COMBUSTION AND EMISSION CHARACTERISTICS OF A DIESEL ENGINE FUELLED WITH JATROPHA AND DIESEL OIL BLENDS

by

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The depletion of oil resources as well as the stringent environmental regulations has led to the development of alternate energy sources. In this work the combustion, performance and emission characteristics of a single cylinder diesel engine when fuelled with blends of jatropha and diesel oil are evaluated. Experiments were conducted with different blends of jatropha oil and diesel at various loads. The peak pressures of all the blends at full load are slightly lower than the base diesel. There is an increase in the ignition delay with biodiesel because of its high viscosity and density. The results show that the brake thermal efficiency of diesel is higher at all loads followed by blends of jatropha oil and diesel. The maximum brake thermal efficiency and minimum specific fuel consumption were found for blends upto B20. The specific fuel consumption, exhaust gas temperature, smoke opacity and NOx were comparatively higher. However there is an appreciable decrease in HC and CO_2 *emissions while the decrease in CO emission is marginal. It was observed that the combustion characteristics of the blends of esterified jatropha oil with diesel followed closely with that of the base line diesel.*

Key words: *Alternate fuel, Jatropha Oil, Blends, Combustion, Emission, Performance*.

1. Introduction

Conventional energy sources, such as coal, oil and natural gas, have limited reserves that are expected not to last for an extended period. World primary energy demand is projected to increase by 1.5% per year between 2007 and 2030, from just over 12,000 million tones of oil equivalent to 16,800 million tones – an overall increase of 40%. As world reserves of fossil fuels and raw materials are limited, it has stimulated active research interest in nonpetroleum, renewable, and nonpolluting fuels. With this scenario the need for an alternate fuel arises to maintain the economy of the country. Biodiesel have received significant attention both as a possible renewable alternative fuel and as an additive to the existing petroleum-based fuels. The projected petroleum production in India as given in the eleventh five year plan is shown in table 1. In India edible oils are much more valuable as a cooking fuel and as such, our concentration is going to be on development of biodiesel from non-edible oils only. The objective of the present study is to determine the properties of transesterified Jatropha oil and diesel blends and to study the performance and emission characteristics of these blends when applied in different proportions in a stationary diesel engine. Anand et al [1] investigated the effect of injecting the fuel at 200 bar and 250 bar on the performance and emission characteristics of a single cylinder diesel engine and reported a marginal decrease in brake thermal efficiency and an increase in particulate matter emissions for blends of jatropha methyl esters compared to diesel. Avinash Kumar Agarwal [2] reported that blending the vegetable oil with diesel and alcohol oxygenates have improved thermal efficiency than pure vegetable oil. Performance and emission characteristics have been investigated by Banapurmath et al [3] on a diesel engine operating with different biofuels. Breda keg [4] investigated the influence of biodiesel on the injection, spray, and engine characteristics to reduce harmful emissions in a bus diesel engine. Carraretto A. et al [5] have bench-tested the diesel engines and then installed on urban buses for normal operation. Distances, fuel consumption and emissions have been monitored, in addition to devices wear and tear, oil and air. A significant increase of SFC over the entire speed range is registered with biodiesel (about +16% average), due to its lower LHV and greater density. Kalam M.A. and H.H. Masjuki [6] investigated the effect of anticorrosion additive in biodiesel. The experimental results reported by D. Laforgia and V. Ardito [7] on a diesel engine have shown an improvement of brake thermal efficiency of about 10% with biodiesel. Md. Nurun Nabi et al [8] investigated the combustion and exhaust gas emission characteristics when the engine was fuelled with blends of methyl esters of neem oil and diesel. The optimum blend of biodiesel and diesel fuel, based on the trade-off of particulate matter decrease and NOx increase, was a 20/80 biodiesel/diesel fuel blend. After an injection delay of 3^o NOx emissions reduced while maintaining emission reductions associated with fueling a diesel engine with a 20/80 biodiesel/diesel fuel blend. The retarded timing reduced the time for combustion to occur in the cylinder, reducing the peak pressures and temperatures that enhance the formation of NOx emissions. Mustafa Canakcia, Ahmet Erdil B, and Erol Arcakliog [9] used Artificial Neural Network for analyzing and predicting the performance and exhaust emissions from diesel engines. Blends of varying proportions of jatropha curcas oil and diesel were prepared, analyzed and compared with diesel fuel for the compression ignition (C.I.) engine by K. Pramanik [10]. Among the various blends, the blends containing up to 30% jatropha oil have viscosity values close to that of diesel fuel. The blend containing 40% vegetable oil has a viscosity slightly higher than that of diesel. Heating the blends further reduced the viscosity. The viscosity of the blends containing 70% and 60% vegetable oil became close to that of diesel in the temperature ranges of 70–75°C and 60–65°C, respectively. From the engine test results, it is established that up to 50% jatropha curcas oil can be substituted for diesel for use in C.I. engine without any major operational difficulties. 70–80% of diesel may be added to jatropha oil to bring the viscosity close to diesel fuel and thus blends containing 20–30% of jatropha oil can be used as engine fuel without preheating. From the properties of the blends it is observed that biodiesel containing more than 30% jatropha oil has high viscosity compared to diesel. A reasonably good thermal efficiency of 22.44% was also observed with the 50:50 J/D blend. Maximum thermal efficiency of 27.11% was achieved with diesel, whereas only 18.52% thermal efficiency was observed using jatropha curcas oil. The emission test results reported by W.G. Wang et al [11] have shown that the heavy trucks fueled by B35 emitted significantly lower particulate matter and moderately lower carbon monoxide and hydrocarbon than the same trucks fueled by diesel. The heavy trucks that were tested had performed well when the originally equipped compression-ignition engine (diesel engine) was fueled with B35 without any engine modifications. A significant increase of specific fuel consumption over the entire speed range with biodiesel was reported. Oxides of nitrogen (NOx) emissions from B35 and diesel however, were generally in the same level. Ejaz M. Shahid and Younis Jamal [12] in their study reported that chocking of injector nozzles occur after a long run when the engine was fuelled with biodiesel. Tajima *et al.* [13] obtained better combustion rate and lower smoke using the waste vegetable oil methyl ester in a high-speed direct injection test engine when compared to gas oil. Though many researchers [14-20] have taken efforts to address the issues of biodiesel, the technology is yet to be fully exploited. This study is to determine the extent to which blending can be done with diesel without scarifying much in the performance and emission characteristics of a diesel engine when fuelled with these blends without any engine modifications. Fuel blends were prepared in house and their properties were evaluated. The potential effects of these blends on the combustion, performance and emission are evaluated to determine a possible alternate to diesel fuel in internal combustion engines. A detailed and appropriate discussion on the results of the examinations on the blends are presented giving emphasis to the cylinder dynamic pressure, specific fuel consumption, brake thermal efficiency and emissions such as oxides of nitrogen and smoke opacity with diesel being the bench mark.

