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Comparative Performance Study of Kolanut Biodiesel and Conventional Fossil Diesel

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Abstract

The research studied the difference in performance between synthesised bio-lubricant from kolanut and conventional fossil diesel. The kolanut oil was extracted from kolanut seeds by soxhlet extraction using petroleum ether as the solvent, after which the physiochemical characterisation of the oil was done to determine its suitability for use as biodiesel. This characterised oil was modified to have superior low-temperature properties through the process of esterification. The modified oil was further synthesised to biodiesel blends through a two-stage trans-esterification process, after which appropriate additives were infused through a blending of the developed biodiesel and the petro-diesel fuels in the following volume ratios: 100:0, 80:20, 60:40, 40:60, and 20:80 (B100, B80, B60, B40, B20) respectively. The synthesised blends of bio-lubricant were subjected to performance analysis in a C. I diesel engine test-bed. The conventional fossil diesel was also subjected to the same test. From the overall analysis, it was shown that biodiesel produced from kolanut pod oil has the potential to be an alternative fuel to conventional Compression Ignition (CI) engines without any further modifications to the engines. The tests revealed that the variation of engine torque with speed for varying speeds and constant load test conditions for the biodiesels, the blends and the conventional diesel fuel show that the biodiesels, due to their higher cetane numbers, have higher torque, higher braking power, higher thermal efficiency with lower calorific values compared to the conventional petro-diesel fuel. The fossil diesel fuel did better than the biodiesel blend when considering the Specific Consumption (SFC) with brake power, but holistically, it is seen that the investigated biodiesel samples performed marginally better than the conventional petro-diesel fuel analysed.

Keywords: Performance, Physiochemical characterisation, Biodiesels, Additives , Two stage trans-esterification, Fossil diesel.

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1 | Introduction

Diesel is the by-product of the catalytic destruction or refraction of crude oil. Crude oil is a substance found in the earth's crust and is usually referred to as fossil fuel because it is created by the decay of fossils over a very long period [1]. This being the case, it contains a high amount of hydrocarbons which when exposed to the environment and the human body has negative consequences [2]. All these instances make it a paramount issue to source substitutes in place of crude oil by-products of diesel, petrol, kerosene, etc. In response to this, research has gone into the development of environmentally friendly and enhanced performance substitutes for fossil fuels.

Rudolf Diesel, the inventor of the diesel engine, ran the first diesel engine on groundnut oil at the Paris Exposition of 1900 [3]. This was the origin of the use of vegetable oils as fuel for diesel engines. However, due to the abundant supply of fossil diesel, Research & Development activities on vegetable oil were not seriously pursued. It received attention only recently when it was realized that petroleum fuels were dwindling fast, and environment-friendly renewable substitutes must be identified, the commonest of which is biodiesel [4].

Biodiesel is a clean, smouldering, renewable fuel that is usually produced from vegetable oils, animal oil or fats, waste cooking oil and grease [5], [6]. In biodiesel production, many different feedstock have been used. Biodiesel can be produced by utilizing edible oils and non-edible oils as resources [7]. However, the usage of edible oil can result in competition between usages of food and fuel. This also can increase the condemnation of sustainable edible oils for biodiesel production [8].

Besides, non-edible oils have a reasonable price and are easily obtainable in tropical countries. Many types of non-edible oils have been used as feedstock for biodiesel production. These include Jatropha curcas, Pongamia pinnata (Karanja), Madhuca indica (Mahua), Linseed, Cottonseed, Azadirachta indica (Neem), Camelina, Reutealis Trisperma, Calophyllum Inophyllum, Hevea Brasiliensis, Ricinus Communis, Ceiba Ceiba pentandra, Schleichera Oleosa, Cerbera manghas and beauty leaf tree [9], [10].

