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Melon oil methyl ester: an environmentally friendly fuel

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Abstract

Demand for energy is growing across the globe due to the direct relationship between the well-being and prosperity of people and energy usage. However, meeting this growing energy demand in a safe and environmentally friendly manner is a key challenge. To this end, methyl esters (biodiesels) have been and are being widely investigated as alternatives to fossil fuels in compression ignition engines. In this study, melon (Colocynthis Citrullus Lanatus) oil was used to synthesize biodiesel (methyl ester) using the transesterification method in the presence of a sodium hydroxide promoter. The emissions profile of the biodiesel was investigated by setting up a single-cylinder four-stroke air-cooled CI engine connected to a TD115-hydraulic dynamometer and an Eclipse Flue Gas Analyzer (FGA) with model number EGA4 flue gas analyzer. The engine was run at engine speeds of 675, 1200 and 1900rpm for biodiesel/diesel blends at 21°C on a volume basis of 0/100(B0), 10/90(B10), 20/80(B20), 30/70(B30), 40/60(B40) and 50/50(B50). The test showed a downward trend in the emissions profile of the biodiesel, with remarkable reductions of about 55% in the dangerous-carbon monoxide exhaust gas pollutant and 33.3% in the unfriendly SOX from 100% diesel to B30-biodiesel concentration. Increasing the speed from 675 to 1200 and then to 1900 rpm also afforded further reductions in CO and SOX exhaust emissions. NOX however increased marginally by 2.1% from the same 100% diesel to the B30-biodiesel composition. Based on the remarkable reduction in CO and SOX and the marginal increase in NOX as the concentration of the biodiesel increased in the blends, the study concludes that melon oil methyl ester is an environmentally friendly fuel.

1. Introduction

The renewable and environmentally friendly nature of biodiesels make them an attractive area of study. The conservation of our natural environment is key to the existence and survival of humanity. Melon (*Colocynthis citrullus*) oil is a viable candidate for potential exploitation for preservation of our ecosystem. Melon seed contains about 50% oil **[1]** which can be synthesized to methyl esters using a suitable catalyst (such as potassium chloride, potassium hydroxide and sodium methoxide). In fact, many countries are giving incentives to increase the use of biofuel. This will give rise to commensurate conservation of our natural environment and the attainment of the Kyoto Protocol accord. Biodiesel as a renewable fuel is becoming an area that is capable of displacing the finite fossil source of conventional diesel. Melon oil contains unsaturated fatty acid at a level of about 71.9%, 14.5% is monounsaturated fatty acids and the remaining 57.4% is polyunsaturated fatty acids **[2]**. The extraction, production and characterization of melon oil-based biodiesel have been studied previously **[3]**. The quality of fuels supplied to the market specifically for internal combustion engines (ICE) is of paramount importance in order to reduce the level of pollutants and emissions arising from the use of these fuels, which may result in severe health and ambient environmental hazards.

Biodiesel is typically produced by alcoholysis of triglycerides and animal fats in the presence of a catalyst **[4]**. The transesterification process produces two liquid phases. The biodiesel phase (at the top) is less dense than the glycerol. The glycerol could be tapped off from the bottom of the separatory funnel. ICEs require high quality fuels. Water and solid particles are the most common contaminants. Other contaminants could be residual catalysts and free glycerol, while incomplete transesterification reaction may also result in monoglycerides and diglycerides. Washing will substantially remove these contaminants. Biodiesels have properties similar to those of petro-diesel. This characteristic gives them miscibility with conventional diesel. In addition to this, biodiesel can be used in its straight form in a compression ignition engine with little or no modification. The viscosity of biodiesel is a very significant advantage, especially in the area of lubrication of the ICE **[5]**. Biodiesel is known to have slightly higher viscosity when compared with conventional diesel. It can be used as an additive in the formulation of fuels blends to increase the lubricity of pure Ultra-Low Sulfur Diesel (ULSD) fuel which can be used in diesel engines as a renewable hybrid fuel. At low temperatures, increases in the viscosity of the fuel hinders the shearing of vegetable oil based-fuel resulting in poor atomization of the fuel spray and the operation of the fuel injector is lowered **[6]**. Increased numbers of vehicles and stationary ICEs as a result of increasing population across the world has been a major source of harmful carbon monoxide (CO) emissions. Nitrogen oxides (NO_x) also contribute to photo-chemical smog. A control of these malicious emissions is essential for the healthy existence of humanity. Internal combustion engine manufacturers are working assiduously to manufacture engines that are renewable oil compliant.