Table 1. Projected production of crude oil of India in MMT (2007-2012)

Company	2007 - 2008	2008 - 2009	2009 - 2010	2010 - 2011	2011 - 2012	Total
ONGC	27.16	28.00	29.00	28.53	27.37	140.06
OIL	3.50	3.55	3.73	3.91	4.30	18.99
Joint Venture	10.57	10.78	9.76	8.75	7.85	47.71
Total	41.23	42.33	42.49	41.19	39.52	206.76
Actual Production	34.12					

Source: Draft eleventh five year plan document

2. Experimental method

2.1 Preparation and Properties of Jatropha and diesel oil blends

Transesterified jatropha oil was blended with diesel oil in varying proportions to reduce its viscosity close to that of the diesel fuel. It is evident [10] that blending of transesterified vegetable oil with the conventional diesel fuel would bring the viscosity close to diesel. The required physical and chemical properties of the biodiesel thus prepared were found using standard methods. The blends prepared were stable under normal conditions. The important properties of the blends are shown in table 2. When compared with the properties of the mineral diesel oil the results show that the calorific value of all the blends was lower than diesel oil. The kinematic viscosity, specific gravity and the flash point were higher.

Table 2. Properties of Jatropha and diesel oil blends

S.No	Blend	Kinematic Viscosity at 40°C (mm^2/s)	Flash Point (°C)	Specific Gravity	Calorific Value (kJ/kg)
1.	B10	4.1	74	0.865	43647
2.	B20	4.2	79	0.868	43093
3.	B30	4.3	86	0.872	42207
4.	B40	4.5	92	0.876	41542
5.	B50	4.6	98	0.882	40877
6.	Diesel	4.0	70	0.853	44755

2.2 Methodology

A stationary single cylinder, air-cooled, four-stroke, direct injection diesel engine is used for the present study. The schematic arrangement of the experimental setup is shown in Fig. 1. Cooling of the engine is accomplished by a fan attached to the engine. The engine is loaded by an eddy current dynamometer.

