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Combustion, Performance and Emission Characteristics of a Diesel Engine fuelled with *Azadirachta indica*, Non-edible Oil

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Abstract – *In the present work, experimental tests are carried out to analyze the combustion, performance and emission characteristics of a diesel engine fuelled with neem oil (Azadirachta indica) and its diesel blends (20%, 30% and 50% vol) vis-à-vis diesel at different loads and constant engine speed. The experimental results show that peak cylinder pressure and heat release rate is lower for neat neem oil and its blends than those of diesel fuel. The brake thermal efficiency is lower for neem oil and its diesel blends than that of diesel except NO20 blend. It has also been found that there was a decrease in* NO_x *emission for neem oil and its diesel blends along with a significant increase in HC, CO and smoke emissions.*

Keywords – Combustion, diesel engine, emission, neem oil, performance.

1. INTRODUCTION

The world has been confronted with energy crisis due to the decrease of fossil fuel resources and the increase of environmental restrictions. Therefore attention has been focused on developing the renewable or alternative fuels to replace the petroleum based fuels for transport vehicles. There are several alternative sources of fuel like biogas, biomass, primary alcohols and vegetable oils, which are all renewable in nature. Among these fuels, vegetable oils appear to have an exceptional importance as they are renewable and widely available, biodegradable and non-toxic, and environmental friendly. In agriculture-based country, like India, the use of vegetable oils has to be identified and initiated in order to prevent environmental degradation and reduce dependence on imported fossil supplies by partially replacing them with renewable and domestic sources. Since, vegetable oils have much or less similar properties of diesel fuel in terms of energy density, cetane number, heat of vaporization and stoichiometric A/F, they can be used in existing compression ignition engines with little or no modifications.

It has been reported by Murayama [1] *et al.*, that vegetable oils generated an acceptable engine performance and emission levels for short-term operation only, but they caused carbon deposits build up, piston ring sticking after extended operation. They also suggested practical solutions to overcome the problem, such as increasing the fuel temperature to over 200^{o}C, blending 25 vol% diesel fuel in the vegetable oil, blending 20 vol% ethanol in the fuel, or converting the vegetable oils into methyl esters. A comparison of engine performance and emissions of diesel with those of vegetable oil and its blends showed lower thermal efficiency, lower NO_x emission and higher CO and HC emissions [2]-[4]. It has been reported by Avinash [4] *et al.*, that vegetable oil blends up to 50% (v/v) would replace diesel for running diesel engine for lower NO_X emissions and improved performance. The diesel engine would run successfully without any modification on various blends of vegetable oil and diesel [5]-[6]. The engine performance with linseed oil, mahua oil, rice bran oil and their ester blends of diesel is close to that of diesel [7]. Various researchers [8]-[15] made a comparison of engine performance and emissions of diesel with those of vegetable oil blends. However few of them [3], [9], [11], [15] evaluated the engine performance, combustion and emissions using 100% straight vegetable oils. Therefore there is limited literature available on the investigation of the combustion characteristics of 100% straight vegetable oils. Literature suggests that vegetable oils can substitute for diesel fuel if reduction in viscosity is achieved by blending it with diesel. In rural areas, where grid power is not available, vegetable oils can be used to fuel single cylinder diesel engines, which can be used for standby power generation applications. Considering this in mind, experimental investigations have been carried out using various blends of neem oil with diesel and neat neem oil in an engine, which is typically used for agriculture and irrigation.

In the present work, experiments are conducted to study the combustion, performance and emission characteristics of diesel (D100), neem oil (*Azadirachta indica)* blends (%v/v) with diesel namely 20%, 30%, 50% and 100% (NO20, NO30, NO50 and NO100). The properties of all the fuels have been determined and summarized in Table 1. The determination of specific gravity, calorific value, viscosity, flash and fire point, and cloud and pour point has been carried out, as per the ASTM code standard, by using a hydrometer, a Bomb calorimeter, a Redwood viscometer, Pensky-Martins closed cup apparatus, and cloud and pour point apparatus respectively.