The ultimate goal is to develop specific characteristics and properties of biodiesel through bffflends and other modifications to have better alternatives to conventional diesel with enhanced efficiency in terms of performance and emissions in internal combustion engines [11]. Consequently, this study aimed to ascertain the potential of using waste kolanut pod oil and its blends as biodiesel in internal combustion engines through Computational Fluid Dynamics (CFD) and Artificial Neural Networks (ANN). The use of CFD and ANN in combustion studies was deemed necessary because of the versatility of both tools. They are very essential in their distinct areas of application [12].

Statement of Research fv

The main focus of this research is to compare the performance of synthesised lubricant and the petrol-diesel mix produced from petroleum resources. The specific objectives include the following:

I. Analyse the performance of a C.I. diesel engine test-bed when operated on the biodiesel blends as well as the conventional fossil diesel and compare the results.

II. Carry out an exhaust gas analysis of the biodiesel and compare the results of its environmental impacts with those found in the literature.

2 | Methodology

2.1 | Materials and Methods

Major equipment for the experimentation includes soxhlet extractor, glass wares and glass reactor, reflux condenser, consumables, analytical grade reagents, electronic equipment, Fourier Transform Infrared (FTIR) and Scanning Electron Microscopy (SEM) devices, heating mantle, stirrer, thermometer, and a separating funnel. However, for the engine performance and emission characteristics test, a Compression Ignition (CI) engine test bed with embedded instrumentations and measurement indicators will be used. Grey Wolf optimizing and analytical tools will be used to analyze the experimental design and optimization.

2.2 | Sample Collection, Preparation and Oil Extraction

Processed millet and corn chaff wastes will be obtained from local agricultural processing plants. It will be allowed to dry in open air, and the dried samples will be sieved. The sieved samples will be stored in an airtight container, and the oil will be extracted using a Soxhlet extractor.

2.3 | Biodiesel Production (Transesterification)

The transesterification process involves the conversion of triglycerides (high-quality bio-oil) through a chemical reaction with methanol (to shift the production equilibrium) and a strong acid or/and base catalyst (to accelerate the conversion to biodiesel) to produce biodiesel (methyl esters) glycerol [13]. The setup for the biodiesel production will involve placing a glass reactor on a heating mantle equipped with an electromagnetic field to actuate the agitation effect of the stirring nob when switched on and preheating to eliminate residual moisture [2].

3 | Results and Discussion

3.1 | Characterization of the Blended Feedstock Oil and the Produced Biodiesel

After the oil was extracted via a soxhlet apparatus, the oil samples were sent for characterisation. Results of this exercise are shown in *Table 1* and *Table 2*. The properties of fossil-derived diesel are shown in *Table 3*.

Table 1. Characterization of the kolanut pod oil.

Parameters	Determined Vales for oil
Refractive index @ 29^{o}C	1.4584
Moisture (%)	9.68
Density (g/ml)	0.927
Ash content @ 15^{0}C	0.69
Carbon content	5.53
Kinematic viscosity @ 40^{o}C (mm^2s^{-1})	32.994
Energy value (J/g)	29967
Flashpoint (^{o}C)	245
Fire point (^{o}C)	257
Cloud point (^{o}C)	19.90
Pour point (^{o}C)	14.59
Oil yield (%)	18.63
Acid value (mgKOH/g)	0.5549
Saponification (mgKOH/g	221.10
Peroxide value (meq/kg)	0.77
Iodine value (mg/100g)	18.80
Molecular weight (g/mol)	767.33
Volatile matter	84.10

From *Table 1*, the bio-oil yield produced was 18.63%, which was higher than the value (16%) obtained by Ofoefule et al. [1] in the "Biodiesel production from tiger nut (Cyperus esculentis) oil and characterization of its blen with petro-diesel". This was attributed to its low FFA (acid) value (0.5549 mgKOH/g) and the peroxide value (0.77meq/kg) compared to those of the tiger nut with 8.97 mgKOH/g and 8.33meq/kg, respectively. The high energy value and low ash content of the kola nut pod oil indicate that the fuel sample would serve as a good feedstock for biofuel production since the inherent energy content would increase the combustion efficiency.