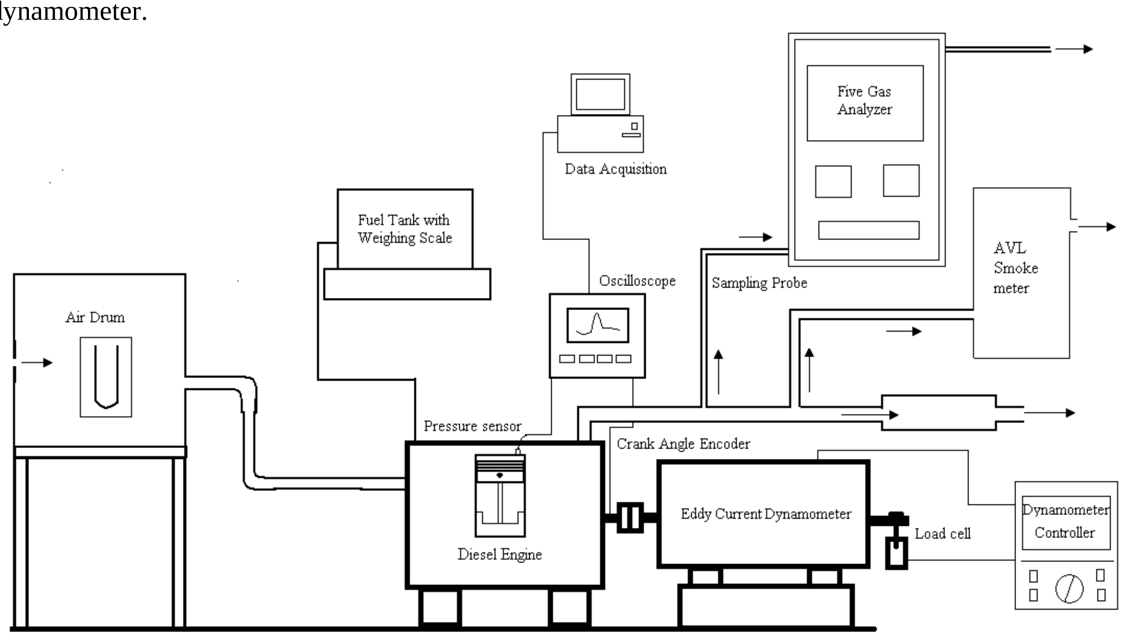

Figure 1. Schematic arrangement of the experimental setup

The cylinder pressure is measured by a Kistler pressure sensor and the crank angle by a crank angle encoder. A load cell is attached with the dynamometer for the measurement of the torque. The load on the engine is varied with the help of the controller provided with the dynamometer. Fuel flow rates are measured using an electronic weighing scale. Exhaust gas temperature is measured using the thermocouples. An AVL smoke meter and a five gas analyzer are used for the measurement of smoke opacity and NO_X, CO_2, CO and UBHC respectively. Technical details of the engine are given in Table 3. The engine was run at the rated speed of 1500 rpm for few minutes to attain steady state before every measurement is taken.

Table 3. Engine Specifications

Make & Type	:	Kirloskar & Air cooled diesel engine
Number of cylinder	:	1
Stroke x Bore	:	87.5 mm x 110 mm
Compression Ratio	:	17.5:1
Rated speed	:	1500 rpm
Brake Power	:	4.4 kW
Injection timing	:	23° bTDC
Injection pressure	:	200 bar

2.3 Testing procedure

Experiments were conducted with esterified jatropha oil and diesel blends having 10%, 20%, 30%, 40% and 50% esterified jatropha oil on volume basis at different load levels. Tests of engine performance on pure diesel were also conducted as a basis for comparison. The percentage of blend and load, were varied and engine performance measurements such as brake specific fuel consumption, air flow rate, and exhaust gas temperature and emissions (HC, CO_2, CO, NO_X and smoke Opacity) were measured to evaluate and compute the behavior of the diesel engine. Each time the engine was run at least for few minutes to attain steady state before the measurements were made. The experiments were repeated and the average values were taken for performance and emission measurements.

3. Results and discussion

A series of engine tests were carried out using diesel and biodiesel to find out the effect of various blends on the performance and emission characteristics of the engine. Investigations are carried out on the engine mainly to study the effect of specific fuel consumption, brake thermal efficiency, exhaust gas temperature and emissions such as NOx, CO, CO_2, HC and smoke opacity. It was found that the specific fuel consumption decreases from 0.649 to 0.336 kg/kW-hr at varying loads in the range of 0 – 3.9 BkW while K. Pramanik [10] reported a decrease in SFC from 0.693 to 0.332 kg/kW-hr. The brake thermal efficiency varies from 0 - 29.39% in the load range of 0 – 3.9 BkW while K. Pramanik [10] reported a maximum brake thermal efficiency of 27.11% for a load range of 0 – 3.078 BkW in his studies on a single cylinder diesel engine coupled with a hydraulic dynamometer. Exhaust gas temperature and NOx emission increases with increase in BkW for all the cases. NOx emission reaches a maximum of 1656 ppm for a blend of 50% at full load while a maximum of 1800 ppm for biodiesel was reported in the literature by the researchers [5]. These trends and the variations in the fuel properties such as viscosity and density for various blends are in accordance with the findings of many such researchers [5-10]. A detailed discussion on the NOx, CO, CO_2, HC and smoke opacity were presented here under to understand the behaviour of the engine running on biodiesel.

