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

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ABSTRACT
Stringent emission norms and depletion of oil resources have led the researchers to find alternative fuels for internal combustion engines. The main objectives of this study are to investigate the effects of using different types of fuel samples in terms of emission characteristics and feasibility of using alternative fuels. A total of four fuel samples, such as 100% diesel fuel (D100); 20% jatropha biodiesel and 80% diesel fuel (JB20); 20% palm biodiesel and 80% diesel fuel (PB20); and 10% jatropha biodiesel, 10% palm biodiesel and 80% diesel fuel (JPB20) respectively were used to analyze the performance on the basis of brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature and exhaust emissions referring to carbon monoxide, carbon dioxide, and oxides of nitrogen. Short-term engine performance tests are conducted on a single-cylinder, four-stroke, variable compression ratio, compression ignition engine using the four fuel samples mentioned above at load of 0, 2, 4, 6, 8 Kg and at compression ratios of 12, 14, 16. It is found from the results that biodiesels differ very little from diesel in performance and are better than diesel with regard to hydrocarbon and carbon monoxide emissions. However oxides of nitrogen are found to be higher for biodiesels but not significantly higher when compared with diesel.

Keywords: *Diesel Engine, Jatropha Biodiesel, Palm Biodiesel, Engine performance, Exhausts Emissions*

1. INTRODUCTION

The scarcity of conventional fossil fuels, growing emissions of combustion generated pollutants, and their increasing costs will make biomass sources more attractive [1]. On the other hand, biomass use, in which many people already have an interest, has the properties of being a biomass source and a carbon-neutral source [2-4]. Experts suggest that current oil and gas reserves would suffice to last only a few more decades. To meet the rising energy demand and replace reducing petroleum reserves, fuels such as biodiesel and bioethanol are in the forefront of alternative technologies. Accordingly, the viable alternative for compression-ignition engines is biodiesel [5-7].

Biodiesel is the monoalkyl esters of vegetable oils or animal fats. Biodiesel is the best candidate for diesel fuels in diesel engines. Biodiesel burns like petroleum diesel as it involves regulated pollutants. On the other hand biodiesel probably has better efficiency than gasoline. Biodiesel also exhibits great potential for compression-ignition engines. Diesel fuel can also be replaced by biodiesel made from vegetable oils. Biodiesel is now mainly being produced from soybean, rapeseed, and palm oils. The higher heating values (HHVs) of biodiesels are relatively high. The HHVs of biodiesels (39 to 41 MJ/kg) are slightly lower than those of gasoline (46 MJ/kg), petro diesel (43 MJ/kg), or petroleum (42 MJ/kg), but higher than coal (32 to 37 MJ/kg) [8-11].
Biodiesel is pure, or 100%, biodiesel fuel. It is referred to as B100 or "neat" fuel. A biodiesel blend is biodiesel blended with petro diesel. Biodiesel blends are referred to as BXX. The XX indicates the amount of biodiesel in the blend (i.e., a B80 blend is 80% biodiesel and 20% petro diesel).

The majority of energy demand is fulfilled by conventional energy sources like coal, petroleum, and natural gas. Petroleum-based fuels are limited reserves concentrated in certain regions of the world. These sources are on the verge of reaching their peak production. The scarcity of known petroleum reserves will make renewable energy sources more attractive [12]. World energy demand continues to rise. The most feasible way to meet this growing demand is by using alternative fuels. One such fuel that exhibits great potential is biofuel, in particular biodiesel [13-14]. The term bio-fuel can refer to liquid or gaseous fuels for the transport sector that are predominantly produced from biomass [15]. Biofuels include energy security reasons, environmental concerns, foreign exchange savings, and socioeconomic issues related to the rural sector. In developed countries there is a growing trend toward using modern technologies and efficient bioenergy con-version using a range of biofuels, which are becoming cost wise competitive with fossil fuels [16].

It is well known that transport is almost totally dependent on fossil-, particularly petroleum-, based fuels such as gasoline, diesel fuel, liquefied petroleum gas (LPG), and natural gas (NG). An alternative fuel to petro diesel must be technically feasible, economically competitive, environmentally acceptable, and easily available. The current alternative diesel fuel can be termed biodiesel. Biodiesel use may improve emissions levels of some pollutants and deteriorate others. However, for quantifying the effect of biodiesel it is important to take into account several other factors such as raw material, driving cycle, vehicle technology, etc. Use of biodiesel will allow a balance to be sought between agriculture, economic development, and the environment [17-19].

The production of palm biodiesel is in excess in some countries, whilst in other countries research is focused on jatropha biodiesel, jatropha biodiesel, could be blended with palm methyl ester [20]. Jatropha biodiesel has poor oxidation stability with good low temperature properties and on the other hand, palm biodiesel has good oxidative stability, but poor low temperature properties. The combination of jatropha and palm produces an additive effect on these two critical properties of biodiesel. Since palm biodiesel has poor low temperature properties like cloud point and pour point, the blending of jatropha biodiesel would improve these. Therefore, optimum mixture of jatropha biodiesel with palm biodiesel can lead to a synergistic combination with improved oxidation stability and low temperature properties.

2. BIODIESEL PREPARATION METHODOLOGY

First of all sample jatropha oil and palm oil was to be collected from various sources. This sample was taken to MERADO (Mechanical Engineering Research and Development Organisation) Laboratory situated at Ludhiana (Punjab). The main parameter for any sample of vegetable oil or animal fat to convert it into biodiesel is to check its FFA (free fatty acid) value. FFA value should be less than 0.5 for any sample of vegetable oil or animal fat to convert it into biodiesel. If the FFA value of any sample is greater than 0.5 than it cannot be converted into the biodiesel and hence rejected. If the FFA value is 0.5 or less then only it can be converted into biodiesel. Otherwise the free fatty acid value can also be decreased to some extent by the use of some acid like sulphuric acid (H_2SO_4). Now then take the required quantity of the sample of oil and convert that oil sample to Biodiesel by the process known as transesterification. After the biodiesel was prepared from transesterification process, the viscosity was the main parameter to be checked to use it as a fuel for an internal combustion engine. The viscosity of biodiesel should be equal to or less than 5.0 centiStokes(cSt) to use it as a fuel in internal combustion engine. The yield of biodiesel oil should also be checked whether it is appropriate or not.

2.1. Biodiesel preparation

As two different oils were used for the extraction of biodiesel, thus two different processes were employed. Because of high Free Fatty Acid (FFA) content for Jatropha oil a 2-stage transesterification process which includes an acid catalyzed transesterification followed by a base catalyzed tranesterification was carried out. Whereas for Palm oil a single stage base catalyzed transesterification was carried out.

2.1.1. Jatropha biodiesel preparation

First stage (Acid catalyzed transesterification):
Some known quantity of crude oil was taken in a conical flask. The oil in the flask was then heated on a heating plate upto a temperature of 60°C. A mixture of known quantity of sulphuric acid (H_2SO_4) as acid catalyst and methanol was then mixed with the preheated crude oil. The preheated oil mixture was then subjected to 1 hour constant stirring at a constant temperature of 60°C inside a water bath shaker. After 1 hour of constant stirring the mixture was poured into a separating funnel for impurities to settle down. After 4-5 hours the settled down impurities were separated from the remaining oil.

