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Effect of Blending Nano additive with Cashew Nut Shell Liquid Bio-oil on Performance, Combustion and Emission Characteristics of Four Stroke Diesel Engine – An Experimental Study

T. Pushparaj[1], P. P. Shantharaman[2], D. John Panneer Selvam[3]

[1]Department of Mechanical Engineering, Kings College of Engineering, Thanjavur, Tamil Nadu, India

[2]Department of Mechanical Engineering, Kings College of Engineering, Thanjavur, Tamil Nadu, India

[3]Department of Mechanical Engineering, PSNA College of Engineering and Technology, Dindigul, Tamil Nadu, India

Abstract: ***The purpose of this study is (i) to investigate the impact of cerium oxide nanoparticles added at 20, 40 and 60 ppm levels to 20% cashew nut shell liquid (CNSL) bio-oil blended with No.2 diesel fuel, in terms of the performance and exhaust emissions on a 4-cylinder naturally-aspirated direct-injection diesel engine, and (ii) to determine the best cerium oxide- bio-oil combination that offers enhanced engine performance and pollutant reduction. Experiments were conducted under five engine loads at a steady speed of 1500 rpm. The influence of blends on carbon monoxide (CO), nitrogen oxide (NO), hydrocarbon emission and smoke opacity were investigated. The experimental results revealed a substantial enhancement in the performance of engine and reduction in harmful emissions for cerium oxide nanoparticle blends compared to those of bio-oil blend and diesel. The 20 % biodiesel with 40 ppm cerium oxide nanoparticle additive reduces the NO emission by 27% when compared to 20% bio-oil blends, CO emission is reduced by 37% and smoke opacity reduced by 29% at full load compared to No.2 diesel.***

Keywords: Cashew Nut Shell Liquid (CNSL), Cerium oxide nano additive, CI Engine, Emissions

1. Introduction

Biodiesel is the alternative for diesel engine fuel. It is produced from bio and renewable resources. Biodiesel is easily mixed with petro diesel. Biodiesel can be blended with petroleum diesel and it is called biodiesel blend. It can be used as fuel in unmodified diesel engine. Misra and Murthy experimentally found the strength and weakness of biodiesel usage in diesel engine [1]. The chemical name of biodiesel is methyl or ethyl ester. According to literature, the continuous use of vegetable oil as fuel in diesel engines causes several engine problems, namely, poor fuel atomization, severe engine deposits, and injector chocking and low volatility originated from its high viscosity [2]. The use of high viscous biodiesel for a long period of time cause serious engine failures like injector damage, piston ring sticking and valve leaks [3].

The use of biodiesel is good for the environment because it is made from bio resources and has lower emission compared to petroleum diesel. The transesterification is made with monohydric alcohols like methanol and ethanol in the presence of a catalyst. Biodiesel and its blends with petroleum-based diesel fuel can be used in compressed ignition (CI) engines without any engine modifications [4]. The merits of biodiesel are that it displaces petroleum to a large extent and thereby reducing global warming gas emissions. The emission of particulate matter, hydrocarbons, carbon monoxide, and other air toxics are also reduced while using biodiesel. Biodiesel improves lubricity and reduces premature wearing of fuel pumps [5]. The major portion of biodiesel is made from eatable vegetable nuts. Mostly these nuts are used for production of edible oil, so the search is on to identify a new raw material which cannot be used for food. The other area of production of biodiesel is shell oil's. Coconut shell oil and cashew nut shell oil play a major role in bio oil production and waste utilization.

