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Performance Evaluation of Biodiesel Sourced from Groundnut Oil for an I.C Engine

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Abstract

The production and performance evaluation of biodiesel from crude groundnut oil via transesterification was achieved using a base catalyst (potassium hydroxide) which was basically use to reduce the viscosity of the oil. The characterization and performance evaluation of the fuel show great resemblance in terms of combustion of an I.C. engine. The pure produced biodiesel is having a kinematic viscosity of 4.296 mm^2s^{-1}, a specific gravity of 0.889 and a flash point of 125 ^{0}C compared to that of the petroleum diesel 2.419 mm^2s^{-1}, 0.8426 and 65.67 ^{0}C respectively; this parameters shows the safety attribute of biodiesel in terms of storage and transportation. The sulphur content of produced biodiesel is approximately 0 %, showing no trace of sulphur, hence there is no formation of SOx. Similarly, there is a great reduction in exhaust gas emission for the case of COx and a gradual increase of NOx, due to the heat generated within the combustion chamber or the temperature of exhaust gas. The cold weather properties of biodiesel makes unfit for use during a very cold weather, this is because the cloud point is 10 ^{0}C as compared to -2 ^{0}C for petroleum diesel and a pour point of 6 ^{0}C as compared to -4 ^{0}C of petroleum diesel.

1. Introduction

The troubles of using fossil fuels have made researchers to think of finding replacement fuels. Since biodiesel has similar properties to the traditional diesel fuel and less environmental troubles occur from using it, is one of the main candidates for replacing diesel fuel in engines. Biodiesel is a viable substitute for petroleum-based diesel fuel. Its advantages are improved lubricity, higher cetane number, cleaner emissions (except for NOx), reduced global warming, and enhanced rural development. It's cold flow properties and oxidative stability merit attention but the problems have shown to be manageable by conventional means such as blending and additives. Vegetable oil has potential as an alternative energy source. However, vegetable oil alone will not solve our dependence on foreign oil within any practical time frame. Use of this and other alternative energy sources could contribute to a more stable supply of energy. Major production centers on the level of modern petroleum refineries have not been developed. However, the number of plants is expanding rapidly and many additional ones are under study. The economics of biodiesel fuels compared to traditional petroleum resources are marginal; public policy needs to be revised to encourage development, [1]. According to [2-3] final report of California biodiesel multimedia evaluation emphasizes the impact of various additives that may be used with biodiesel. These additives may affect fuel quality or storage stability in unintended ways. Because the properties of additives can potentially alter the characteristics of biodiesel, increasing its environmental and health risks, there is a need for additional tests on biodiesel with specific concentrations of additives. In particular it is necessary to assess the impact of cold flow property controllers on surface water- biodiesel interaction and on subsurface multiphase transport of biodiesel, as well as biocides and anti-oxidants on biodegradation, and finally additives on human and ecosystem toxicity. Navindgi *et al*. [4] refer biodiesel as a non-flammable and non-explosive, with a flash point of 150^0C compared with 64^0C for fossil diesel. Biodiesel has a flash point that is considerably higher than petroleum based diesel fuel. This means that the fire hazard associated with transportation, storage and utilization of biodiesel is much less than petroleum based diesel fuels. The flash point is thus a parameter that determines the safety of biodiesel during its handling and storage based on [5-6]. On the other hand, the term biodiesel commonly refers to fatty acid methyl esters are made from vegetable oils or animal fats, whose properties are good enough to be used in diesel engines. Biodiesel has a major advantage over petroleum diesel, since, it is derived from renewable sources it is a clean burning fuel that does not contribute to the increase of carbon dioxide, being environmentally friendly. As the world faces energy crisis, higher oil prices, energy security and economics OECD's member countries designed a common energy strategy, considering two main factors: energy security and environmental problems. The environmental problems is on the increase due to unlimited use of fossil energy. The effects of climate change to support and provide an incentive to use of new and renewable energy includes ratification of the Kyoto Protocol. Clean Development Mechanism (CDM), greenhouse gas emission reduction and emission trading based on [7-8]. Since, biodiesel is more lubricating than fossil diesel fuel, it increases engine life and it can be used to replace sulphur, a lubricating agent, that when burned, produces sulphur oxide; the primary component in acid rain. The performance analysis under specific fuel consumption shows that fossil diesel had a lower values than that of biodiesel (69.09/KWh and 129.21/KWh) respectively, indicating that biodiesel had a slightly higher viscosity compared to fossil diesel. The use of groundnut methyl esters as diesel substitute differs from the use of crude groundnut oil, which does not require any modification of the engines. Groundnut oil biodiesel does not produce explosive air/fuel vapour. Groundnut biodiesel is biodegradable, where up to 98% biodegrades within three weeks, harmlessly disappearing. The economic viability of groundnut methyl ester as diesel substitute will depend on the costs of diesel, crude groundnut oil and glycerin. In Malaysia, a blend of 5% palm biofuel and 95% regular diesel is called a B5 blend and branded as "Envodiesel" nationwide. The palm oil industry is also embarking on the production of palm methyl esters as biodiesel for export and as a substitute for diesel in taxis, buses, trucks, tractors and stationary engines. Environmental issues with fossil fuels also help promote clean alternative energy sources. In 2007, USA Congress proposed the Energy Independence and Security Act (EISA) to address these issues and promote alternative, clean energy sources for the United States. EISA plans to increase biofuel production to 36 billion gallons by the year 2022 (EISA). Since Biodiesel is made entirely from vegetable oil, it does not contain any sulphur, aromatic hydrocarbons, metals or crude oil residues. The absence of sulphur means a reduction in the formation of acid rain by sulphate emissions which generate sulphuric acid in our atmosphere. Biofuels will play a part in expanding the range of energy sources available in the future. In testing Biodiesel in the CytoCulture Mercedes Benz diesel station wagon over the past 4 years, there was about a 15% net decline in the mileage obtained using neat Biodiesel versus petro diesel. No change in power, acceleration or engine temperature was observed, but the engine was quieter and smoother at idle when fueled with Biodiesel. At a 20% blend with petroleum diesel, the fuel consumption differences are practically unnoticeable, [9]. The aim of this research work is to produce and evaluate the performance of Biodiesel made from groundnut oil.