Second stage (Base catalyzed transesterification):
Remaining oil quantity was measured and again heated upto 60°C. A mixture of known quantity of Potassium hydroxide (KOH) as base catalyst and methanol was then mixed with the remaining preheated oil. The preheated oil mixture was then again subjected to 1 hour constant stirring at a constant temperature of 60°C inside a water bath shaker. After 1 hour of constant stirring the mixture was poured into a separating funnel for glycerol to settle down. After 2-3 hours settled down glycerol was separated and removed. Remaining is methyl ester (biodiesel) of crude jatropha oil (Yield 82%) which is further purified through washing and drying for removal of excess KOH, methanol and water.

2.1.2. Palm biodiesel preparation

Single stage (Base catalyzed transesterification):

Some known quantity of palm oil was taken in a conical flask. The oil in the flask was then heated on a heating plate upto a temperature of 60°C. A mixture of known quantity of Potassium hydroxide (KOH) as base catalyst and methanol was then mixed with the oil. The preheated oil mixture was then subjected to 1 hour constant stirring at a constant temperature of 60°C inside a water bath shaker. After 1 hour of constant stirring the mixture was poured into a separating funnel for glycerol to settle down. After 2-3 hours settled down glycerol was separated and removed.

2.2 Fuel characterization

The characteristic fuel properties of Palm oil and biodiesel were determined in accordance with standards of Bureau of Indian Standards, New Delhi and the Institute of Petroleum, London.

Table 1. Properties of diesel, jatropha biodiesel and palm biodiesel

Properties	**Diesel**	**Jatropha Biodiesel**	**Palm Biodiesel**
Relative density at 15^0C	0.839	0.877	0.864
Kinematic viscosity at 38^0C (cS)	3.12	3.45	4.41
Cloud point (^{0}C)	2.6	4	-6
Pour point (^{0}C)	-2.0	0	-12
Flash point (^{0}C)	54.3	160	181
Fire point (^{0}C)	59.4	165	186
Carbon residue content (%)	0.16	0.03	0.07
Ash content (%)	0.0080	0.0200	0.0066

2.3 Experimental methodology

After the biodiesel were prepared, four fuel samples, such as 100% diesel fuel (D100); 20% jatropha biodiesel and 80% diesel fuel (JB20); 20% palm biodiesel and 80% diesel fuel (PB20); and 10% jatropha biodiesel, 10% palm biodiesel and 80% diesel fuel (JPB20) respectively. For a short term time period up to B20 blend can directly be used in an internal combustion engine without any further modification in the engine [4]. Pictorial view of variable compression ratio compression ignition engine setup along with the online performance evaluation system is shown in Plate 1. A tilting cylinder block arrangement was used for varying the compression ratio without stopping the engine. Setup was provided with necessary instruments for combustion pressure and crank-angle measurements. These signals were interfaced to computer through engine indicator for P–V diagrams. Provision was also made for interfacing airflow, fuel flow, temperatures and load measurement. The setup has stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters were provided for cooling water and calorimeter water flow measurement. Lab view based Engine Performance Analysis software package "Enginesoft" was provided for on line performance evaluation. Emission characteristic were estimate with the aid of FGA (Flue Gas Analyzer) and HA (Horiba Analyzer).

Plate 1. Variable compression ratio compression ignition engine experimental setup

Table 2. Detailed specification of engine setup

Components	**Specification**
Product	VCR Engine test setup 1 cylinder, 4 stroke, Diesel (Computerized)
Product Code	234
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
Dynamometer	Type eddy current, water cooled, with loading unit
Propeller Shaft	With universal joints
Air Box	M S fabricated with orifice meter and manometer
Fuel Tank	Capacity 15 lit with glass fuel metering column
Calorimeter	Type Pipe in pipe
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.
Piezo Powering Unit	Make-Cuadra, Model AX-409.
Digital Milivoltmeter	Range 0-200mV, panel mounted
Temperature Sensor	Type RTD, PT100 and Thermocouple, Type K
Temperature Transmitter	Type two wire, Input RTD PT100, Range 0–100 Deg C, Output 4–20 mA and Type two wire, Input Thermocouple, Range 0–1200 Deg C, Output 4–20 mA
Load Indicator	Digital, Range 0-50 Kg, Supply 230VAC
Load Sensor	Load cell, type strain gauge, range 0-50 Kg
Fuel Flow Transmitter	DP transmitter, Range 0-500 mm WC
Air Flow Transmitter	Presure transmitter, Range (-) 250 mm WC
Software	“EnginesoftLV” Engine performance analysis software
Rotameter	Engine cooling 40-400 LPH; Calorimeter 25-250 LPH
Pump	Type Monoblock

3. RESULT AND DISCUSSION

3.1. Performance characterization

3.1.1. Effect of load on brake power for various fuel blends:

Graph of the brake power (BP) as a function of load obtained during engine operation on different blends of biodiesel i.e. PB20, JB20 and JPB20 with diesel (D100) at compression ratio of 12:1, 14:1 and 16:1 have been shown in Figure 1 to 3.

Brake power of the engine increases with increase in the load on the engine. Brake power is the function of calorific value and the torque applied. Diesel has more calorific value than the biodiesel, so diesel has the highest brake power among the different blends of biodiesel. It can also be seen that as we increases the load, torque increases and thus there is an increase in brake power with the load.

