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Performance and Emission Evaluation of a Diesel Engine fueled with 20% Neem Methyl Ester and Nano Fuel Additive

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***Abstract*— The objective of this paper was to study the scope of neem oil as an alternative fuel for diesel engines. Neem oil was chosen due to it being one of the most readily available and non-edible plants, and was transesterified after acid pretreatment. After transesterification, neem methyl ester was blended with diesel in a ratio of 20:80 by volume. The fuel properties were determined for both blended and unblended biodiesel, after which the fuel's effect on performance and emissions were determined by running the blended fuel in a computerized CI engine. Positive results in efficiency, fuel consumption, combustion, CO emissions, HC emissions and smoke emissions were obtained, but NO_x emissions were extremely high. The engine test was repeated again with the same blend, but with cobalt oxide nano additive added to it in a 200 ppm concentration. The obtained results showed a reduction in NO_x emissions when compared to the biodiesel blend without additive, but were still higher than the NO_x emissions of diesel. Thus the results indicated that cobalt oxide, when used as a nano fuel additive, has wide scope as a fuel additive.**

Key Words - **BSFC, BTHE, Emissions, N_20, NME**

I. Introduction

Biodiesel is an alternative fuel that can be prepared from natural sources such as vegetable oils and animal fats. But since most of these natural sources have high viscosity and density due to their long molecular chains, they cannot be atomized properly, resulting in poor performance and emission results. In order to overcome this, the alkyl ester group of these oils is interchanged with that of an alcohol's by the process called transesterification, in the presence of a suitable catalyst. Since neat biodiesel [1] has lesser calorific value than biodiesel with diesel in it or just neat diesel, biodiesel blends chosen in the right proportion provide the perfect balance of performance and emissions. [2]

S. Ramkumar et al. [4] found out that while transesterifying neem oil, a large amount of soaps was produced due to the saponification side reaction in which neem oil faces attack from water due to its high FFA and low moisture content. Thus, in order to overcome this, neem oil is pretreated with conc sulphuric acid and then transesterified so that there is a proper biodiesel yield.

Yadav et al. [5] conducted performance and emission tests on a CI engine fuelled with blends of Palm oil methyl ester (PME). It was observed that the 20% blend (P20) had lesser specific fuel consumption and greater thermal efficiency than other biodiesel blends. It also had better emission results than most other blends, thus indicating the P20 was the most promising biodiesel blend in terms of performance and emissions.

Ganesh et al. [1] conducted performance and emission tests on a CI engine with neat jatropha methyl ester. The obtained results were compared with diesel and a drop in performance but improvement in emissions was seen. To try and improve the results, nano additives were used. When additive was just added and ultrasonicated, the nanopowder just settled down after sometime. Therefore, the obtained dispersion was not stable. To overcome this, a surfactant, i.e. a compound charged oppositely to the particle to be suspended should be added, as it forms a shield-like layer to ensure that agglomeration does not occur. Since both additives are positively charged, a negatively charged organic surfactant was used.

II. EXPERIMENTAL SETUP

When A single cylinder, four stroke, water cooled, direct injection diesel engine with a rated power of 5.2 kW was used as the test rig for the study. Figure 1 shows the experimental setup. The technical specifications of the engine are given in Table 1. An automatic solenoid controlled burette was used to measure the fuel consumption. AVL 444 exhaust gas analyzer

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is used to measure the amount of unburnt hydrocarbons (HC), oxides of nitrogen (NO_x) and carbon monoxide (CO) in the exhaust emissions. An AVL437C smoke meter is used to measure the amount of smoke in the exhaust by opacity method. Initially, the engine was operated with diesel in order to get the reference data. Then, the experiments were conducted with N20 and N20 with cobalt oxide as additive.

Figure 1: The experimental setup

Table 1: Specification of the engine

Engine Make	Kirloskar TV1
Type	4 stroke, single cylinder Diesel engine
Cubic capacity	661 cc
Rated power	5.2 kW @ 1500 rpm
Bore x stroke	87.5 x 110 mm
Compression ratio	17.5:1
Orifice diameter	20 mm
Dynamometer type	Eddy Current
Dynamometer arm length	185 mm

NANO FLUID PREPARATION

Commercially available cobalt oxide nanoparticles were added to N20 along with cetyl trimethyl ammonium bromide (CTAB) at a concentration of 200 ppm, and then ultrasonicated using an ultrasonic bath. Both cobalt oxide and CTAB were measured and added in equal amounts in order to prevent the nanoparticles from settling down due to their high surface energy, thus preventing agglomeration and creating a stable nanofluid. [1]

A. *Abbreviations and Acronyms*

N20 – Neem Methyl Ester blended with with diesel in the ratio 20:80.

