Experimental and empirical study of diesel and biodiesel produced from blend of fresh vegetable and waste vegetable oil on density, viscosity, sulphur content and acid value

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Abstract
Not quite long, researchers are motivated to explore the mixture of edible and inedible oils to improve fuel properties and reduce the cost of biodiesel production. Even though the tropics are renowned for abundant waste vegetable oil (WVO) generated from restaurant and food processing and frying shops, the fresh vegetable oil (FVO) seems to cause competition between food and fuel utilization if explored for biodiesel production. The current study attempted to derive one-dimensional models to determine key fuel characteristic of hybrid biodiesel-diesel fuel blends. Hybrid vegetable oil methyl ester (HVOME), which has been produced through alkaline transesterification was analyzed for important fuel properties and blended with diesel fuel (DF) at 10, 20 and 40 on a volume basis. Standard methods as specified by (ASTM D6751) standards and the European standards (EN 14214) used. The effects of temperature and biodiesel content were investigated on viscosity were. Statistical regression technique was employed to derive one-dimensional models. The models were further adopted to correlate basic fuel properties with biodiesel blends. The kinematic viscosity, flash point and acid value increased while sulphur content decreased with increasing biodiesel fraction in HVOME-DF blends. The kinematic viscosity of fuel blends decreased with the increasing temperature. The empirical models show high regression value (R2) between properties and HOVME-DF blend. In conclusion, the results of this study can be adopted for thermophysical property collection for hybrid feedstocks’ utilization and guide for regression modelling in biodiesel fuel industry.

Keywords: Hybrid vegetable oil methyl ester; Diesel fuel; Blend, Characterization

1. Introduction
Advantages of biodiesel over fossil diesel or Automotive Gas Oil (AGO) include higher superior flash point, biodegradability, reduced toxicity, improved cetane number, negligible sulphur content and improved lubricity. Pollution problems caused by the widespread adoption of fossil fuels, finite trend of diesel fuel and energy transition from crude oil to renewable energy have sparked the interest of researchers and stakeholders in biofuel industry to seek for alternative means of energy that are affordable, sustainable and technically feasible [1, 2]. Biodiesel is a reliable alternative to diesel as it provides fuel from renewable resources and has lower emissions than fossil diesel [3-4]. Biodiesel is mostly defined as a domestic renewable
fuel for diesel engines derived from natural oils like soybeans, canola, palm kernel, waste cooking oil, etc. which certify the specification of ASTM D 6751 [1, 5]. The adoption of waste oil for biodiesel is to reduce the burden of waste disposal and to reduce the cost of biodiesel production [6]. The production of biodiesel entails the transesterification of lipid feedstock and alcohol with the aid of a suitable catalyst [7]. However, it can be adopted in its pure form or as a blend in diesel engines [8, 9]. The significance of characterizing biodiesel cannot be jettisoned since it is relevant for effective modelling of engine combustion [10-11]. The authors further remarked that the effect of differing thermo-physical properties of varying biodiesel and fossil diesel blends can influence behaviour of engine performance and emissions characteristics. Bhandare and Naik [12] stressed the importance of characterizing fuel by their thermo-chemical properties, in that they are more affected by the concentration of the blends. Literatures [13-15] indicated that biodiesel produced from vegetable oil often possess high density, viscosity and cloud and pour points. These properties remarkably influence the combustion and emissions from diesel engines [16]. Owing to this, pure biodiesel might not suitable for powering diesel engines and heating elements. Thermo-physical properties of biodiesel/diesel blends are very relevant for spray characterises, combustion, and emission characteristic in internal combustion engines [17, 18]. A perusal of literatures has shown that thermophysical properties of biodiesels production from oils such as palm oil, jatropha oil, coconut, etc. and its biodiesel blends have been critically examined. However, To the authors’ knowledge, fuel properties of biodiesel produced from inedible and non-edible is rarely reported in literature. waste vegetable oil/fresh vegetable oil blends and diesel have not adequately examined. The current study attempted to derive one-dimensional models to determine key fuel characteristic of hybrid biodiesel-diesel fuel blends.

The study aimed to investigate the impact of blends of biodiesel from mixture of fresh vegetable and waste vegetable oil and diesel on basic fuel properties and develop regression equations. The models were further adopted to correlate basic fuel properties such as kinematic viscosity, sulphur content and acid value with biodiesel blends Temperature dependence on kinematic viscosity of hybrid vegetable oil methyl ester with diesel fuel blends was examined.