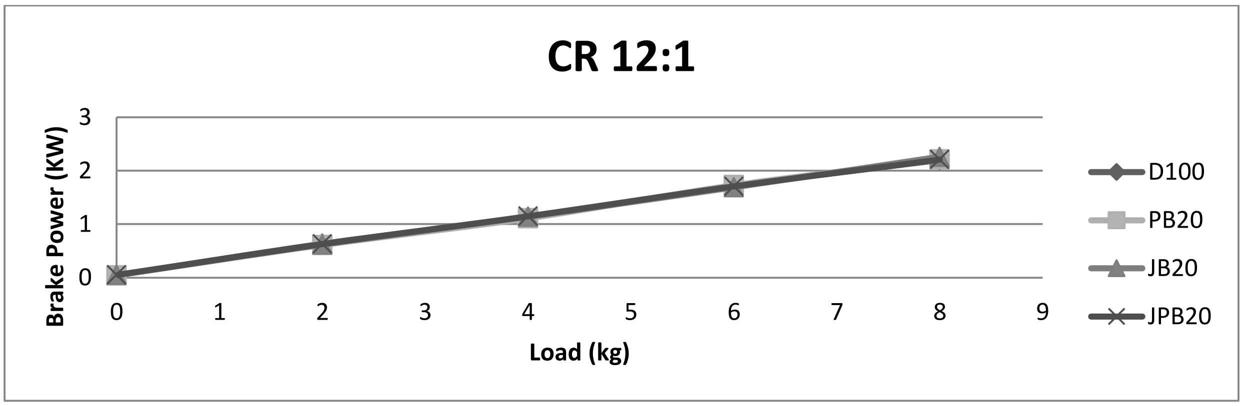

Figure 1. Variation of brake power with respect to load for 12cr

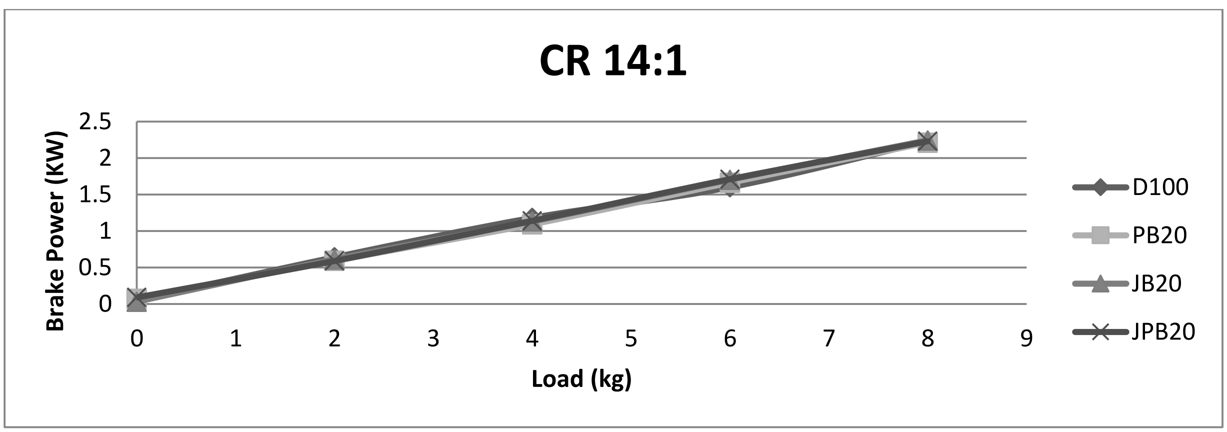

Figure 2. Variation of brake power with respect to load for 14cr

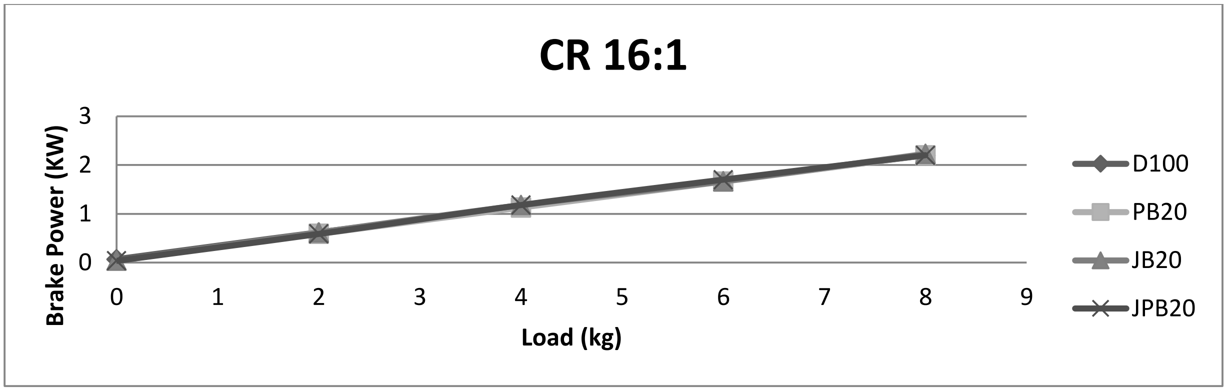

Figure 3. Variation of brake power with respect to load for 16cr

3.1.2. Effect of load on brake thermal efficiency for various fuel blends

The variation of brake thermal efficiency with load of the engine for different fuel blends is shown in Figure 4 to 6. Brake thermal efficiency increase with increase in load on the engine. This may be due to reduction in heat loss and increase in power with increase in load. Maximum brake thermal efficiency of 25.15 % was obtained for JPB20 at full load condition for CR 12. For D100, PB20, JB20 and JPB20, it is respectively 24.02 %, 23.44 %, 24.04% and 25.15 % at full load for compression ratio of 12. For D100, PB20, JB20 and JPB20, it is respectively 22.81 %, 23.03 %, 23.13 % and 22.72 % at full load for compression ratio of 14. For D100, PB20, JB20 and JPB20, it is respectively 22.17 %, 21.71 %, 22.32 % and 23.01 % at full load for compression ratio of 16. Brake thermal efficiency increase with increase in percentage of ethyl ester in the fuel. Increase efficiency with increase in percentage of ethyl ester in the fuel might be due to increase fuel temperature as blends contain more oxygen. So, higher fuel temperature reduced its viscosity and might have reduced the ignition lag also, resulting in better combustion and hence increase efficiency.