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Table 1. The properties of neem oil and its blends with diesel.

Sl. No	Fuel blend	Calorific value, MJ/kg	Specific gravity	Kinematic viscosity (@ 40^0C) (cSt)	Flash point ^{0}C	Fire point ^{0}C	Cloud point ^{0}C	Pour point ^{0}C
1	Diesel	43.2	0.823	3.9	56	68	-8	-20
2	N20	42.3	0.838	6.14	95	109	-3	-15
3	N30	41.9	0.848	7.72	127	138	0	-11
4	N50	41.0	0.871	12.2	149	163	3	-7
5	NO100	39.1	0.926	38	245	268	14.5	5.6
Testing Procedure		ASTM D4809	ASTM D445	ASTM D2217	ASTM D92	ASTM D92	ASTM D97	ASTM D97

2. TEST ENGINE AND EXPERIMENTAL PROCEDURE

Experiments have been conducted in a single-cylinder, four-stroke, naturally aspirated, direct injection diesel engine (Figure 1). The detailed specification of the engine is given in Table 2. The engine is coupled with an eddy current dynamometer which is used to control the engine torque. Engine speed and load are controlled by varying excitation current to the eddy current dynamometer using dynamometer controller. A piezoelectric transducer is installed in the cylinder head in order to measure the combustion pressure. Signals from pressure transducer are fed to charge amplifier. A high precision crank angle encoder is used for delivering signals for TDC and crank angle. The signals from charge amplifier and crank angle encoder are acquired using data acquisition system. An AVL exhaust -gas analyzer (Model: diGas 444) and AVL Smoke meter (Model: 437) are used to measure emission parameters CO, HC, and NO_x and smoke intensity respectively. The list of instruments for measuring various parameters and the range, accuracy and the uncertainties are given in Table 3. Loads are changed in five levels from no load to the maximum load. The engine is operated at the rated speed i.e., 1500 rpm for all the tests. For all the tests, the engine is started with diesel fuel and allowed to stabilize for 45 minutes. After the engine is warmed up, it is then switched to NOME blends. For each experiment, three measurements are taken to average the data so as to determine the repeatability of the measured data and have an estimate of measured accuracy. At the end of test, the fuel is switched back to diesel and the engine is kept running for a while before shutdown to flush out the NOME blends from the fuel lines and injection system.

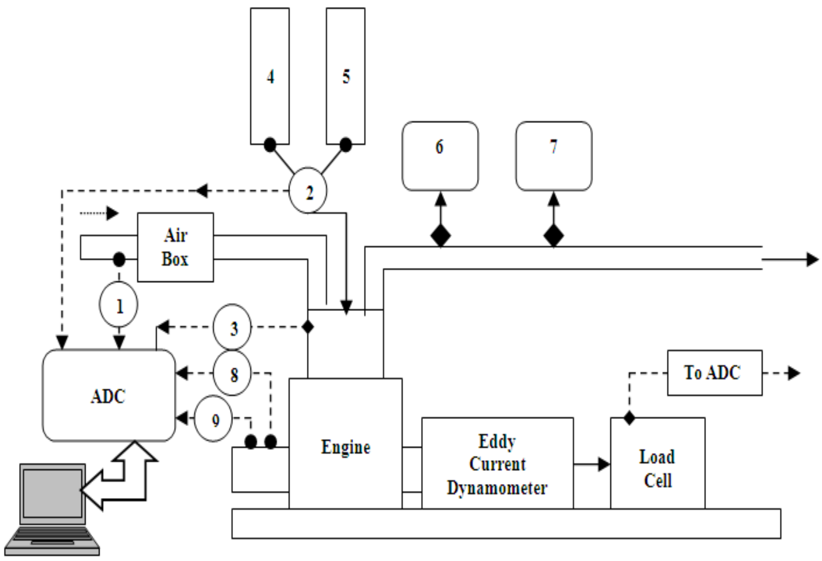

Fig. 1. Experimental set-up.