2. Material and Methods

The following materials were used to carry out this research work:soxhlet apparatus, magnetic stirrer, electric cooker, separating funnel (500ml), conical flask (250ml –300ml), beakers (300ml - 500ml), ,pipette (10ml) measuring cylinder, electric oven, crude groundnut oil, methanol, sodium hydroxide pellet / potassium hydroxide pellet, sulphuric acid. warm water, cotton wool, aluminium foils, alkaline cuprous chloride, flash point control unit, internal combustion engine.

2.1. Experimental method of production

The groundnut biodiesel production is achieved base on three modification processes namely; transesterification, emulsification and pyrolysis

2.1.1Transesterification

Transesterification is the reaction of a fat or oil with an alcohol to form esters and glycerol. Alcohol combines with the triglycerides to form glycerol and esters. A catalyst is usually used to improve the reaction rate and yield. Since the reaction is reversible, excess alcohol is required to shift the equilibrium to the product side. Among the alcohols that can be used in the transesterification process are methanol, ethanol, propanol, butanol and amyl alcohol. Alkali-catalyzed transesterification is much faster than acid-catalyzed transesterification and is most often used commercially according to [10-11]. The use of a base to catalyse the reaction presents restrictions, regardless of the transesterification agent employed (methanol or ethanol). The vegetable oil or animal fat to be transesterified through these base-catalysed processes must be neutral. If there is any form of acidity in the oil, the processing will form soaps, producing emulsions and making it difficult to purify. In addition, if the alcohol is not anhydrous the water present will prevent the reaction from proceeding smoothly, reducing the yield drastically. [12-13].