3.2|Engine Performance Analysis of the Fuel Samples

Charts in *Figs. (1)-(5)* are the experimental and the performance test results of the respective fuel samples obtained from the CI engine test bed. The experimental data were obtained after the tests were conducted at constant load and constant speed test conditions, which were correspondingly used to generate their performance results using the Scilab 6.0.1 software program. The computer program codes were systematically applied to the respective equations of the performance criteria for the CI engine and solved to output the results generated.

3.2.1|Variation of torque with speed

The variation of engine torque with speed for varying speeds and constant load test conditions for the biodiesels, the blends and the conventional diesel fuel is shown in *Fig. 1*. The transmitted torque from the figure decreases as the engine speed increases because the radius from the axis of rotation of the shaft relating the net load, W (being the constant standard weight on the dynamometer hanger) to the applied torque (T), reduces at varying increased speed of the engine [14]. As the engine speed increases, the fuel temperature increases and viscosity reduces, thus increasing the volumetric flow rate of the fuels and decreasing the developed torque. This reduces the force needed to overcome friction, and hence, the initial torque decreases [15]. Because of their higher cetane numbers, biodiesels have higher torque and lower calorific values compared to conventional petro-diesel fuels. The biodiesels respectively have about the same cetane number (46.1, 47.5, 48.5, 50.6, 51.8) and calorific values (42.55, 41.84, 41.70. 41.35, and 46.1 MJ/kg) for B20, B40, B60, B80 and B100 (*Table 3* and *Table 4*), and as such, have similar behaviour and performances. Since the biodiesels have higher densities (862, 865, 867, 873, and 880 kg/m) than the petro-diesel (835 kg/m), their volumetric output was higher as more fuel was drawn into the chamber for combustion, leading to higher torque, thus revealing that the investigated biodiesel samples performed marginally well than the conventional petro-diesel fuel analysed.

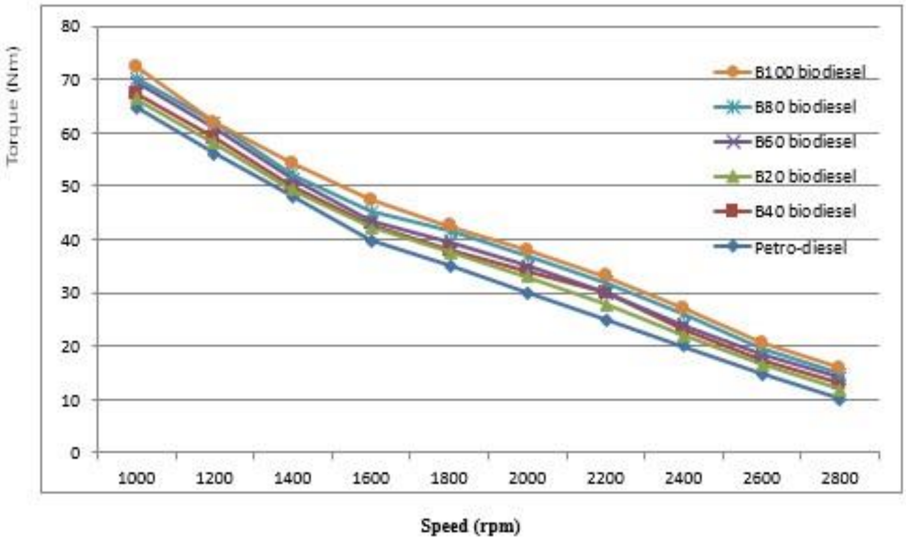
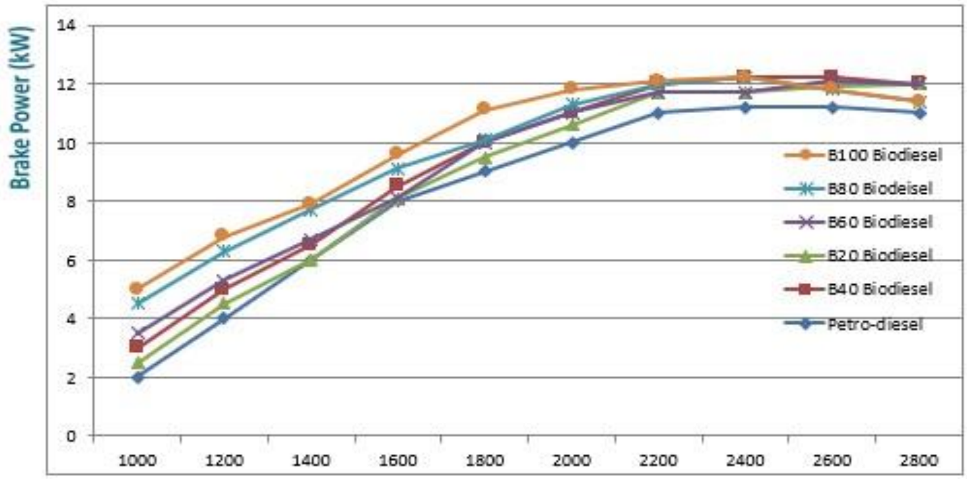


