EXPERIMENTAL INVESTIGATION ON A DIESEL ENGINE USING NEEM OIL AND ITS METHYL ESTER

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Fuel crisis and environmental concerns have led to look for alternative fuels of bio-origin sources such as vegetable oils, which can be produced from forests, vegetable oil crops and oil bearing biomass materials. Vegetable oils have energy content comparable to diesel fuel. The effect of neem oil (NeO) and its methyl ester (NOME) on a direct injected four stroke, single cylinder diesel engine combustion, performance and emission is investigated in this paper. The results show that at full load, peak cylinder pressure is higher for NOME; peak heat release rate during the premixed combustion phase is lower for neat NeO and NOME. Ignition delay is lower for neat NeO and NOME when compared with diesel at full load. The brake thermal efficiency is slightly lower for NeO at all engine loads, but in the case of NOME slightly higher at full load. It has been observed that there is a reduction in NOx emission for neem oil and its methyl ester along with an increase in CO, HC and smoke emissions.

Keywords: *Neem oil, Neem Oil Methyl Ester, Combustion, Performance, Diesel Engine.*

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 alternate fuels to replace the petroleum based fuels for transport vehicles. There are several alternative sources of fuel like vegetable oils, biogas, biomass, primary alcohols 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. A great deal of research has been conducted on their feasibility and the researchers have concluded that neat vegetable oils hold promise as alternative fuels for diesel engines for short-term use [1-4]. However researchers have reported that the use of neat vegetable oil causes enginerelated problems. High viscosity, low volatility and poor cold flow conditions of these fuels cause severe engine deposits, injector coking, piston ring sticking and difficulty in starting especially in cold weather. There are four ways to use neat vegetable oils in diesel engine [5-8]. 1. Direct use or blending in diesel fuel, 2.Micro emulsions in diesel fuel, 3. Thermal cracking of vegetable oils, 4. Transesterification. Out of these, transesterification is the most popular and best way to use neat vegetable oils [8].

Sahoo et al [9] have experimented with jatropha, karanja and polanga biodiesel in a diesel engine. They reported higher peak cylinder pressure and shorter ignition delay for all biodiesels when compared with diesel. Banapurmath et al[10] have experimented with methyl esters of honge(HOME), jatropha(JOME) and sesame(SOME) in a single cylinder, four stroke, direct injection CI engine and reported a higher emission of CO, HC and smoke and lower NO_x as compared to that of diesel. Edwin et al[11] have studied the combustion process of rubber seed oil (RSO) and its methyl ester (RSOME) and also reported a higher emissions of CO, HC and smoke emissions and lower NO_x as compared to that of diesel. Balusamy et al[12] have experimented with methyl ester of thevetia peruviana seed oil (METPSO) and reported a lower emissions of CO, HC emissions and a higher NO_x as compared to that of diesel. Qi et al[13] have compared the combustion characteristics of diesel and biodiesel from soybean oil in a single cylinder, naturally aspirated diesel engine and concluded that the peak cylinder pressure of biodiesel is close to that of diesel. They also reported that the peak rate of pressure rise and peak heat release rate during premixed combustion phase are lower for biodiesel.

Research studies on the utilization of neem oil as an alternative diesel engine fuel are very little. Avinash et al [5] and Anjana Srivastava et al [7] have highlighted the suitability of neem oil for diesel engines. Narun Nabi et al [14] have conducted experiment with diesel fuel and diesel-NOME blends in a four stroke naturally aspirated diesel engine. More research work on the engine performance, combustion and emission characteristics is required for complete evaluation of using neem oil as an alternative diesel engine fuel. The specific objective of the present work is to evaluate comparatively the performance, combustion and emission characteristics of a diesel engine using neat neem oil and its methyl ester, prepared by a method of two step 'acid -base' process.

