Effect of NiO/SiO2 on thermo-chemical conversion of waste cooking oil to hydrocarbons

J. Sani a,*, A.M. Sokoto b, A.D. Tambuwal b, N.A. Garba c

a Sokoto Energy Research Center, Usman Danfodiyo University, Sokoto, Nigeria
b Department of Pure and Applied Chemistry, Usman Danfodiyo University, Sokoto, Nigeria
c Department of Chemistry, Federal University, Gusau, Nigeria

* Corresponding author.
E-mail address: Samanja0472@Yahoo.Com (J. Sani).

Abstract

Increase in organic waste generation, dwindling nature of global oil reserves coupled with environmental challenges caused by waste oil disposal and burning of fossil fuels necessitated the need for alternative energy resources. Waste cooking oil obtained from the frying fish outlet was analyzed for its physicochemical properties using ASTM D-975 methods. Acid and Iodine values of the oil were 30.43 ± 0.32 mgKOH/g and 57.08 ± 0.43 mgI2/100 g respectively. Thermo-chemical conversion of the oil using NiO/SiO2 at different reaction conditions (pressure, temperature, and catalyst concentration) at a residence time of 3 h yielded 33.63% hydrocarbons. Hydro-catalytic pyrolysis of waste cooking oil at 400 °C, H2 pressure of 15 bars, and catalyst to oil ratio of 0.25 g/100 cm3 resulted in highest hydrocarbon yield (41.98%). The fuel properties of the product were: cetane number (71.16), high heating value (41.43 MJ/kg), kinematic viscosity (2.01 mm²/s), density (0.94 g/ml), saponification value (185.1 ± 3.96 mgKOH/g), and iodine value (20.57 ± 0.20 I2/100 g) respectively. These results show that the NiO/SiO2 could be a suitable catalyst for conversion of waste vegetable oil to hydrocarbons.

Keywords: Energy, Chemical engineering
1. Introduction

Reducing anthropogenic greenhouse gas (GHG) emissions globally is a key driver for the development of renewable energy sources. A key route towards achieving this is to replace conventional fossil-based fuels with renewable and low carbon energy technologies such as biofuels. Biofuels, which provides about 10% of the total global energy supplies, are the most important renewable energy source used and could play a vital role in contributing towards reducing the dependence on finite fossil fuels, and reduce GHG emission (Satyarthi et al., 2013). First-generation bioethanol and biodiesel primarily produced from cereal grain and edible vegetable oil respectively, are currently the most common form of biofuels. Although these technologies have proven to be a promising alternative or substitutes to conventional gasoline in the transportation sector, they are yet to be sufficient to meet the growing demand for conventional fossil fuel presently consumed worldwide each year (Miller, 2009; Mamedova et al., 2010). Furthermore, there is growing ethical concerns about the use of food as fuel raw materials, which has led to global food vs fuel debate about whether to use, for instance edible vegetable oil as biodiesel feedstock or as human food (Yanyong et al., 2012). This has led researchers to work on more acceptable non-food, inedible sources containing such as waste cooking oil/fats for biodiesel production due to their high energy density (Satyarthi et al., 2013). These oils can be used as alternative fuels in compression ignition engines after modifying the fuel structure or properties or modifying the engine (Boyle, 2004; Chhetri et al., 2009).

First generation biodiesel is primarily produced from edible vegetable oils that are more expensive than the conventional fossil based diesel fuel. Thus, biodiesel produced from edible vegetable oil is currently not economically feasible (Stella, 2013). Alternatively, wastes cooking oils, restaurant grease and animal fats have shown to have huge potential for biodiesel in recent times (Canakci and Van Gerpen, 2001; Corsini et al., 2015). Waste cooking oil, which currently represents one-third of the global total fats and oil production are mostly devoted to industrial uses and animal feed (Canakci and Van Gerpen, 2001).