1 – Air Flow Sensor 2 – Fuel Flow Sensor 3 – Pressure Sensor 4 – Diesel Tank
5– Neem oil Tank 6– Five Gas Analyzer 7 – Smoke Meter 8 – Speed Sensor
9 – Crank Angle Encoder

Table 2. Engine specifications.

Particulars	Specifications
Make and Model and Type of engine	Kirloskar –TV 1,4 Stroke, water cooled and direct injection diesel engine
Type of fuel injection	Pump-line-nozzle injection system
Nozzle type	Multi hole (3 holes)
Piston type	Bowl-in-piston
Compression ratio	16.5:1
Bore and Stroke	80 mm and 110mm
Load indicator	Digital, range 0-3.5 kW
Dynamometer	Type-eddy current, water cooled
Load sensor	Strain gauge load cell
Fuel flow sensor	Optical sensor
Air flow sensor	Pressure transmitter
Temperature sensor	K-type thermocouple
Injection timing and pressure	23^{o} before TDC and 210 bar

Table 3. List of instruments for measuring various parameters and the range, accuracy and the uncertainties.

Sl. No	Instruments	Principle of measurement	Range	Accuracy
1	Pressure pick up		0-110 bar	± 1 ppm
2	Crank angle encoder			± 1^0
3	Exhaust gas Analyzer			
	NO_x	Electrochemical	0-5000 ppm	± 10 ppm
	CO	NDIR (non-dispersive infra red)	0-10 % vol	± 0.01%
	HC	NDIR	0-20000HC	± 5 ppm
4	Smoke intensity		0-100 opacity in %	±2%
Sl. No	**Calculated Parameter**			**Percentage Uncertainties**
1	Kinematic viscosity			± 1.3%
2	BTE			± 1%
3	BSEC			± 1.5%
4	Brake Power			± 0.5%

3. RESULTS AND DISCUSSION

Characterization of Neem Oil and its Blends with Diesel

The specific gravity of neem oil is found to be 11.1% higher than that of diesel. The specific gravities are found to increase with the increase in neem oil percentage in the blends. The higher specific gravities of neem oil may be attributed to the higher molecular weights of triglyceride molecules present in them. The calorific value for neem oil is 9.4% lower than those for diesel. This could be due the presence of oxygen molecule in the molecular structure of neem oil. The calorific values of the blends are found to decrease with the increase in neem oil concentration in the blends. The kinematic viscosity of neem oil is found to be about 38 cSt, which is 10 times more than that of diesel. The viscosity of the blends is found to increase with the increase in neem oil concentration in the blends. The flash point of neem oil is found to be 245^{0}C respectively, which is quite higher compared to 56^{0}C with diesel. The flash points of all the blends are also higher than that of diesel. A similar phenomenon in fire point is also observed. Flash point and fire points are important to satisfy performance and emissions requirements. The cloud and pour points of neem oil are higher than those of diesel. The cloud and pour points of all the blends are also higher than that of diesel. The cloud and pour points are important for cold weather conditions.

Combustion Analysis

The variation of cylinder pressure with crank angle for neem oil and its diesel blends at no load and full load is shown in Figures 2a-2b. It can be seen that at all loads, the combustion starts earlier for neem oil and its blends than diesel. This may be due to short ignition delay and advanced dynamic injection timing for neem oil and its blends (because of a higher bulk modulus and higher density) [11]. The peak cylinder pressure is higher for neem oil and its diesel blends at no load. This may be due to the increase of ignition delay with the engine load decreasing. Due to longer ignition delay, the combustion starts later for diesel than neat neem oil as seen in pressure-crank angle diagram (Figure 2). This can be confirmed by the heat release rate (Figures 3a-3b) diagram. Therefore, at no load the peak cylinder pressure for diesel attains a lower value as it is further away from the TDC in the expansion stroke. As the engine load increases, the combustion start points come closer for all the fuels. As a result, at full load, initiation of combustion before TDC takes place and the pressure rises more quickly for diesel. The peak pressure for NO20 is close to that of diesel. In case of NO30, NO50 blends, the difference in peak pressure is not significant at full load.

