

Experimental Investigations of Jatropha Biodiesel Blends with Ethenol Additives in Variable Compression Ratio Diesel Engine

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ABSTRACT: In this article, a comparative study of mineral diesel and Jatropha biodiesel blended with Ethenol as an oxygenated additive has been done. Biodiesel was synthesized from Jatropha oil by the well-known process of transesterification with NaOH as a catalyst. To investigate performance of the engine, experiments were carried out using blends of Jatropha biodiesel and diesel. The performance parameters like brake specific fuel consumption, brake thermal efficiency and exhaust emissions of CO, CO₂, HC and NO_x were determined for the three blends i.e. JB-20, JB-35 and JB-50 with E-6 and E-10 as an additive for various engine loads and at compression ratio of 14, 16 and 18. The results of the Jatropha blends were compared with those obtained using mineral diesel.

KEYWORDS: Biodiesel, Bio fuels, Blending, Jatropha, renewable energy sources.

I. INTRODUCTION

Petroleum based fuels play a vital role in rapid depletion of conventional energy sources. Along with their increasing demands, these are also major contributors of air pollution which is contributing to greenhouse effect and consequently to ozone layer depletion. Major portion of today's energy demand in India is being met with fossil fuels. Hence, it is high time that alternate fuels for engines should be derived from different indigenous sources. As India is an agricultural country, there is a wide scope for the production of vegetable oils (both edible and non-edible) from different oil seeds. The work presented here focused only on non-edible oils as fuel for diesel engines, as the edible oils are in great demand and far too expensive.

Jatropha carcus is non-edible oil being singled out for large-scale for plantation on wastelands. Jatropha curcas plant can thrive under adverse conditions. It is a drought-resistant, perennial plant, living up to fifty years and has capability to grow on marginal soils. It requires very little irrigation and grows in all types of soils (i.e. from coastline to hill slopes). The production of Jatropha seeds is about 0.8 kg per square meter per year. The oil content of Jatropha seed ranges from 30% to 40% by weight and the kernel itself ranges from 45% to 60%. The fact that Jatropha oil cannot be used for nutritional purposes without detoxification makes its use as an energy/fuel source is very attractive. [2]

In the present work, tests were carried out on a typical single cylinder, four-stroke, water-cooled, direct-injection, variable compression ratio, compression ignition engine to analyse the performance and exhaust emissions. The effect of Jatropha biodiesel blendings i.e. JB-20, JB-35 and JB-50 with Ethenol (i.e. E-6 and E-10) as an additive on brake specific fuel consumption, brake thermal efficiency, CO, CO₂, HC and NO_x emissions were examined. The blends i.e. JB-20, JB-35 and JB-50 were considered by mixing diesel and esterified Jatropha in the following proportions by volume: For JB-20 E-6 blend (20% Jatropha biodiesel, 74% Diesel and 06% Ethanol), For JB-20 E-10 blend (20% Jatropha biodiesel, 70% Diesel and 10% Ethanol). For JB-35 E-6 blend (35% Jatropha biodiesel, 59% Diesel and 06% Ethanol) For JB-35 E-10 blend (35% Jatropha biodiesel, 55% Diesel and 10% Ethanol). For JB-50 E-6 blend (50% Jatropha biodiesel, 44% Diesel and 06% Ethanol) For JB-50 E-10 blend (50% Jatropha biodiesel, 40% Diesel and 10% Ethanol). The presented work aimed to explore the technical feasibility and sustainability of Jatropha Biodiesel in direct injection compression ignition engine without any hardware modifications in the engine.

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II. MATERIALS AND METHODS

A lot of research has been done to use vegetable oils directly in the diesel engines. But as it has seen from the earlier researches that the use of neat vegetable oil in diesel engines is possible but not preferable; as it could impose a lot of problems to the engine like injector choking, piston ring sticking, problems with atomisation and spray patterns of the fuel which would lead to incomplete combustion and carbon deposits in the engine. Moreover, problems such as fuel line choking were seen with the use of neat vegetable oils because of its high viscosity and low volatility. Efforts have been done worldwide to reduce the viscosity of neat vegetable oils. Following are some well-known processes used to reduce the viscosity of vegetable oils:

Blending with diesel

Emulsification

Pyrolysis

Transesterification

Among these, the transesterification is the commonly used commercial process to produce biodiesel from the vegetable oils.

Transesterification Process: In the process of transesterification, methyl esters of Jatropha are produced from Jatropha oil. The process involves reaction of the triglycerides of Jatropha oil with methyl alcohol in the presence of Sodium Hydroxide (NaOH) as a catalyst to produce glycerol and methyl esters of Jatropha oil. Firstly methyl alcohol and sodium hydroxide as a catalyst is mixed. The catalyst is taken in a very small amount for example for 500 ml of methanol; 13-15 grams of NaOH is used. The alcohol/catalyst mixture is then put up in reaction vessel and 1000 ml Jatropha oil (for 500 ml of methanol) is added. Use of excess alcohol is always favourable, as it ensures total conversion of the fat or oil to its esters. As the reaction completes, two major products i.e. glycerine and biodiesel are obtained. The amount of glycerine produced in the reaction depends on the amount of Jatropha oil used, the process followed and the amount of excess methanol used. If needed, mixture is then neutralized. Next thing is to remove methanol from the reaction and neutralisation of glycerine. The glycerine by-product contains unused catalyst and soaps which are neutralized with an acid and sent to storage as crude glycerine. The most important aspects of biodiesel production to ensure trouble free operation, complete reaction, removal of glycerine, removal of catalyst, removal of alcohol and absence of free fatty acids.

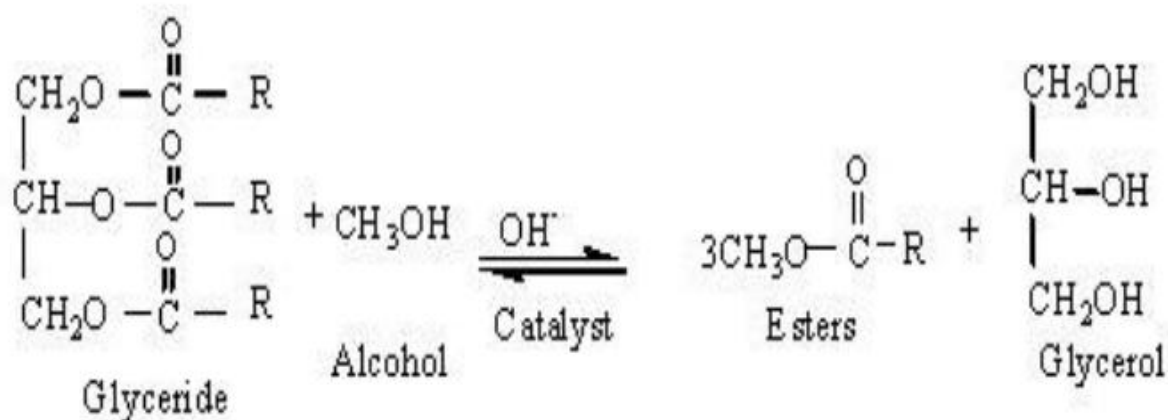


Fig 1: Transesterification process

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Properties of Jatropha Biodiesel, Jatropha Biodiesel blends and Diesel fuel: The fuels (Diesel, Jatropha biodiesel and its blends) were tested for several physical, chemical and thermal properties. The test results are listed in following table:

Test Description	Ref. Std. (ASTM 6751)	Diesel	Jatropha Biodiesel (JB 100)
Density (kg/m ³)	D 1448- 1972	830	875
Kinematic viscosity (cst)	D 445	2.72	5.72
Calorific value (kj/kg)	D 6751	42500	39500
Cetane no.	D 613	51	53
Cloud point (Deg. Celsius)	D 2500	-6	14
Flash point (Deg. Celsius)	D 93	64	138
Fire point (Deg. Celsius)	D 93	70	142

Table 1: Comparison of Diesel fuel and Jatropha biodiesel for various properties

Jatropha biodiesel was found slightly heavier than the mineral diesel fuel. This allow the use of splash blending by adding bio-diesel on top of diesel fuel for making Jatropha bio-diesel blends.

Viscosity of Jatropha biodiesel was found to be 5.72 cst at 40°C against that of 2.72 cst of diesel fuel. It was observed that viscosity of Jatropha oil decreases remarkably with increasing temperature and it becomes close to diesel at temperature above 90°C.

It was seen that the calorific value of Jatropha biodiesel was approximately 90% that of the diesel fuel, which makes its use to be more viable in diesel engines. The most distinguishing property that observed was related to cetane number. The cetane number of Jatropha biodiesel was found higher than diesel fuel which adds to notion that Jatropha biodiesel could be used in diesel engines.

The flash and fire points of Jatropha oil was found quite high compared to diesel fuel. Hence, Jatropha oil is extremely safe to handle. Cloud point is the temperature at which a cloud or haze of crystals appear in the fuel under test conditions and thus becomes important for low temperature operations. Cloud point of Jatropha biodiesel was found higher than diesel and it has been seen from previous literature that Pour point of Jatropha biodiesel also found higher than diesel. Higher cloud and pour point reflect unsuitability of Jatropha oil as diesel fuel in cold climatic conditions. Preheating of Jatropha biodiesel is advisable in such cases.

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Similarly the Jatropha Biodiesel blends were tested and the test results are shown below:

Properties	Diesel	JB20	JB35	JB50	JB100
Density (kg/m ³)	830	836.54	843.29	850.04	875
Kinematic viscosity (cst)	2.72	3.32	3.7	4.1	5.72
Calorific value (kj/kg)	42500	41148.05	40691.96	40243.10	39500
Cetane no.	51	51.09	51.2	51.8	53

Table 2: Properties of Diesel and Jatropha Biodiesel Blends with Ethenol 6 as an additive

Properties	Diesel	JB20	JB35	JB50	J100
Density (kg/m ³)	830	832	836	845	875
Kinematic viscosity (cst)	2.72	3.15	3.27	3.8	5.72
Calorific value (kj/kg)	42500	42000	41590	41200	39500
Cetane no.	51	51.2	51.4	51.9	53

Table 3: Properties of Diesel and Jatropha Biodiesel Blends with Ethenol 10 as an additive

As far as the Jatropha blends are concerned, i.e. JB-20, JB-35 and JB-50 with E-6 and E-10 as an additive, the densities appeared to be quiet similar which reflects the suitability of these blends at all operating conditions. Higher viscosity is a major problem in using vegetable oil as a fuel for diesel engines. In the present investigation, viscosity was reduced by transesterification process. The kinematic viscosities for E-6 and E-10 blends were investigated and it appeared to be closer with diesel fuel. JB-20 blend showed viscosities values 3.15 cstand 3.32cst which are the closest among all blends compared to the viscosity of diesel fuel. The calorific values for all Biodiesel blends were slightly lower than the diesel fuel. The calorific values for E-10 appeared to be closer with diesel fuel. For all the Biodiesel blends with E-6 and E-10 additive, the cetane no. was found slightly higher than the diesel fuel.

III.EXPERIMENTAL SETUP

The experimental set up consists of a Single cylinder, four stroke, direct injection, water cooled, variable compression ratio compression ignition engine test rig with:

1. A fuel input measuring arrangement coupled with sensor. (fuel tank capacity of 15 liter with glass fuel metering column)
2. Loading arrangement through electrical dynamometer (Eddy current type, Water cooled) coupled with load sensors.
3. A tilting block arrangement for varying the compression ratio.
4. An arrangement for measuring the heat carried away by cooling water from exhaust gases by exhaust gas calorimeter.
5. An arrangement for measuring the heat carried away by cooling water from engine jacket.
6. Temperature sensors to measure the temperature at various points in the set up

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- a) Temperature of water inlet and outlet to engine jacket.
 - b) Temperature of exhaust gases.
 - c) Temperature of exhaust gases inlet and outlet to exhaust gas calorimeter.
 - d) Ambient air temperature.
 - e) An arrangement for measuring the water supply to engine and calorimeter.
7. An Air box with orifice meter and manometer.
 8. Data acquisition device.
 9. Lab View Engine performance analysis software and
 10. An Exhaust gas analyzer fitted to the engine for the exhaust analysis of CO, CO₂, HC and NO_x.

The VCR engine provides excellent fuel flexibility, since the compression ratio can be varied and adjusted to suit the properties of the fuel, and therefore the engine could run at the compression ratio best suited for the fuel being used. Compression ratio is an important parameter in any engine which decides performance of the engine. With increase in compression ratio in diesel engine, brake power increases. This also leads to increase in mechanical efficiency. Further relative decrease in clearance volume leads to increase the volumetric efficiency.

Manufacturer	M/s Kirloskar Oil Engines Ltd.
Model	TV 1
Cycle	4 Strokes
Rated Power	5 HP @ 1500 RPM
Type of Combustion	Direct Injection
No. of Cylinders	1 Cylinder
Bore/Stroke	87.5 /110 mm
Compression Ratio	17.5 : 1 Modified to VCR 12 to 18 : 1
Swept Volume	551 cc
Type of Cooling	Water Cooled
Fuel Injection	Inline

Table 4: Engine Specification



Fig 2: Engine used for Experimentation

IV. EXPERIMENTAL PROCEDURE

Initially engine was run at no load and a speed of 1500 ± 40 rpm was maintained. The various Jatropha blends like JB-20, JB-35 and JB-50 with E-6 and E-10 additives and diesel fuel were tested at 20%, 40%, 60%, 80% and 100% loading at compression ratio of 14, 16 and 18. For all blends of Jatropha and diesel fuel, the engine was run for a period of 10 minutes for all engine loads and compression ratios. The engine performance was calculated in terms of performance parameters like brake specific fuel consumption, brake thermal efficiency and exhaust emissions of CO, CO₂, HC and NO_x.