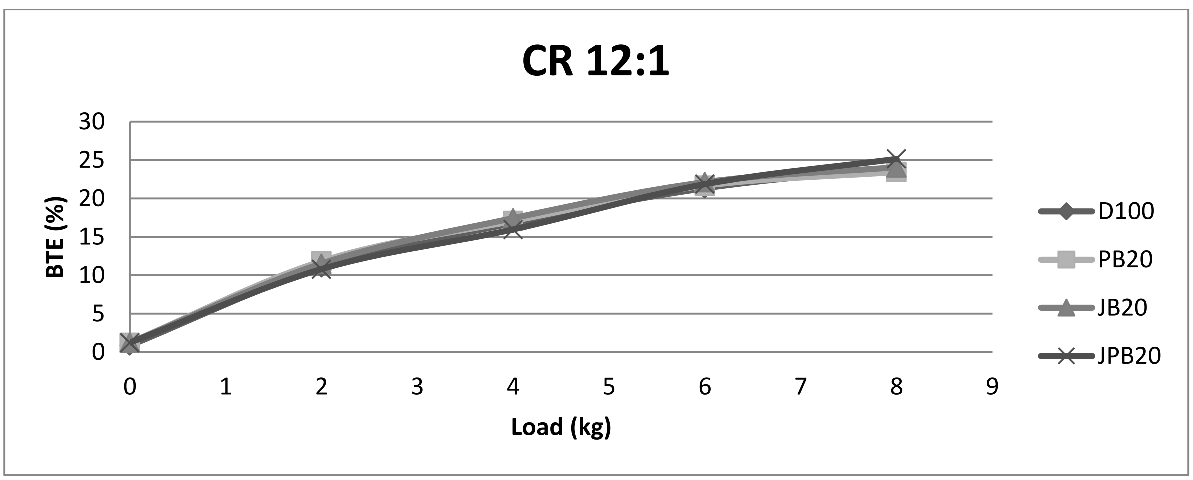

Figure 4. Variation of Brake thermal efficiency with respect to load for 12cr

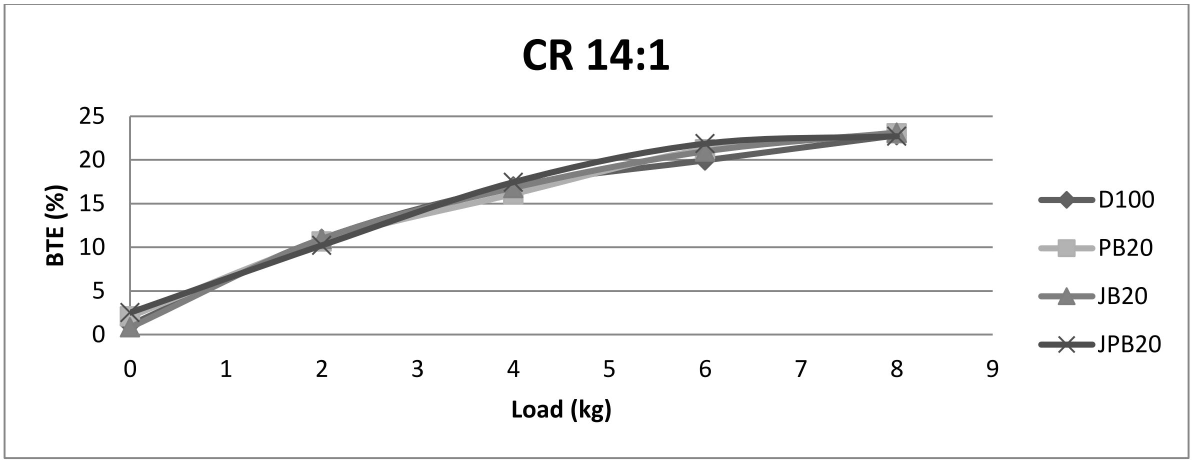

Figure 5. Variation of Brake thermal efficiency with respect to load for 14cr

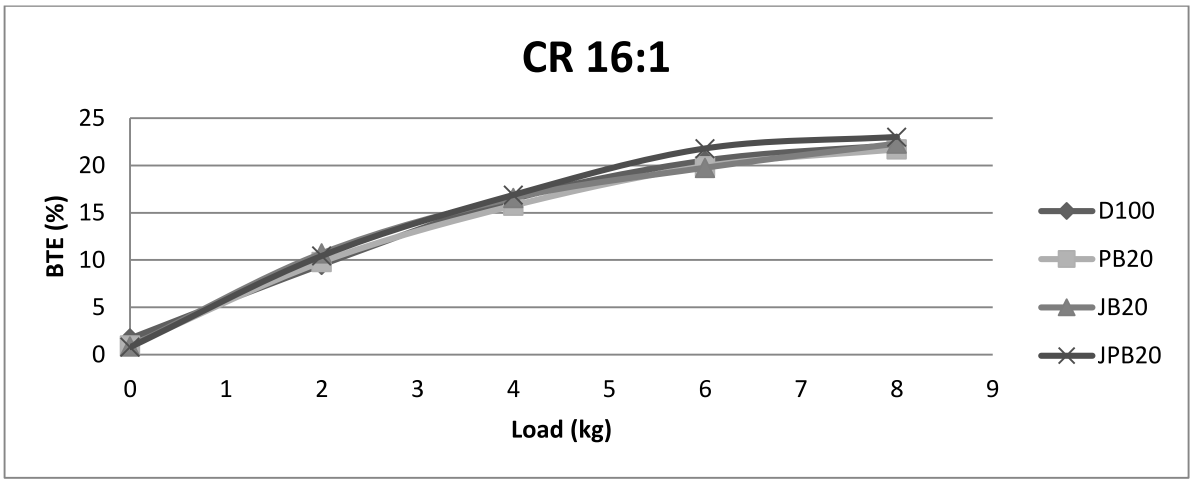

Figure 6. Variation of Brake thermal efficiency with respect to load for 16cr

3.1.3. **Effect of load on brake specific fuel consumption for various fuel blends**

The variation of brake specific fuel consumption with load of the engine for different fuel blends is shown in Figure 7 to 9. Brake specific fuel consumption decrease with increase in load on the engine for all fuel blends. This reduction could be due to higher percentage of increase in brake power with load as compared to fuel consumption. Brake specific fuel consumption for D100, PB20, JB20 and JPB20 blends varied from 0.78 to 0.36, 0.72 to 0.37, 0.74 to 0.36 and 0.79 to 0.34 kg/kWh respectively as the load was increased from no load to full load for compression ratio of 12. Brake specific fuel consumption for D100, PB20, JB20 and JPB20 blends varied from 0.78 to 0.38, 0.80 to 0.37, 0.78 to 0.37 and 0.84 to 0.38 kg/kWh respectively as the load was increased from no load to full load for compression ratio of 14. Brake specific fuel consumption for D100, PB20, JB20 and JPB20 blends varied from 0.65 to 0.39, 0.87 to 0.39, 0.80 to 0.38 and 0.82 to 0.38 kg/kWh respectively as the load was increased from no load to full load for compression ratio of 16. The increase in brake specific fuel consumption with increase in concentration of blends in diesel fuel is attributed to lower heat values.

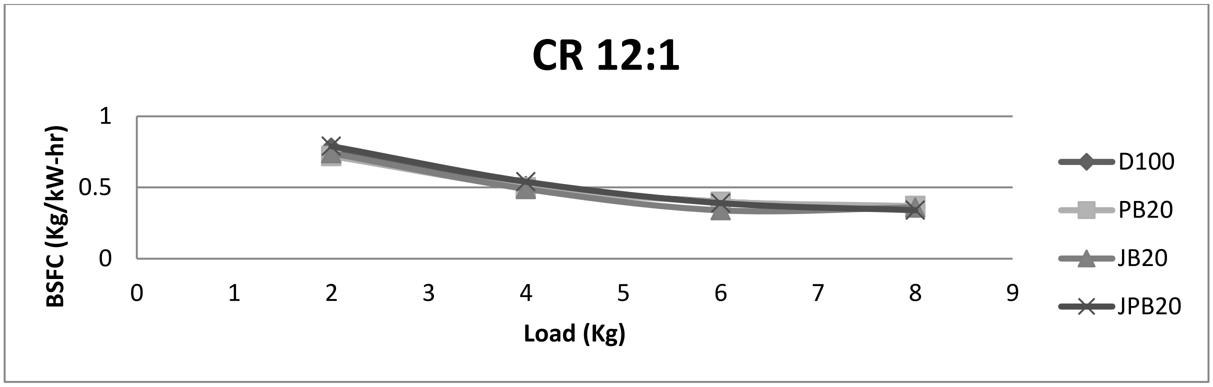

Figure 7. Variation of Brake specific fuel consumption with respect to load for 12cr

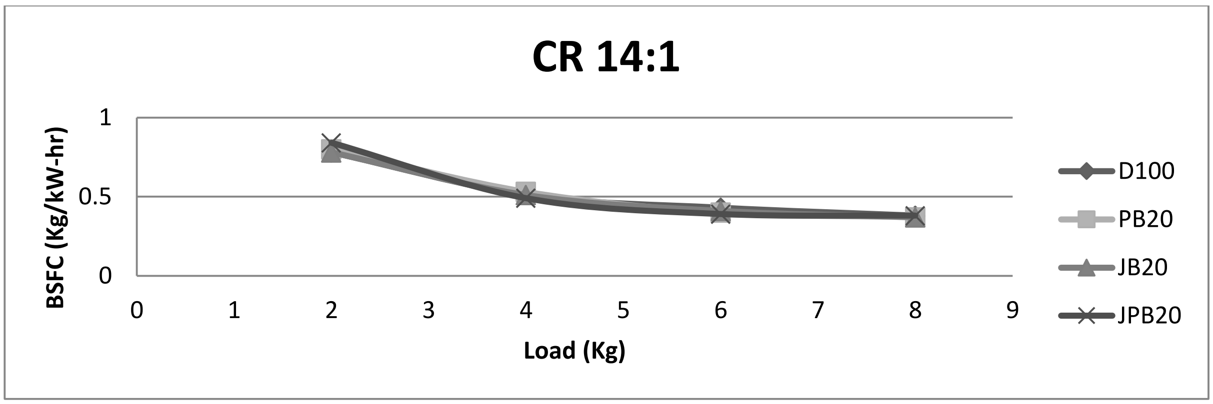

Figure 8. Variation of Brake specific fuel consumption with respect to load for 14cr