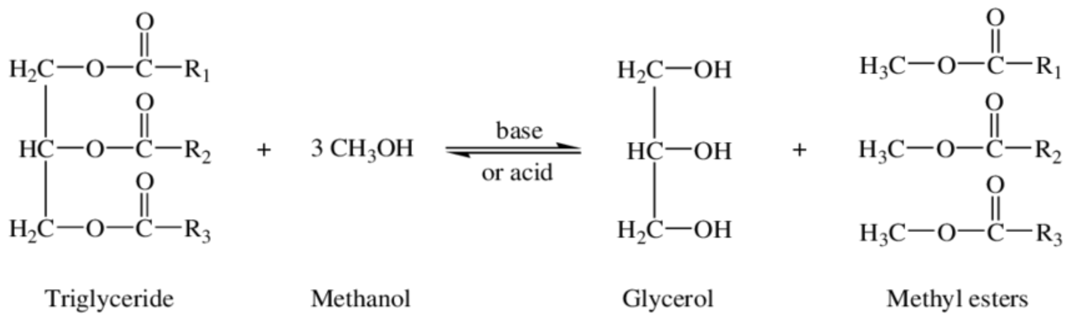

Figure 1: Transesterification reaction scheme [14]

2.1.2. Micro-emulsions

The problem of the high viscosity of vegetable oils was solved by micro-emulsion s with solvents such as methanol, ethanol, and 1-butanol [15-16]. A microemulsion is defined as a colloidal equilibrium dispersion of optically isotropic fluid microstructures with dimensions generally in the 1-150nm range formed spontaneously from two normally immiscible liquids and one or more ionic or non-ionic amphiphiles [11]. The components of a biodiesel micro- emulsion include diesel fuel, vegetable oil, alcohol and surfactant and cetane improver in suitable proportions. Alcohols such as methanol and ethanol are used as viscosity lowering additives, higher alcohols are used as surfactants and alkyl nitrates are used as cetane improvers. Micro-emulsions can improve spray properties by explosive vaporization of the low boiling constituents in the micelles. Micro-emulsion results in reduction in viscosity, increase in cetane number and good spray characters in the biodiesel. According to [17] short term performance of micro-emulsions of aqueous ethanol in soybean oil was nearly as good as that of petroleum diesel, despite the lower cetane number and energy content.

2.1.3. Pyrolysis

Pyrolysis also referred to as thermal cracking is the conversion of one substance into another by means of heat or by heat in the presence of a catalyst. The paralyzed material can be vegetable oils, animal fats, natural fatty acids or methyl esters of fatty acids. The pyrolysis of fats has been investigated for more than 100 years, especially in those areas of the world that lack deposits of petroleum. Many investigators have studied the pyrolysis of triglycerides to obtain products suitable for diesel engine. Thermal decomposition of triglycerides produces alkanes, alkenes, alkadines, aromatics and carboxylic acids. [11]; and [18-19].

2.2. Experimental Procedure for Groundnut oil Biodiesel

Biodiesel was produced from 100 ml of groundnut oil, 28 mL of methanol and 0.5 g of potassium hydroxide (KOH) as a catalyst, that is, the ratio of oil to methanol is approximately 4:1 accounting for loss of methanol during dissolution of KOH. Potassium hydroxide (KOH) and methanol were mixed in separate containers. Oils were contained in 300 ml flasks and heated to a reaction temperature of 60 ^{0}C, at which time the methanol/KOH solution was added and the mixture subsequently stirred for 90 minute using the Magnetic stirrer. After the reaction time was complete, the mixture was transferred to a 500 ml separating funnel for at least 90 minutes. The glycerol layer was decanted and the biodiesel was heated to 65 ^{0}C to remove excess methanol. The product was washed for several times with warm water. The final, washed product was dried and polished by heating using an electric cooker to remove water until boiling ceased. Although the reflux temperature was set within the range of 60^{0}C - 80^{0}C, the reactions temperature and the final product obtained, shows that the temperature required for the complete conversion of oil to fatty acid methyl esters varied from oil to oil as compared to other works on biodiesel production. In the case of palm and sunflower oils, highest yield of 95% and 90% were obtained at 60^{0}C respectively, while for groundnut, coconut, rapeseed and castor oils, the optimum yields obtained were 85%, 75%, 90% and 75% respectively and were obtained at 70^{0}C. It was observed that for reaction temperature below 60^{0}C, saponification of glycerides occurs very fast based on [3]; and [20]. A schematic arrangement of various steps involved during the production of biodiesel is shown in figure 2.