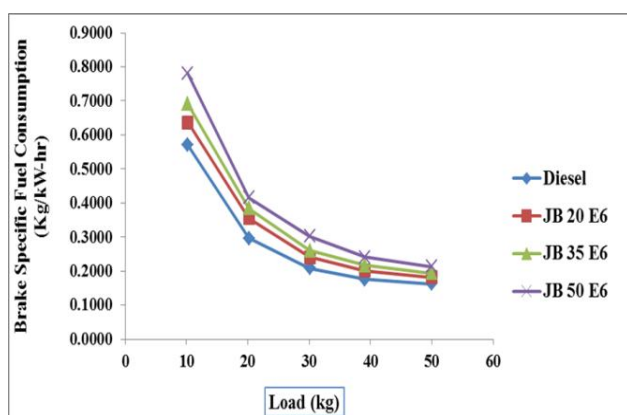
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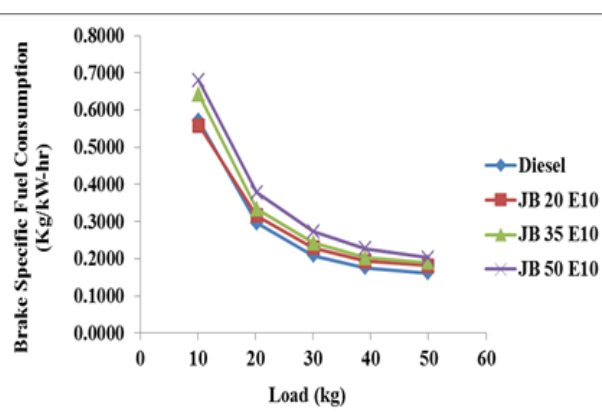
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V. RESULTS AND DISCUSSIONS

Brake Specific Fuel Consumption: It is a measure of the efficiency of the engine, using the fuel supplied to produce work. It is desirable to obtain a lower value of BSFC meaning that the engine should use less fuel to produce the same amount of work. BSFC in general, was found to decrease with the increase in load for all the blends at all compression ratios. It was also found that BSFC increased with increase in biodiesel blend ratio.

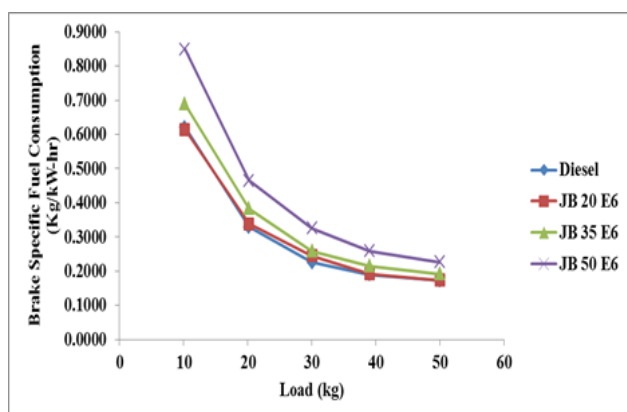


Graph 1: Variation of Brake Specific Fuel Consumption with Engine Load for E-6 additive at CR 14

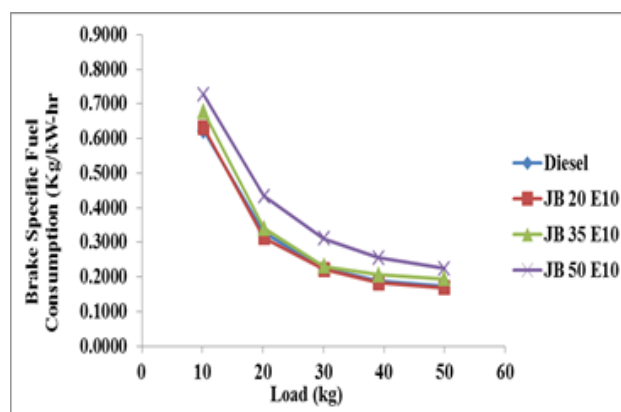


Graph 2: Variation of Brake Specific Fuel Consumption with Engine Load for E-10 additive at CR 14

As seen from the graphs, among the all the blends of Jatropha; JB 20 blend showed least BSFC for the all the loads and compression ratios. Moreover the result of JB-20 was quite similar with diesel fuel whereas for the higher blends i.e. JB-35 and JB-50, the BSFC was found slightly higher than diesel fuel. The reason being lower heating values of higher blends compared to diesel, therefore more amount of biodiesel is needed for higher blends to maintain the power output.



Graph 3: Variation of Brake Specific Fuel Consumption with Engine Load for E-6 additive at CR 16



Graph 4: Variation of Brake Specific Fuel Consumption with Engine Load for E-10 additive at CR 16

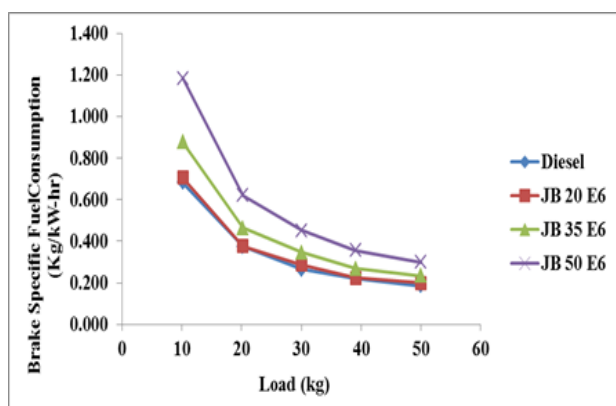
It was also observed that the BSFC of all the blends and diesel increased with increase in compression ratio from CR 14 to CR 18. Also BSFC was slightly better for JB 20, 35 and 50 blends using E-10 as an additive at CR 14 and 16 and at CR 18. So Among the two additives E-6 and E-10, E-10 served well to reduce the BSFC. Reason being the higher percentage of oxygen present in E-10 blend improved properties like fire point, flash point to a great deal

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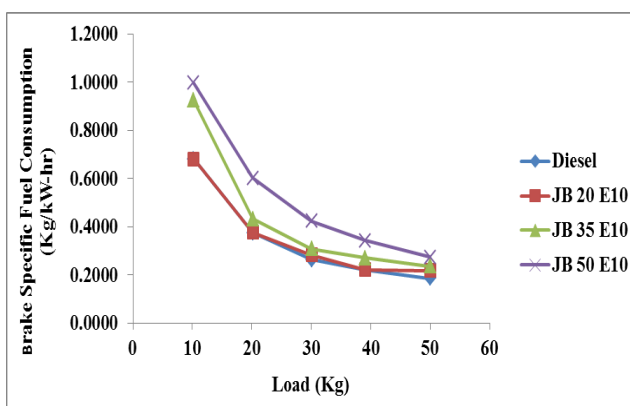
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which resulted in lower ignition delay and proper combustion. Also the higher concentration of oxygen improved the lubricity, pour point, cloud point and viscosity which resulted in reduction of BSFC.