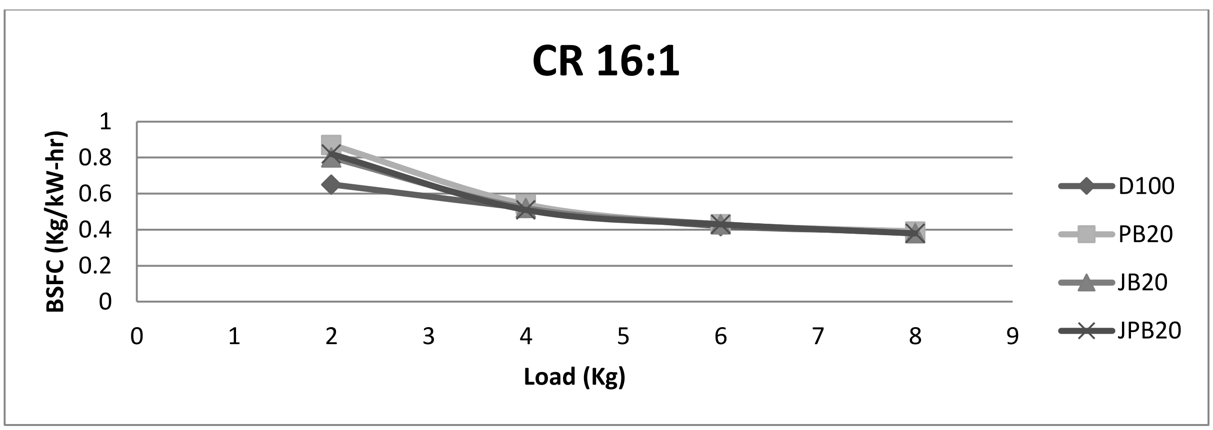

Figure 9. Variation of Brake specific fuel consumption with respect to load for 16cr

3.1.4. Effect of load on exhaust gas temperature for various fuel blends

The variation of exhaust gas temperature with load of the engine for different fuel blends is shown in Figure 10 to 12. Exhaust gas temperature increased with increase in load on the engine. This may be attributed to increase in quantity of fuel injected with the increase in load. The increased quantity of fuel generated greater heat in combustion chamber. Exhaust gas temperature increased for all fuel types because of pressure rise in combustion chamber and an increase in fuel injection rate with increase in brake load. Secondly, this may due to better utilization of heat released during combustion of fuels and increase in brake thermal efficiency on blended fuels.

The biodiesel contains some amount of oxygen molecules in the ester form. It is also taking part in combustion. When biodiesel concentration is increased, the exhaust gas temperature increases by small value. The exhaust gas temperature increases with increase in load. Diesel has the least exhaust gas temperature among the PB20, JB20 and JPB20. The reason of EGT being more in the case of biodiesel blends is the presence of more oxygen atoms in the biodiesel. So, the exhaust gas temperature increases and it increases with increase in load. As the load on the engine increases, more fuel is burnt. So exhaust gas temperature increases continuously with rise in load.