2.3. Yield of Biodiesel by Transesterification

The main objective of this research work are biodiesel production from vegetable oil (groundnut oil). In this research work the vegetable oil was successfully converted into biodiesel by transesterification process using base catalyst. A biodiesel yield of 80% was obtained from groundnut oil by base catalyzed method (Table 1). The main factors affecting the transesterification are free fatty acid (FFA), reaction time, temperature, amount of alcohol and catalyst, catalyst concentration, and rate of mixing. It was observed that FFA increases if the precaution is not taken to store the vegetable oil. Since higher amount of FFA can directly react with the base catalyst to form soaps, and prevents separation of the biodiesel from the glycerol and decrease the yield, it is better to select reactant oils with low FFA content, or reduce FFA by some means. [21-23] :

$$Yield = \frac{Amount\ of\ Biodiesel}{Amount\ of\ oil\ started\ with} \times 10 \quad (1)$$

The most important aspects of biodiesel production to ensure trouble free operation in diesel engines are: complete reaction, removal of glycerin, removal of catalyst, removal of alcohol and absence of free fatty acids, and important reactions parameters for the transesterification are: ratio of alcohol to vegetable oil, temperature, rate of agitation and amount of water present in reaction mixture.

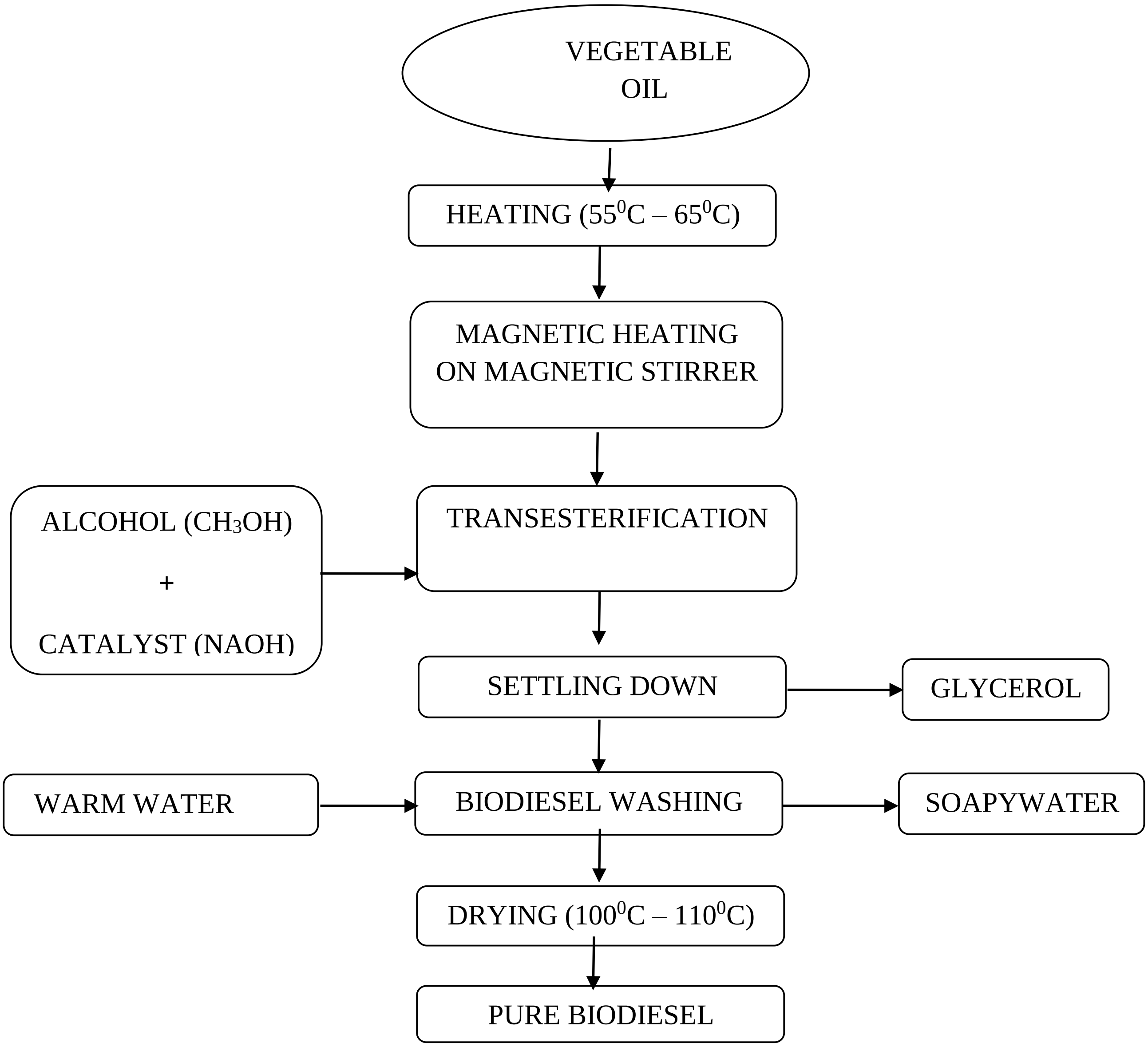

Figure 2: Flow Chart of Biodiesel Production.

Table 1: Yield of Esterification Process.

Input	Volume (%)	Output	Volume (%)
Oil or Fat	87%	Ester	86%
Alcohol	12%	Alcohol	4%
Catalyst	1%	Fertilizer	1%
		Glycerine	9%

Source: National Biodiesel Board Facts (NBB, 2017).

3. Results and discussion

Figure 3 shows the percentage of sulphur content in biodiesel as compared to that of the fossil diesel in the research work. Gasoline and diesel fuels contain sulphur as part of their chemical makeup. Sulphuric acid was produced when sulphur combines with water vapour formed during the combustion process and some of this corrosive compound was emitted into the atmosphere through the exhaust. Oxides of sulphur are acidic, corrosive and poisonous. Sulphuric acid in this case is a major environmental pollutant, coming back to earth in contaminated rainwater. This 'acid rain' was said to be responsible for destroying or degrading vast areas of arable land. As a result, the removal of sulphur from diesel engine fuels has become a major part of most countries vehicle and industrial engine control programs. High sulphur levels in fuel, when combined with water vapour, can also cause corrosive wear on valve guides and cylinder sleeves, which can lead to premature engine failure.