Biodiesel is an oxygenated fuel and the oxygen content facilitates ignition and improves the combustion process (**[7]** and **[15]**). The oxygen in biodiesel raises the bulk temperature during combustion. This property is crucial as higher temperatures close to stoichiometric conditions aids the formation of NOx (**[7]** and **[16]**). Most biodiesels emit more NOx than diesel although there are cases where the opposite occurs. The amount of NOx produced depends on the nitrogen and oxygen content in the biodiesels as well as the combustion dynamics, which can be influenced by the adiabatic flame temperature, duration of high burning gas temperature, spray characteristics and ignition delay. As such, the NOx concentration can vary with the engine speed and loading conditions (**[8]**, **[17]** and **[19]**). Studies have found that there is a correlation between the iodine number, which quantifies the number of double bonds, and NOx emissions (**[7]**, **[8]** and **[20]**). As a rule of thumb, biodiesels with more saturated carbon bonds generally produce less NOx emissions. The iodine number increases with the level of unsaturation and is associated with the biodiesel's carbon-chain structure and its other properties such as cetane number, density, bulk modulus and freezing point (**[18]** and **[21]**). Just as with brakespecific fuel consumption and power, blends of biodiesels can also alter the NOx emissions. CO is one of the consequences of incomplete fuel combustion (**[9]** and **[22]**). Concentration of oxygen during combustion enhances the oxidation rate of CO and leads to less CO formation. This is a major advantage of oxygenated fuels like biodiesel. However, the intensity of the CO reduction can be affected by engine loading and speed conditions. At low speeds, the lower burning gas temperature could hinder the conversion rate of CO to CO2 and more CO can be emitted (**[9]** and **[23]**). It should be noted that the carbon contents of different biodiesels are not the same and most biodiesels have less carbon content than diesel. This could also affect the percentage change in CO emissions. Viscosity determines the liquid's ability to flow and signifies the mean droplet size associated with the atomization process (**[9]** and **[24]**). Larger droplets are usually formed with fuel of higher viscosity. The droplet size becomes important during injection and combustion. Larger droplets prevent adequate breakdown of the fuel during the injection process and their evaporation is more difficult during the combustion stage. These factors can lead to inefficient combustion and produce more black smoke, which is formed primarily due to the incomplete burning of the hydrocarbon and the carbon reaction in the fuel **[9]**.

Although biodiesel often has slightly higher viscosity than diesel, its lower stoichiometric air/fuel ratio compared with neat diesel can lead to less black particulate emissions. The stoichiometric air/fuel ratio in biodiesel is lowered mainly by the bound oxygen and the oxygen-enriched air. The intensity of smoke emission reduction with biodiesel may also depend on the fatty acid compositions and molecular structures of the fuel. Higher content of shorter carbon-chains generally leads to better ignition quality and less smoke emissions (**[9]** and **[25]**). However, biodiesel may contain different compositions by weight of constituents with different molecular structures. As a result, the constituents can burn and evaporate at different rates. Constituents that continue to burn in the late combustion stage contribute to the exhaust gas temperature, while unburned constituents can form soot (**[10]** and **[20]**). Although shorter carbon-chains can improve ignition leading to complete combustion at lower temperatures, the consequence implies that higher brake specific fuel consumption will be needed to support the process. Furthermore, the combustion characteristics of biodiesels are affected by the cylinder gas pressure, heat release rate and ignition delay and these variables can be dependent on loading and speed conditions. For short combustion processes at high speeds, the amount of total hydrocarbon emissions can differ from that at low speeds **[11]** and **[21]**.