2. Experimental

2.1.Test engine and Experimental Procedure

Experiments have been conducted in a single-cylinder, four-stroke, naturally aspirated, direct injection diesel engine (Fig.1). The specification of the engine is given in Tab 1. A mechanical unit pump of helical plunger type made by Bosch is used to deliver the fuel to the multi hole orifice. Two separate fuel tanks with a fuel switching system are used. The fuel consumption can be measured with the aid of an optical sensor. The fuel from the tank was connected by way of a solenoid valve to a glass burette and the same is connected to the engine through a manual ball valve. The fuel solenoid of the tank will open and stay open for 30 sec, during this time fuel is supplied to the engine directly from the fuel tank and also fills up the burette. After 30 sec the fuel solenoid closes the fuel tank outlet, and now the fuel in the burette is supplied to the engine. When the fuel level crosses the high level optical sensor, the sequence running in the computer records the time of this event. Likewise when the fuel level crosses the low level optical sensor, the sequence running in the computer records the time of this event and immediately the fuel solenoid opens filling up the burette and cycle is repeated. Now, volume of the fuel between high level and low level optical sensors (20 cm^3) is known. The starting time of fuel consumption, i.e. time when fuel crossed high level sensor and the finish time of fuel consumption, i.e. time when the fuel crossed low level sensor gives an estimate of fuel flow rate i.e. 20 cm^3/difference of time in sec. The inlet air tank is provided with an orifice. The pressure drop across the orifice is measured using a differential pressure transducer. The output of the differential pressure transducer is amplified using an instrumentation amplifier and fed to the data acquisition system. 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 specification and accuracy of gas analyzer and smoke meter is given in Tab.2. The uncertainties of some of the measured and calculated parameters are given in Tab.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 NeO/NOME. 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 NeO/NOME from the fuel lines and injection system. The performance parameter such as brake thermal efficiency, combustion parameters such as cylinder pressure, ignition delay, rate of heat release and rate of pressure rise, and emission parameters such as like smoke intensity, unburned hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x) emissions are measured for diesel fuel , neat NeO and NOME. Finally, the test results are analyzed and compared.

Tab. 1 - Engine specifications

Particulars	Specifications
Make & Model	Kirloskar –TV 1
BHP & Speed	5 hp @ 1500 rpm
Type of Engine	Direct Injection & 4 Stroke
Compression ratio	16.5:1
Bore & Stroke	80 mm & 110mm
Type of Loading	Eddy current dynamometer
Method of cooling	water cooling

Inlet valve opening	4.5^{o}before TDC
Inlet valve closing	35.5^o after BDC
Exhaust valve opening	35.5^o before BDC
Exhaust valve closing	4.5^o after TDC
Injection timing	23^o before TDC
Injection pressure	210 bar

Tab. 2 - Gas analyzer and Smoke meter specifications

Gas Analyzer Model	**AVL 437 DiGas 444**	**Accuracy**
Pollutant	**Range**	
CO	0-10 % vol	0.01
HC	0-20000HC	± 10 ppm
NOx	0-5000 ppm	± 10 ppm
Smoke meter	**AVL 437**	**Accuracy**
Smoke intensity	0-100 opacity in %	± 1% full scale reading

Tab. 3 – Uncertainties of some measured and calculated parameters

Parameter	**Percentage Uncertainties**
NO_x	± 0.1
CO	± 0.1
HC	± 0.1
Kinematic viscosity	± 1.3%
BTE	± 1%
BSFC	± 1.5%
Brake Power	± 0.5%