CTAB – Cetyl Trimethyl Ammonium Bromide.

III. EXPERIMENTAL PROCEDURE

The blend of NME and diesel was created on 20:80 volumetric basis to create 20% neem methyl ester (N20). Experiments were initially carried out in the test rig for diesel and N20 in order to get baseline readings. Then the tests were repeated, but with N20 + cobalt oxide as the fuel. The engine test rig was stabilized and the tests were conducted at 17.5 compression ratio and 220 bar injection pressure at 0 kg, 5 kg, 10 kg, 15 kg and 18kg engine load. equations consecutively with equation numbers in parentheses flush with the right margin, as in (1).

IV. NEEM METHYL ESTER PREPARATION

The crude neem oil was first pretreated with methanol and concentrated sulphuric acid before transesterification in order to prevent hydrophilic attack of neem oil [4] and prevent soap formation so that there is a good methyl ester yield. 1 litre of crude neem oil was taken and heated for 20 minutes at 60oC. Then, it was heated and mixed with 300ml methanol. 12 ml of concentrated sulphuric acid was then added to the mixture, which was kept @ 50^{o}C and stirred for 90 minutes. The mixture is then poured into a separating funnel, and then the pretreated oil is separated from the water – methanol phase at the top. The pretreated oil was measured and taken in a beaker. 250 ml of methanol was then measured and added. The mixture was heated at 60^{o}C and continuously stirred @ 1500 rpm. 9 g of potassium hydroxide (KOH) was then measured correctly and added. The reaction was allowed for a period of 1.5h. The resulting mixture was then poured into separating funnel and allowed to settle under gravity for 24h for separation of biodiesel. The lower glycerol layer is then tapped off. The properties of diesel, NME, and N20 are listed in Table 2.

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Table 2: Fuel properties

Fuel	Flash point(^{o}C)	Fire point(^{o}C)	Density @ 30^{o}C (kg/m^3)	GCV (kJ/kg)	Kinematic viscosity @40^{o}C (cSt)
Diesel	65	75	830	43015	2.8
NME	120	132	854	37000	5
N20	67	77	830.2	42380	2.82

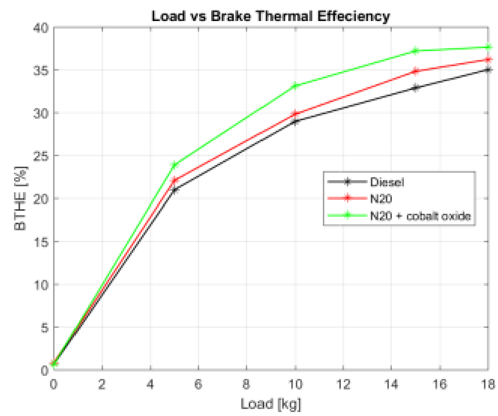
V. RESULTS AND DISCUSSIONS

PERFORMANCE CHARACTERISTICS

A. BRAKE THERMAL EFFICIENCY (BTHE)

The brake thermal efficiency (BTHE) of the fuels is plotted as a function of load on the engine, as shown in Figure 2. The BTHE was seen to increase with load, and the efficiency of the biodiesel blends was benchmarked with diesel. Without cobalt oxide, N20's efficiency was higher than that of diesel due to higher oxygen content, resulting in a diffusive combustion phase [3]. Upon addition of cobalt oxide, the BTHE N20 increased notably and was more than that of diesel due to the metal oxide nano-additive reduced the fuel vaporization time and thus the ignition delay [1], thus improving atomization of fuel.