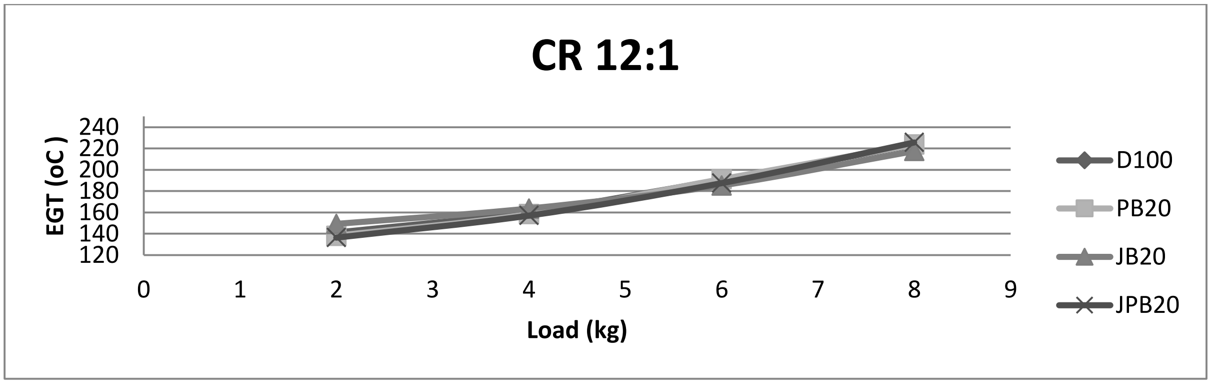

Figure 10. Variation of Exhaust gas temperature with respect to load for 12cr

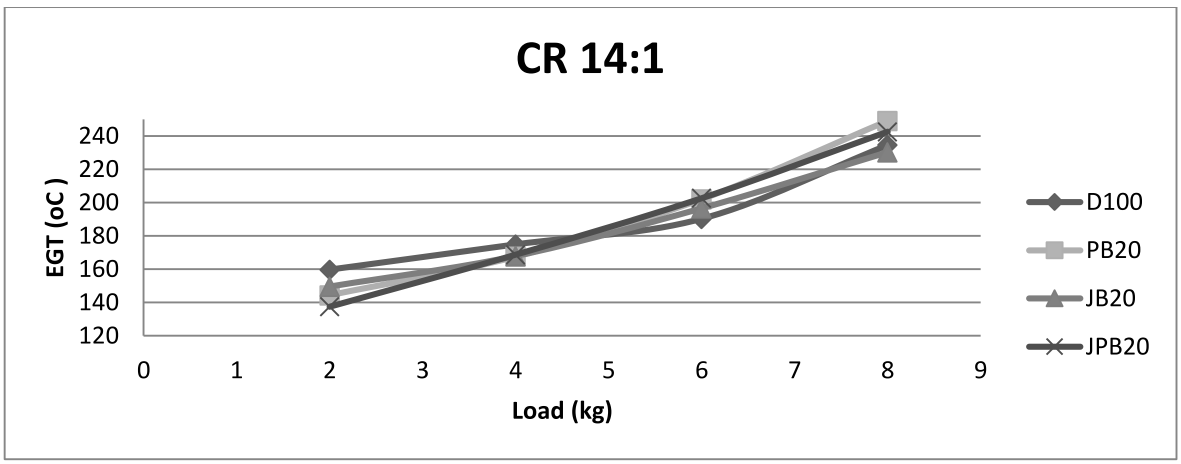

Figure 11. Variation of Exhaust gas temperature with respect to load for 14cr

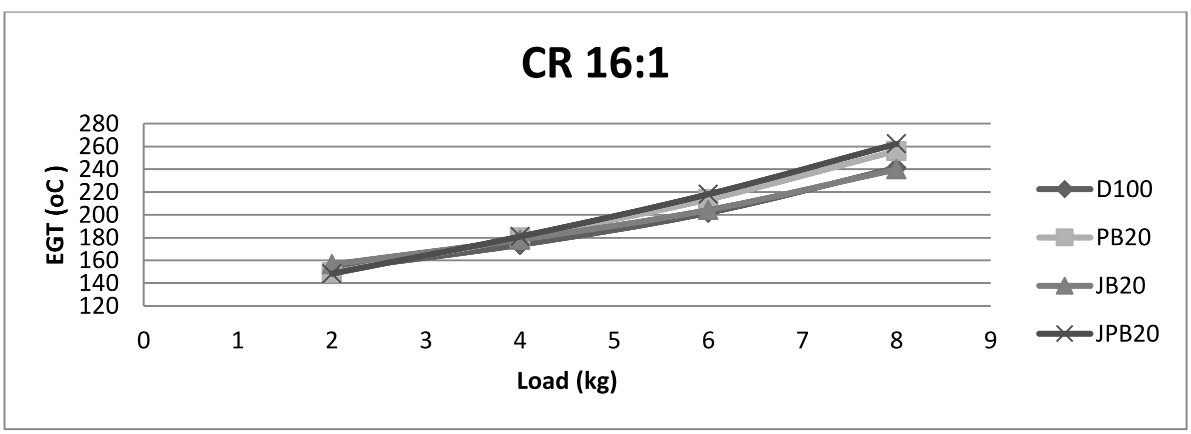

Figure 12. Variation of Exhaust gas temperature with respect to load for 16cr

3.2 Exhaust emission characterization

3.2.1 Effect of load on hydrocarbon (HC) emission for various fuel blends

The variation of hydrocarbon with respect to load for different blends of biodiesel is shown in Figure 13 to 15. Hydrocarbon emission is mainly due to incomplete combustion. HC concentration in exhaust gas was 30, 20 and 10 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 10 ppm at 75% of rated load for compression ratio of 12. HC concentration in exhaust gas was 40, 30 and 10 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 30 ppm at 75% of rated load for compression ratio of 14. HC concentration in exhaust gas was 40, 40 and 20 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 40 ppm at 75% of rated load for compression ratio of 16.

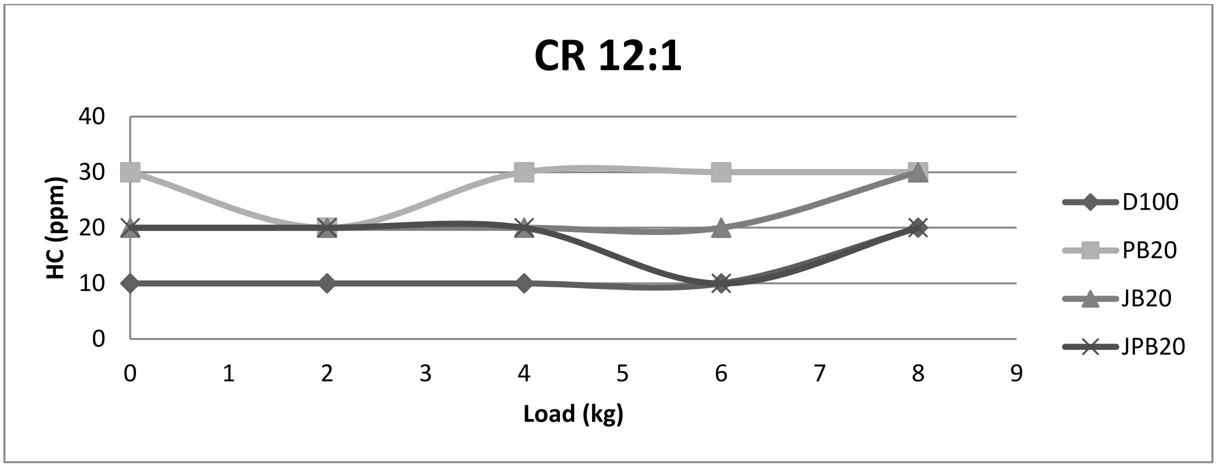

Figure 13. Variation of HC with respect to load for 12cr

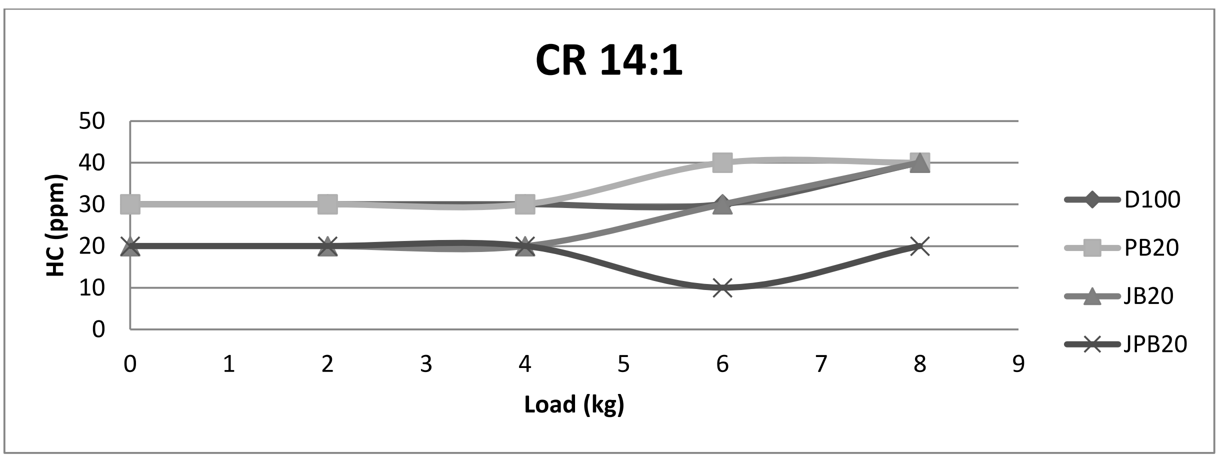

Figure 14. Variation of HC with respect to load for 14cr

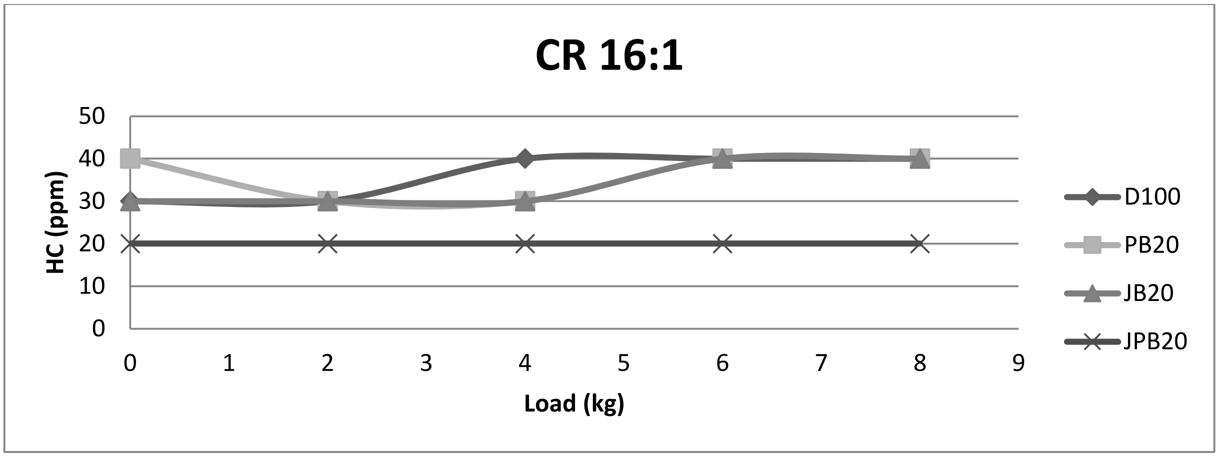

Figure 15. Variation of HC with respect to load for 16cr

3.2.2 Effect of load on carbon monoxide (CO) emission for various fuel blends

The variation of Carbon monoxide (CO) emission with load of the engine for different fuel blends is shown in Figure 16 to 18. Carbon monoxide (CO) emission increased with increase in load on the engine. This may be due to the fact that as the load is increased, the fuel consumption is also proportionately increased and due to insufficient air in the combustion chamber there may be incomplete combustion of fuel and hence increased CO. It was also observed that Carbon monoxide (CO) emission decreased with increase in percentage of ester in the fuel. This reduced emission of Carbon monoxide (CO) may have resulted due to increase combustion efficiency which is reflected in terms of higher brake thermal efficiency because of presence of the oxygen molecules in blended fuels. CO concentration in exhaust gas was 460, 488 and 392 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 490 ppm at 75% of rated load for compression ratio of 12. CO concentration in exhaust gas was 606, 628 and 617 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 672 ppm at 75% of rated load for compression ratio of 14. CO concentration in exhaust gas was 753, 810 and 782 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 909 ppm at 75% of rated load for compression ratio of 16.