Moreover, the conversion of these oils/fats to biodiesel via transesterification reaction has been reported to be affected by some factors such free fatty acids and moisture content of the oil/fats (Zaloa, 2010; Satyarthi et al., 2013). Similarly, ester-based biodiesel was reported to have detrimental effects like increased NOx emission, deposit formation, storage stability problems, and more rapid aging of engine oil (Aatola et al., 2008; Wang, 2012). Waste cooking oils that are generally low in cost and collected from large food processing and service facilities represents an important feedstock for biodiesel production (Kulkarni and Dalai, 2006). Waste cooking oil usually contains a high concentration of free fatty acids, which greatly increase the cost in the production of Fatty Acid Methyl Esther
(FAME) biodiesel (Yanyong et al., 2012). Although research findings have shown that base catalysts are highly active in the conversion of triglycerides to FAME with methanol via transesterification process (Furimsky, 2003), base catalysts have also been reported to lose their activity in the transesterification of high-acid-value waste cooking oil as they react with free fatty acids to form soap (Yanyong et al., 2012). Transesterification is a chemical process of reacting vegetable oils with alcohol such as ethanol, methanol, or butanol in the presence of a catalyst. The catalysts used in transesterification are generally classified in two categories, acidic and alkaline (Wang, 2012).

The chemical conversion of waste cooking oils to biodiesel directly removes glycerin from the triglycerides and replaces it with the alcohol used for the conversion process (Canakci and Van Gerpen, 2001). This process significantly decreases the viscosity as well as maintaining the cetane number and the heating value of the fuel. A number of studies have shown that the properties of biodiesel are very similar to conventional fossil diesel (Aatola et al., 2008). Therefore, biodiesel fuel can be used in diesel engines with little or no modification. Biodiesel has a higher cetane number than diesel fuel, no aromatics, no sulfur, and contains 10–11% oxygen by weight (Aatola et al., 2008). These characteristics of biodiesel reduce the emissions of carbon monoxide (CO), hydrocarbon (HC) and particulate matter (PM) in the exhaust gas compared to conventional fossil based diesel (Satyarthi et al., 2013).

However, according to Encinar et al. (2005), transesterification reaction is affected by several parameters such as the concentration of catalyst, oil to methanol ratio, reaction temperature, moisture, presence of free fatty acids and agitation intensity. Therefore, this paper investigated the optimal production of biodiesel from waste vegetable oil by using different reaction temperature in the presence of NiO/SiO2 catalyst.

2. Methodology

2.1. Sample collection and treatment

Waste cooking oil was obtained from local fish fryers at Unguwar Rogo Area, Sokoto, Sokoto State Nigeria. The waste vegetable oil was first filtered using Wattman filter paper to remove the insoluble impurities, followed by heating at 100 °C for 10 min to remove all the moisture. The oil was later stored in a 1-gallon tank (2.5L).

2.2. Catalyst preparation

20 cm³ of each of aqueous solutions of the nitrate salts of Ni (0.6 M), Mg (0.06 M), and Na₂CO₃ (10 wt%) were pumped into a beaker under constant stirring (600
RPM) at 50 °C. Simultaneously, silica was added. The precipitate was then filtered using Whatman filter paper (11 μm) and washed with warm (80 °C) distilled water (Fetchin, 2017; Lok, 2017; Shakeel and Mazen, 2017). The green filtered cake was dried in an oven at a temperature of 120 °C for 3 h. At the end of the procedure, 10.5 g of the catalyst were prepared.

2.3. Thermal pyrolysis of waste cooking oil

The thermal pyrolysis of the oil was carried out by transferring sample (100 cm³) of the oil sample into a batch reactor. The reactor was purged with N₂ gas for 2 min in order to have an inert environment. The reactor was then heated using a furnace to 300 °C and maintained for 3 h. The reactor was then quenched in cold water. The liquid product formed was taken out and analyzed using GC-MS. The same procedure was repeated at temperatures of 350 °C and 400 °C, respectively.