2. Material and methodology
HVOME obtained from Biotechnology Laboratory, Federal University of Agriculture Abeokuta, Nigeria as used for the study. Diesel fuel was purchased from Jocceco Filling Station, Warri, Delta State, Nigeria.

Equipment such as measuring cylinders (Borosil, India), magnetic stirrer (Corning, USA) and electronic balance (Adam, UK) were adopted for blending of HVOME and diesel fuel.

2.2. Equipment for HVOME/diesel fuel blends testing
Pour, freezing and cloud point analyzer (Lawler, USA), Flash tester (Pensky-Martens Automatic, Italy), density hygrometer (Swaski, India), sulphur content analyzer (Horiba, Japan), and viscosity test equipment (Chongqing, China) were employed to characterize HVOME/diesel fuel blends. Schematic of equipment for the fuel types is presented in Figure 1 and details of equipment and methods are presented in Table 1.
Table 1. Equipment adopted for fuel properties determination

| Property               | Standard method | Equipment                              | Manufacturer     | Model   | Accuracy             |
|-----------------------|-----------------|----------------------------------------|------------------|---------|----------------------|
| Density 40 °C         | ASTM D1250      | Density hygrometer                      | India            | M50     | -                    |
| Kinematic viscosity   | ASTM D445       | Chongqing viscosity test equipment      | China            | VST-2000| 0.5 mm²/s            |
| Flash point           | ASTM D56        | Pensky-Martens flash tester             | Italy            | 750/AUT | 0.1 °C               |
| Acid value            | ASTM D664       | Automated titration system              | Mettler Toledo, Switzerland |       | ± 0.001 mgKOH/g      |
| Cloud point           | ASTM D2500      | Lawler cloud point, pour point and freezing point analyser | USA              | 664     | 0.1 °C               |
| Pour point            | ASTM D97        | Lawler cloud point, pour point and freezing point analyser | USA              | 664     | 0.1 °C               |

Figure 1. Pictorial set-up of equipment for testing biodiesel: (a) hydrometer; (b) Pensky-Martens flash tester; (c) Chongqing viscosity test equipment and (d) Lawler cloud, pour and freezing point
2.3 Preparation of biodiesel-diesel blends

HVOME (B100) and its fossil diesel (B0) blends (B10, B20, B40) and B0 are prepared and presented in Figure 2. The curve fitting entails searching the best polynomial which fit biodiesel/diesel experimental data. The polynomial of order k in X is expressed in Eq. (1).

\[ Y = C_0 + C_1X + C_2X^2 + \cdots + C_kX^k \]  

(1)

Empirical equations for modelling basic properties of HVOME/diesel blends

Regression models were postulated to relate the experimental data obtained from the test conducted for basic properties such as viscosity, flash point and sulphur content with the aid of Microsoft Office Excel 2007 spreadsheets. The plots were drawn and the model were checked by mean of polynomial manipulations, taking into cognizance the magnitude of the coefficients of determination, R².

The density (D, kg/m³) and kinematic viscosity (KV, mm²/s) versus and biodiesel fractions (x) were expressed in Equations (1) and (2), respectively

\[ D = -\phi_1x^2 + \phi_2x + \phi_3 \]  

(1)

\[ KV = \phi_4x^2 + \phi_5x + \phi_6 \]  

(2)

where \( \phi_1, \phi_2, \phi_3; \) and \( \phi_4, \phi_5, \phi_6; \) are the regression coefficients in density and kinematic viscosity, respectively.

The kinematic viscosity (KV) as a function of biodiesel fraction for diesel fuel (B0), 10% (B10), 20% (B20, 40% (B40) and 100% (B100) are expressed by the aid of Equation (3)

\[ KV_{BXX} = -\phi_{i1}t^2 + \phi_{i2}t + \phi_i \]  

(3)

where t is the temperature while \( B_{XX}, \phi_i \) are the types of fuel and regression constant, respectively.

The flash point (FP, °C), sulphur content (SC, mg) and acid value (AV, mg KPH/g) versus biodiesel fraction (x) were modelled by equations (6) to (8).

\[ FP = \phi_7x + \phi_8 \]  

(6)

\[ SC = \phi_9x^2 - \phi_{10}x + \phi_{11} \]  

(7)

\[ AV = -\phi_{12}x^2 + \phi_{13}x + \phi_{14} \]  

(8)

where \( \phi_7 \) and \( \phi_8; \phi_9, \phi_{10}, \phi_{11}; \phi_{12}, \phi_{13}, \phi_{14} \) are the regression coefficients in FP, SC and AV’s regression models, respectively.