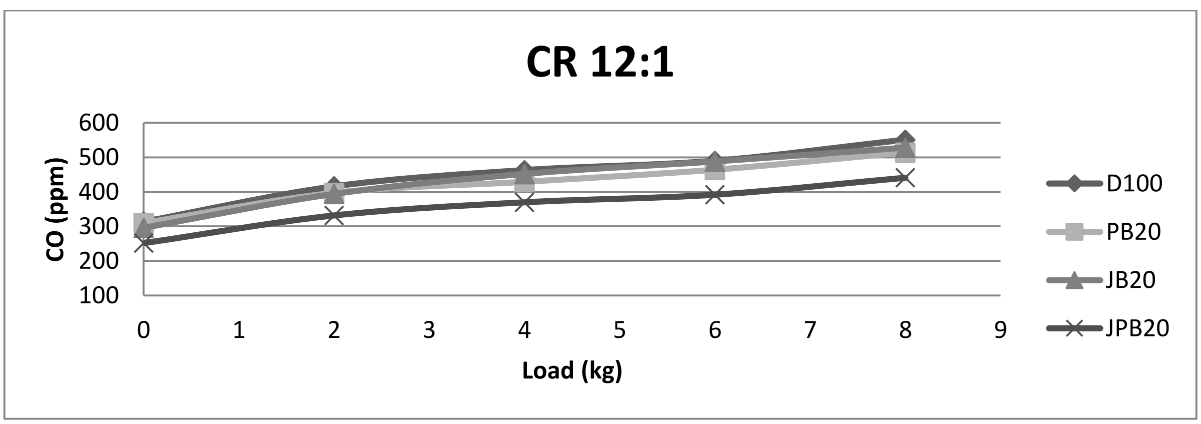

Figure 16. Variation of CO with respect to load for 12cr

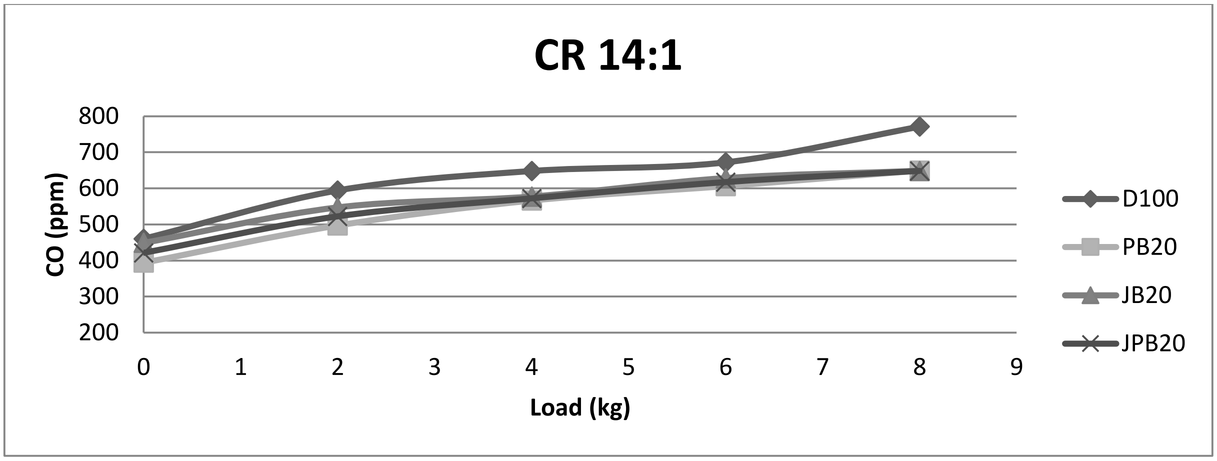

Figure 17. Variation of CO with respect to load for 14cr

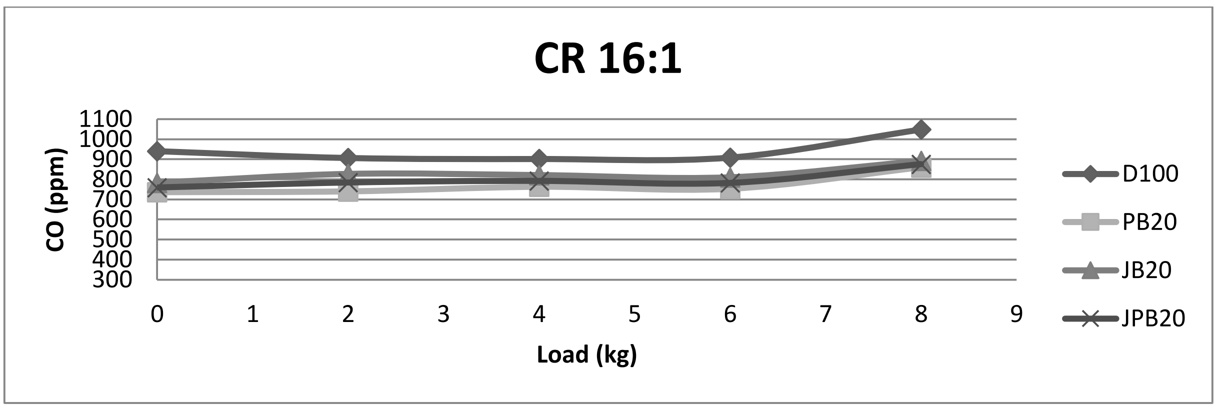

Figure 18. Variation of CO with respect to load for 16cr

3.2.3. Effect of load on nitric oxide (NO_X) emission for various fuel blends

The variation of Nitric oxide (NO_X) emission with load of the engine for different fuel blends is shown in Figure 19 to 21. Nitric oxide (NO_X) emission increased with increase in load on the engine. It was also observed that there was gradual increase in the emission of Nitric oxide (NO_X) with increase in percentage of esters in the fuel. Nitric oxide (NO_X) formation was higher in ethyl ester blended fuels due to higher temperature during combustion phase and better access to oxygen. Another factor causing the increase in Nitric oxide (NO_X) could be the possibility of higher combustion temperature arising from improved combustion because larger part of the combustion is completed before TDC for ester blends compared to diesel due to their lower ignition delay. So it is higher peak cycle temperatures are reached for ester blends compared to diesel. NO_X concentration in exhaust gas was 289, 303 and 293 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 139 ppm at 75% of rated load for compression ratio of 12. NO_X concentration in exhaust gas was 265, 294 and 282 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 138 ppm at 75% of rated load for compression ratio of 14. NO_X concentration in exhaust gas was 252, 308 and 302 ppm at 75% of rated load for PB20, JB20 and JPB20 fuels respectively whereas for D100, it was 132 ppm at 75% of rated load for compression ratio of 16.