Fig. 1. Variation of torque with speed for varying speed test.

3.2.2|Variation of brake power with speed

Fig. 2 presents the variation of brake power with speed for varying speed tests for the fuel samples. From the figure, the brake power of the fuels increased with an increase in speed at constant load until the point of inflexion and indicated that biodiesel requires a higher amount of brake power because it is denser and more viscous than the petro-diesel fuel [16]. The point of inflexion indicated the efficient speed range for the engine, and thus, it was equivalent to a waste of economy to run the engine above this efficient speed range. As the speed increases above the efficient range, the less time available for combustion produces improper combustion, and hence, the brake power decreases. As the brake power decreases for the same load, the Brake Thermal Efficiency (BTE) decreases, which also increases the Specific Fuel Consumption (SFC) [17].

The biodiesels performed well compared to the petro-diesel due to their higher octane number. The brake power increases as speed increases since the Friction and Auxiliary Power (FAP) are the power needed to



overcome the frictional resistance of the engine parts (which is the difference between the indicated power, ip and the brake power, BP) of the engine increased. But the BP of the engine with the fuel samples fell after the maximum values were reached due to the reduction in their volumetric efficiency with increased speed, which would have been influenced by the gas temperature, valve timing, valve mechanism dynamics and pressure fvpulsation patterns in the induction and exhaust manifolds [18].

Fig. 2. Variation of brake power with speed for varying speed tests.

3.2.3 | Variation of brake thermal efficiency with speed

The variation of BTE of the fuel samples with engine speed at constant load and varying speed test conditions are shown in *Fig. 3*. The biodiesels were presented to be more efficient than the conventional petro-diesel fuel in this regard. The efficiency of diesel fuel dropped faster than that of biodiesel due to better combustion of the biodiesel because of their higher cetane numbers and higher oxygen contents, which improved the ignition and combustion qualities of the fuels. The BTE of the fuel samples increased as the engine speed increased since at higher speeds above 100 rpm, more fuels were injected into the engine cylinder per cycle. Hence, at subsequent higher speeds (1200 rpm and above), all the fuel samples would have been burnt out completely in a short time, thereby resulting in increased efficiency. Consequently, the efficiency of the petro-diesel fuel dropped faster than that of the biodiesels since the volumetric output of the conventional diesel fuel was lower than the biodiesels, thus allowing lesser fuel to be drawn into the combustion chamber, producing lower torque due to its lower density [19].