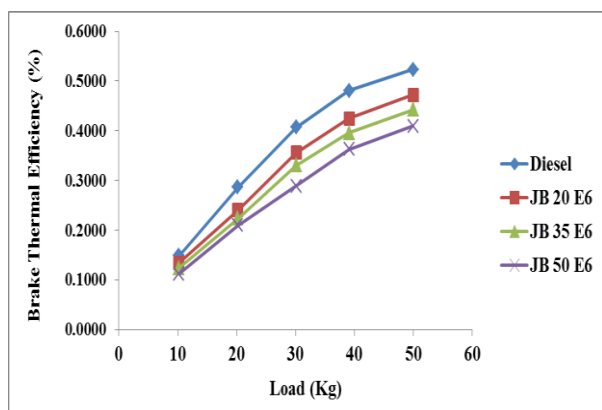
Graph 5: Variation of Brake Specific Fuel Consumption with Engine Load for E-6 additive at CR 18



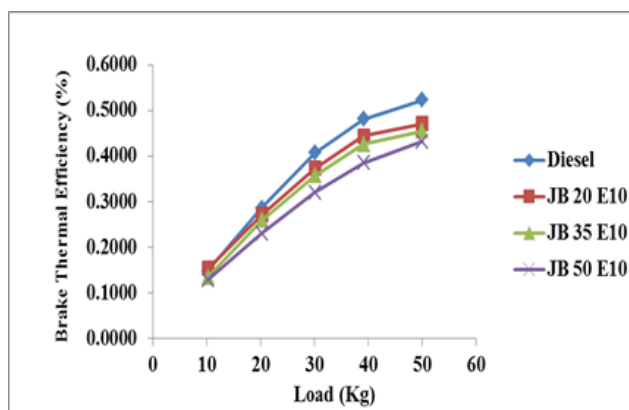
Graph 6: Variation of Brake Specific Fuel Consumption with Engine Load for E-10 additive at CR 18

Moreover, with Ethenol blends the cetane no. was found quite similar to diesel which was one of the reasons that BSFC of Jatropa blends with E-10 and E-6 additives was slightly closer to diesel fuel.

Brake Thermal Efficiency: Brake thermal efficiency is the ratio between the power output (B.P.) and the energy input through fuel. It was observed that the brake thermal efficiency of biodiesel blends was slightly lower than that of standard diesel fuel at all loads.



Graph 7: Variation of Brake thermal efficiency with Engine Load for E-6 additive at CR 14



Graph 8: Variation of Brake thermal efficiency with Engine Load for E-10 additive at CR 14

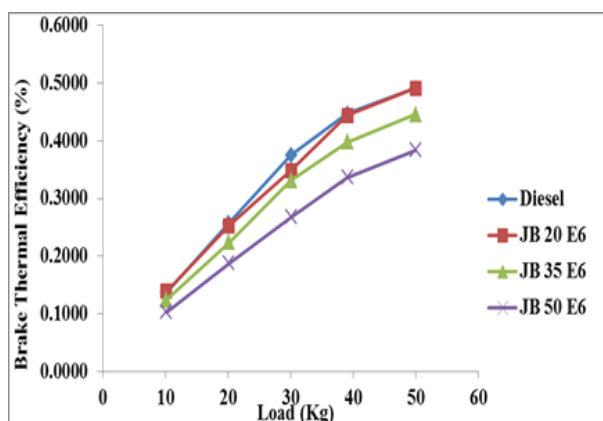
It was noticed that the brake thermal efficiency of all biodiesel blends increased with increase in engine load, decreased with increase in blend ratio of the biodiesel. The reason for increase in BTE is due to better combustion of biodiesel blends at higher loads due to higher oxygen content and better lubricity.

The decrease in brake thermal efficiency with increase in blend ratio was due to lower heating value of biodiesel at higher blends, higher viscosity and poor volatility which lead to poor atomisation and poor combustion characteristics. It was also seen that the JB-20 fuel blends showed higher efficiencies at all loads followed by JB-35 and JB-50.

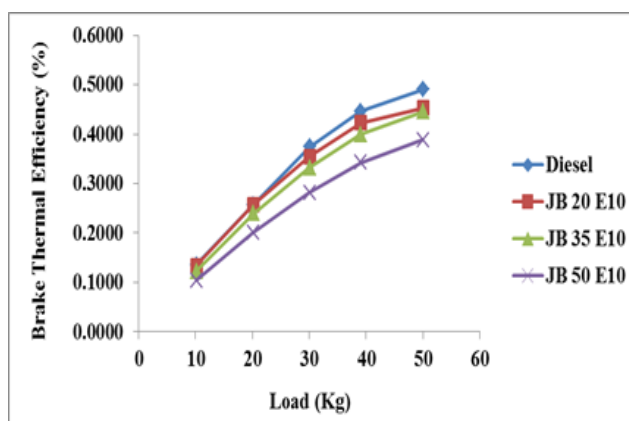
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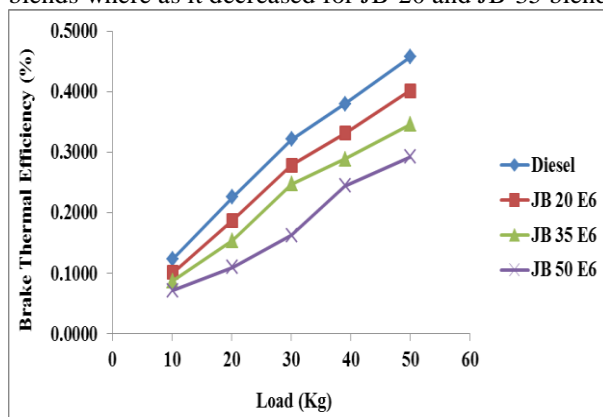


Graph 9: Variation of Brake thermal efficiency with Engine Load for E-6 additive at CR 16

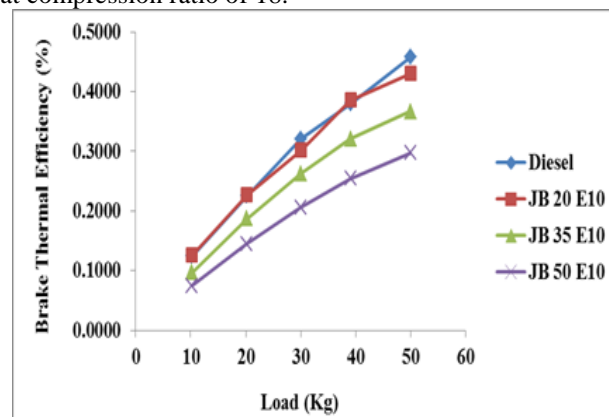


Graph 10: Variation of Brake thermal efficiency with Engine Load for E-10 additive at CR 16

The brake thermal efficiencies of JB-20 blends were quiet similar that of the diesel fuel at CR-14 and 16, for both E-6 and E-10 additive. Among the two additives, E-10 served well to increase the BTE compared to E-6. The brake thermal efficiencies were found to be increased as the compression ratio increases from 14 to 16 for JB-20 and JB-35 blends where as it decreased for JB-20 and JB-35 blends at compression ratio of 18.