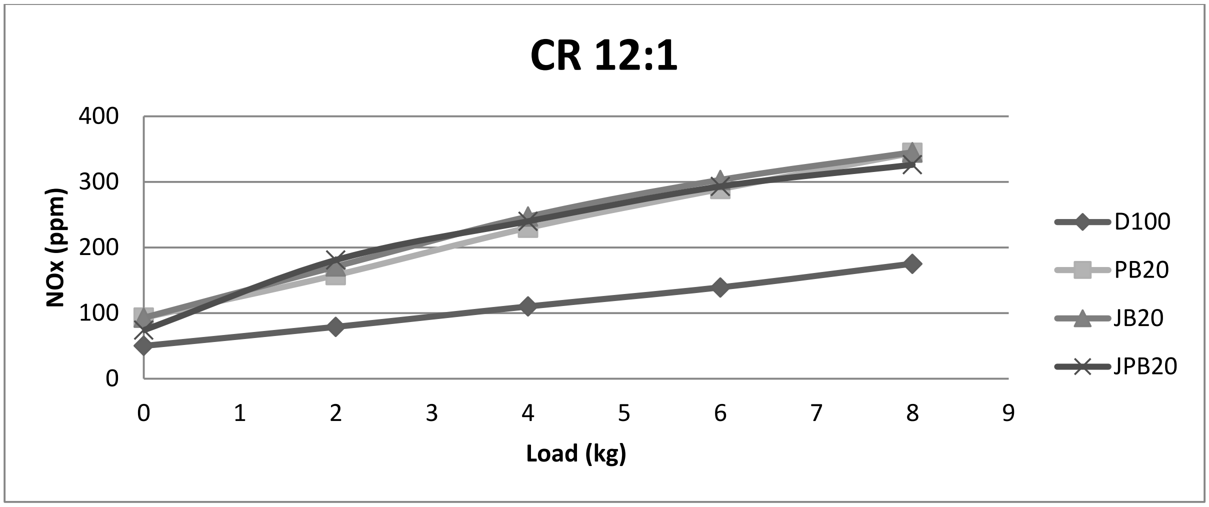

Figure 19. Variation of NO_X with respect to load for 12cr

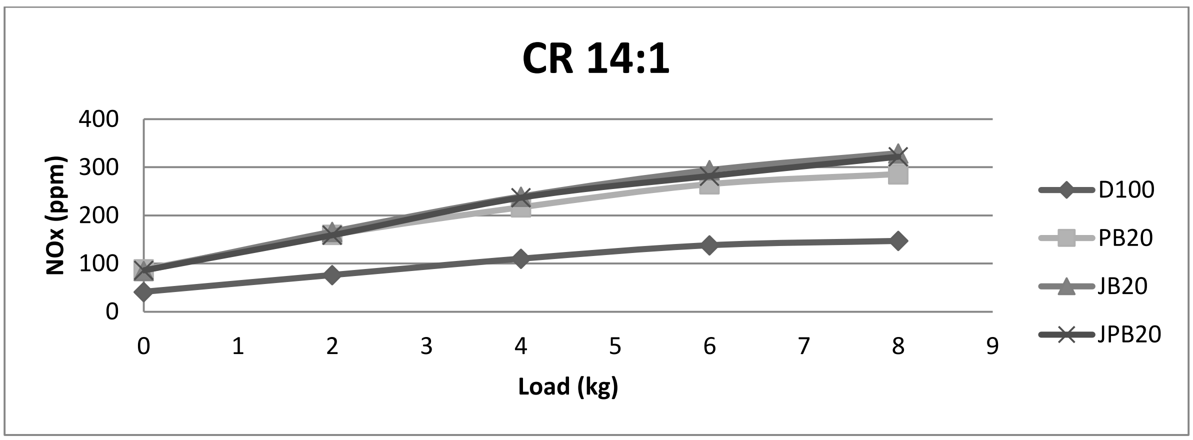

Figure 20. Variation of NO_X with respect to load for 14cr

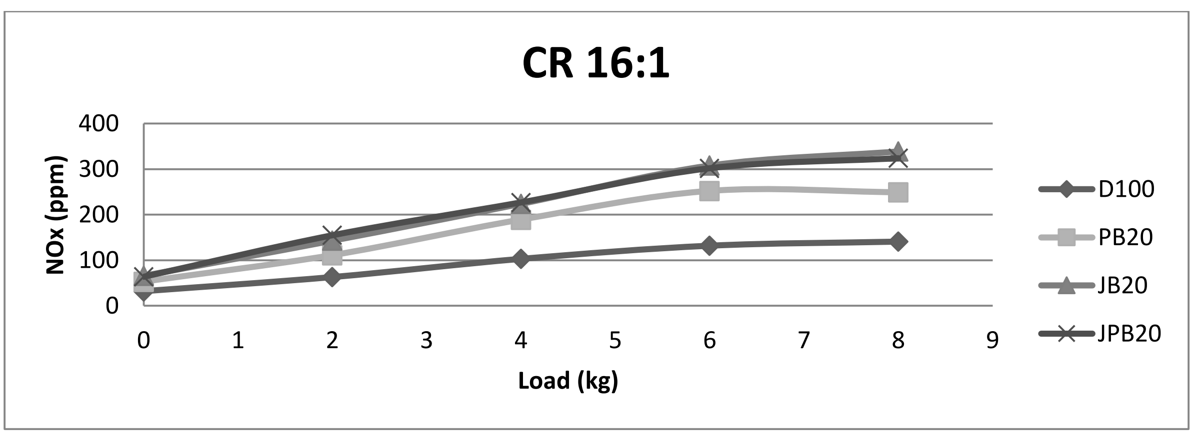

Figure 21. Variation of NO_X with respect to load for 16cr

4. CONCLUSION

Jatropha oil and Palm oil was esterified with methyl alcohol to obtain Jatropha biodiesel and Palm biodiesel (methyl ester) having lowest possible kinematic viscosity. On the basis of the results obtained from the whole experiment the following conclusions were drawn:

- Brake thermal efficiency increase with increase in load on the engine. Brake thermal efficiency increase with increase in percentage of ethyl ester in the fuel. Brake thermal efficiency of JPB20 were found to be 2.48%, 9.62% and 6.18% higher than that of D100 at 75% of rated load for compression ratio of 12, 14 and 16 respectively.

- Brake specific fuel consumption decrease with increase in load on the engine for all fuel blends. The increase in brake specific fuel consumption with increase in concentration of blends in diesel fuel is attributed to lower heat values. Brake specific fuel consumption of JPB20 were found to be 2.5% and 9.30% lower than that of D100 at 75% of rated load for compression ratio of 12 and 14 respectively. But for compression ratio of 16 Brake specific fuel consumption of JPB20 were found to be 2.38% higher than that of D100 at 75% of rated load.

- The EGT was higher for JPB20 compared to that of D100 at full load.

- Nitric oxide (NO_X) emission increased with increase in load on the engine. It was also observed that there was gradual increase in the emission of Nitric oxide (NO_X) with increase in percentage of esters in the fuel. The Nitric oxide (NO_X) emission was higher for JPB20 compared to that of D100 at full load.

- Carbon monoxide (CO) emission increased with increase in load on the engine. It was also observed that Carbon monoxide (CO) emission decreased with increase in percentage of ester in the fuel. Carbon monoxide (CO) emission of JPB20 were found to be 20%, 8.18% and 13.97% lower than that of D100 at 75% of rated load for compression ratio of 12, 14 and 16 respectively.

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