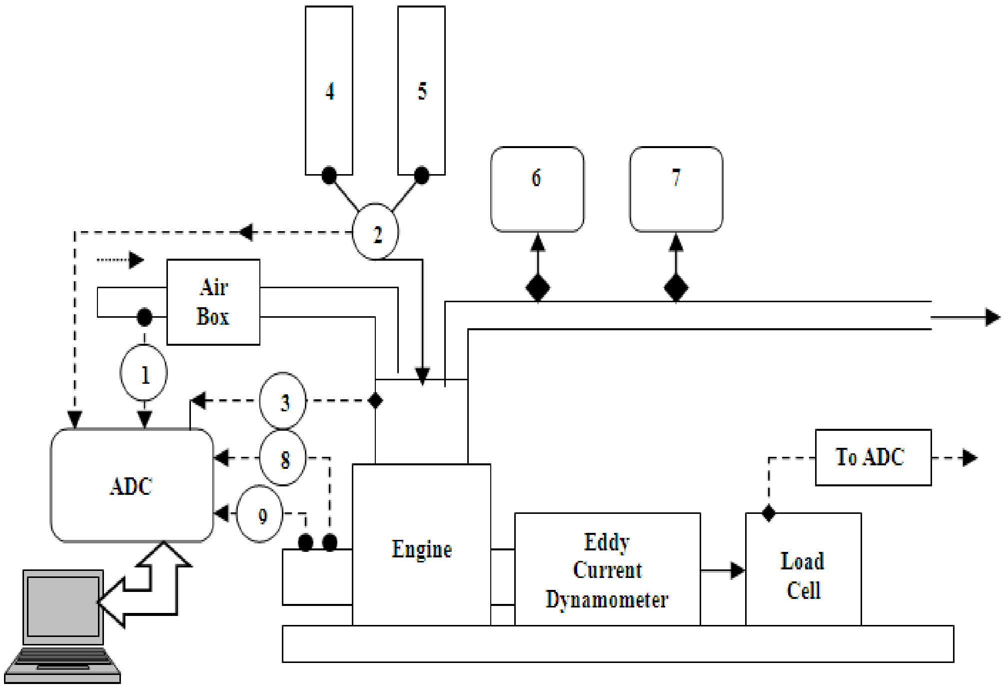

Fig.1. Experimental Set Up

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

2.2.Fuel Preparation

Transesterification is the process of reacting a triglyceride with alcohol in the presence of a catalyst to produce fatty acid esters and glycerol. It is difficult to produce ester from neem oil using alkaline catalyst (NaOH/KOH) because of its high free fatty acid (FFA). Therefore, a two step transesterification process is chosen to convert the non-edible neem oil to its methyl ester. The first step acid catalyzed esterification reduces the FFA value of the oil to about 2%. The second step, alkaline catalyzed transesterfication process converts the products of the first step to its mono-esters and glycerol.In acid esterification, 1000 ml neem oil is heated to about 50^{o}C, 250 ml methanol is added and stirred for a few minutes. With this mixture 2% H_2SO_4 is also added and stirred at a constant rate with 50^{o}C for one hour. After the reaction is over, the solution is allowed to settle for 24 hrs in a separating funnel. The excess alcohol along with sulphuric acid and impurities floats at the top surface and is removed. The lower layer is separated for further processing (alkaline esterification).In alkaline catalyzed esterification, the products of the first step are again heated to about 50 to 55^{o}C. With this mixture, 5g KOH dissolved in 250 ml methanol is added and stirred for 60 minutes. After the reaction is over, the solution is again allowed to settle for 24 hrs. The glycerin settles at the bottom and esterified neem oil rises to the top. This esterified neem oil is separated and purified with warm water. After washing the final product is heated up to 60^0C for 10 min. The esterified neem oil so prepared is referred as methyl ester of neem oil (NOME).

3. Results and Discussion

3.1. Characterization of Biodiesel from Neem Oil

The important physiochemical properties of diesel, NeO and NOME are shown in Tab.4. The determination of specific gravity, calorific value, viscosity, flash point, and fire point are carried out, as per the ASTM standard, by using a hydrometer, a Bomb calorimeter, a Redwood viscometer and Pensky-Martins closed cup apparatus. The present results show that transesterification process improved the fuel properties of the neem oil. The kinematic viscosity of the NOME is found to be 4.5 cSt, which is approximately 15% higher than that of diesel. The specific gravity of NOME is 0.867, which is approximately 6.67% higher than that of diesel. The lower calorific value of NOME is 41MJ/kg, which is 5% lower than that of diesel. Therefore more amount of biodiesel needs to be injected into the combustion chamber to produce the same amount of power. The flash and fire point of NOME are higher than that of diesel as seen in Tab.4. This is beneficial during transportation.