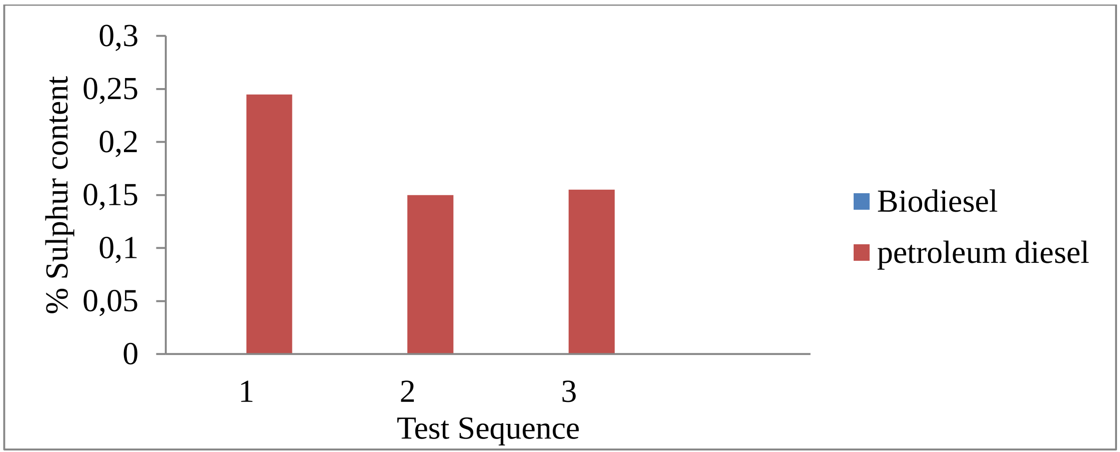

Figure 3 Percentage Sulphur Content of Biodiesel and Petroleum Diesel.

The use of proper lubricant and correct oil drain intervals helps combat this effect and reduces the degree of corrosive damage. Sulphur reduces catalyst efficiency in modern vehicle and diesel engines operating with high sulphur gasoline. On the contrary, biodiesel which is sulphur free does not present the environment with any pollutant associated with either sulphur or any of its compounds. Studies have shown that, biodiesel mostly softens the pressure pipes and hose and rubber tubes when come in contact. Table 2 shows the data of a sulphur test carried out on biodiesel. This shows that there is no trace of sulphur present in the biodiesel produced from the ester of groundnut oil. The formation of various oxides of sulphur (SO_x) is only possible in the presence of sulphur in the fuel.

Table 2 Sulphur content in biodiesel made from groundnut oil and petroleum diesel.

Sequence No.	Measurement time (sec.)	Petroleum diesel (%).	Sulphur content (%).
1	30	0.245	0.00594
2	30	0.150	0.00521
3	30	0.155	0.00692
AVERAGE		0.183	0.00582 (K0.08139)
STD DEV			**0.00055 (K0.00027)**

Figure 4 shows the variation of flash point of biodiesel and that of petroleum diesel, this shows that a very low flash point leads to a delay during the ignition process. As such the power stroke in an IC engine as compared to that of petrol diesel was low. A low flash point in diesel is caused by contamination of the diesel with lighter petroleum product such as; kerosene or gasoline. Similarly, a high flash point can be achieved by mixing the diesel with a lighter fuel such as dry ethanol. Table 3 shows the various temperature of flash point.

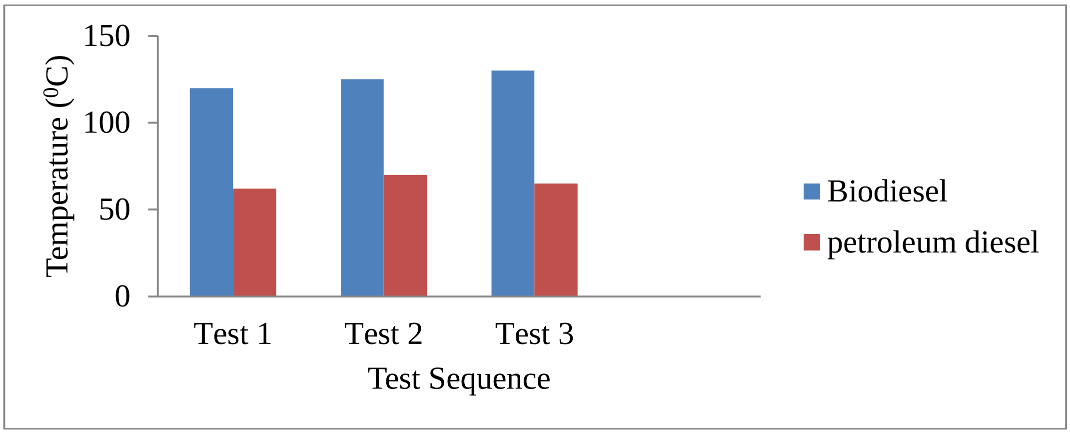

Figure 4 Flash Point of Biodiesel and Petroleum Diesel

Table 3. The differences between flash point of biodiesel and petroleum diesel.