2.4. Thermo-catalytic pyrolysis of waste cooking oil

100 cm³ of the oil sample were measured and transferred into a batch reactor and 0.25 g of the catalyst was added using a catalyst holder (i.d: 3 cm; length: 40 cm). The reactor was purged with N₂ gas for 2 min, sealed and heated to 300 °C for 3 h. The reactor was then quenched in cold water and the product obtained was centrifuged, decanted, and analyzed using GC-MS. The same procedure was repeated at temperatures of 350 °C and 400 °C, respectively.

2.5. Hydro-pyrolysis of waste cooking oil

Hydro-pyrolysis of the oil sample was carried out by transferring 100 cm³ of the sample into the batch reactor. The reactor was later sealed and N₂ gas was used to purge the reactor for 2 min in order to have an inert atmosphere. H₂ was introduced into the reactor until the pressure reached 15 bars. The system was sealed and then heated at 51 °C/min to 300 °C at which it was held for 3 h. Thereafter, the reactor was quenched in cold water. The liquid product obtained was analyzed using GC-MS. The same procedure was also repeated at temperatures of 350 °C and 400 °C, respectively.

2.6. Catalytic-hydro pyrolysis of waste cooking oil

The catalytic hydro pyrolysis of the oil sample was conducted by transferring 100 cm³ of the sample into the batch reactor and then 0.25 g of the catalyst was added into the reactor through catalyst holder (i.d: 3 cm; length: 40 cm). The reactor was purged with N₂ gas for 2 min and then sealed. H₂ was introduced into the reactor until the pressure reached 15 bars. The system was sealed and then heated at 51 °C/min to 300 °C for 3 h. The reactor was later quenched in cold water and allowed to
cool. The product obtained was centrifuged, decanted, and analyzed using GC-MS. The same procedure was repeated at 350 °C and 400 °C, respectively.

2.7. GC-MS analysis of waste cooking oil

Gas chromatographic analyses were performed at National Research Institute for Chemical Technology (NARICT) Zaria using a Shimadzu GCMS-QP 2010 that was equipped with a capillary column Petrocol™DH 24160-U, (100 m length, 0.25 mm diameter, 0.5 μm stationary phase) using a 1:0 split ratio operating at 80 °C for 1 min at the heating rate of 10 °C/min until 200 °C was reached and kept at this temperature for 4 min, then heated at 10 °C/min until 280 °C and kept at this temperature for 5 min. A quadrupole mass (MS) detector was used with a 70 eV electron impact ions generator, operating in the range 40–450 m/z. Total ion chromatography (TIC) was obtained with a signal/noise ratio of five, and composition was reported as percent peak areas without any response factor correction. Compounds were identified using the NIST mass spectral library (Jinang et al., 2013).

3. Results and discussion

3.1. Results

In this study, the characteristics of the waste cooking oil were analyzed and the correlation between biodiesel yield and reaction temperature (300 °C, 350 °C, and 400 °C) were analyzed using alkaline transesterification. Table 1 shows the results for preliminary characteristics of the waste cooking oil used in the research. Results revealed that the oil has high acid value, which is a characteristic of waste vegetable oil from frying.

Table 1. Physicochemical Properties of Waste Cooking Oil.

| Parameter                      | Values     |
|--------------------------------|------------|
| Saponification value (mgKOH/g) | 190 ± 1.05 |
| Acid value (mgKOH/g)           | 30.43 ± 0.32 |
| Iodine value (mgI/100 g)       | 57.08 ± 0.43 |
| Density (g/cm³)                | 0.91 ± 0.08 |
| Viscosity (at 40 °C) (mm²/s)   | 3.35 ± 0.20 |

Values are mean ± SD of triplicate measurements.
3.1.1. Physicochemical properties of waste cooking oil

Iodine value was used as an indicator of the level of saturation of oil. It is the amount of iodine required to iodize all the double bonds in the oil. Saturated fats/oil produces fuel with superior oxidative stability and high cetane number (Garpen et al., 2004). The iodine value (57.08 ± 0.43 mgI/100 g) of waste cooking oil is relatively lower than the value (71.14) reported by Sokoto et al. (2011a). This might be due to higher oxidation reaction leading to the splitting of double bonds (Huseyn et al., 2011). This value (57.08 ± 0.43) is an indication that the fuel to be produced will be better fuel in terms of oxidative stability, and cetane number.