The cetane number refers to the ease with which the fuel can ignite. A high cetane number ensures good cold start and is associated with shorter ignition delay and shorter premixed combustion, resulting in a faster burning rate without late combustion in the expansion stroke **[12]**. These factors lead to lower exhaust temperatures. Besides higher combustion efficiency, the lower energy content of most biodiesels compared with diesel also leads to lower exhaust gas temperatures. Hess et al., **[10]** and Noureddini and Zhu **[13]** found that the ignition timing of biodiesel may be advanced due to its higher isentropic bulk modulus. Exhaust gas temperature can be affected by the changes in ignition delay, with longer ignition delay often resulting in delayed combustion and a higher exhaust gas temperature (**[14]** and **[24]**). The performance of various biodiesels indicates that NOx emissions can be higher, while CO and smoke emissions are generally lower than conventional diesel (**[7]** and **[9]**). Carbon monoxide, nitrogen dioxide and smoke emissions are known to be very hazardous to our health **[8]**. In this regard, the optimization of blends of biodiesel with fossil diesel is very important. Most countries use a system known as the "B" and "E" factors to state the amount of biodiesel for the former and ethanol for the latter in any fuel mixture. Fuel blending (Bxx) can result in different emission patterns. The 'xx' represents the percentage of biodiesel in the mixture of automotive gas oil and chemically modified vegetable oil. In order to understand how environmentally friendly melon oil based biodiesel can be, this study investigates the emissions characteristics of its blends when combusted in a compression ignition engine (ICE).

2. Methodology

2.1 Materials Preparation

Melon seeds were obtained from Ita-Akogun market and diesel was obtained from a government approved-Adeyanju Total filling station in Lagere, Ile-Ife, Osun State, Nigeria. The melon seeds were grounded into flakes. The ground melon seeds were poured into a mortar, some amount of local pepper and onions were added to the ground melon seeds, and this was pounded together until vegetable oil started to flow out. The importance of the local pepper and onion added was to serve as a catalyst in the system. The oil was subsequently heated on a hot plate for 1-hour at $50^{O}C$ to remove the water content. The oil yield was evaluated to be 53% using the ratio of weight of the extracted oil to the weight of the melon seed sample, as given by equation 2.1 below.

$$Percentage\ oil\ yield = \frac{weight\ in\ grams\ of\ extracted\ oil}{weight\ in\ grams\ of\ powder\ sample} x100 \quad (2.1)$$

2.2 Biodiesel Production

Sodium hydroxide (1.12 g) was measured and dissolved in 40 ml of methanol until a homogeneous mixture was formed. 120ml of melon seed oil was measured into a conical flask and preheated on a hot plate at $50^{O}C$. The resulting mixture of methanol and the sodium hydroxide was then mixed into the preheated oil on the hot plate in a molar ratio of methanol (6): sodium hydroxide (0.2): melon oil (1), and then allowed to reflux for 1.5h at the boiling point of methanol (78 ^{O}C) and with a magnetic stirrer set at 700 rpm. The resulting products were poured into the separatory funnel. Glycerol, being the heavier product, was tapped-off, and the crude melon oil methyl ester was later washed and dried with silica gel to improve its quality.

2.3 Properties Characterization

Before blending the biodiesel with conventional diesel in order to investigate its emission profile in a diesel engine, the study firstly analyzed the physio-chemical properties of the fuel as previously determined in one of our previous studies **[3]** (See **Table 1**). The essential properties of the fuels earlier determined were the pour point, flash point, relative density, kinematic viscosity, Iodine value and acid value. The conformity of these properties with standards is key to the effective running of the diesel engine with the fuel, as many engine failures and power loss problems may be related to fuel quality. Hence, the quality of the fuel is not unimportant.