3.1 Analysis of the Combustion characteristics

The variation of cylinder pressure with respect to crank angle for diesel and different blends of jatropha and diesel oil at full load is presented on fig. 2. Peak pressures of 67.8 bar 65.62 bar, 68.12 bar 66.2 bar, 66.5 bar and 64.38 bar are found for pure diesel, B10, B20, B30, B40 and B50 respectively. From the test results it is observed that the peak pressure variations are less. Since the properties such as calorific value, viscosity and density are brought closer to diesel after transesterification of the vegetable oil, no major variation in the pressures are found.

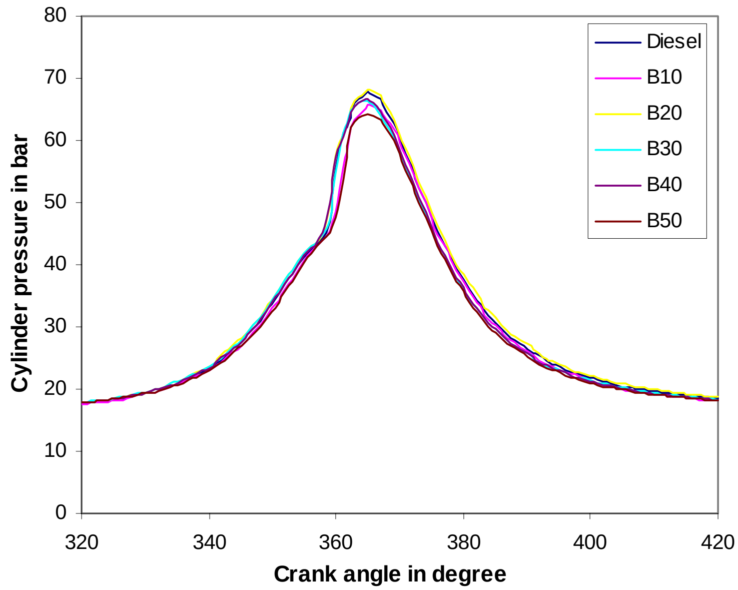

Fig. 2 Variation of cylinder pressure with crank angle

Figure 3 shows the variation of heat release rate with crank angle for various blends as well as diesel. It was observed from the graph that there is an increase in the ignition delay for the blends. Though the start of injection is consistent for all blends and pure diesel the start of combustion is delayed when compared to pure diesel. The start of combustion is defined in terms of the change in slope of the heat release rate that occurs at ignition. Among the fuels tested B20 is found to have higher ignition delay. For B20 start of injection was at 335º. The initial dip in the heat release rate curve after 334º is due to the energy absorbed by the injected fuel for evaporation. Ignition occurred at 343º as can be seen by the positive heat release following the initial evaporation dip. Thus the ignition delay is about 9 degree crank angle. This resulted in an increase in the premixed combustion phase duration which has led to an increase in the amount of fuel burned during the premixed combustion phase. During the ignition delay the fuel droplets have sufficient time to spread over a wide around fresh air. Most of the fuel admitted would have evaporated and formed a combustible mixture with air which results in complete combustion. Hence peak pressure is higher for B20. Fuels with longer ignition delay result in higher cylinder pressures as given by Yoshiyuki kidoguchi et al [21]. As the volume of jatropha in the blend increases beyond 20% by volume the peak pressure decreases.

