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PERFORMANCE AND EMISSION CHARACTERISTICS OF COMPRESSION IGNITION ENGINES USING BIODIESEL AS A FUEL: A REVIEW

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ABSTRACT

Performance and emission characteristics of compression ignition (C.I.) engines were reviewed in this work. This study was conducted by reviewing works that were carried out using biodiesel derived from the oils of: cotton seed, mahua, rice-bran, canola, Shea butter and Jatropha; and biodiesel from waste frying oil, waste palm oil, blend of ethanol and biodiesel, and diesel-biodiesel-ethanol fuel blend. The results showed that while using biodiesel and its blends; brake power was reduced by 4-5% and brake specific fuel consumption increased by 5-10%. CO_2 emissions were reduced by 5-8% and NOx increased by 11-22%. Neat biodiesel was better up in CO_2 reduction by about 22.5% at higher loads when compared to B20. However, the increase in NOx emission and power losses resulting from neat biodiesel suggest that low blend biodiesel such as B20 has the potential of becoming optimum blend. The works under review revealed that biodiesel exhibits similar performance on diesel engine when compared to fossil diesel and possesses better emission characteristics. These findings identified biodiesel as a renewable and prospective future fuel that will protect our environment.

Keywords: Performance, Emission, Biodiesel, Engine, Environment

INTRODUCTION

The use of diesel engines has presently increased rapidly because of their low fuel consumption and high efficiencies. Nowadays, diesel engines are used in transportation, power generation, construction and industrial activities. These wide fields of usage led to increased demand for petroleum fuel which is presently confronted with crises of reservations and concerns about environmental degradation. The world reserves of primary energy and raw materials are, obviously, limited. According to an estimate, the reserves will last for 218 years for coal, 41 years for oil, and 63 years for natural gas, under a business as- usual scenario. The present energy scenario has stimulated active research interest in non-petroleum, renewable, and nonpolluting fuels (Liaquat et al., 2011).

The increase of exhaust emissions has become another major problem, which causes increase in greenhouse effect, global warming, weakening of ozone layer, and acid rains. These are responsible, one way or the other, for damaging the respiratory system, nervous breakdown, skin diseases, and mutagenic (Shahid and Jamal, 2011). Environmental concerns and regulations to reduce greenhouse gas emission and fluctuation of fossil fuel price have in the recent years encouraged research on alternative fuels. Scientists around the world have explored several alternative energy resources, which have the potential to quench the ever-increasing energy thirst of today’s population. Various biofuel energy resources explored include biomass, biogas, primary alcohols, vegetable oils, etc (Deshmukh et al., 2008). The

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Vol. 2 No. 4 December 2013

situation of energy crisis is not desired and there is need to find a solution in the use of cleaner and renewable fuels. Replacement of fossil diesel with biodiesel in diesel engines can significantly improve our environment.

As an attempt to justify the use of biodiesel as an alternative fuel in Nigeria, researchers have carried out a number of studies in different parts of the country. Woulandakoye et al., (2007) reported on Biodiesel Production from Jatropha Curcas Oil: A Nigerian Perpective at CST, Waziri Umaru Federal Polytechnic, Birnin Kebbi-Nigeria. Highina et al., (2011) worked on Liquid Biofuels as Alternative Transport Fuels In Nigeria and reported in Journal of Applied Technology in Environmental Sanitation. Sani (2011) investigated the Performance of Diesel Engine Run on Jatropha Based Biodiesel for Electricity Generation as M. Eng. dissertation at Department of Mechanical Engineering, Bayero University Kano, Kano-Nigeria. Idusuyi et al., (2012) reported on Biodiesel as an Alternative Energy Resource in Southwest Nigeria at Mechanical Engineering Department, University of Ibadan, Ibadan-Nigeria. Musa & Folorusho (2012) worked on Characteristics of a Typical Nigerian Jatropha curcas oil Seeds for Biodiesel Production at Department of Chemical Engineering, Federal University of Technology Minna, Minna-Nigeria. Such attempts, however, cannot yield the expected results without a comprehensive review, taking cognizance of research activity around the globe.