The world production figures of cashew crop, published by Food and Agriculture Organization, were around 2.7 million tons per annum. India ranks first in area utilized for cashew production, though its yields are relatively low. Collectively, Vietnam, India and Brazil account for more than 90% of all cashew kernel exports. India is the largest producer and exporter of cashew *Anacardium occidentale Linn.*, in the world. In India, Cashew cultivation now covers a total area of 0.70 million hectares of land, producing over 0.40 million metric tons of raw cashew nuts. Presently, cashew nut shell liquid (CNSL) is obtained as a by-product of cashew industry. The Cashew nut has a shell of about 3 mm thickness, with soft honeycomb structure inside, containing a dark brown viscous liquid. It is called CNSL, which is peri carp fluid of the cashew nut. Generally CNSL is extracted by roasting nuts and collecting expelled liquids. Superheated steam treatment method and solvent extraction method are also available for CNSL extraction [6]. Now a day, pyrolysis is used for bio mass conversion. Pyrolysis is one of the thermo chemical processes in which a partial supply of air is used for chemical conversion [7]. CNSL is obtained majorly by pyrolysis process. Risfaheri et al. summarized the pyrolysis procedure of CNSL production [8]. Pyrolysis is done in a reactor at a negative pressure of 5kN/m^2 and at various maximum temperatures between 400-600°C, with an addition of 50°C for each experiment. The evaporative removed on pyrolysis are slowly condensed in a condensing pan, from atmospheric condensation to condensation in an ice bath (5-7°C). CNSL is a mixture of four components, all substituted phenols: anacardic acid, cardanol, cardol and 2-methyl cardol. The decarboxylated cardanol is termed as CNSL bio-oil. It is renewable, economic, easy combustible and easily mixed with diesel [9].

Research studies on the utilization of CNSL bio oil as alternatative fuel for diesel engine are very little. The researchers found CNSL was used as CI engine fuel and the performance did not improve but it was used as low cost alternate fuel for CI engine [10]. The experimental results of various studies especially on emissions were not uniform and provided different results. In the present paper, an extensive and comprehensive study was carried out to evaluate the CNSL bio-oil and No.2 diesel blend, blend with nano additive from many angles.

More number of experimental works was available for analyzing the combustion and performance of direct injection diesel engine with CNSL bio oil as a fuel. From the research works, CNSL can be used as a potential fuel in diesel engines without any engine modifications. The researchers conclude that using a 20% blend would not give any negative impact, and therefore a 20% blend is taken for analysis [11]. Savariraj et al experimentally investigated the performance and emission characteristics of a diesel engine while using 1, 4 dioxane as additive found that the emission of NOx was decreased [12]. Balamurugan et al studied the effect of nano-copper particles additive with soya bean methyl ester and diesel blend in a single-cylinder, water-cooled diesel engine [13]. Lenin et al observed that the viscosity, flash point and fire point of diesel were increased by the addition of nanometal oxide additive [14]. So in this study cerium oxide nano particles are taken as an additive and the changes in performance and emissions in C.I engine were measured.

2. Experimental Setup and Procedure

2.1 Test fuel and preparation of blends

In this research work the CNSL bio oil is used as fuel to prepare the blends. The volume ratio of CNSL bio oil and No.2 diesel, 20/80 is called B20, and the 20 ppm cerium oxide nano additive was added to B20 blend and is called B20 + C20, 40 ppm cerium oxide nano additive was added to B20 blend and is called B20 + C40 and 60 ppm cerium oxide nano additive was added to B20 blend and is called B20 + C60. The required quantity of the nanoparticle was measured using a precision electronic balance and mixed with the fuel by means of a mechanical agitator, applying a constant agitation time of 15 minutes to make a uniform suspension. The blends were utilized immediately after preparation, in order to avoid any settling. The properties of CNSL bio oil and diesel are given in Table I. Cerium oxide has the ability to act as oxygen buffer causing simultaneous oxidation of hydrocarbons as well as the reduction of oxides of nitrogen, thus reducing emissions, especially in the stoichiometric conditions. Cerium oxide nanoparticles could probably exhibit high catalytic activity since their large surface area per unit volume, foremost to enhancement in the fuel efficiency and decrease in the emissions. However, the effect of these nanoparticles on the environment is yet to be calculated.