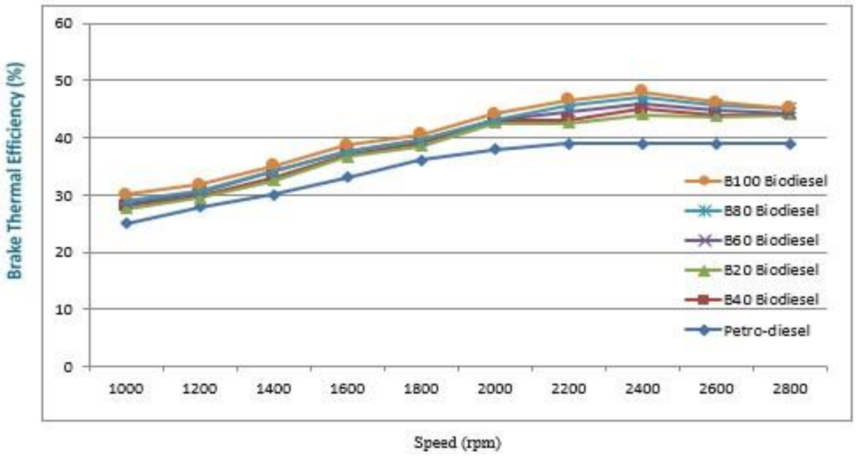
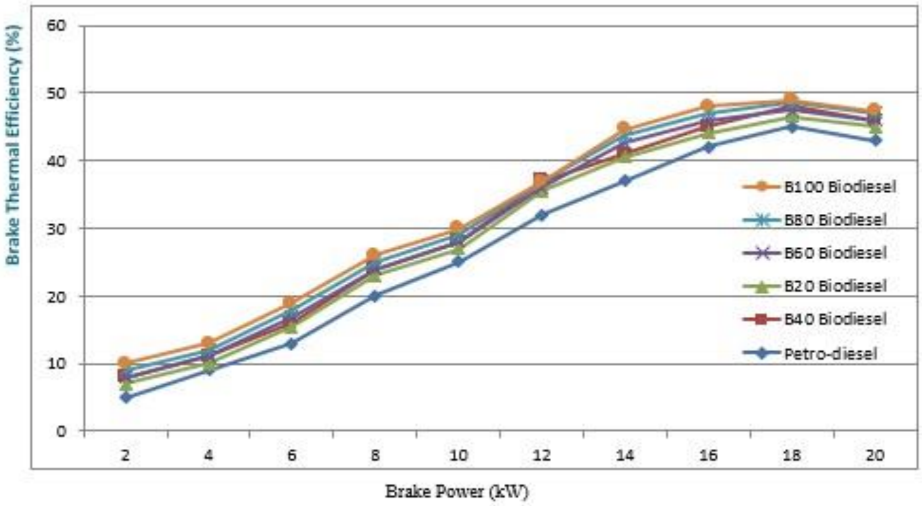


Fig. 3. Variation of BTE with speed for varying speed tests.

3.2.4 | Variation of brake thermal efficiency (η_{BT}) with brake power

Presented in *Fig. 4* is the variation of BTE (η_{BT}) with brake power for the fuel samples at a constant speed and varying loads of the engine. From the figure, it is shown that the η_{BT} of the respective fuels at any applied load on the dynamometer generally increased as the bp of the engine increased. This is probably due to the higher densities and cetane numbers of the biodiesels compared to the petro-diesel, which increased the η_{BT} of the biodiesel, their good performances in engine output, reduction in heat loss due to improved combustion due to greater oxygen content in their molecules and better ignition quality [20]. The η_{BT} increased



when the load was increased for the fuels because of the decreasing influence of FAP consumption as bp increases, as well as improved combustion. Also, the figure indicated that the trend of the biodiesel sample was almost similar from the start of the engine as they possess similar behaviour in their properties until at a bp of about 10 kW, after which the B100 sample produced the highest η_{BT} followed by the B80, B60, B40 and B20 in that order [21].

Fig. 4. Variation of BTE (η_{BT}) with brake power for a constant speed test.