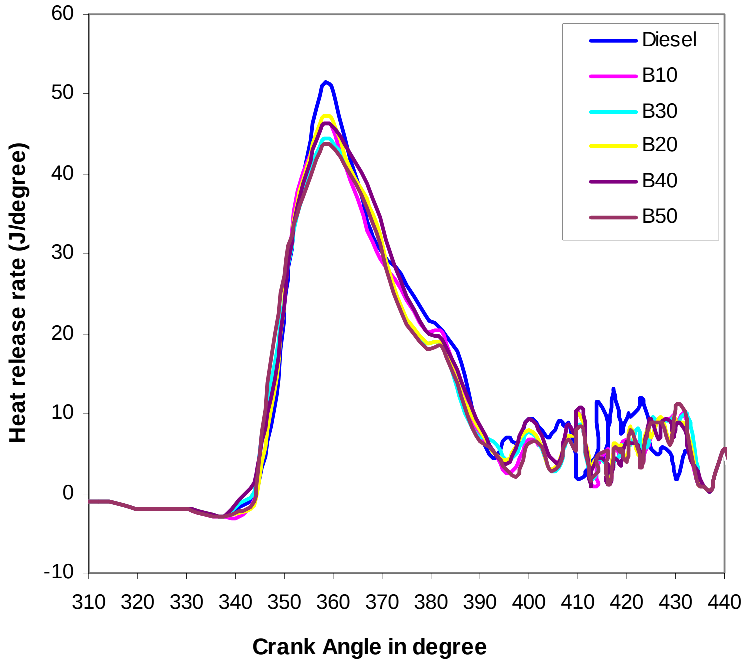

Fig. 3 Variation of heat release rate with crank angle

3.2 Effect of brake power on specific fuel consumption

The variation of the brake specific fuel consumption of diesel and various blends of jatropha and diesel oil at different loads is shown on fig. 4. It is found that the specific fuel consumption for the blend B20 is close to diesel. However if the concentration of jatropha oil in the blend is more than 30 percent by volume the specific fuel consumption is found to be higher than diesel at all loads. This is because of the combined effects of lower heating value and the higher fuel flow rate due to high density of the blends. Higher proportions of jatropha oil in the blends increases the viscosity which in turn increased the specific fuel consumption due to poor atomization of the fuel.

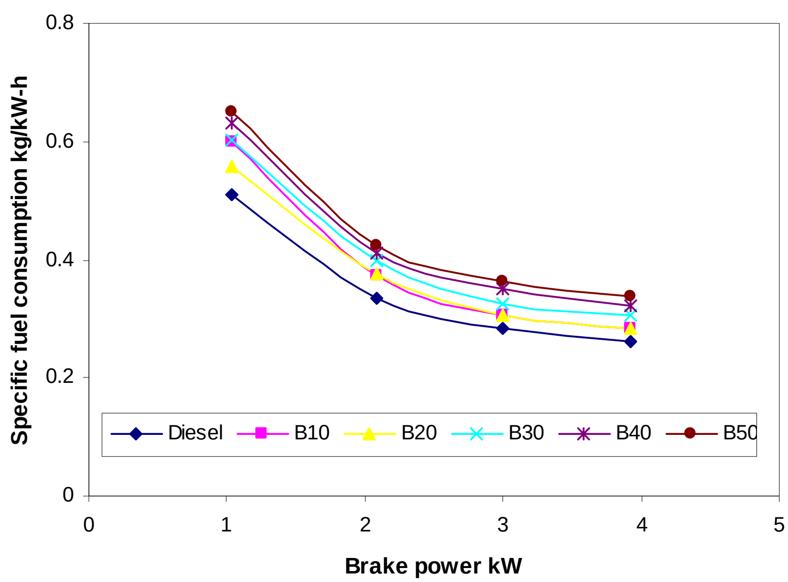

Fig. 4 Variation of specific fuel consumption with brake power

3.3 Effect of brake power on brake thermal efficiency

The variation of brake thermal efficiency of the engine with various blends is shown in fig. 5 and compared with the brake thermal efficiency obtained with diesel. It shows that brake thermal efficiencies of all the blends are lower at all load levels. Among the blends B20 is found to have the maximum thermal efficiency of 29.40% at a brake power of 3.9 kW while for diesel it is 30.9% and for B50 it decreased to 26.1%. It is found that as the proportion of jatropha oil in the blends increases the thermal efficiency decreases. This is due to the decrease in the rate of diffusion combustion of the blends. The decrease in brake thermal efficiency with increase in jatropha oil concentration is also due to the poor atomization of the blends due to their higher viscosity. However the decrease in brake thermal efficiency can be effectively improved by adding alcohol based additives.