2.2 Experimental apparatus and procedure

The engine used is Kirloskar make single cylinder, naturally aspirated, four stroke, water cool, 16.5:1 compression ratio, direct injection diesel engine, and the maximum engine power is 3.7 kW at 1500 rpm. The engine speed was measured directly from the RPM sensor attached near its flywheel. A Kirloskar A.C generator with resistance bank loading arrangement was also incorporated. The outlet temperatures of cooling water and exhaust gas were measured directly from the thermocouples (Cr–Al) attached to the corresponding passages. All the data were interfaced with computer using software.

The engine exhausts NO, CO, HC were measured with AVL-444 Di gas analyzer and the smoke opacity was measured by AVL-437C smoke meter after reducing the pressure and temperature in the expansion. The accuracies of the measurements and the uncertainties determined by uncertainty analysis in the calculated results are shown in Table II. The test engine RPM was kept at 1500. The engine was started at no load and the feed control was so attuned that it can attain the rated speed and steady state condition. Fuel consumption, rpm, exhaust gas temperature, and break power were measured. The engine was loaded progressively to keep the speed within the allowable range. Each experimental reading was taken three times and the mean value was taken for analysis.

Table 1: Properties of the fuels

Properties	*No-2 Diesel*	*CNSL*
Kinematic Viscosity (cSt)	2.82	29.77
Density (kg/m^3)	840	884
Lower Heating Value (MJ/kg)	42.3	39.4
Cetane Number -	46	54
Flash Point (°C)	70	157

Table 2: The accuracies of measurements and the uncertainties in the calculated results

Measurements	*Accuracy*
Speed	± 2 rpm
Temperature	± 1°C
CO	± 0.03 %
CO_2	± 0.5 %
NO	± 50 ppm
HC	± 10 ppm
Opacity	± 0.1 %
Calculated results	*Uncertainty*
Brake power	± 2.50 %
BSFC	± 2.64 %
Pressure	± 1 bar

3. Results and Discussions

3.1 Combustion pressure and crank angle

In Fig. 1, the variation in the cylinder pressure with crank angle for diesel, B20 and B20 + C60 blends at maximum engine loads are shown. It is clear that the peak cylinder pressure is higher for biodiesel [15]. One of the most important parameters in the combustion phenomenon is the ignition delay. The combustion starts earlier for biodiesel than for diesel. This is owing to a short ignition delay and advanced injection timing for biodiesel [16]. In this study, the ignition delay was calculated in terms of the crank angle between the start of fuel injection and the start of combustion. The peak pressure was found at 66.6 bar, 64 bar, and 51.1 bar for B20, diesel and B20 + C60 respectively, at full loads. However the maximum cylinder pressure is obtained nearly the same crank angle positions about 4 to 8 degree after top death centre for all test fuels. Because of the longer ignition delay, the peak cylinder pressure is reduced [17].

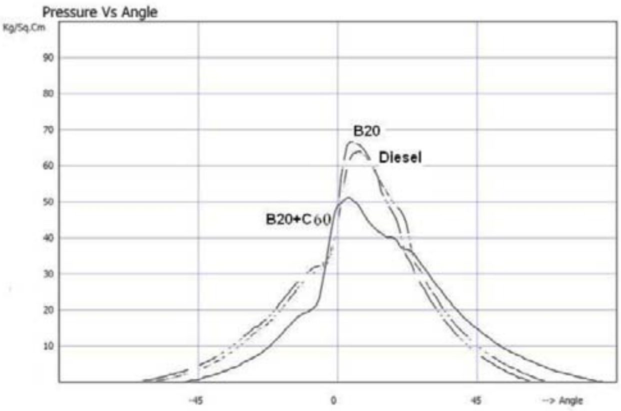

Figure 1: Variation of cylinder pressure with respect to crank angle for diesel, B20 and B20+C60 at 0.579MPa load