Tab. 4 - Properties of diesel, NeO, NOME.

Property	**Diesel (D100)**	**NeO**	**NOME**	**ASTM Code**
Chemical formula	$C_{14}H_{22}$	$C_{18}H_{34}O_2$	$C_{18}H_{34}O_2$	-
Calorific value, MJ/kg	43.2	39.0	40.1	D4809
Specific gravity	0.823	0.926	0.867	D445
Kinematic viscosity (at 40^oC) (cSt)	3.9	38	4.5	D2217
Flash point ^oC	56	245	152	D92
Fire point ^oC	64	278	158	D92
Cetane number	48	47	51	-

3.2 Combustion Analysis

The variation of cylinder pressure with crank angle at full load is shown in Fig.2. It is clear that the combustion starts earlier for NeO and NOME due to shorter ignition delay and advanced dynamic injection timing (because of higher bulk modulus and higher density of NeO and NOME).It can also be observed that NOME has a higher peak pressure than NeO and diesel. Due to longer ignition delay of NOME compared to NeO, more fuel is accumulated in the combustion chamber which leads to higher peak pressure at the time of premixed combustion stage. On the other hand, while running with diesel, due to longer ignition delay, the combustion starts later for diesel compared to NOME, which leads to lower peak cylinder pressure. The location of the peak pressures for NeO and NOME are comparable with that of diesel and are within 1- 10 crank angle degree after the TDC. The peak pressure for NeO and NOME is 55 bar occurring at 7^o CA after TDC, 57 bar occurring at 8^o CA after TDC, respectively, while in the case of diesel, it is 56 bar occurring at 9^o CA after TDC.

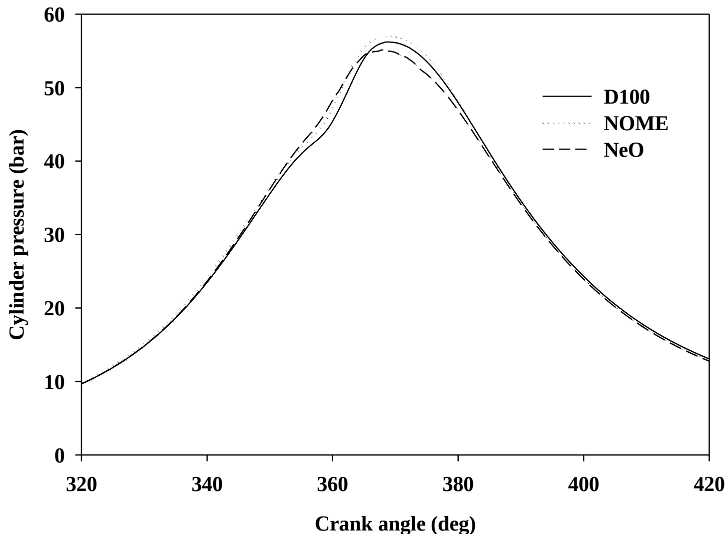

Fig.2. Cylinder pressure vs crank angle at full load.

The variation of ignition delay with brake power for NeO, NOME and diesel is shown in Fig.3. The ignition delay is observed to be lower in case of NeO compared to diesel and NOME at all engine loads. The reason may be that a complex and pre-flame reaction takes place at higher temperatures. As a result of higher cylinder temperature existing during fuel injection, neem oil may undergo thermal cracking and lighter compounds are produced, which might have ignited earlier, resulting in a shorter ignition delay.