BIODIESEL

Biodiesel is a renewable, nontoxic, biodegradable and environment friendly fuel which can be obtained from vegetable oils and animal fats. It can be used in all types of compression ignition engines directly or in the blended form. The history of biodiesel begun when Dr. Rudolf Diesel invented the diesel engine to run on a myriad of fuels such as coal dust suspended in water, heavy mineral oil, and vegetable oil. Dr. Diesel's first engine experiments were catastrophic failures. Nevertheless, by the time he showed his engine at the World Exhibition in Paris, in 1900, his engine was running on 100% peanut oil.

Biodiesel is an oxygenated fuel, so its combustion is better than that of mineral diesel resulting in lower harmful emissions than mineral diesel (Shahid and Jamal, 2011). Engines run on biodiesel exhibit reduced amount of pollutant gasses such as soot, THC, CO_2, CO, particulate matter (PM), oxides of sulfur (SOx), carcinogenic polycyclic hydrocarbons, and polycyclic aromatic hydrocarbons (PAH).

Production of Biodiesel

Biodiesel is produced from different feed stocks like edible and non-edible vegetable oils, waste cooking oil, animal tallow, algae etc. It is commonly prepared by transesterification process from the raw feedstock using a base catalyst. For esterification reaction, H_2SO4 is added as a catalyst and for transesterification KOH is added as the catalyst with methanol. Methanol is chosen as the alcohol as it takes a lower reaction time and also has a low cost.

Transesterification

This is the process by which the heavier molecules of vegetable oils or animal fats are converted into methyl ester (biodiesel). In this process, the oils are reacted with methanol or ethanol in the presence of acid or base catalysts. Three moles of methanol react with one mole of oil to form three moles of methyl ester and one mole of glycerol.

Properties of Biodiesel

The engine performance and exhaust emission characteristics are pre-determined by the properties of biodiesel injected into the combustion chamber. Important biodiesel properties

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Vol. 2 No. 4 December 2013

include: Higher Heating Value, Flash Point, Lubricity, Kinematic Viscosity, Cetane Number, Physical Distillation, Water Sediment, Cloud Point, Acid Number, Total Glycerin, Alkali Metals, Blend Fraction, Stability and etc.

Table 1. Standard Fuel Properties of Biodiesel and Diesel (ASTM, 2008)

S.No	*Fuel Property*	*Biodiesel*	*Diesel*
1	Density (kg/L)	0.87-0.89	0.84-0.86
2	Kinematic Viscosity (cSt)	3.5-5.2	1.92-4.1
3	Higher heating Value (MJ/kg)	Min. 39.2	Min. 45.2
4	Cetane Index	Min. 50	Min. 40
5	Flash Point (^{0}C)	Min. 100	Min. 52
6	Distillation Range (^{0}C)	Max. 360	Max. 342

PERFORMANCE AND EMISSION CHARACTERISTICS OF C.I. ENGINES ON BIODIESEL FUEL

A number of experimental studies have been carried out in this area by government institutions, scientists, engineers and private bodies (Liaquat et al., 2011). It is surely expected that more works will still emerge as a result of energy crisis and concern on environmental issues.

A study carried out by Datta and Mandal (2012) revealed that biodiesel fueled CI engines perform more or less in the same way as that fueled with the mineral fuel. Exhaust emissions are significantly improved due the use of biodiesel or blends of biodiesel and mineral diesel.

It can be seen from Figure 1 that at lower loads there is a sharp decline of Brake Specific Fuel Consumption (BSFC) with increase in load up to about 30kW. Thereafter, only slight variations were observed and these became hardly noticeable at higher loads. The highest consumption was exhibited by B100 (neat biodiesel), this can be attributed to the fact that B100 has lower calorific value when compared with traditional diesel. The trend of consumption reduces gradually across the blends with B0 exhibiting the least consumption.