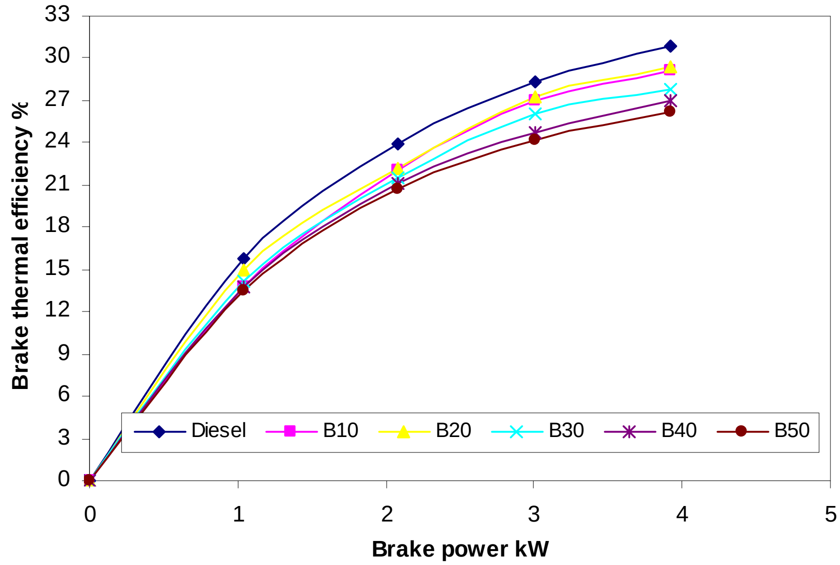

Fig. 5 Variation of brake thermal efficiency with brake power

3.4 Effect of brake power on smoke opacity

The variation of smoke opacity with brake power is shown in fig. 6. It is observed that the smoke opacity of the exhaust gas increases with increase in load for all the blends. It also shows that the smoke opacity increases with the concentration of jatropha oil in the blends. For diesel the opacity is 26.2% at full load, while for the blends it varies from 27.9% to 35.7% at full load. This is caused mainly due to the poor atomization and combustion because of the higher viscosity of the blends. The opacity for diesel showed a similar trend as that of the blends, however the values are comparatively lower at all loads. This is caused mainly due to the poor volatility and improper mixing of the fuel droplets with air because of the higher viscosity of the blends. The increase in smoke opacity with increase in the concentration of jatropha oil is found to be in agreement with the reported results of Banapurmath et al [3].

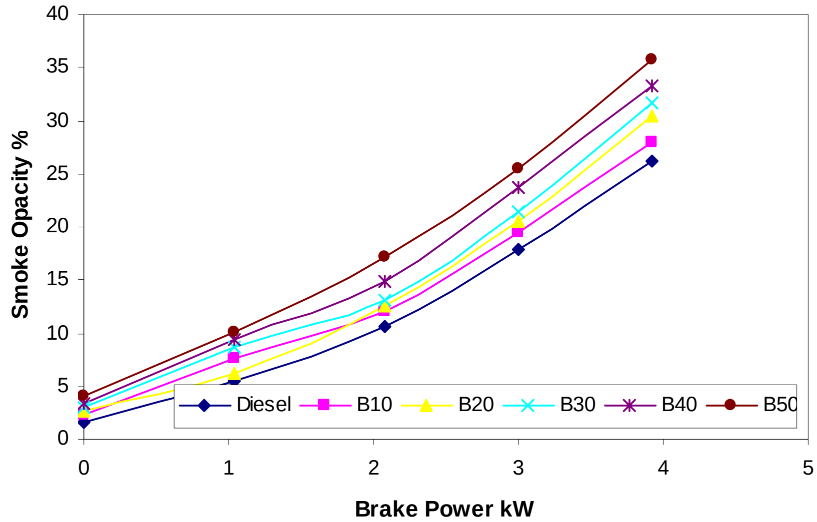

Fig. 6 Variation of smoke opacity with brake power

35 Effect of brake power on exhaust gas temperature

The variation of exhaust gas temperature with load for various blends and diesel is represented on fig. 7. At all loads, diesel is found to have the lowest temperature and the temperatures for various blends show an upward trend with increasing concentration of jatropha oil in the blends. As the combustion is delayed for the blends and more of the heat is released during mixing controlled combustion phase higher amount of heat goes with exhaust gas. Hence exhaust gas temperatures are higher.