Saponification value is a parameter that entails the saponifiable fatty acid content of the oil. Saponification value obtained (190 ± 1.05 mgKOH/g) is an indication that the oil contains a high amount of saponifiable fatty acids as compared to 183.66 mgKOH/g reported by Sokoto et al. (2011a) and slightly lower than 194 mgKOH/g (Zahoor et al., 2014). This shows that the oil is of good quality in terms of fuel production because it contains a very appreciable amount of ester.

Acid value is a direct measure of the free fatty acids in the oil/fuel. The free fatty acids can lead to corrosion and may be a symptom of water in the fuel (Garpen et al., 2004). High acid value was observed in the waste cooking oil (30.43 ± 0.32 mgKOH/g) as compared to 4.03 mgKOH/g reported by Zahoor et al. (2014). This might be because of the time taken in contact with water during the hydrolysis process.

Kinematic viscosity is the resistance to flow of a fluid under gravity. High viscosity value of oil is the major hindrance preventing the direct use of vegetable oil and animal fats in diesel engines (Yunus et al., 2011; Surachai, 2015). According to Garpen et al. (2004), the high viscosity of oil hinders the performance of the engine. The waste cooking oil has an appreciable viscosity of 2.35 mm²/s as it is within the standard range (1.9–4.1 mm²/s) ASTM D-975. This might be due to numerous degradation reactions it has undergone during frying. Since viscosity depends on the structural composition of the oil/fuel. Viscosity increases with the number of CH₂ moieties in the fatty ester chain (Sokoto et al., 2011a).

Density is a measure of how much energy is in a given volume of fuel. The density of the waste cooking oil is 0.91, which conformed the value of 0.9013 reported by Zahoor et al. (2014). This means that the waste cooking oil contains an appreciable amount of energy which can be converted to fuel.

3.1.2. Thermal pyrolysis of waste cooking oil

Thermal decomposition of waste cooking oil at high temperature may result in the formation of hydrocarbons or oxygenates (Donnis et al., 2009; Yanyong et al., 2012). Results presented in Table 2 revealed that the highest hydrocarbon yield...
was observed at 400 °C, which indicates that at high temperatures, decomposition of oil to hydrocarbon is favored. This is an indication that temperature plays a vital role in the production of hydrocarbon from waste cooking oil because of the lower temperature, zero yield of hydrocarbon was recorded. However, temperature of 300 °C favors C_{20+} and oxygenates formation in preference to gasoline-distillate (0%). Thus, according to the results obtained, thermal decomposition of waste cooking oil for hydrocarbon production could best be achieved at 400 °C compared to the range of values considered in this research (300 °C and 350 °C.)

3.1.3. Thermo-catalytic pyrolysis of waste cooking oil

The catalyst is a substance that speeds up the rate of reaction. Catalyst is one of the factors that influence the product yield during hydrotreatment processes. Thermo-catalytic decomposition was carried out in order to ascertain the suitability or otherwise of the synthesized catalyst on thermal decomposition of waste cooking oil to hydrocarbon. Results presented in Table 3 indicate that high hydrocarbon yield (33.63%) was observed at 400 °C. The yield (33.63%) was higher than (13.05%) obtained from thermal decomposition at the same temperature (400 °C) in the absence of a catalyst. This is an indication that the synthesized catalyst (NiO/SiO_2) is effective.