3. Result and discussion

3.1 Properties hybrid vegetable oil methyl estes

The different fatty acids with their weight composition of hybrid vegetable oil methyl esters (HVOME) are depicted in Figure 3. Biodiesel contains significant amount of saturated fatty
acid (84.6%) and less amount of unsaturated fatty acid (15.4%). Fuel having higher saturated fatty acid compositions influences cold flow properties but improve cetane number [19, 20].

3.2. Major properties of pure hybrid vegetable oil methyl esters and diesel blends

Table 1 presents the properties of hybrid vegetable oil methyl ester (HVOME), coconut oil ethyl ester (COEE), jatropha oil methyl ester (JOMEE), waste frying oil (WFOME) and diesel fuel (DF). The density of the HVOME (883.63 kg/m³) is comparable with those of COEE (884.0 kg/m³), JOMEE (864.8 kg/m³) and WFOME (883.34 kg/m³) stipulated by Samuel et al. [21], Mofijur et al. [22] and Samuel et al. [23], respectively. HVOME’s density conforms with the range of EN 14214 (860-900 kg/m³) specification but greater than that of DF (861.3 kg/m³). Vehicular diesel engine powered with biodiesel produces higher brake power and soot emission [24-25]. The problem can be resolved by optimizing engine fuel injection [26]. However, inclusion of biodiesel with diesel can improve its density [4, 27]. Figure 4 depicts the effect of diesel and HOVME blend on density. As observed, the densities of the blends B10 and B20 (861.3 kg/m³ and 865.3 kg/m³) are very close to that of DF (861.3kg/m³). As the percentage of HVOME-DF blends shifted from 10% to 40%, the density of the biodiesel blends increased from 862.6 to 871.2 kg/m³ but they are within the range of EN14214 (860-900 kg/m³) specification. Al-Hammare and Yamin et al. [28] attributed that more fuel is injected by mass as the fuel density increases. There is a tendency for the increase in fuel consumption as the blend in the HVOME increases. The second-degree equation such as $-3 \times 10^{-4}x^2 + 0.2608x + 860.67$ is found suitable for the change of density vs. biodiesel fraction because of having high regression coefficient of 0.996. The high $R^2$ from the density empirical equation shows that over 99.6% of the data is captured.

![Figure 3. Fatty acid composition of hybrid oil methyl ester](image-url)
The kinematic viscosity of the HVOME (5.1282 mm²/s) is comparable with those of COEE (4.629 mm²/s²), JOMEE (4.723 mm²/s²) and WFOME (4.31 mm²/s²) respectively indicated elsewhere [21, 22, 23]. HVOME’s viscosity conforms with the range of ASTM D6751 (1.5-6.0 mm²/s²) but exceeds that of EN 14214 (3.5-5.0 mm²/s²) and DF (4.8162 mm²/s²). Vehicular diesel engine fuelled with biodiesel having high viscosity results into improper atomization of the fuel injector [29].

The quadratic equation such as $(-1 \times 10^{-5}x^2 + 0.0046x + 4.814)$ is found suitable for the change of kinematic viscosity vs. biodiesel fraction because of having high regression coefficient of 0.9978 (See Figure 5). The high $R^2$ from the density empirical equation shows that over 99.8% of the data is captured.

The viscosity-temperature curve for fossil diesel and their blends is depicted in Figure 6. As can be observed, viscosity of the fuel types decreased quadratically with temperature. The result is consistent with the reports of earlier researchers [30, 31]. Owning to these characteristics, second order degree models are found suitable to correlate viscosities and temperature variation.

**Figure 4.** Variation of density with hybrid vegetable oil methyl ester blends

**Figure 5.** Variation of kinematic viscosity with hybrid vegetable oil methyl ester blends
Figure 6. Comparisons of kinematic viscosities of hybrid vegetable oil methyl ester blends at varying temperature

The Flash Point (FP) of HVOME (139 °C) certified the safety requirement for both standards and compared favourably with those of COEE (160 °C), JOME (182.3 °C) and WFOME (152 °C) but higher than that of fossil diesel (69 °C). The FP values about non-linearly increased with HVOME fraction, as depicted in Figure 7. A higher value of the FP is often attributed to a reduced risk of fire. This property gives an advantage of biodiesel over fossil diesel.