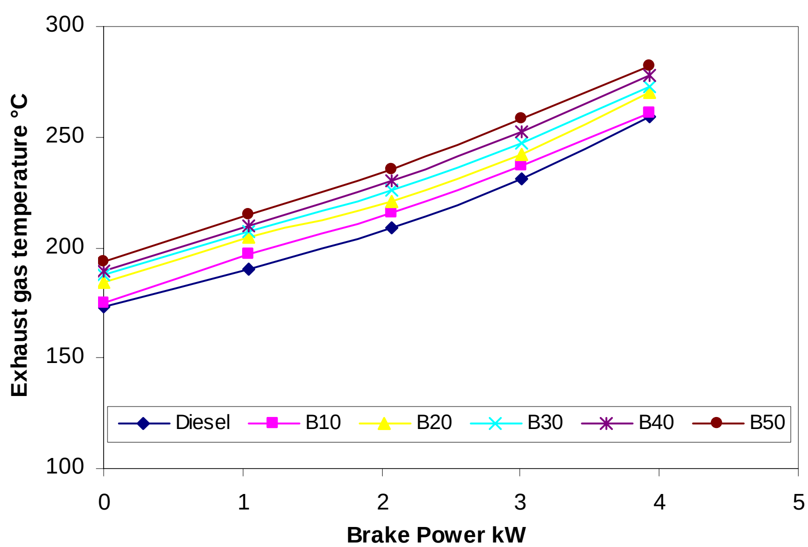

Fig. 7 Variation of exhaust gas temperature with load

3.6 CO_2 Emission

The emission levels of CO_2 for various blends and diesel is shown in fig. 8. Test measurements reveals that the CO_2 emission for all blends are less as compared to diesel at all loads. The rising trend of CO_2 emission with load is due to the higher fuel entry as the load increases. For diesel it was 9.1%.

For a blend of B10 it decreased to 8.9% and for B50 it was the lowest at 7.1%. Measurements have shown that the CO_2 emission for the blends were less as compared to diesel ranging from 2% to 8.9% from no load to full load. Higher density of the blends increases the fuel flow rate as the load increases which in turn increases the CO_2 emission with load. Biodiesel contains lower carbon content as compared to diesel and hence the CO_2 emission is comparatively lower.

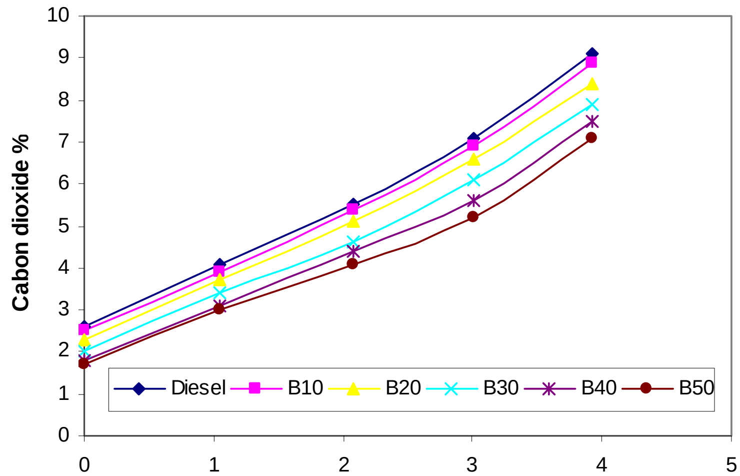

Fig. 8 Variation of Carbon dioxide with brake power

3.7 NO_X Emission

The variation of NO_X emission for different blends is indicated in fig. 9. The NO_X emission for diesel and all the blends followed an increasing trend with respect to load. For the blends an increase in the emission is found at all loads when compared to diesel. NO_X is formed generally at high temperatures. Since the exhaust gas temperatures are higher the NO_X emissions are also higher.

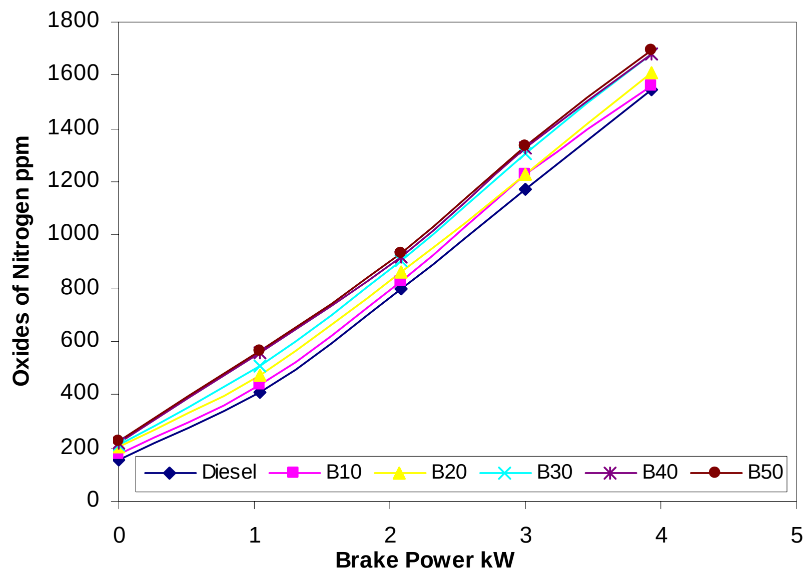

Fig. 9 Variation of Oxides of nitrogen with brake power

3.8 CO Emission

The variation of CO emission with brake power is shown in fig. 10. It is observed that the engine emits more CO for diesel at part load conditions when compared to the blends. But as the proportion of jatropha oil in the blend increases the percentage of emission decreases. However the percentage variation of carbon monoxide for all the blends when compared with base line diesel is very much less.