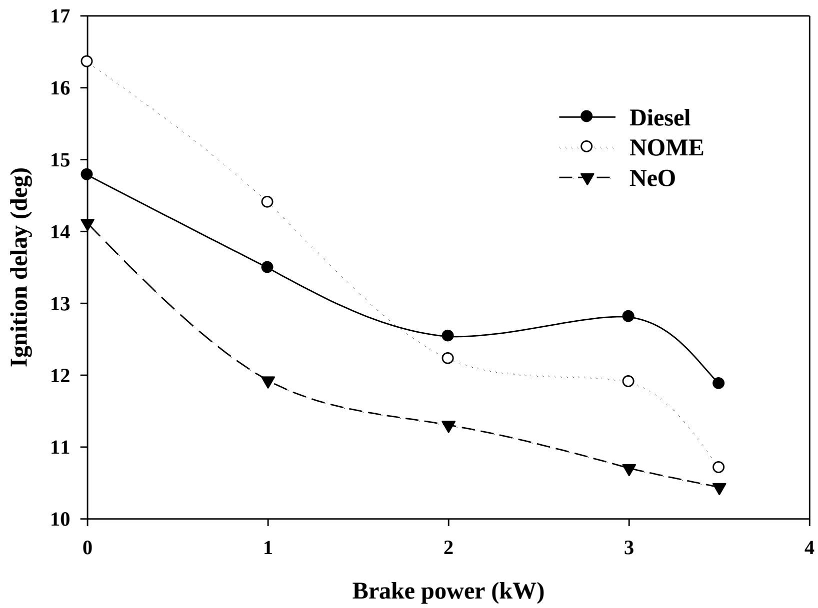

Fig.3. Ignition delay vs Brake power

The variation of heat release rate with crank angle at different loads for NeO, NOME and diesel is shown in Fig. 4. It can be observed that peak heat release rate is higher for diesel than NOME and NeO. This may be due higher volatility and better mixing of diesel with air. Another reason may be, as a consequence of the longer ignition delay, the intensity of premixed combustion phase for diesel is more. It can also be observed the diffusion burning indicated by the area under second peak is dominant for NeO. 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.

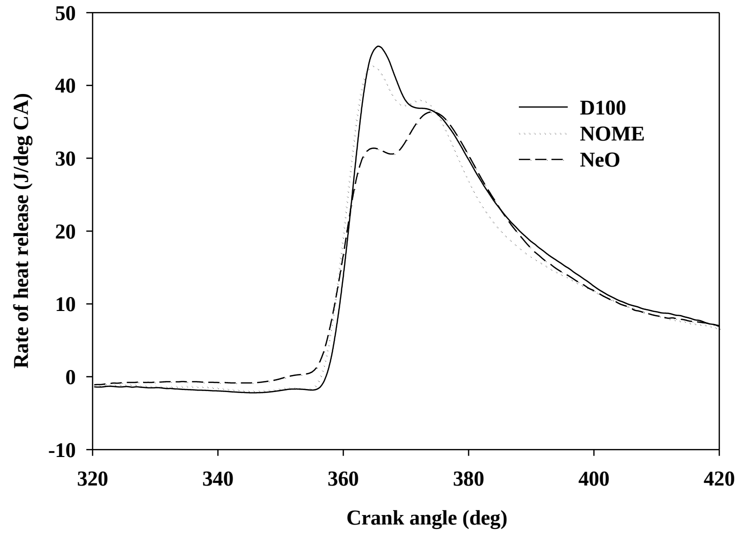

Fig.4. Heat release rate vs Crank angle at full load.

The variation of rate of pressure rise with crank angle for NeO, NOME and diesel at full load is shown in Fig.5. The peak rate of pressure rise is lower for NeO and NOME compared to diesel at full load. This is because neem oil contains heavier hydrocarbon molecules which have higher viscosity and lower volatility. As a result, lower rates of heat release at the time of premixed combustion stage are produced for NeO and NOME compared to diesel.