Table 1: Properties of melon oil biodiesel, AGO and melon oil

Properties	Melon oil	Melon oil biodiesel	Automotive gas oil (AGO)	ASTM D-6751
Specific gravity @ 15°C	0.981	0.843	0.86	*NSL
Kinematic viscosity @ 40°C (mm^2/s)	46.615	3.976	3.183	1.9-6.0
Flash point (°C)	172	144	49	130 (minimum)
Pour point (°C)	25	-5	-15	*NSL
Iodine value (g I_2 /100g)	115.23	103.55	11	120
Acid value (mg KOH/g)	1.06	0.2	0.06	0.5max
Water content (% vol.)	0	0	0	0.05

* NSL = No specified limit

2.4 Biodiesel blending and emission characterization

The performance test was conducted in a single cylinder air cooled four stroke CI engine rig. The rig consisted of a single cylinder four stroke air cooled compression ignition engine connected to a TD115-hydraulic dynamometer and Eclipse EGA4 Combustion Analyzer. The engine was run at full engine load for biodiesel/diesel blends at 21°C on a volume basis of 0/100 (B0), 10/90 (B10), 20/80 (B20), 30/70

(B30), 40/60 (B40) and 50/50 (B50). The flue gas analyzer was used to measure CO, SO_x and NO_x for each blend. **Figure 1** shows detail of the experimental rig. The specifications of the engine are shown in **Table 2**, and **Table 3** gives details of the accuracy of the exhaust gas analyzer and this presentation is in agreement with the convention used by Mofijur et al., **[27]**.

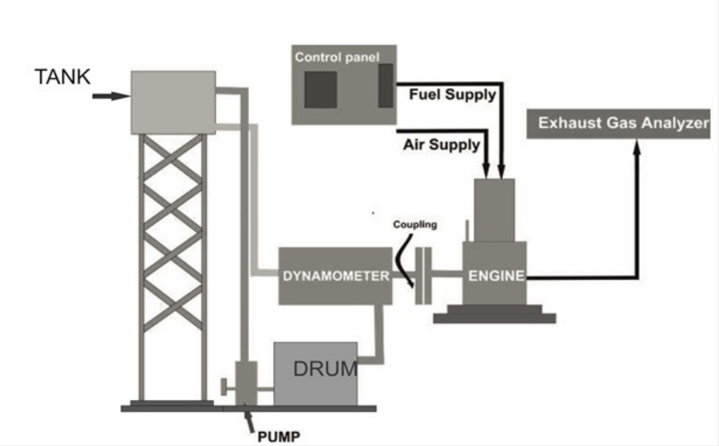

Figure 1: Detail of the experimental rig

Table 2: Engine Specification

Engine variables	Specifications
Trade name	Bholson
Engine speed	2000rpm
Engine fuel	Diesel
Power output	1.5-8KW
Weight of the engine	44kg
Cylindrical bore	700mm
Length of stroke	300mm

3. Results and discussion

3.1 Fuel Properties

Based on the extraction process in this study, the oil content of the melon seeds was evaluated to be 53% and is in agreement with Giwa et al., **[26]**. This large percentage of oil content in melon seeds makes it a viable candidate as a diesel fuel substitute in compression ignition engines (CIE). In addition, the extraction of the oil consumes less energy as it can easily be milled to flakes. The conditions for the alcoholysis process used for the production of the biodiesel were easy to control on a laboratory scale. **Table 1** shows the properties of the biodiesel produced. It also presents the characteristics of the fossil-based diesel (Automotive Gas Oil) and the parent melon seed oil used. The viscosity and the specific gravity of the parent melon seed oil was reduced from 46.615mm^2/s, 0.9812 to 3.976mm^2/s, 0.8430 respectively by transesterification. There was a significant reduction of about 91.5% in the viscosity of the oil after the transmethylation process. Viscosity of melon oil at 46mm^2/s may cause severe problems in the fuel filter and the engine. Pillay et al., **[9]** reported that high viscosity of untransesterified oils and fats leads to operational problems in the diesel engine such as deposits on the engine parts. The higher flash point (144°C) in melon oil biodiesel will be helpful in handling and storage. However, the pour point (-5°C) is also a good result for the cold starting of the engine. There was no sign of water content in the biodiesel. Therefore, long-term storage will be enhanced and hydrolytic degradation will be diminished. Combustion will also take place more efficiently. The comparison between the melon oil biodiesel and automotive gas oil (AGO) was close, especially for specific gravity and kinematic viscosity. This will afford blending the biodiesel with AGO in any ratio. Most of the properties were in conformity with international standards (ASTM) for biodiesel fuels.