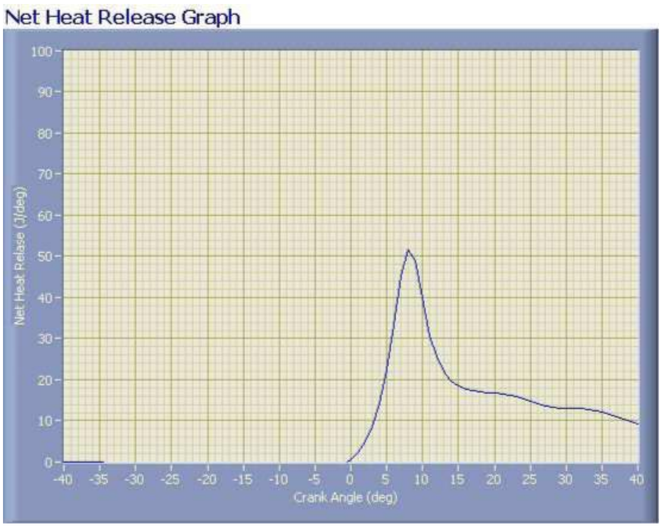

Figure 2: Heat release rate with crank angle at 0.579MPa load for B20+C60 blends

3.2 Heat release rate

The variation of heat release rate with crank angle at full load for B20+C60 was shown in Fig. 2. The peak heat release rate is higher for diesel was observed; this is due to higher volatility and longer ignition delay and other hand due to lower volatility and high viscosity of bio oil blend the peak heat release rate was lowered.

3.3 Engine performances

The engine brake thermal efficiency (BTE) variations with load in terms of brake mean effective pressure (BMEP) for the studied fuels where shown in Fig. 3. The results show that the brake thermal efficiency of the diesel engine is improved by the addition of cerium oxide in the fuel. The cerium oxide nanoparticles present in the fuel promote longer and more complete combustion, compared to the base fuel as cerium oxide acts as an oxygen buffer and thus increases the efficiency. The maximum BTE was 25.6. % for B20+C20 blends and that is higher than the value for diesel (24.56%) at full load.

3.4 Pollutant emissions

The variation of Carbon monoxide (CO) emissions with engine loading for different fuel blends is compared in Fig. 4. The minimum and maximum CO produced was 0.01and 0.08% (vol). It can be observed from Figure, that the CO initially decreased up to 80% load, and later increased sharply up to full load.

Lower CO emissions were observed in B20 + C40 blend, the amount is about 37% lower than that of diesel at full load condition. This is due to their more complete oxidation as compared to diesel. Some of the CO produced during combustion of biodiesel might have converted into CO_2 by taking up the extra oxygen molecules present in the biodiesel chain and thus reduced CO formation [18]. As for higher engine load there may not be enough time for complete combustion and hence more CO emissions again [19].

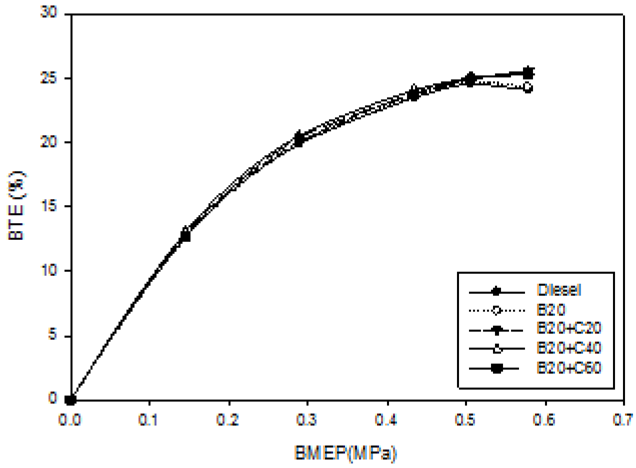

Figure 3: Variation of BTE with respect to engine loads

Hydrocarbons (HC) emission variation with engine loads for the analyzed fuels is shown in Fig. 5. In general, the magnitude of HC emission for the biodiesel fuels was enhanced, owing to the higher accumulation of fuel in the premixed combustion phase as a result of prolonged ignition delay. This effect could have led to increased HC emissions for the biodiesel fuel compared to that of diesel fuel. In the case of nanoparticle blended biodiesel fuels, the magnitude of HC emissions is reduced while comparing B20+C20 blend. This decrease in HC emission may be explained as the oxygen content in the biodiesel fuel blend helps to complete combustion [20].

