase of NO_x emissions with CR for biodiesels may be attributed to the presence and greater availability of oxygen in them. At lower CR, less oxygen is available from fuel to form NO_x due to incomplete combustion of fuel which is due to less heat of compressed air. At higher CR, NO_x emissions for biodiesels are found to be higher as compared to that of DO because of greater availability of oxygen due to higher heat of compressed air which initiates early combustion reducing the ignition delay and ensuring complete combustion. As the CR increases from 14 to 18 the NO_x emissions increase from 132ppm to 166ppm for KME, 130ppm to 162ppm for JME and 135ppm to 170ppm for PME while it reduces from 225ppm to 125ppm for diesel.

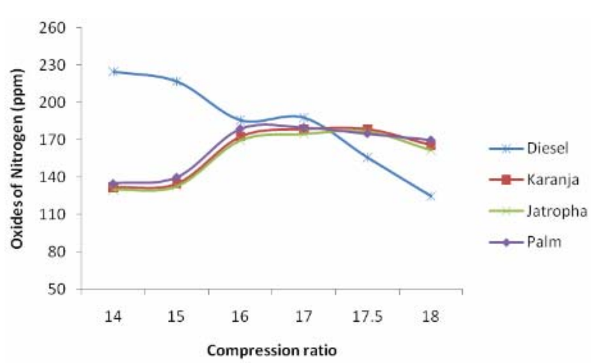

Figure-12. Variation of oxides of nitrogen with CR for tested fuels.

From Figure-13, which shows the variation of NO_x emissions with IP at torque of 20Nm and CR of 18, it can be seen that NO_x emissions for DO are found to be

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less as compared to KME, JME and PME at all the three IP tested. The figure shows that NO_x emissions increase by 26.08%, 37.31%, 32.6% and 43.41% for DO, KME, JME and PME, respectively when IP is increased from 150bar to 250bar.

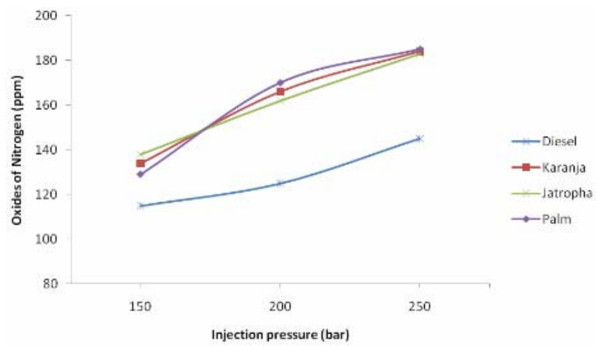

Figure-13. Variation of oxides of nitrogen with IP for tested fuels.

Unburnt hydrocarbon (HC)

In general, as can be seen in Figure-14, HC emissions for all the fuels increase with torque with an order of magnitude less for KME, JME and PME as compared to DO. This can again be attributed to the higher oxygen content in biodiesels due to which smooth and complete combustion of biodiesels take place inside the cylinder. As the torque is increased the variation in HC emissions for biodiesels is not uniform. As seen from the graph the peak HC emissions are at a torque of 5Nm for PME, 10Nm for JME and 20Nm for KME and these peak values correspond to 4ppm for all the biodiesels. The highest HC emissions for DO are observed at a torque of 20 Nm and the value correspond to 8ppm which is higher compared to that for biodiesels.

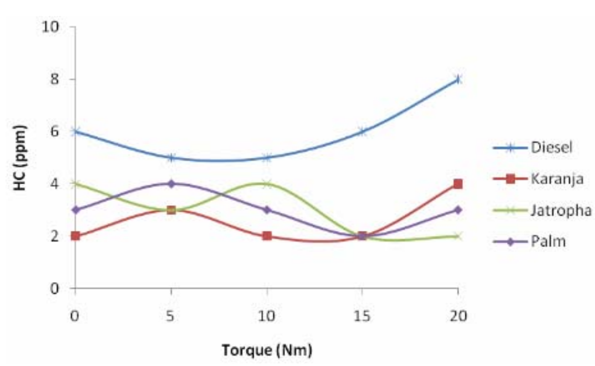

Figure-14. Variation of HC with torque for tested fuels.