The variation of heat release rate with crank angle for neem oil and its diesel blends at no load and full load is shown in Figures 3a-3b. At the beginning, the negative heat release is observed due to the vaporization of the fuel accumulated during the ignition delay, and after the initiation of combustion, heat release rate becomes positive. The premixed heat release is always higher for diesel due to its higher volatility and better mixing of diesel with air. It can also be seen that the premixed combustion phase is dominant for all the fuels at no load, but at full load, the diffusion burning indicated by the area under second peak is dominant for neat neem oil. This is consistent with the expected effects of neat neem oil viscosity on the fuel spray and reduction of air entrainment and fuel/air mixing rates [2]. At the time of ignition less air-fuel mixture is prepared for combustion with neat neem oil. As a result more burning occurs in the diffusion burning combustion phase rather than in the premixed combustion phase. Due to this more amount of energy is released in the later part of the combustion process, which lead to reduction in thermal efficiency.

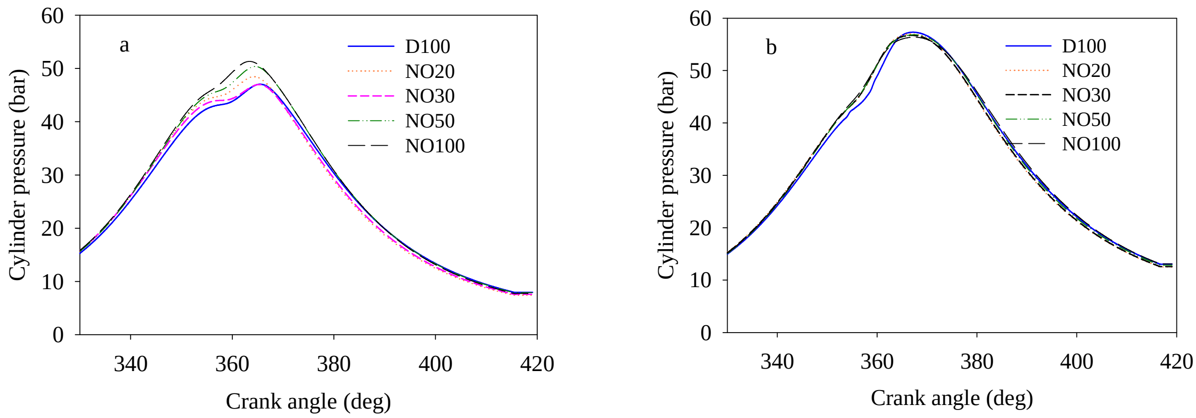

Fig. 2. Pressure vs. crank angle for diesel and neem oil blends at (a) no load (b) full load.