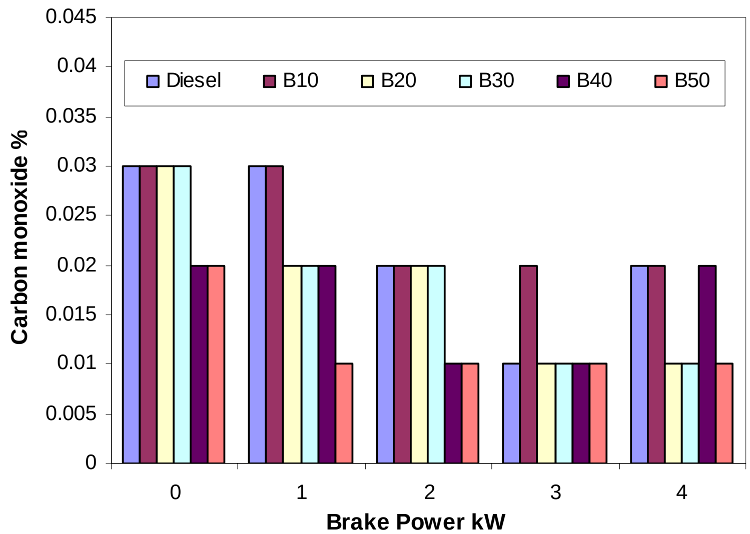

Fig. 10 Variation of CO with brake power

3.9 HC Emission

The HC emission variation for different blends is presented on fig. 11. It is observed that the HC emission decreased up to a load of 2.1 kW and then increased slightly with further increase in load for diesel. The HC emission for the blends also followed a similar trend but comparatively the values are lower. The presence of oxygen in the jatropha oil aids combustion and hence the hydrocarbon emission reduced. However at higher loads the effects of viscosity have increased these emission levels for the blends.

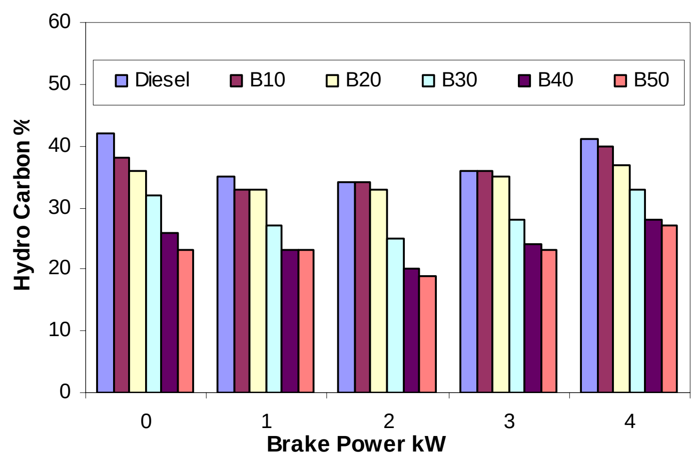

Fig. 11 Variation of Unburned HC with brake power

4. Conclusion

Combustion characteristics, engine performance and emission results of blends of transesterified jatropha oil and diesel were compared with the results obtained with mineral diesel. The variation in the peak pressures is not significant but an increase in the ignition delay of about 6 to 9 degree in crank angle was observed for the blends when compared to diesel. The specific fuel consumption is slightly higher for B20 but closer to diesel among all the blends. When the concentration of jatropha oil in diesel is more than 30% by volume there is an appreciable increase in the specific fuel consumption. The smoke opacity is found to be higher than diesel for all blends, but blends up to 20% substantially reduce CO_2 emissions with a marginal decrease in brake thermal efficiency. A maximum brake thermal efficiency of 29.4% was achieved for B20 while for diesel it was 30.9% for the same power output. However the decrease in brake thermal efficiency can be effectively improved by adding alcohol based additives. Experimental investigations show that blending of jatropha methyl esters up to 20 % by volume with diesel for use in an unmodified diesel engine is viable.

Nomenclature

J/D	-	Jatropha and Diesel
SFC	-	Specific Fuel Consumption
bTDC	-	Before Top Dead Centre
NOx	-	oxides of nitrogen
CO_2	-	carbon dioxide
CO	-	carbon monoxide
UBHC	-	Un Burnt Hydro Carbon
rpm	-	revolutions per minute
kg	-	kilogram
kWh^{-1}	-	kilowatt-hour
ppm	-	parts per million
B20	-	20% by volume esterified oil and 80% diesel
B10	-	10% by volume esterified oil and 90% diesel

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