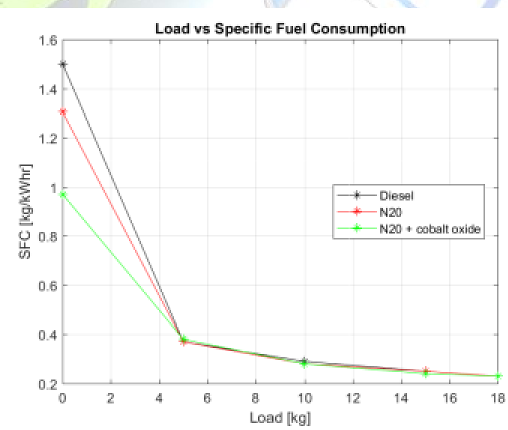
Figure 2: Brake Thermal Efficiency



B. SPECIFIC FUEL CONSUMPTION (SFC)

The brake specific fuel consumption (SFC) for each fuel is plotted with respect to load on the engine as shown in Figure 3. At no load condition, SFC is highest because the mixture is rich [3]. Diesel has the highest SFC when compared to N20 since the biodiesel blend uses up lesser amount of fuel to produce the same amount of power that the engine would produce when diesel is the fuel, due to higher oxygen content. After load is increased to 5 kg, there is no significant difference in SFC values between all blends. When cobalt oxide is added, SFC decreases even more during starting condition because of the improvement of combustion due to the catalytic chemical oxidation caused by the nano fuel additive [1].

Figure 2: Specific Fuel Consumption



EMISSION CHARACTERISTICS

A. Carbon Monoxide (CO)

The figure above shows the plot for CO vs load. CO is an indication of incomplete combustion. Diesel

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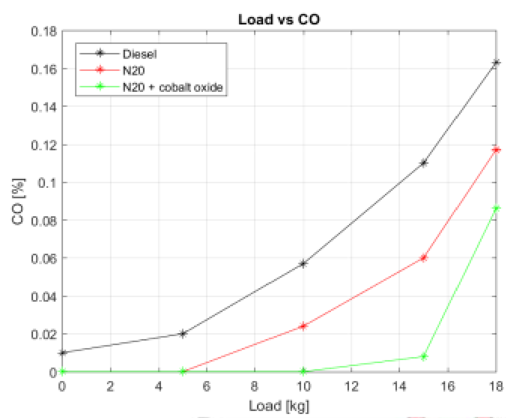
lacks oxygen and thus it does not combust completely [3]. Upon blending with methyl esters, it receives an oxygen boost [2] and thus shows excellent combustion properties. Higher oxygen supplied by methyl esters oxidizes more CO to CO_2.

$$2CO + O_2 \rightarrow 2CO_2$$

Upon addition of nano additive, there is no CO emission until a load of 10 kg is applied. CO emissions reduce due to reduction in soot oxidation temperature. Furthermore, there is oxygen enrichment in oxygen content due to surface and lattice oxygen [1], which facilitates oxidation of CO into CO_2. N20 with cobalt oxide has the least CO emissions due to it already having higher oxygen content.

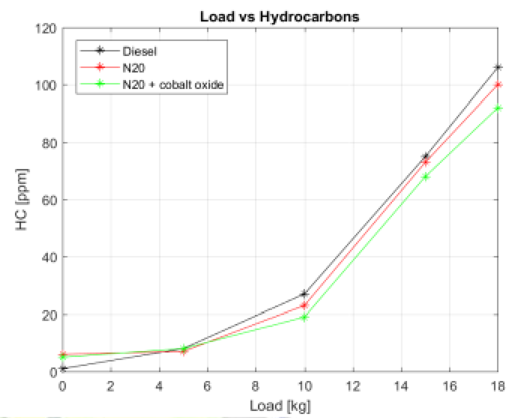
Figure 4: CO emissions



B. Unburnt Hydrocarbons (HC)

Figure 5 shows the proportions of unburnt hydrocarbons plotted as a function of load. As load increases, amount of HC in the exhaust emissions also increases in a non-linear fashion. At no load, diesel has the lowest HC emission among all other fuels, but however the overall HC emission is lower for other fuels. This is because the fuel rich zones in the chamber during combustion are reduced due to higher fuel bound oxygen. Flame quenching, fuel rich zones and misfiring are the major reasons for HC emissions. Methyl esters have higher cetane numbers [2] due to which they have lower ignition delay. This, along with improvement in atomization reduces reducing fuel quenching and misfiring. When cobalt oxide is added, it gives its lattice oxygen and acts as an auxiliary oxygen source, thus reducing fuel rich zones & further improving atomization and hence a further drop in HC emissions is seen [1]. Furthermore, the fuel burns completely, reducing the HC emission even more.