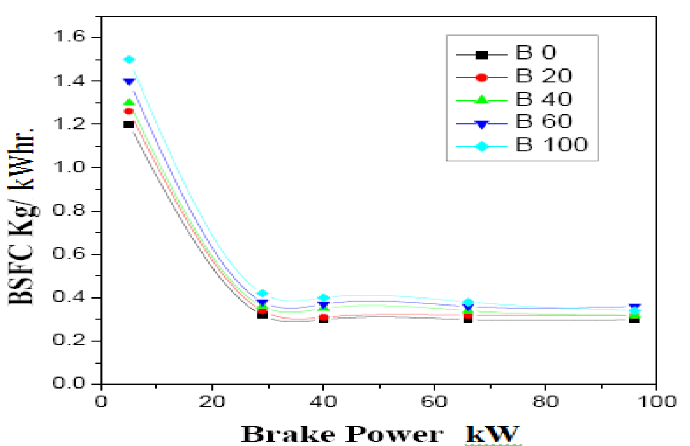

Figure 1. Variation of BSFC with Brake Power (Datta and Mandal, 2012)

Exhaust gas temperature is an indication of the amount of waste heat which increases with increase in load. The blends of mineral fuel are oxygenated and as such exhibited a bit higher exhaust gas temperatures, with neat biodiesel having the highest.

It was reported by Shahid and Jamal (2011) that experimental results showed that an engine using B100 resulted in about 10% higher brake specific fuel consumption and about 10% lower brake thermal efficiency as compared to the use of B0. The engine emissions were almost free from SOx, having reduced amount of CO, CO2, and THC, but having higher amount of NOx, when B100 was used as fuel. Biodiesel is becoming more popular due to the reduction in nasty pollutant emissions.

The trends of brake thermal efficiency indicate that it increases with increase of load for diesel and biodiesel blends up to the optimum range of the load. It increases till 70% load for B0 and till 80% load for B100, while its peak value is between 70 and 80% load for blends of diesel and Cotton Seed Oil Methyl Ester (CSOME) in different ratios. This might be due to better combustion and less losses at higher loads.

The study revealed that relatively less amount of CO2 is emitted when engine uses more percentage of CSOME. The amount of carbon dioxide reduces from 25.4 kg/hr to 19 kg/hr for 89% load, when the engine is shifted from diesel fuel to CSOME. The reason may be that the biodiesel fuel has less number of carbon atoms and its carbon to hydrogen ratio is lower as compared to diesel. Karabektasa et al. (2008) also showed similar results. The amount of CO2 per kW decreases with increase of load, this is due to better fuel combustion at higher load, and so less fuel per kW is consumed resulting in lower emission of CO2.

The oxides of nitrogen (NOx) emissions are precarious pollutant emissions, which are produced, when the fuel is burnt at high temperature causing dissociation of N2, which ultimately leads to the formation of nitric acid. NOx is also responsible for weakening the ozone layer.

From the results of the test NOx is very low at lower loads, this amount increases with increase in load from B0 to B100. The engine temperature increases at higher loads, which is responsible for raising the level of NOx in the exhaust gases. The NOx level increases further, with the increase of percentage of CSOME in the blended fuels. The rise is not very much appreciable up to B20, but it rises sharply for higher ratios of CSOME. The main reason of this phenomenon is the presence of oxygen in the fuel, which facilitates the NOx formation. Similar results were also shown by Rakopoulos et al. (2008).

Lenin et al. (2013) reported a work where important properties of Mahua Methyl Esters (MME) were compared with diesel standards. The test results indicated that B25 fuel can be used in diesel engines without any engine modifications. It is important to note that a high gap of blend percentage (in form of B25, B50, etc.) was used in this work. A better result could be expected if the tests were carried out with blend ratios lower than B25.

Sinha and Agarwal (2007) reported that steady state engine dynamometer test at full throttle conditions was carried out to evaluate the performance and emission characteristics of a medium duty transportation DI diesel engine. The engine was fuelled with various blends of rice-bran oil methyl ester (ROME) and mineral diesel ranging from 5% biodiesel to 100% biodiesel (B5, B10, B20, B30, B50, and B100%). Performance and emission data were compared to the baseline data obtained using mineral diesel. The same engine without any hardware modification was adopted for tests on all fuel blends. The results of this experimental investigation showed that biodiesel and biodiesel blends exhibited almost similar torque and power characteristics. B20 produced slightly higher torque and improved

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Vol. 2 No. 4 December 2013

performance. Improvement in fuel conversion efficiency was found for lower concentration blends i.e. up to B20. Lowest efficiency was found for B100 biodiesel blend. All the biodiesel blends emitted lower total hydrocarbon, carbon monoxide emissions and smoke opacity but slightly higher NOx emissions during the full throttle tests. Emission tests with all the fuel blends were carried out using European 13 MODE test (ECE R49) procedure. Drastic reduction in THC and CO and slight increase in NOx was observed. It is interesting to observe that B20 produced slightly higher torque than B50 as reported in the study.