The engine's Nitrogen oxide (NO) emission level for the analyzed fuels at different loads is presented in Fig. 6. Due to the presence of oxygenated components in the experimental fuels at minimums loads have an insignificant influence on the NO emission level. At medium and high engine loads the NO emission level was greater for B20 blend compared to diesel fuel. The increased NO emission level is explained by the increased fuel combustion temperature, concentration of oxygen and nitrogen atoms, time of oxygen and nitrogen reaction, injection timing and peak cylinder pressure and oxygen content in biodiesel, which results in the generation of NO [21]. But the NO emission was observed to be reduced

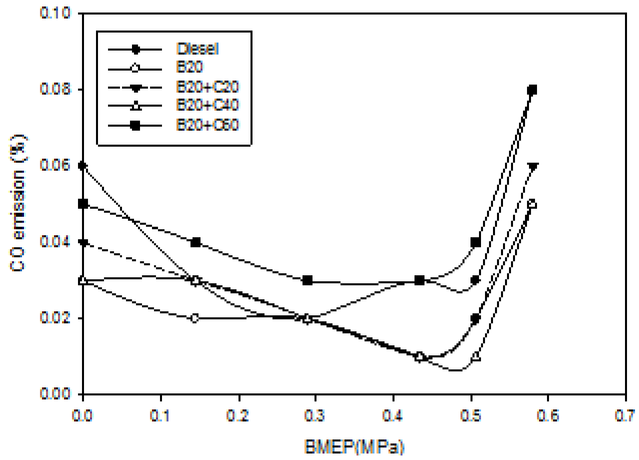

Figure 4: Variation of CO emission with respect to engine loads

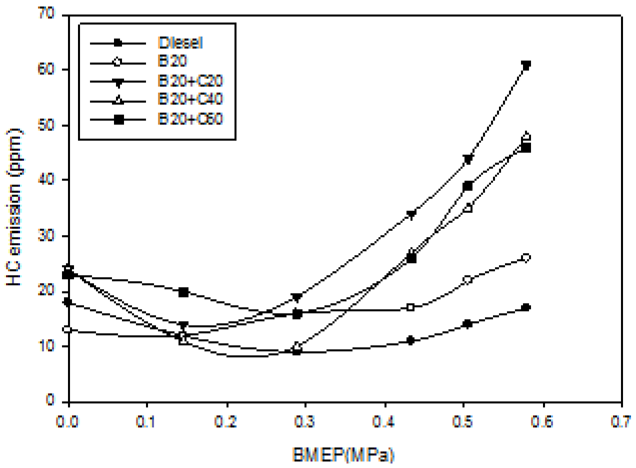

Figure 5: Variation of HC emission with respect to engine loads

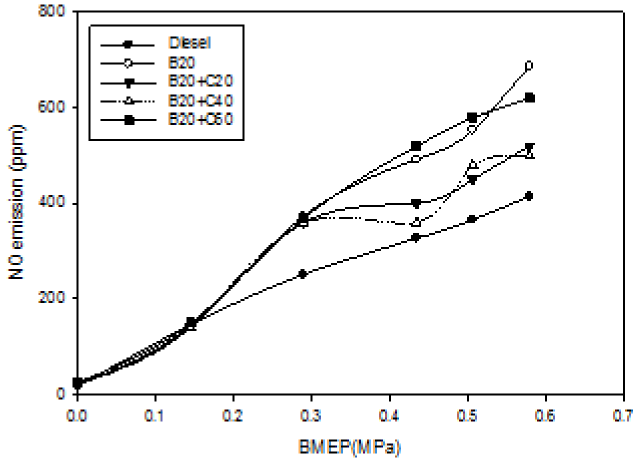

Figure 6: Variation of NO emission with respect to engine loads

on the adding of cerium oxide nanoparticles to bio oil, where an average reduction of around 27% was found to occur with a dose level of 40 ppm nanoparticles while comparing with B20 blend. In broad, there is a reduction in NO emission owing to the addition of cerium oxide.