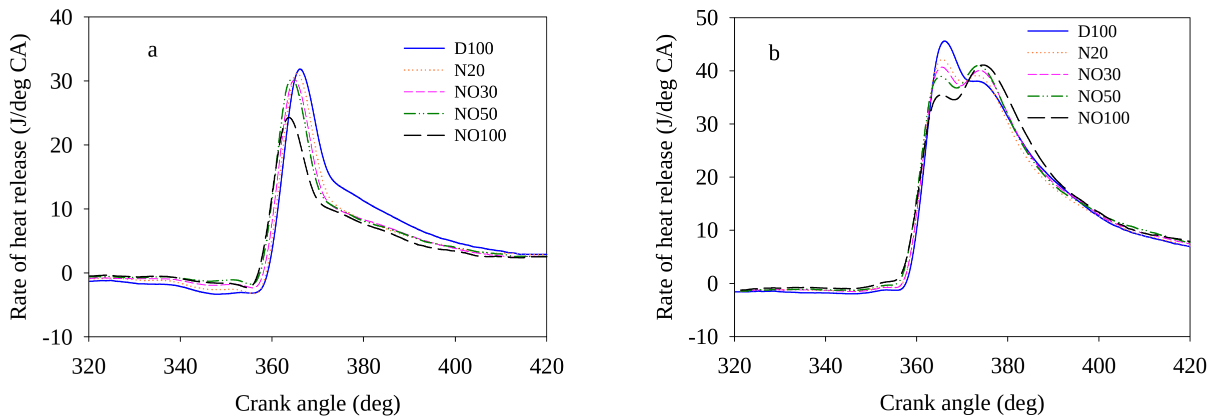

Fig. 3. Heat release rate vs. crank angle for diesel and neem oil blends at (a) no load (b) full load.

Performance Analysis

The variation of brake thermal efficiency with brake power for neem oil and its diesel blends is shown in Figure 4. The brake thermal efficiency decreases with the increasing percentage of neem oil in the blends. The thermal efficiency for NO20 is more than that of diesel. The possible reason is that neem oil molecules have some oxygen which takes part in combustion and results in complete combustion. The thermal efficiency for higher blends is observed to be lower compared with diesel. It may be due to larger differences in viscosity, specific gravity and volatility between diesel and neat neem oil. Poor spray formation and reduced spray angle cause reduction in air entrainment and fuel-air mixing rates [2].

The variation of BSEC with brake power for diesel and neem oil blends is presented in Figure 5. The BSEC is an ideal parameter for comparing the engine performance of fuels having different calorific values and specific gravities. The BSEC is calculated as the product of brake specific fuel consumption and lower calorific value. Initially BSEC of the engine is improved with increasing concentration of neem oil in the blend (NO20) for all loads. It can be seen that after a certain limit with respect to diesel-neem oil blend, brake thermal efficiency starts decreasing as a function of the concentration of the blend. At full load, the BSEC of neem oil is 14% lower than that of diesel. This may be due to the combined effects of lower calorific value, higher viscosity and specific gravity of neem oil.

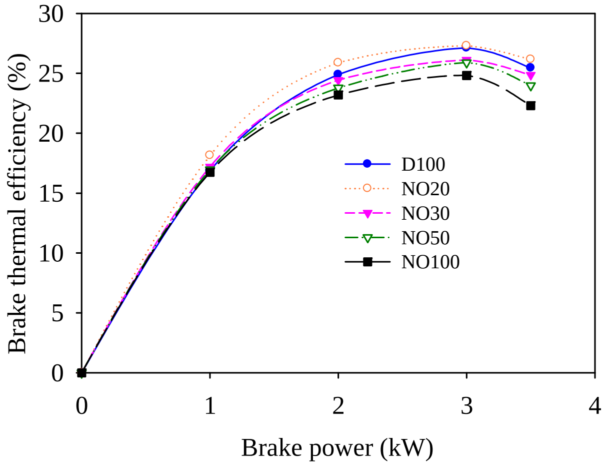

Fig. 4. Brake thermal efficiency vs. brake power for diesel and neem oil blends.

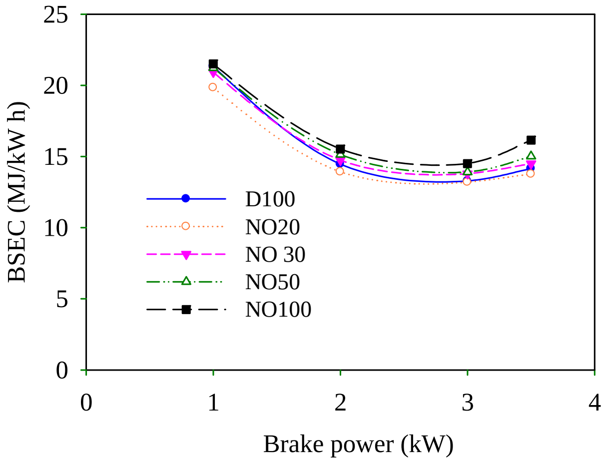

Fig. 5. Brake specific energy consumption vs. brake power for diesel and neem oil blends.