Figure 5: HC emissions



C. Oxides of Nitrogen (NO_x)

In diesel engines, thermal NO_x is the major contributor to emissions due to high cylinder temperature because of combustion [3]. Due to this, N_2 and O_2 react to give NO through the following reaction:

$$N_2 + O_2 \rightarrow 2NO$$

The rate at which NO_x forms increases as temperature increases. Figure 6 shows NO_x vs load plot, and the ppm of NO_x emitted shows an increasing trend with load. It is observed that the biodiesel blends have higher NO_x emissions due to more complete combustion which causes higher cylinder temperatures than that of diesel, and also due to their higher oxygen content which further promotes NO_x production. N20 produces the overall highest amount of NO_x. When nano additive is added, there is an effective reduction in NO_x and it shows better results at all loads. Since it is an active metal oxide catalyst, it promotes the decomposition of NO_x [1]. The results obtained upon addition of additive are better than that of N20, but still diesel has the best NO_x emissions since the temperature reached during combustion is lesser than the temperatures achieved when methyl ester blends are used. Christo Ananth et al.[6] discussed about E-

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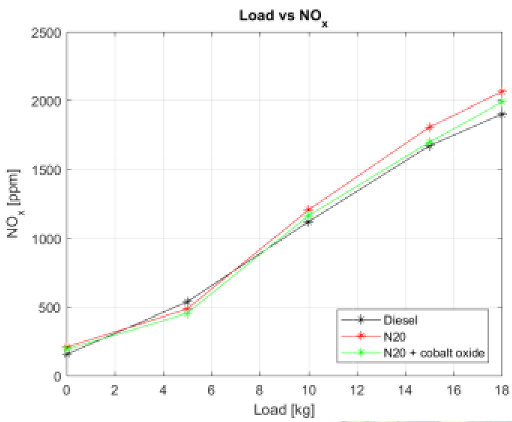
plane and H-plane patterns which forms the basis of Microwave Engineering principles.

Figure 6: NO_x emissions



D. Smoke

Smoke is nothing but soot suspended in the exhaust due to improper combustion of fuel. It is produced due to the following reasons [3]:

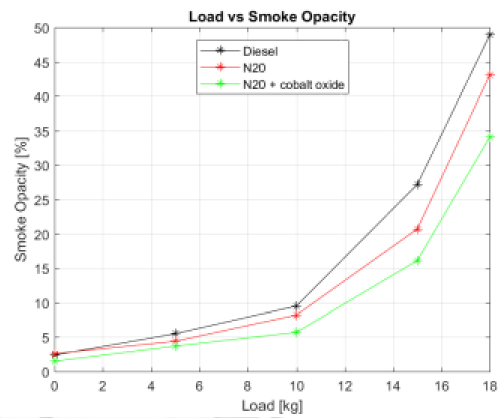
i. Incorrect air-fuel ratio
ii. Low cetane number
iii. Ignition delay
iv. Higher injection nozzle dia
v. Low quality lubricating oil
vi. Poor engine maintenance.

Diesel gives the highest amount of smoke, while biodiesel gives significantly lesser amounts. Therefore the addition of methyl ester to diesel gave a reduction in overall smoke emission. The amount of smoke was determined by opacity method. Figure 7 shows opacity plotted against load. N20 had lesser opacity than diesel. This is because of the following reasons:

i. Improved oxidation due to higher oxygen content
ii. Higher combustion temperature
iii. Longer combustion duration
iv. Rapid flame propagation

Upon addition of cobalt oxide, the smoke content in the exhaust goes down even more. This is once again due to both lattice and active oxygen of cobalt oxide, which further enhances the reasons listed above [1]. Moreover, cobalt oxide reacts with carbon in the soot to give carbon dioxide, therefore giving very small amounts of smoke. N20 with cobalt oxide has the least opacity.

Figure 7: Smoke Opacity



VI. CONCLUSION

In today's energy and pollution crisis, biodiesel has proved to be a valuable alternative. It can virtually be made from any source of oil, be it poultry fat, used cooking oil or fresh vegetable oil. The results of the engine test are summarized below:

i. Brake thermal efficiency of CI engine using N20, N20 with cobalt oxide and diesel are 36.19%, 37.63% and 35.10% respectively at full load. N20 with cobalt oxide gave the highest efficiency, compared to N20 and diesel.
ii. Specific fuel consumption for CI engine for diesel, N20 with and without additive was 1.5, 1.396 and 0.97 kg/kWh, indicating that N20, with or without additive, may have better fuel economy than diesel.
iii. Exhaust emissions such as CO, HC are decreased when N20 and N20 with cobalt oxide are using in the CI engine. However, NO_x emissions are greater for N20, and this comes down when cobalt oxide is added.
iv. Smoke emissions are much lesser for N20 and N20 with cobalt oxide when compared to diesel.

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