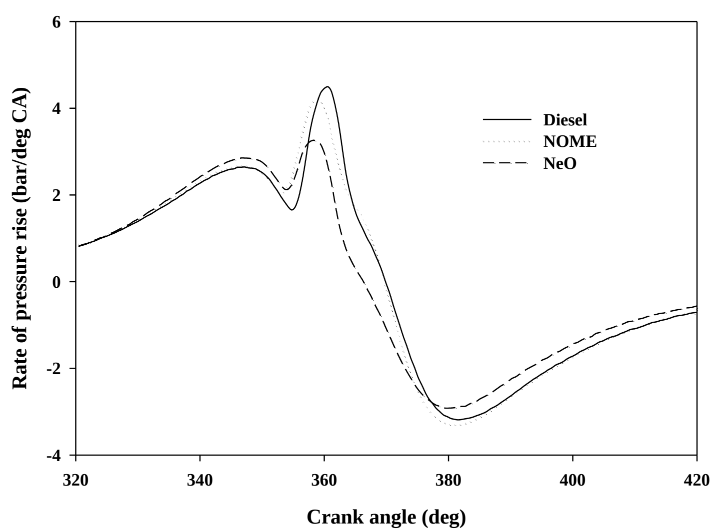

Fig.5. Rate of pressure rise vs crank angle at full load.

3.3 Performance Analysis

The variation of brake thermal efficiency with brake power for diesel, NOME and NeO is shown in Fig.6. The thermal efficiency is lower for NeO than that of NOME and diesel. It may be due to larger differences in viscosity, specific gravity and volatility between diesel and NeO. The Poor spray formation and reduced spray angle causes reduction in air entrainment and fuel-air mixing rates [2]. It can be observed that there is an improvement in thermal efficiency of about 3% with NOME at full load.

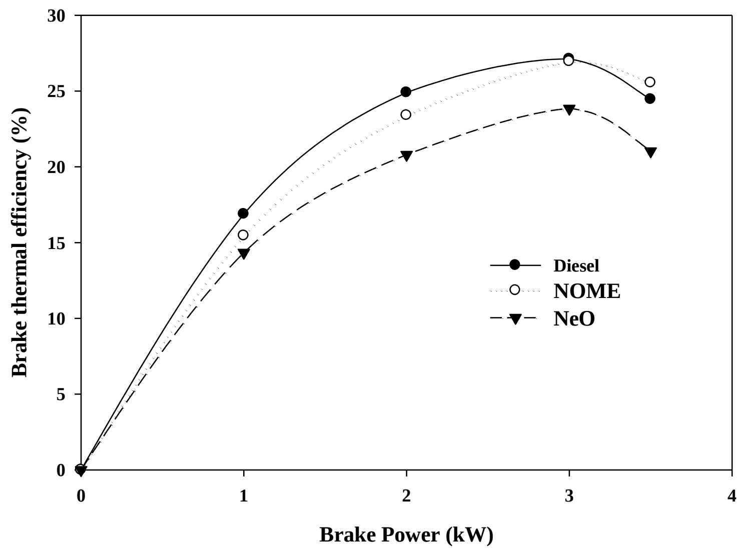

Fig.6.Brake thermal efficiency vs Brake power

3.4 Emission Analysis

The variation of smoke intensity with brake power for diesel, NOME and NeO is shown in Fig. 7. It can be observed that smoke emission is higher with NeO as compared to NOME and diesel due to poor mixture formation tendency. Due to heavier molecular structure and higher viscosity of NeO, atomization becomes poor which leads to sluggish combustion, leading to higher smoke emission. The smoke intensity value of NOME lies in between diesel and NeO.