Emission Analysis

The variation of oxides of nitrogen with brake power for neem oil and its diesel blends is shown in Figure 6. The NO_x emission is increased with the engine load increasing due to the higher combustion temperature. This indicates that the NO_x emission strongly depends upon the combustion temperature and availability of oxygen. From Figure 6, it can be seen that the NO_x emissions from neat neem oil and its blends are lower than those of diesel. The vegetable oils have higher viscosity therefore the fuel droplet size in the engine is expected to be larger than the diesel. Larger droplets have longer combustion duration and they demonstrate significant energy release during later part of the combustion process. This suggests that the maximum combustion temperature is possibly lower (less intensity of heat release in the premixed combustion phase as well as mixing controlled combustion phase), which leads to lower emission of NO_x for neat neem oil and its diesel blends compared with diesel [4]. The NO_x emissions are highly undesirable as they lead to respiratory illness and environmental effects. The NO_x emission is the most harmful gaseous emissions from diesel engines; its reduction is always the aim of engine researchers and engine manufacturers.

The variation of HC emission with brake power for diesel, NO blends is shown in Figure 7. As seen in Figure 7, the HC emissions from NO20 are lower compared to diesel. With increase in neem oil content in the blends, the HC emission increases for all loads. The effect of fuel viscosity on fuel spray quality could be expected to produce some HC emission with vegetable oils. Due to high viscosity, the air-fuel mixing process is affected by the difficulty in the atomization and vaporization of neem oil and its blends. The resulting locally rich mixture causes more in-complete combustion products such as HC and CO [3], [6], [11], and [12].

The variation of CO emission with brake power for diesel and neem oil blends is shown in Figure 8. As seen in Figure 8, the CO emissions from NO20 and NO30 are comparable with diesel. However in case of N50 and NO100, the CO emissions are 16% and 60% higher than that of diesel. The higher viscosity and poor atomization tendency of neem oil leads to poor combustion and higher CO emission [3], [6], and [11]. It can also be seen that the engine emits very small CO emissions for all the fuels, which are less than 0.09%, so that a small change of the CO content will cause a big change in percentages.

The variation of smoke emission with brake power for neem oil and its diesel blends is shown in Figure 9. The smoke emission from neat neem oil and its diesel blends is higher than that of diesel except NO20 blend. This may due to heavier molecular structure and higher viscosity of neem oil and its diesel blends; atomization becomes poor and this leads to higher smoke emissions [3], [6], and [11].

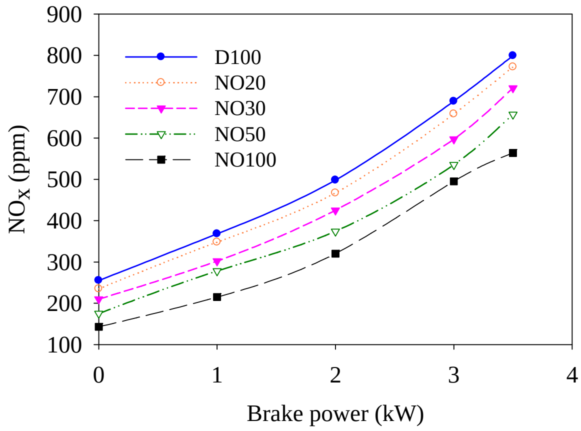

Fig. 6. Oxides of nitrogen vs. brake power for diesel and neem oil blends.