Table 2. Hydrocarbon Production From Thermal Pyrolysis of Waste Cooking Oil (% Yield).

| Temp (°C) | YIELD (%) | Total HC (%) | Total oxygenate (%) |
|-----------|-----------|--------------|---------------------|
|           | C_5-C_{10} | C_{11}-C_{20} | C_{20+}           |
| 300       | –         | 91.75        | 8.25               | 100                   |
| 350       | 2.81      | 93.99        | 3.20               | 7.78                  | 92.22                 |
| 400       | 2.05      | 93.33        | 4.62               | 12.47                 | 87.53                 |

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However, temperature of 300 °C favors C_{20+} and oxygenates formation in preference to gasoline-distillate (0%). Thus, according to the results obtained, thermal decomposition of waste cooking oil for hydrocarbon production could best be achieved at 400 °C compared to the range of values considered in this research (300 °C and 350 °C.)

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Table 3. Relative Percentage yield of Hydrocarbon from Thermal Decomposition of Waste Cooking Oil using NiO/SiO_2 catalyst.

| Temp (°C) | YIELD (%) | Total HC (%) | Total oxygenate (%) |
|-----------|-----------|--------------|---------------------|
|           | C_5-C_{10} | C_{11}-C_{20} | C_{20+}           |
| 300       | –         | 81.12        | 18.88              | 0.67                  | 99.33                 |
| 350       | 4.43      | 88.16        | 11.84              | 1.11                  | 98.89                 |
| 400       | 2.20      | 86.83        | 10.97              | 33.63                 | 66.37                 |
SiO₂) has an appreciable activity towards thermal decomposition of waste cooking oil to hydrocarbons. Similarly, there was also an increase in the hydrocarbon yield at 300 °C (0.67%) which contrasted with (0%) yield when catalyst was not used. However, a drastic decrease in the hydrocarbon yield was observed at 350 °C (from 7.78% to 1.11%). Still, the effect of temperature follows the same trend because the low yield (0.67%) was recorded at 300 °C. The highest yield of C₂₀+ (18.88%) was recorded at this temperature (300 °C). Results presented in Table 3 shows a significant increase in the C₂₀+ yield. Hence, it can deduce that the activity of the synthesized catalyst (NiO/SiO₂) is more favorable at 400 °C.

3.1.4. Hydrotreatment of waste cooking oil

Due to the presence of unsaturated C≡C bonds and C≡O bonds in the triglycerides and free fatty acids of the waste cooking oil, H₂ pressure is one of the important reaction conditions for hydrotreatment processes (Sotelo-Boyas et al., 2017). From Table 4, it shows that it is rather economical to produce hydrocarbons from both thermal and thermo-catalytic decomposition of waste cooking oil than from hydrotreatment processes. However, it favors the percentage yield of C₁₁-C₂₀. Similarly, the trends of hydrocarbon yield conforms to thermal and thermo-catalytic decomposition in which the highest yield (5.82%) was observed at 400 °C, with 300 °C having the least (4.08%). Thus, it can be deduced that production of hydrocarbons from waste cooking oil cannot be economically achieved using hydrotreatment.

3.1.5. Hydro-catalytic treatment of waste cooking oil

Results presented in Table 5 revealed that the highest percentage hydrocarbon yield (41.98%) was achieved at 400 °C. This result is almost similar to the result obtained by Bambang et al. (2014) (42.76% hydrocarbon and 57.23% oxygenates) when Pd/zeolite catalyst was used at the same temperature (400 °C). More so, the presence of gasoline-distillate (2–8.2 wt%) in the sample is also desirable in order to improve the fluidity of the fuel (Yanyong et al., 2012; Zhang et al., 2015).

| Temp (°C) | YIELD (%) | Total HC (%) | Total oxygenate (%) |
|----------|-----------|--------------|---------------------|
|          | C₅-C₁₀    | C₁₁-C₂₀     | C₂₀+               |
| 300      | –         | 92.15        | 7.85               | 4.08                | 95.92                 |
| 350      | –         | 91.74        | 8.26               | 5.33                | 94.67                 |
| 400      | 3.85      | 96.15        | –                  | 5.82                | 94.18                 |

Table 4. Hydrocarbon Production From Hydro treatment of Waste Cooking Oil (% Yield).
these results (Table 5) the effect of H₂ pressure has manifested with an increase of about 8% (i.e. From 33.63–41.98%) compared to the result obtained (33.63%) when catalyst was used alone, as deoxygenation of fatty acids is favored by the presence of hydrogen. Likewise, it can be seen from Tables 3 and 5, that a gasoline-distillate was formed in all the runs conducted at 400 °C. This could be due to cracking of C₁₅H₃₂-C₁₈H₃₈ normal paraffins (Yanyong et al., 2012).