S/N	Petroleum diesel (^{0}C)	Biodiesel (^{0}C)
1	62	120
2	70	125
3	65	130
Average	**65.67**	**125**

The flash point is often used as a descriptive characteristic of liquid fuel and it is also used to help characterize the fire hazards of liquids. "Flash point" refers to both flammable liquids and combustible liquids. Figure 5 shows difference in emission of Carbon (IV) oxide, Carbon (II) oxide and Nitrogen oxide for a biodiesel blend of B20 and petroleum diesel. Except for nitrogen oxide, all other pollutant gases are highly contained in petroleum diesel as compared to that of the biodiesel blend. The increase in nitrogen oxide is as result of the fact that biodiesel contains much oxygen molecules than the petroleum, which favours the reaction between nitrogen and oxygen in the presence of heat. Oxides of nitrogen are produced when combustion of fuels occurs at high temperatures. The major sources of these pollutants (e.g. NO, NO_2) are from the exhaust of transportation vehicles. Oxides of sulphur and nitrogen dissolve in rainwater to produce acids. This results in the fall of acid rain which is harmful to plant and animal life, buildings and metal structures. Since biodiesel is sulphur free, the issue of acid rain has be greatly reduced even though the engines run conveniently with blends instead of 100% biodiesel. Oxides of nitrogen do increase with engines using biodiesel, but they too can be reduced to levels below that of fossil fuel diesel by changing fuel injection timing. Oxides of nitrogen react with sunlight to produce secondary pollutants such as ozone, nitrogen dioxides and alkanals. These, together with the solid pollutants and water droplets in air, form the constituents of smog. Also, the oxides of nitrogen and sulphur cause irritation of the eyes, nose, throat and respiratory tissues. Carbon monoxide is a colourless, odourless and poisonous gas. It is produced in large amounts when the carbon in fuel is burnt incompletely. Motor vehicles are the largest single source of carbon monoxide emission.

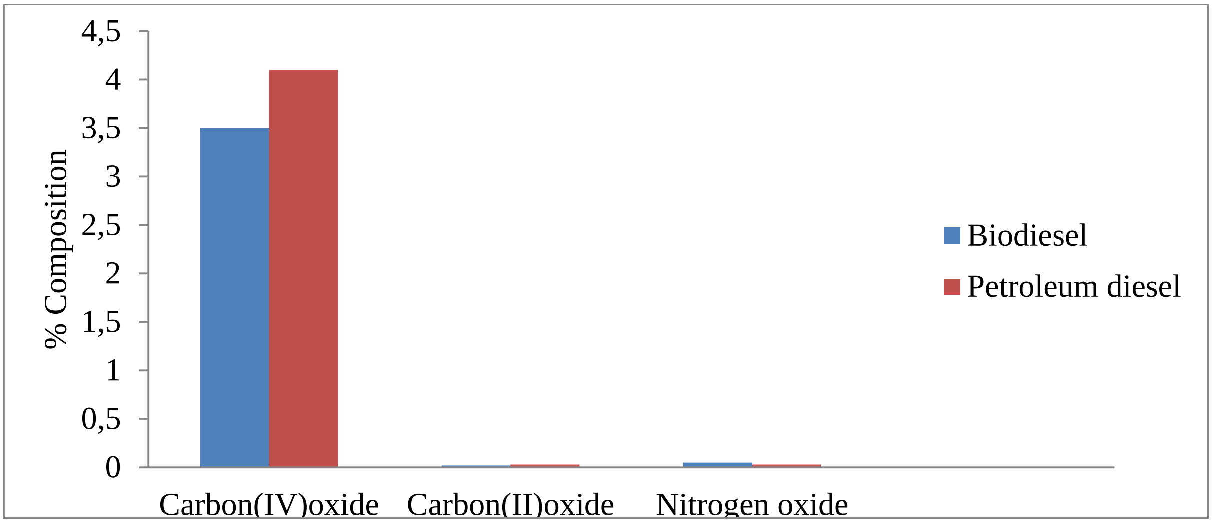

Figure 5 Exhaust Gas Emissions of an I.C Engine Operating on Biodiesel Blend (B20) and Petroleum Diesel.