Graph 11: Variation of Brake thermal efficiency with Engine Load for E-6 additive at CR 18



Graph 12: Variation of Brake thermal efficiency with Engine Load for E-10 additive at CR 18

For JB-50 blend, the brake thermal efficiency was found to be decreasing as the compression ratio increased from 14 to 18. The possible reason being the high viscosity and poor combustion characteristics of higher blends.

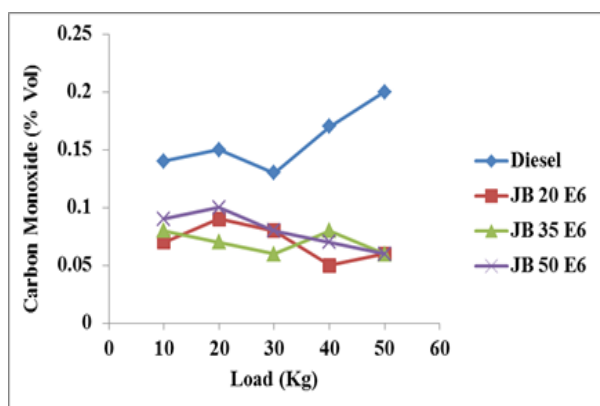
CO Emissions: CO emissions are results of the lack of oxygen and low combustion temperature.

It can be seen from the graphs that CO emissions are pretty much lesser for all the biodiesel blends i.e. for JB-20, JB-35 and JB-50 compared to diesel fuel at all loads and all compression ratios. The trend of CO emissions is non-linear as seen from the below graphs. The CO emissions seemed to be increased initially as load increased and further it decreased with the increase in the load. This was observed for all compression ratios.

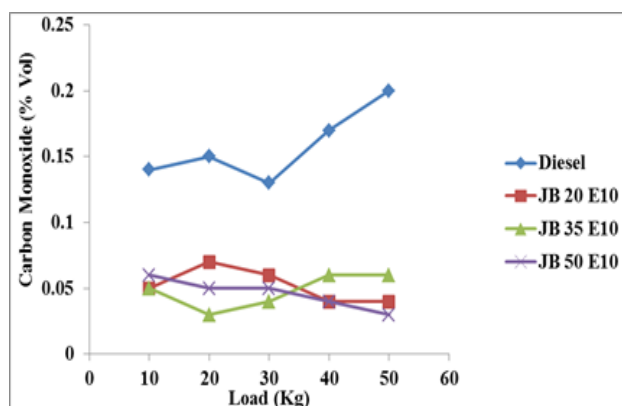
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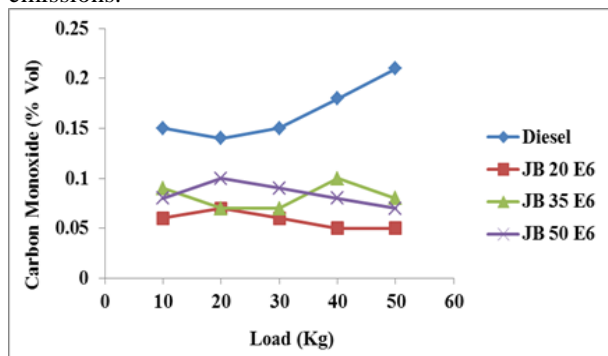
Graph 13: Variation of CO Emissions with Engine Load for blends for E-6 additive at CR 14



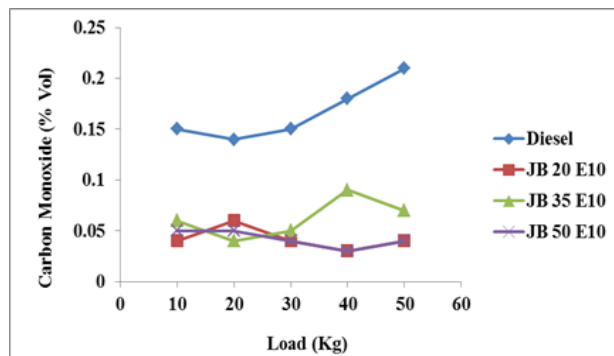
Graph 14: Variation of CO Emissions with Engine Load for blends for E-10 additive at CR 14

The amount of CO emission was found lower in case of biodiesel blended fuels compared to diesel, because of the complete combustion in biodiesel blended fuels. The reason is the greater oxygen content in biodiesel. Also E-6 and E-10 are oxygenated additives which supports the complete combustion resulted in lower CO emissions. At higher loading because of elevated temperature, the performance of engine improved with relatively better burning of the fuel which resulted in decrease of CO emission for biodiesel blends.

The other possible reason for decrease in CO emissions being the higher cetane no. of biodiesel blends. Higher is the cetane no., lower is the probability of forming fuel rich zones resulted in complete combustion and lower CO emissions.



Graph 15: Variation of CO Emissions with Engine Load for blends for E-6 additive at CR 16



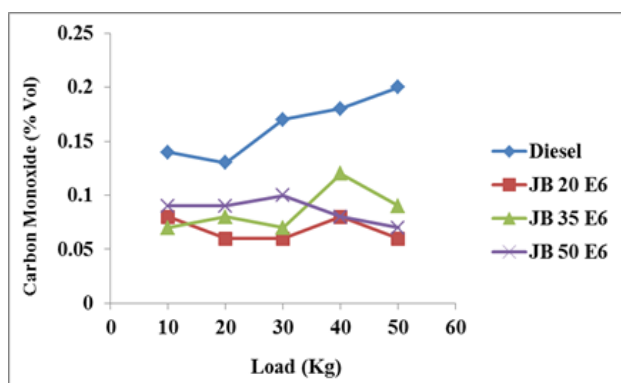
Graph 16: Variation of CO Emissions with Engine Load for blends for E-10 additive at CR 16

When compared the results of emissions of E-10 blended fuels with E-6 blends, it was seen that the CO emissions were pretty much lower for E-10 blends compared to E-6, especially for higher blends like JB-35 and JB-50; the emissions of CO were decreased considerably.