3.2.5 | Variation of specific consumption with brake power

The variation of the SFC with bp for the biodiesel, blends and conventional diesel fuel samples at constant speed and varying load conditions is shown in *Fig. 5*. The figure generally indicates that the SFC of the fuel samples decreased as bp increased within the range tested, due to the increase in their combustion efficiencies and decrease in the effect of FAP consumption. However, the fuel consumption of the biodiesels was relatively higher than that of the petro-diesel at all load conditions due to the lower calorific values and volume flow rates and higher specific gravities and viscosities (*Table 3* and *Table 4*). These results were in line with the values obtained by Lotero [21], where the rate of fuel delivery to engine speed was greatly affected by the density, specific gravity and viscosity of the fuels. Consequently, it could be that the percentage increase in fuel required to operate the engine was less than the percentage increase in bp output due to a relatively smaller portion of the heat energy losses at higher loads, attributable to a lower temperature gradient at warmed-up conditions [22].

Moreso, since SFC depends upon the fuel consumption and by related to the IP and fap of the engine part, it implies that as $bp \to 0$, the fuel samples would still be consumed by the engine to provide the power that would overcome the fap. As such, the SFC $ratio \to \infty$, a hence becomes very high, thus enabling the share of bp in the ip to increase as bp increases. However, at some value of bp (about 20kW), the utilization of IP to produce bp enables the combustion of the fuels to tend towards the more efficient conditions, thus reaching the optimal design and decreasing the SFC until it reaches the minimum value. Beyond that value, the combustion efficiency decreases, and the SFC increases again. The good performance of the petro-diesel with its lower SFC over the biodiesels may be due to the higher calorific value and higher carbon content of the petro-diesel sample [23].

From all the analysis performed, it can be concluded that the biodiesel samples generally performed better in comparison with the petro-diesel fuel counterpart about load, BTE (η_{BT}), with speed at constant load respectively [24]. However, the conventional petro-diesel sample performed better than the biodiesel fuel samples in regards to the variation of SFC with bp at a constant speed and varying load. Consequently, the analysis presented the B100 sample as marginally the best fuel from the engine performance perspective. However, the engine performance as it relates to the biodiesel blends tested was very close, which overall, indicated that the investigated biodiesel samples are good candidates for conventional petro-diesel fuel substitution for power production in the CI engine, since in all, but the SFC, they performed significantly better than the petro-diesel fuel (*Table 3* and *Table 4*).

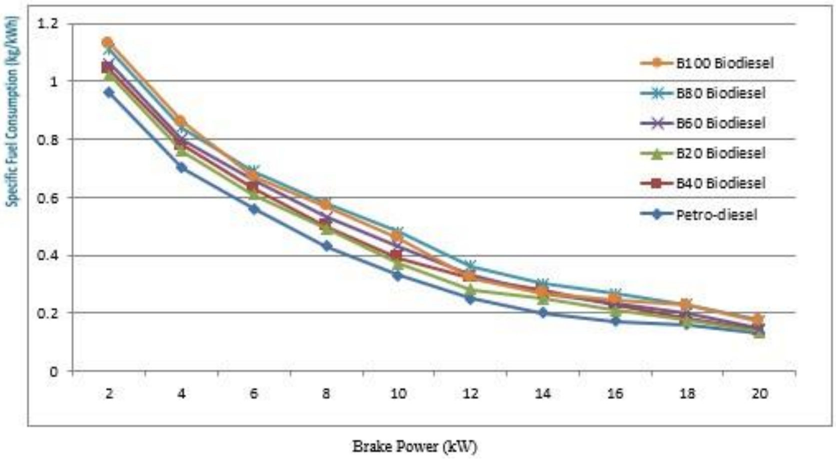


Fig. 5. Graph of SFC versus brake power for a constant speed test.

4 | Conclusion

The tests revealed that the variation of engine torque with speed for varying speeds and constant load test conditions for the biodiesels, the blends and the conventional diesel fuel show that the biodiesels, due to their higher cetane numbers, have higher torque, higher braking power, higher thermal efficiency with lower calorific values compared to the conventional petro-diesel fuel. The fossil diesel fuel did better than the biodiesel blend when considering the SFC with brake power, but holistically, it is seen that the investigated biodiesel samples performed marginally better than the conventional petro-diesel fuel analysed.

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