Figure 7. Variation of flash point with hybrid vegetable oil methyl ester blends

The sulphur content (SC) of HVOME (0.0071 mg/kg) met the specification of both ASTM D6751 (0.05 mg/kg) and EN 14214 (10 mg/kg) standards. The SC of HVOME is relatively lower than that of DF (0.2905 mg). SC values quadratically reduce with increasing HVOME fraction, as depicted in Figure 8. Taravus et al. [32] indicated the low value of SC is mostly...
linked to marginal reduction in exhaustion emission profile during combustion system. This tends to make biodiesel more eco-friendly compared to diesel fuel.

![Graph](image)

**Figure 7.** Variation of sulphur content with hybrid vegetable oil methyl ester blends

The performance indices for low temperature properties of HVOME were based on cloud point and pour point (CP and PP, respectively). HVOME provided CP and PP values of 7.3 °C and 2.86 °C, respectively. It was observed that CP and PP are higher than those of diesel fuel (-9 °C, -15 °C). However, both standards failed to mention standard for CP and PP. This is attributed to the variation of climatic condition globally. The high CP and PP will limit wide application of HVOME in artic region. However, to improve cold flow properties of biodiesel, blending biodiesel with varied improving agents and winterization have been suggested [33].

The Acid Value (AV) of HVOME (0.297 mg KOH/g) is appreciably higher than that of AGO (0.12 mg KOH/g). However, this value concurs with the norms of both standards. SC values quadratically increase with increasing HVOME fraction, as depicted in Figure 9. Fuel having high AV has been remarked to cause formation of deposits in diesel engine and degradation of fuel in service [34]
**Figure 6.** Variation of acid value with hybrid vegetable oil methyl ester blends

**Table 2.** Properties of hybrid vegetable oil methyl ester

| Property                  | Unit             | HVOME<sup>a</sup> | ASTM D6751 | EN 14214 | COEE<sup>b</sup> | JOME<sup>c</sup> | WFOME<sup>d</sup> | DF<sup>e</sup> |
|---------------------------|------------------|-------------------|------------|----------|------------------|------------------|------------------|----------------|
| Density                   | Kg/m<sup>3</sup> | 883.63            | -          | 860-900  | 884              | 864.8            | 883.34           | 861.3          |
| Kinematic viscosity, 40 °C | mm/s<sup>2</sup> | 5.1282            | 1.9-6.0    | 3.5-5.0  | 4.629            | 4.723            | 4.31             | 4.8162         |
| Flash point               | °C               | 144               | 130 min    | 120 min  | 160              | 182.3            | 152              | 72             |
| Cloud point               | °C               | 7.3               | -          | -        | -3               | 3                | -2               | -15            |
| Pour point                | °C               | 2.86              | < 0        | < 0      | -13              | 3                | -12              | -9             |
| Sulphur content           | mg               | 0.0071            |            |          |                  |                  |                  | 0.2905         |
| Acid value                | mgKOH/g          | 0.297             | 0.50       | 0.50     | 0.31             | 3.02             | 0.459            | -              |

<sup>a</sup>Present study, <sup>b</sup>[21]; <sup>c</sup>[22]; <sup>d</sup>[23]; <sup>e</sup>diesel fuel

**4. Conclusion**
In this study, aside reduction of cost of biodiesel production and prevention of health implication associated with waste vegetable oil, feasibility of utilization of hybrid vegetable oil methyl oil methyl ester (HVOME) and diesel fuel (DF) blends are investigated by determining its basic fuel properties and compared with biodiesel international standards. New correlations were fitted to the measurements for estimating these properties. In the light of this study, (i) other important property (cetane number, calorific value, oxidation stability, iodine value, methanol content, etc.) of spectrum HVOME-DF blends and (ii) surface tension and rheology of the HVOME-DF blends can be examined for the future study. The following conclusions can be deduced from the study: The basic fuel properties of HVOME were within the ASTM standards of biodiesel. Density, viscosity, flash point and acid value increased with increasing biodiesel content in the fuel types while that of sulphur content decreased.

The proposed empirical models of fuel properties of the HVOME can be utilized to predict the properties of biodiesel-diesel fuel at any blend, which will be a substantial assistance to design the fuel system of biodiesel engine.

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