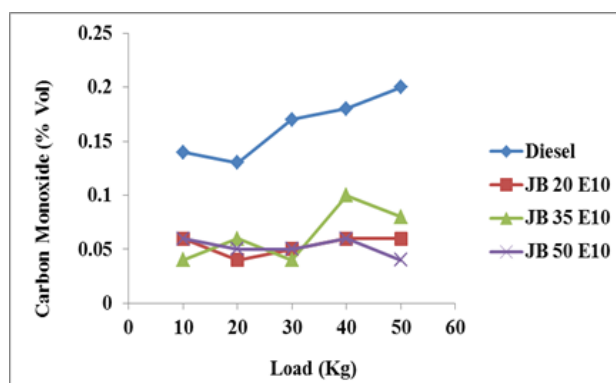
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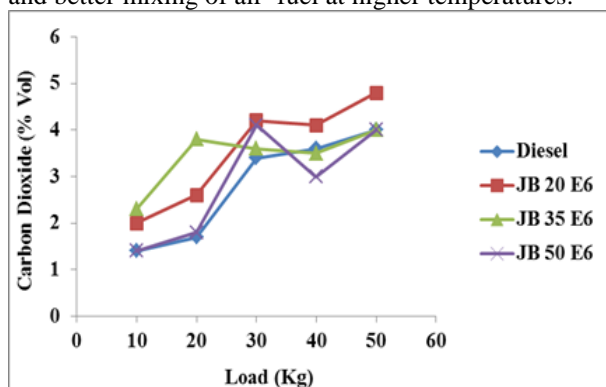


Graph 17: Variation of CO Emissions with Engine Load for blends for E-6 additive at CR 18

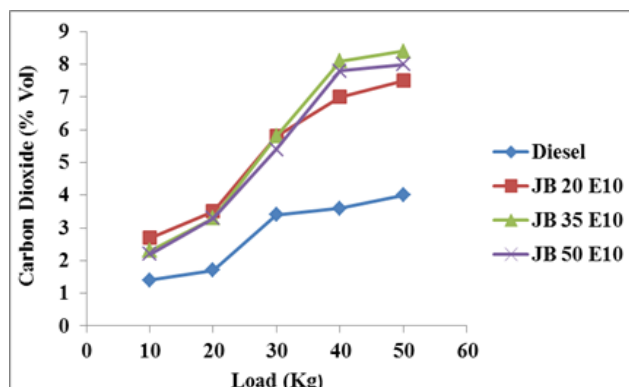


Graph 18: Variation of CO Emissions with Engine Load for blends for E-10 additive at CR 18

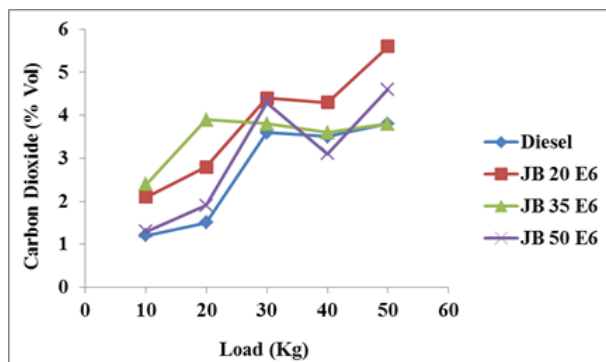
Carbon Dioxide Emissions (CO₂):CO₂emissions were found to be increased for all the biodiesel blends at all loads and compression ratios. This is because of better combustion of fuel due to increased temperature inside the cylinder and better mixing of air–fuel at higher temperatures.



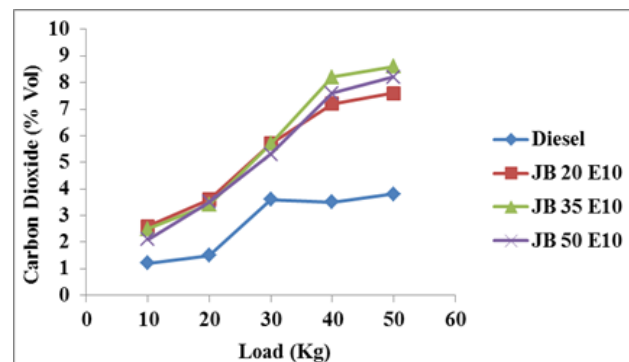
Graph 19: Variation of CO₂ Emissions with Engine Load for E-6 additive at CR 14



Graph 20: Variation of CO₂ Emissions with Engine Load for E-10 additive at CR 14



Graph 21: Variation of CO₂ Emissions with Engine Load for E-6 additive at CR 16



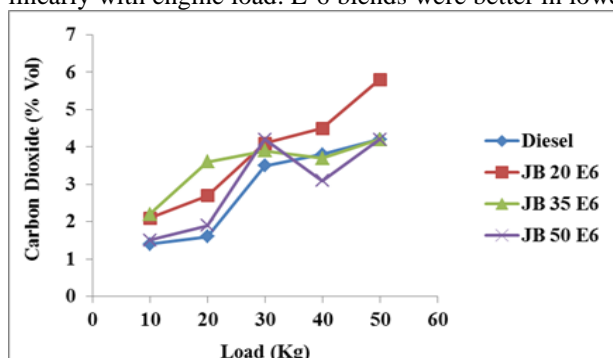
Graph 22: Variation of CO₂ Emissions with Engine Load for E-10 additive at CR 16

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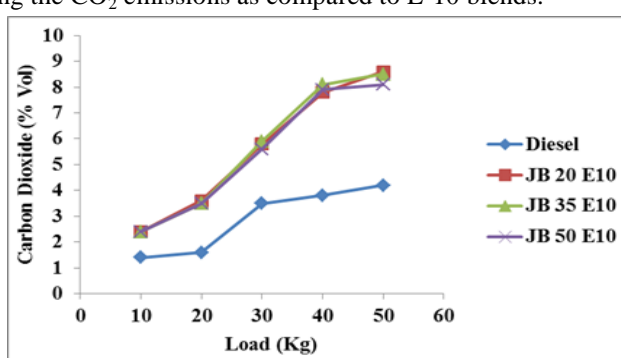
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All the biodiesel blends for all load and all compression ratios showed more carbon dioxide emission than that of the diesel fuel. The reason for this increase in CO₂ emission for biodiesel blends is due to more oxygen content in the biodiesel with increase in biodiesel proportion due to which CO₂ emissions increased. Also because of the same reason, blends with E-10 additives showed more CO₂ emissions compared to E-6. The CO₂ results varied almost linearly with engine load. E-6 blends were better in lowering the CO₂ emissions as compared to E-10 blends.