3.2 CO exhaust gas emission

Carbon monoxide (CO) emissions were assessed from combustion of the melon oil biodiesel blends in a compression ignition engine. **Figure 2** shows the pattern of the emission profile for this lethal emission gas. The experiment also assessed 100% petro-diesel to give

Table 3: Details of the exhaust gas analyzer

Eclipse EGA4 Combustion Analyzer	Sensor Type	Range	Resolution	Max. Response	Accuracy
CO	Electro Chemical	0-8000 ppm	1 ppm	50 Sec.	±10ppm < 300ppm
					±4% rdg up to 2000ppm
					±10% rdg else where
NO_x	Electro Chemical	0-1000 ppm	1 ppm	50 Sec.	±5ppm < 125ppm
					±14% rdg else where
SO_x	Electro Chemical	0-4000 ppm	1 ppm	40 Sec.	±5ppm < 125ppm
					±14% rdg else where

a sound basis of comparisons. The profile shows a general reduction in CO emissions as the quantity of melon oil biodiesel increased in the blends. This could result from the fact that biodiesel is a renewable green fuel that contains oxygen **[7]**. This oxygen significantly aids the combustion process, leading to the downward trends in CO exhaust emissions. This also showed that biodiesel is environmentally friendly. At higher speeds of 1200 rpm, there is also reduction in the lethal CO emission as the whole profile is completely below the profile at 675 rpm. The same downward CO reduction was noticed for higher 1900 rpm speed. This showed a tremendous tendency for reduction in CO emissions when the engine is run at very high speeds. This downward trend in CO emission in line with increased engine speed must have been occasioned by the continuity in combustion which tends to combust any fuel left over from previous cycles thereby leading to an absence of incomplete combustion that could have given rise to CO formation. There is a remarkable reduction of about 55% in CO emissions for B30.

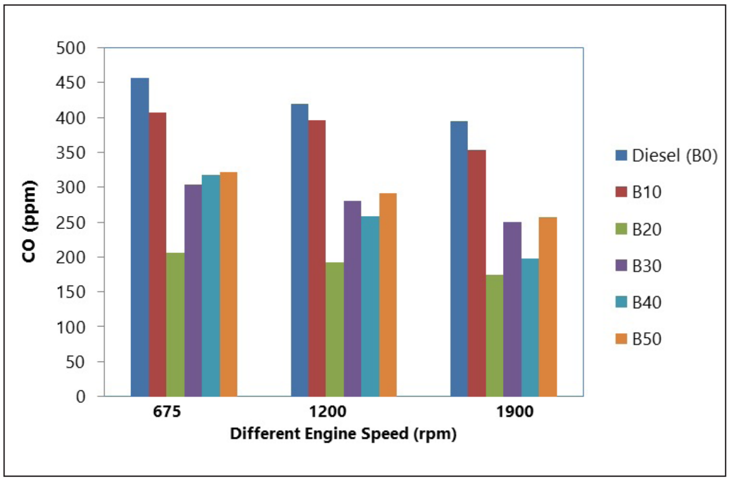

Figure 2: Graph of CO emissions at different blend percentages

3.3 NO_x exhaust gas emissions

In **Figure 3** as the percentage blend of the biodiesel increases, gradual increases in NO_x emissions can be seen. This rise in NO_x formation is associated with increased temperatures in the exhaust and the complete combustion process that took place in the combustion chamber due to the presence of oxygen in the greener fuel. The upward trend in NO_x, which is in line with increased engine speed, must be associated with the continuous combustion process which led to complete combustion and ultimately increased temperature of the exhaust, since the thermal mechanism better predicts the formation of NO_x in a combustion process.