Due to better combustion of fuel taking place at higher CR, HC emissions are found to be less for biodiesels (Figure-15). As the CR increases from 14 to 18 the HC emissions reduces by 13ppm for DO, 10ppm for KME, 7ppm for JME and 11ppm for PME. At a CR of 14, the lowest HC emission is observed for JME and the value corresponds to 10ppm while at 18CR the HC emission is found lowest for KME and PME corresponding to 2ppm. For DO the HC emission are 18ppm at 14CR and 5ppm at 18CR.

With higher IP, better combustion of fuel takes place (Figure-16) and hence less HC emissions are observed. The HC emissions reduce by 13ppm, 7ppm, 7ppm and 9ppm for DO, KME, JME and PME, respectively when the IP is increased from 150bar to 250bar.

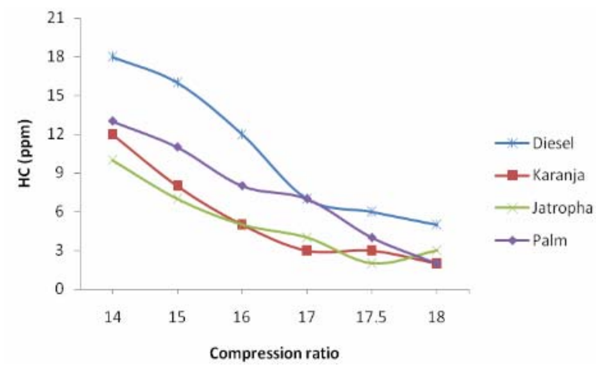

Figure-15. Variation of HC with CR for tested fuels.

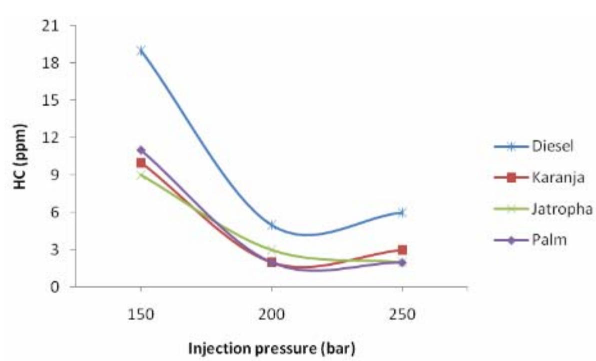

Figure-16. Variation of HC with IP for tested fuels.

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CONCLUSIONS

The following conclusions can be drawn from the results obtained in the experiments conducted using biodiesels of Karanja, Jatropha and Palm oils.

- Biodiesel produced from Karanja, Jatropha and Palm oils can be successfully used as alternative fuels in existing diesel engines without any major modifications.
- The properties of Karanja, Jatropha and Palm biodiesels which are prepared through a series of processes including transesterification, are within the specifications and close to conventional diesel.

- The BSFC decreases with increase in torque, CR and IP for all fuels. It is lowest for 20Nm, 18CR and 250IP. The difference between fuel consumption of biodiesel and diesel is not significant.
- At full torque, the BTHE for Karanja, Jatropha and Palm is less by 2.6%, 5.94% and 2.58% than that for diesel respectively. The biodiesels have lower heating value due to which lower BTHE is obtained for biodiesels. With the increase in CR from 14 to 18, the BTHE increased up to 7% for all fuels. When the IP increases from 150 bar to 250 bar the BTHE increases by 1.45%, 0.66%, 1.2% and 0.95% for DO, KME, JME and PME respectively.
- The EGT for biodiesels is slightly less as compared to that for diesel. The highest value of EGT for DO, KME, JME and PME are 350.750C, 343.770C, 319 0C and 329.910C, respectively. The variation in EGT is proportional to torque and IP and inversely proportional to CR.
- It is observed that HC emissions are less in case of biodiesel whereas NOx is more with biodiesel. There is reduction in HC emissions with the increase in CR and IP whereas no significant variation is observed with increase in torque. At a condition of 20Nm, 18CR and 200IP the HC emissions are 5, 2, 3 and 2 ppm for diesel, Karanja, Jatropha and Palm biodiesels respectively. At a torque of 20Nm, the NOx levels measured in ppm for KME, JME and PME are 179, 170 and 176 ppm respectively. The NOx emissions increase with increase in torque, CR and IP.

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