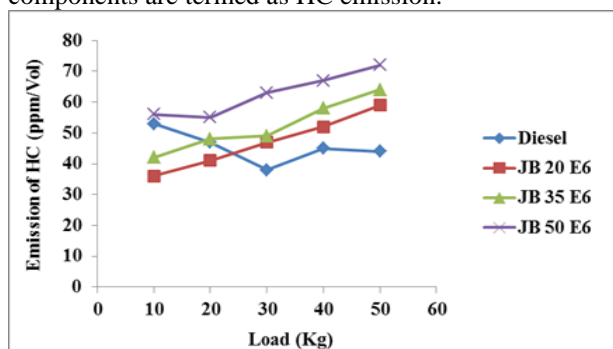


Graph 23: Variation of CO₂ Emissions with Engine Load for E-6 additive at CR 18

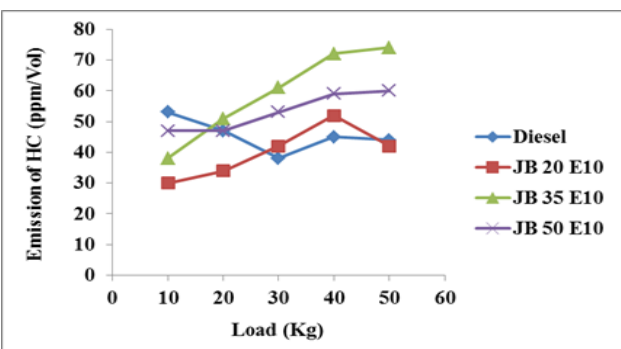


Graph 24: Variation of CO₂ Emissions with Engine Load for E-10 additive at CR 18

Hydrocarbon Emissions (HC): The unburned fuel components in the engine's exhaust consist of hydrocarbon components are termed as HC emission.



Graph 25: Variation of HC Emissions with Engine Load for E-6 additive at CR 14



Graph 26: Variation of HC Emissions with Engine Load for E-10 additive at CR 14

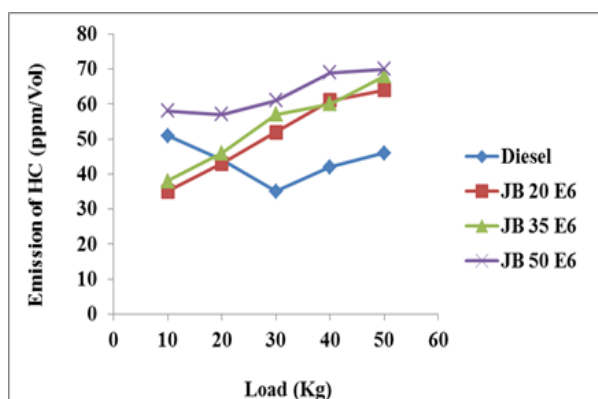
Emissions of unburnt hydrocarbons occur due to incomplete combustion of fuel molecules. The major cause of HC emission is non-homogeneity of fuel-air mixture. Due to this non homogeneity of fuel- air mixtures, either too lean or too rich mixtures are formed which are difficult to burn, resulting in emissions of hydrocarbons.

From the above graphs it can be seen that the HC emissions are increased slightly as the load increases for the all the biodiesel blends i.e. JB-20, JB-35 and JB-50 compared to diesel. For diesel fuel, the HC emissions increased at start and then it decreased.

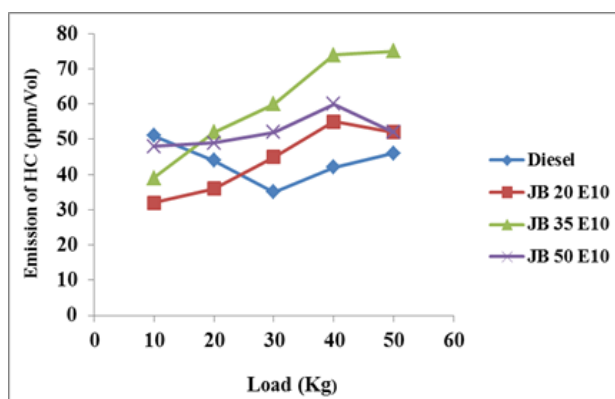
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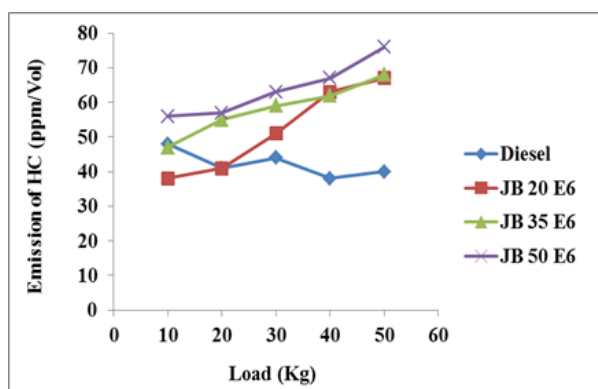


Graph 27: Variation of HC Emissions with Engine Load for E-6 additive at CR 16

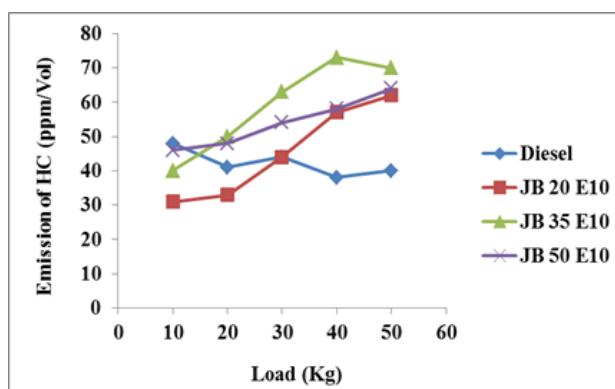


Graph 28: Variation of HC Emissions with Engine Load for E-10 additive at CR 16

One can observe that the HC emitted by the diesel fuel was lower than it was for the corresponding biodiesel-diesel blended fuels, at all engine load conditions and all compression ratios. This is due to the higher cetane number of diesel fuel, which reduced the combustion delay; such a reduction was main reason to decreases the HC emissions in diesel fuel. Moreover, biodiesel blends too show HC emissions results slightly closer to diesel fuel due to the oxygen content in the biodiesel molecule, which leads to a complete and cleaner combustion. When the results of E-10 blended fuel was compared with E-6 blends, no such large variations were seen with HC emissions but for E-6 blends the HC emissions were slightly lesser than those for E-10 blends.



Graph 29: Variation of HC Emissions with Engine Load for E-6 additive at CR 18



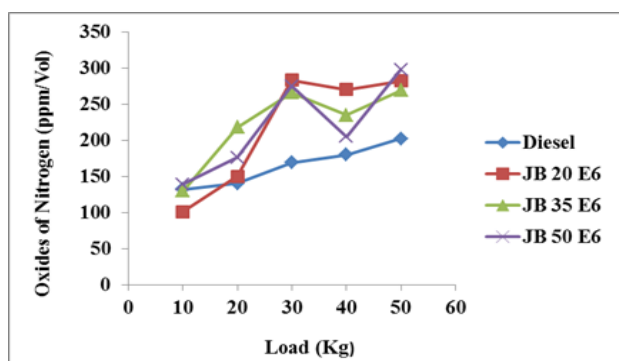
Graph 30: Variation of HC Emissions with Engine Load for E-10 additive at CR 18

Oxides of Nitrogen Emissions (NO_x): NO_x are formed by the combination of nitrogen and oxygen in air at high temperatures. Higher combustion temperatures in CI engines results in higher NO_x emission. The combustion temperature increases with increase in load. At higher temperature in the combustion chamber the oxygen present reacts with nitrogen to produce oxides of nitrogen i.e. $N_2 + O_2 = 2 NO$.