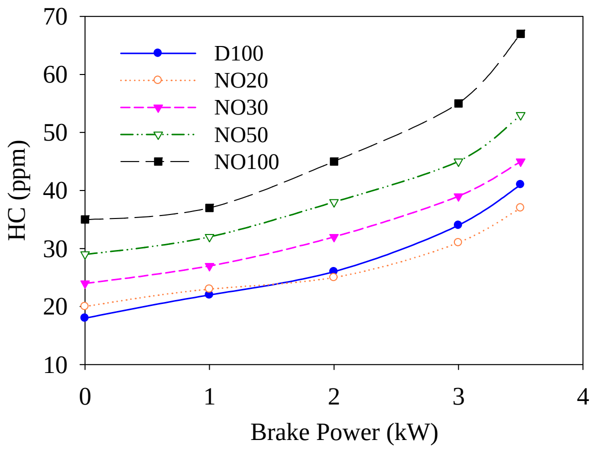

Fig. 7. Hydrocarbon vs. brake power for diesel and neem oil blends.

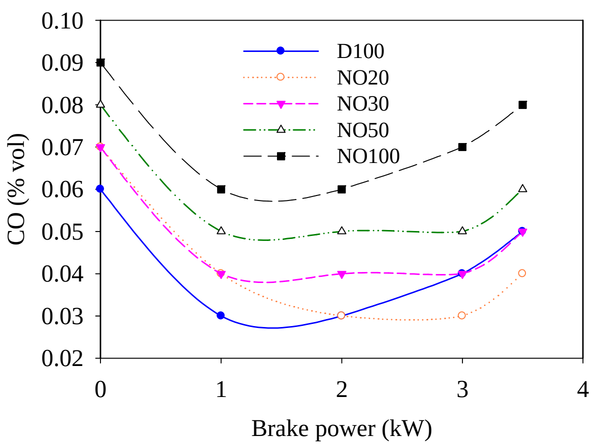

Fig. 8. Carbon monoxide vs. brake power for diesel and neem oil blends.

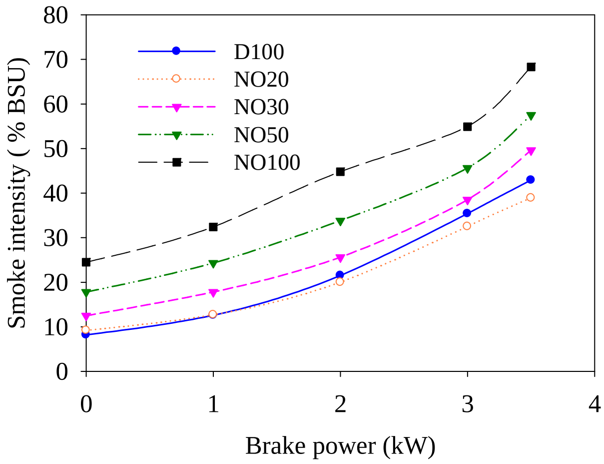

Fig. 9. Smoke intensity vs. brake power for diesel and neem oil blends.

4. CONCLUSIONS

A Single cylinder diesel engine was operated successfully using neem oil, its diesel blends without any modification in the engine hardware.

1. The combustion analysis revealed that at full load, the neem oil and its blends show the lower peak cylinder pressure and peak heat release rate than diesel.
2. The brake thermal efficiency for NO20 blend is slightly higher by about 3% than that of diesel.
3. The NO_x emissions for neat neem oil and its diesel blends are lower in the entire operating conditions. The NO_x emissions for NO20 blend and neat neem oil at full load decrease to about 3% and 29%, respectively, compared with diesel fuel at full load.
4. The CO, HC and smoke emissions from neat neem oil and its diesel blends are higher than those of diesel except in the case of NO20 blend. At full load, the CO and HC emissions for NO20 blend decrease to about 20% and 9.7%, respectively, compared with diesel. The smoke emission for NO20 blend decreases to about 9% compared with diesel.

The experimental results prove that neem oil blends with diesel up to 20% (v/v) are potentially good substitutes for diesel engines.

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