The diesel engine's smoke emissions were evaluated through exhaust gases density measurements, made obvious by the light absorbing coefficient. The observed smoke opacity of exhaust emission is in fact an indication of particulate matter. Smoke formation mostly takes place in the fuel-rich region at high temperature and high pressure, mainly within the core region of fuel spray, and is caused by high temperature disintegration. If the fuel is partially oxygenated, it could reduce locally over-rich regions and limit primary smoke formation [22]. Fig. 7 shows the smoke opacity of tested fuels in the exhaust. The smoke was found to be reduced on the addition of cerium oxide nanoparticles to biodiesel, when compared diesel fuel at full load, where an average reduction of around 29% was found for B20+C40 blend. The adding of nanoparticles to the bio oil fuel reduces ignition delay, improved evaporation, and superior combustion characteristics. Due to the above property, in the nanoparticle blended biodiesel fuels, sufficient fuel could be introduced in the combustion chamber former to the ignition, making a homogeneous mixer and foremost to enhanced combustion.

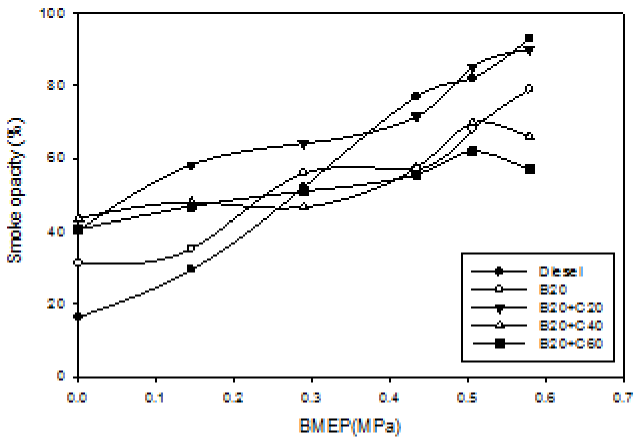

Figure 7: Variation of smoke opacity with respect to engine loads

Conclusions

In the present experimental work, CNSL bio oil, which was obtained from cashew nut shell, was measured as a potential alternative fuel for diesel engines. As the CNSL bio oil is a derivative of cashew nut industries, the cost is cheap. It need not require the transesterification process. The important properties of this bio oil are rather close to that of diesel. The performance and emission characteristics of the 20 percent CNSL bio oil and diesel fuel with 20ppm, 40ppm, and 60ppm of cerium oxide nanoparticles as additive used as fuel in a compression ignition engine, were analyzed. The B20 with C40 reduced CO, NO and smoke emission in exhaust effectively. But the dosing level of cerium oxide nanoparticles in the blends increased the negative results were obtained. Therefore, 40ppm of cerium oxide nanoparticles can be used as additive with B20, which improves the performance and reduces exhaust emission in diesel engines and also less nanoparticle emission. CNSL bio oil as alternative fuel can significantly improve the agricultural economy and reduce need on the ever depleting fossil fuels.

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Author Profile

Dr.T.Pushparaj is working as Professor in the department of Mechanical Engineering at Kings College of Engineering, Thanjavur, Tamilnadu, India. He has completed his B.E. Mechanical Engineering degree from National Institute of Technology, Tiruchirappalli, M.E. Thermal Plant Engineering degree from Bharathidasan University, Tiruchirappalli and Ph. D degree from Anna

University Chennai, Tamil Nadu. He has sixteen years of teaching experience and three years of industrial experience. He has published more than ten research articles in the reputed international journals.