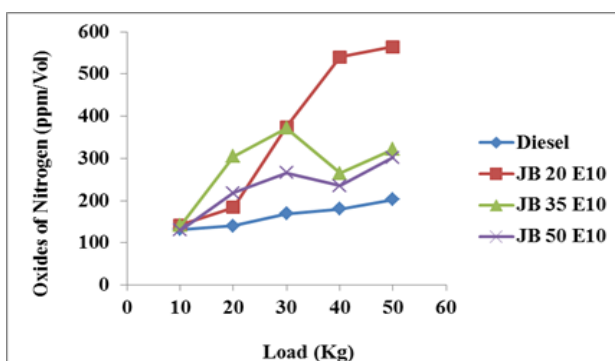
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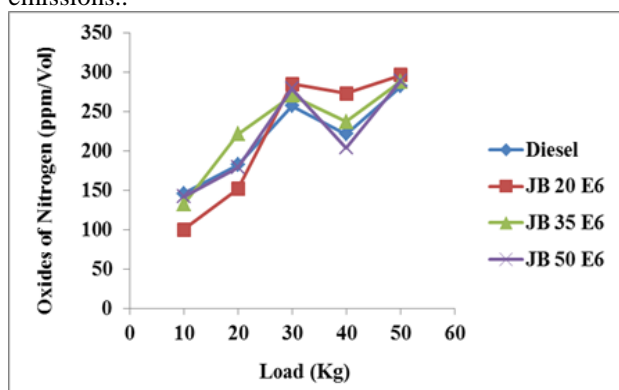


Graph 31: Variation of NO_x Emissions with Engine Load for E-6 additive at CR 14

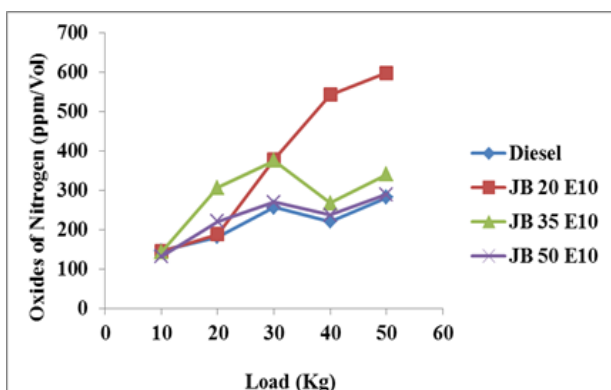


Graph 32: Variation of NO_x Emissions with Engine Load for E-10 additive at CR 14

NO_x emissions were found to be increased with increase in load and CR for all the biodiesel blends. The reason for this increase in NO_x emission in biodiesel blends using Ethenol additive is due to increase in oxygen content in higher biodiesel blends. Because of this higher oxygen content more oxygen reacts with available nitrogen to produce NO_x emissions..

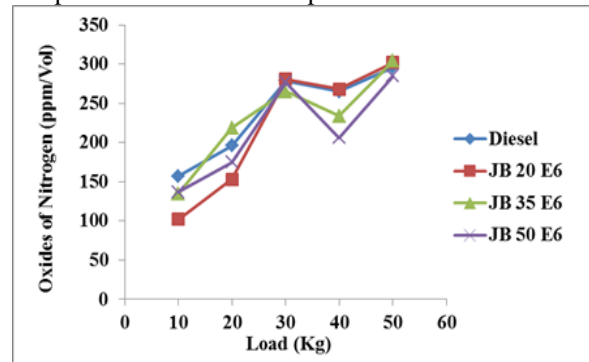


Graph 33: Variation of NO_x Emissions with Engine Load for E-6 additive at CR 16

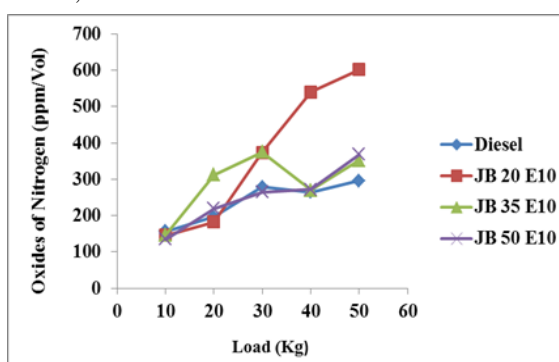


Graph 34: Variation of NO_x Emissions with Engine Load for E-10 additive at CR 16

NO_x emissions were pretty much lesser for diesel compared to all the biodiesel blends for all engine loads and compression ratios. As compared to blends with E-10 additives, blends with E-6 additives showed less NO_x emissions.



Graph 35: Variation of NO_x Emissions with Engine Load for E-6 additive at CR 18



Graph 36: Variation of NO_x Emissions with Engine Load for E-10 additive at CR 18

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VI.CONCLUSIONS

Key findings of the experimental work on VCR engine using diesel and Jatropha biodiesel blends as fuel with E-6 and E-10 additives are:

- The JB-20 blends with both the additives showed very close values of brake thermal efficiency at all load conditions and compression ratios as that of the diesel fuel. The brake thermal efficiency was found higher for blends with E-10 additives compared to blends with E-6 additive. The brake thermal efficiency was found higher at compression ratio 14 and 16 for all the fuel blends as compared to compression ratio of 18. The brake thermal efficiency of biodiesel blends was slightly lower than that of standard diesel for JB-35 and JB-50 blend at all loads.
- Among the all the blends; JB-20 blend showed least BSFC for all the loads and followed by JB-35 and JB-50 blends. The BSFC was found to be lower for blends with E-10 additives compared to blends with E-6 additive. The BSFC was low at compression ratio 14 and 16 for all the fuel blends as compared to compression ratio of 18.
- It was seen that CO emissions were pretty much lesser for the entire biodiesel blends i.e. for JB-20, JB-35 and JB-50 with E-6 and E-10 additives compared to diesel fuel. The CO emission decreased with the increase in load and with increase in compression ratio for all the fuels tested.
- It was seen that as the load increases, the CO₂ emission increased for all the biodiesel blends. All the biodiesel blends for all load conditions, shown more carbon dioxide emission than that of the diesel fuel. It was also seen that CO₂ emissions were much lesser for JB-50 blend compared to JB-35 and JB-20 blends with both the additives.
- It was observed that the HC emissions increased as the load increases for the all the biodiesel blends JB-20, JB-35 and JB-50 whereas for diesel fuel, the HC emissions increased at start and then it decreased. Lower HC emissions were seen for JB-20 blends followed by JB-35 and JB-50 blends.
- NO_x emissions were found increasing with increase in load and CR for all the biodiesel blends and diesel fuel. Among biodiesel blends, JB-50 blend has shown lesser NO_x emissions followed by JB-35 and JB-20.

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