Pugazhvadivu and Jeyachandran (2005) reported on experimental investigation using waste frying oil as an alternative fuel for diesel engine. The high viscosity of the waste frying oil was reduced by preheating. It was determined that the waste frying oil requires a heating temperature of 135 °C to bring down its viscosity to that of diesel at 30 °C. The performance and exhaust emissions of a single cylinder diesel engine was evaluated using diesel, waste frying oil (without preheating) and waste frying oil preheated to two different inlet temperatures (75 and 135 °C). The engine performance was improved and the CO and smoke emissions were reduced using preheated waste frying oil. It was concluded from the results of the experimental investigation that the waste frying oil preheated to 135 °C could be used as a substitute fuel instead of traditional diesel for short-term engine operation.

The performance, combustion and injection characteristics of a direct injection diesel engine were investigated experimentally by Ozsezen and Canakci (2010) when the engine was fueled with canola oil methyl ester (COME) and waste (frying) palm oil methyl ester (WPOME). The experiments were conducted at constant engine speeds under full load condition of the engine. The results indicated that when the test engine was fueled with WPOME or COME instead of petroleum based diesel fuel (PBDF), the brake power reduced by 4–5%, while the brake specific fuel consumption increased by 9–10%. On the other hand, methyl esters caused reductions in carbon monoxide (CO) by 59–67%, in unburned hydrocarbon (HC) by 17–26%, in carbon dioxide (CO_2) by 5–8%, and smoke opacity by 56–63%. However, both methyl esters produced more nitrogen oxides (NOx) emissions by 11–22% compared with those of the PBDF over the speed range. Figure 2 depicts the relationship between Unburned HC and Engine Speed.

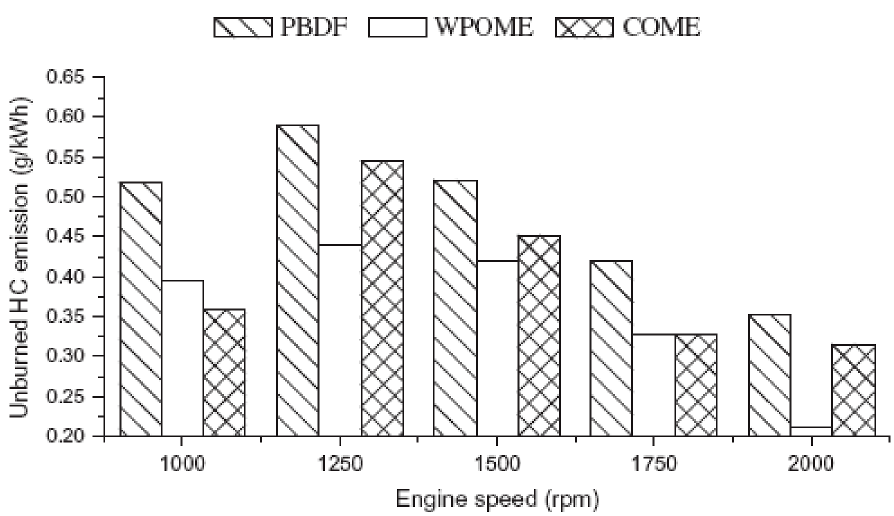

Figure 2. Relationship between Unburned HC and Engine Speed (Ozsezen and Canakci, 2010).

Hira et al. (2012) reported a study where blends of ethanol and biodiesel with diesel in varying proportions were used. Various performance parameters like brake thermal

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Vol. 2 No. 4 December 2013

efficiency, BSFC and emission characteristics such as smoke density, HC, CO and exhaust temperature were investigated. The experimental results showed that BE20 fuel gave the best performance when compared to conventional diesel with fairly reduced exhaust emission.