It is known as Carbon (II) oxide, if inhaled, competes with oxygen for the haemoglobin in the blood. This causes a reduction in the amount of oxygen that is carried to the body tissues. A Carbon (II) oxide concentration of 0.005% (less than the value indicated in Figure 5) in the atmosphere could, over prolong periods, cause brain damage. At lower concentrations, Carbon (II) oxide causes dizziness, headache, fatigue and lethargy. Due to higher concentration of oxygen molecules in biodiesel, there is a better combustion of all carbon molecules, hence lower emission of carbon monoxide and better environment for living things. Carbon (IV) oxide is produced by many processes which use fossil fuel as a source of energy as shown in Figure 5 and Table 4; Carbon dioxide has the highest emission level as compared to other constituents of the exhaust gas. This excessive production of the gas, together with deforestation, has caused an increase in the level of atmospheric Carbon (IV) oxide. This oxide helps to retain a certain amount of the infrared ray (heat ray) that is radiated by earth.

Table 4 the percentage composition of carbon dioxide, carbon monoxide and nitrogen oxide in biodiesel as compared to that of petroleum diesel.

Pollutants	Petroleum diesel (% composition)	Biodiesel (% composition)
Carbon dioxide	4.1	3.25
Carbon monoxide	0.03	0.02
Sulphur dioxide	0.01	-
Sulphates	0.00016	-
Nitrogen oxides	0.03	0.05

An increase in the level of atmospheric carbon dioxide would result in a greater retention of infrared ray, giving rise to the greenhouse effect; a gradual warming of our planet. Such an occurrence would cause the polar caps to melt and submerge many of the coastal regions and islands on earth. To curtail the problem of global warming, biodiesel blends provide a much convenient emission of carbon dioxide which will provide the shade against infrared rays as well as living a considerable composition for the plant and some aquatic lives. While anthropogenic (man-made) CO_2 production accounts for only about 4-5% of the net CO_2 emissions, it is sufficient to have caused a net gain over the past decades. Fossil fuel combustion accounts for 70% of the total anthropogenic CO_2 contribution. Supplementing our dwindling fossil fuel reserves with biomass-based fuels (Biodiesel, for petroleum diesel) helps reduce the accumulation of CO_2.Table 4 also shows the percentage composition of carbon dioxide, carbon monoxide and nitrogen oxide in biodiesel as compared to that of petroleum diesel.

Conclusion

Base on the two major standards of measuring the quality of biodiesel, ASTM D6751 in United States and EN 14214 in the European Union, the production of the biodiesel produced for the performance evaluation in an I.C engine compile with the major factors to be considered as specified by the bodies mentioned above. Factors such as; removal of free glycerine, removal of all alcohol's, removal of the catalyst, the absence of free fatty acids, a complete reaction, cold weather properties, sulphur content and acid value were successfully met. The performance evaluation of biodiesel blend (B20) as compared to that of petroleum provides a platform from which the following was deduce; The combustion of biodiesel produced was much more efficient compare to petroleum diesel due to the presence of excess oxygen in the biodiesel which reduces the possibility of smoky exhaust and reduces the formation of carbon monoxide and carbon dioxide. The no sulphur content of biodiesel made the fuel to be more environmentally friendly with no possibility of formation of oxides of sulphur as compared to the petroleum diesel having a composition range of ≥ 0.005 which has a great effect to the terrestrial and aquatic lives. And finally, increase in the formation of nitrogen dioxide set a drawback for biodiesel. This is because; the reaction between nitrogen and oxygen is endothermic in nature; in the presence of excess oxygen, nitric oxide, NO reacts with oxygen to form NO_2. Also the exhaust temperature contributes to the formation of nitrogen dioxide, as the reaction was enhanced at higher temperature.

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