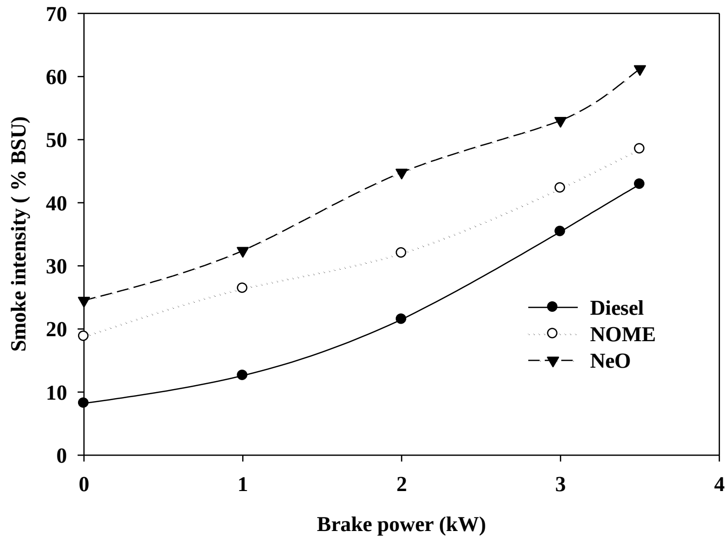

Fig.7.Smoke intensity vs Brake power

The variation of oxides of nitrogen with brake power for diesel, NOME and NeO is shown in Fig. 8. It can be observed that the NOx emission is lower with NeO, NOME as compared to diesel. The most important factors that cause NO_x emission are maximum combustion temperature and locally air-fuel mixture. Since the injection particles of NeO, NOME are greater than those of diesel, the combustion temperatures with NeO, NOME are lower and this leads to lower NOx emissions. Another reason may be due to the lower rates of heat release of NeO, NOME during premixed combustion phase, which leads to lower combustion temperatures.

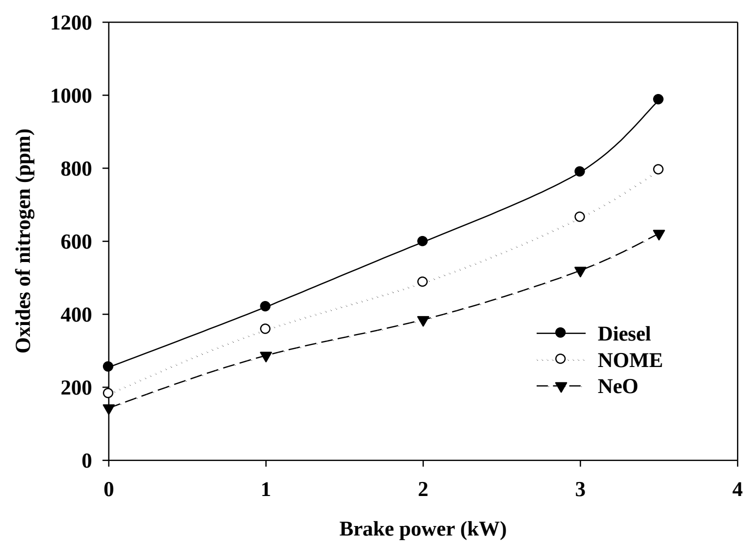

Fig.8.Oxides of nitrogen vs Brake power

The variations in CO and HC emissions with brake power for diesel, NOME and NeO are shown in Fig. 9 and Fig.10. It can be observed that the CO and HC emissions are higher with NeO, NOME as compared to diesel. This may be due to relatively poor atomization and lower volatility of NeO, NOME compared to diesel. As a result, some of the fuel droplets may not get burned. When theses unburned droplets mix with the hot combustion gases, oxidation reactions occur, but do not have enough time to undergo complete combustion. Comparing with neat NeO, relatively lower CO and HC emissions are observed with the NOME.