Selvan et al. (2009) reported that experimental investigation was carried out to establish the performance and emission characteristics of a compression ignition engine while using cerium oxide nano particles as additive in neat diesel and diesel-biodiesel-ethanol blends. In the first phase of the experiments, stability of neat diesel and diesel-biodiesel-ethanol fuel blends with the addition of cerium oxide nano particles was analyzed. After series of experiments, it was found out that the blends subjected to high speed blending followed by ultrasonic bath stabilization improves the stability. The phase separation between diesel and ethanol was prevented using vegetable methyl ester (Biodiesel) prepared from castor oil. In the second phase, performance characteristics were studied using the stable fuel blends in a single cylinder four stroke computerized variable compression ratio engine coupled with an eddy current dynamometer and a data acquisition system. The cerium oxide acted as an oxygen donating catalyst and provided oxygen for the oxidation of CO or absorbs oxygen for the reduction of NOx. The activation energy of cerium oxide acts to burn off carbon deposits within the engine cylinder at the wall temperature and prevented the deposition of non-polar compounds on the cylinder wall which resulted in reduction of HC emissions. The tests revealed that cerium oxide nano particles can be used as additive in diesel and diesel-biodiesel-ethanol blend to improve complete combustion of the fuel and reduce exhaust emissions significantly.

Enweremadu et al. (2011) reported a study on performance of single cylinder diesel engine using blends of shea butter biodiesel. Results from the work showed that the addition of biodiesel to diesel fuel decreases the brake thermal efficiency (BTE) and increases the brake specific fuel consumption. These results are expected due to the lower energy content of biodiesel fuel. On the other hand while the NOx emissions increased with increase in biodiesel content in the fuel blends, the emissions of carbon monoxide (CO), un-burnt hydrocarbon (UHC) and smoke opacity decreased. The engine performance which indicated that the biodiesel has properties and characteristics similar to diesel fuel and the reductions in exhaust emissions make shea butter biodiesel a viable additive or substitute to diesel fuel.

Rao (2011, p. 854) reported the influence of Jatropha biodiesel properties on various characteristics of a direct injection compression ignition engine. Experiments were performed at different engine operating regimes with the injection timing prescribed by the engine manufacturer for diesel fuel. The engine characteristics with Jatropha biodiesel were compared against those obtained using diesel fuel. Observations from the results showed that the biodiesel performance and emissions are lower than that of diesel fuel. However, the NOx emission of Jatropha biodiesel is more than that of diesel fuel. The high NOx emissions were due to the presence of unsaturated fatty acids and the advanced injection caused by the higher bulk modulus (or density) of Jatropha biodiesel. In the study, Jatropha biodiesel was preheated to possibly reduce NOx emissions. The experimental results showed that the retarded injection timing is necessary when using Jatropha biodiesel in order to reduce NOx emission without worsening other engine characteristics. Results also indicated improved performance with the application of preheated biodiesel. However, this resulted in an increased smoke opacity.

CONCLUSION

A review of performance and emission characteristics of compression ignition engines was carried out. The fuels used in the works included biodiesel produced from such oils as: cotton

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Vol. 2 No. 4 December 2013

seed, mahua, rice-bran, canola, Shea butter and Jatropha; and biodiesel from waste frying oil, waste palm oil, blend of ethanol and biodiesel, and diesel-biodiesel-ethanol fuel blend. Biodiesel and its blends reduced brake power by 4-5% and increased brake specific fuel consumption by 5-10%. CO_2 emissions were reduced by 5-8% and NOx increased by 11-22%. Analysis of results identified low blend biodiesel such as B20 to have the potential of becoming optimum blend. The results predominantly correlate and closely agree with the findings of Iowa Central Fuel Testing Laboratory. These significantly identify biodiesel as a renewable and prospective future fuel to protect our environment.

It is recommended that government and private businesses come up with pilot plants for the production, distribution and use of biodiesel in Nigeria. These will also create millions of job opportunities across the nation.

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Vol. 2 No. 4 December 2013

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