3.4 SOx exhaust gas emissions

In **Figure 4** as the percentage composition of biodiesel increases in the blend, noticeable decreases in SOx emissions can be seen. In all, there was a maximum reduction of 33.3% in SO_x at B30-B50. However, as the speed increases, the increases in SOx emissions were weak. The decrease in SOx formation must clearly be associated with the absence of sulfur in the greener biodiesel and the negligible decreases in SOx emissions with increase in engine speeds is a clear indication that the sulfur content of the fuel is the main factor and not the engine speed.

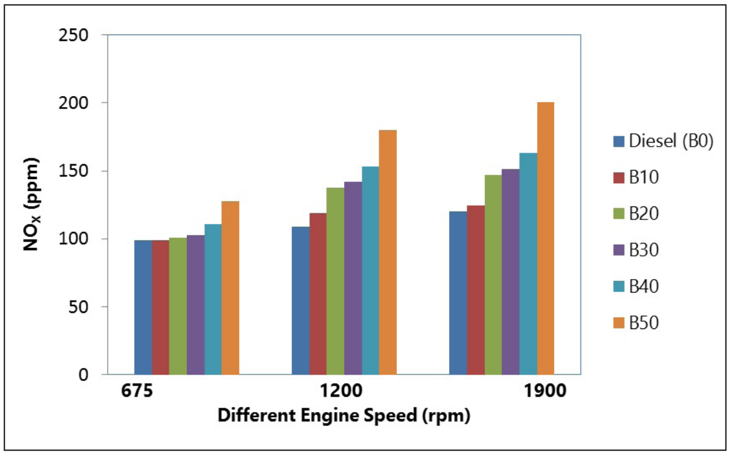

Figure 3: Graph of NO_x emissions at different blend percentages

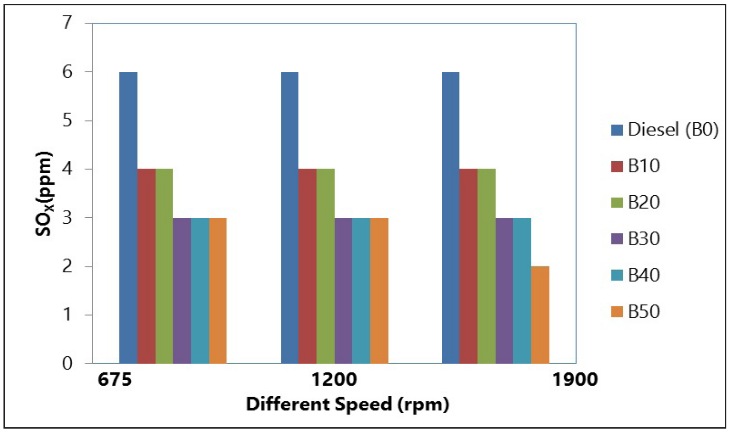

Figure 4: Graph of SO_x emissions at different blend percentages

4. Conclusions

This study establishes that increases in the concentration of melon oil biodiesel in diesel-biodiesel combustion fuel blends will reduce toxic CO and SO_x emissions, and slightly increase NO_x emissions. This observation is in agreement with the literature. Among all the blends investigated in this study, B30 emerged as the optimal with the maximum reduction of about 55% in CO emissions, 33.3% in SO_x and the least increase of 2.1% in NO_x. It is suspected that the reduction in CO emanated from the fact that biodiesel is a renewable green fuel that contains oxygen which significantly aids combustion. The SO_x reduction can be attributed to absolute absence of sulfur in the greener melon oil biodiesel. The slight increase in NO_x is due to complete combustions that took place in the combustion chamber, leading to temperature increases in the exhaust, as it has been established that NO_x increases at higher temperatures. This melon oil-based biodiesel will be attractive for marine applications in environmentally sensitive waters due to its lower venomous emissions. The closeness in the properties of conventional diesel and this melon oil-based biodiesel makes blending easy and fast without any form of separation in commercial applications. These results suggest that adding biodiesel at as low as 10% will go a long way to conserving the depleting fossil fuel and reducing our dependency on it. This will also lead to conservation of our biodiversity.

5. Conflict of interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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