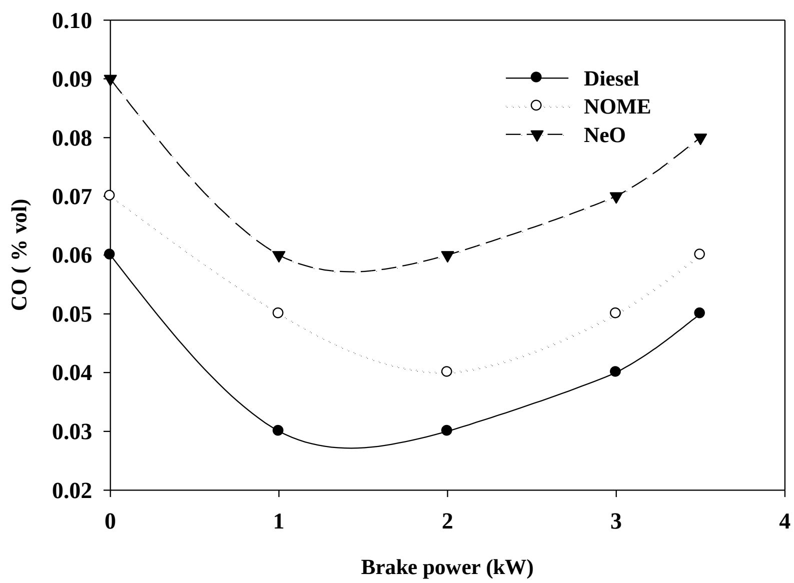

Fig.9.Carbon monoxide emission vs Brake power

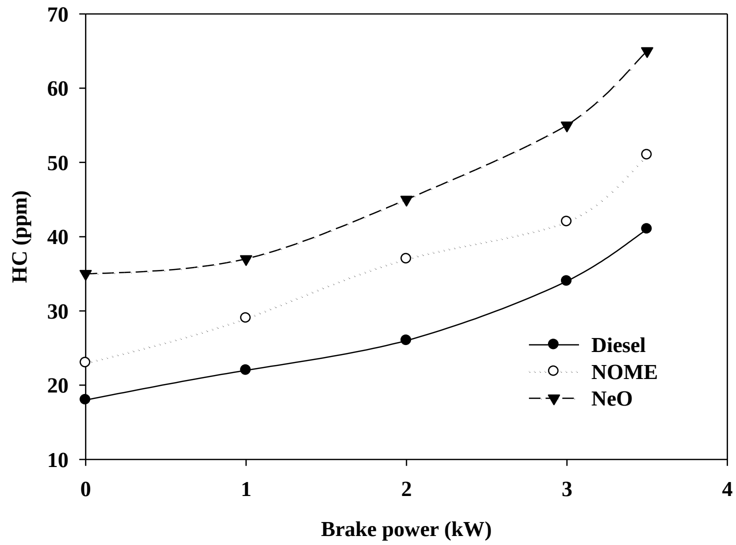

Fig.10. Hydrocarbon emission vs Brake power

4. Conclusions

A single cylinder diesel engine is operated successfully on NeO and NOME. The following conclusions are drawn based on the experimental results:

1. At full load, peak cylinder pressure for NOME is higher as compared to diesel and NeO. The peak heat release rate during the premixed combustion phase and peak rate of pressure rise is lower for NeO and NOME as compared to diesel. Ignition delay is observed to be lower for NeO when compared with NOME and diesel over the entire engine operating conditions.

2. The brake thermal efficiency for NOME is lower than that of diesel at lower engine loads and higher at full load.

3. From the emission analysis it is observed that there is a 37% reduction in NO_x emission for NeO and 19% reduction for NOME at full load. The CO and HC emissions from NeO and NOME are higher than those of diesel. There is an increase in CO emission for NeO and NOME by 40% and 20% at full load respectively. There is an increase in HC emission by 54% in case of NeO and 24% in case of NOME. The smoke emissions for NeO, NOME are higher than that of diesel by 46.8% and 16% at full load respectively.

It is observed that the performance, combustion and emission characteristics of neem oil methyl ester (NOME) are better compared to neat neem oil (NeO). Hence, biodiesel from neem oil is quite suitable as an alternative to diesel.

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