### 3.1.6. Fuel properties of the produced renewable diesel

High heating value is the amount of heat released by a specified quantity of fuel when combusted and it is used to estimate the fuel consumption. The high heat of combustion indicates lower fuel consumption (Sokoto et al., 2011a).

A minimum of 35 MJ/kg heating value is set for biodiesel by European Standard EN 14213 and 37 MJ/kg for hydro treated oil (Elwin, 2016) respectively. From Table 6, all the values obtained from the analyses (41.45–43.97 MJ/kg) are greater than 40.84 MJ/kg as reported by Sokoto et al. (2011a) for biodiesel and 37 MJ/kg for hydro treated oil (Elwin, 2016). This might be due to the presence of saturation in renewable diesel as in contrast to biodiesel, which has one or more degree of unsaturation. Hence, the renewable diesels produced can give a better fuel with favorable high heating value.

Cetane number is determined in order to assess the quality of combustion, emission, and the ability of the fuel to combust when subjected to lower temperature. Moreover, the higher the cetane number, the better the ignition property as it helps to ensure good cold start properties and minimize the formation of white smoke (Sokoto et al., 2011b). from Table 6, the cetane number of 44.58 was observed when raw oil was heated at 400 °C which is in conformity to the value obtained (44.69) when Pd/zeolite was used as a catalyst at a temperature of

| Temp (°C) | YIELD (%) | Total HC (%) | Total oxygenate (%) |
|-----------|-----------|--------------|---------------------|
|           | C₅-C₁₀   | C₁₁-C₂₀     | C₂₀+                |
| 300       | –         | 79.26        | 20.74               | 11.44                | 88.56                |
| 350       | –         | 70.40        | 29.6                | 0.58                 | 99.42                |
| 400       | 2.23      | 96.37        | 1.40                | 41.98                | 58.02                |

As shown in Table 5, it can be seen that the operating condition at 400 °C using NiO/SiO₂ and a H₂ pressure of 15 bars were the appropriate conditions to produce renewable diesel with the largest hydrocarbon content.
Table 6. Fuel Properties of the Produced Renewable Diesel.

| Product       | HHVMJ/Kg | CETANE NO | VISCOSITY mm²/s | DENSITY g/cm³ | IODINE VALUE mg/I/100g | SAP. VALUE mg/KOH |
|---------------|----------|-----------|-----------------|---------------|------------------------|-------------------|
| RD/300 °C     | 42.94    | 76.83     | 2.80            | 0.92          | 28.43 ± 0.49           | 144.8 ± 0.34      |
| RD/350 °C     | 43.93    | 81.74     | 2.66            | 0.94          | 56.03 ± 0.49           | 113.6 ± 0.66      |
| RD/400 °C     | 43.16    | 44.58     | 2.64            | 0.91          | 9.30 ± 0.59            | 149.6 ± 33.9      |
| RD/C/300 °C   | 43.08    | 76.98     | 2.28            | 0.93          | 33.80 ± 0.29           | 142.6 ± 0.45      |
| RD/C/350 °C   | 42.98    | 78.52     | 2.20            | 0.97          | 27.47 ± 0.24           | 151.0 ± 1.11      |
| RD/C/400 °C   | 42.43    | 76.23     | 2.15            | 0.94          | 23.13 ± 0.24           | 166.0 ± 0.87      |
| RD/H₂/300 °C  | 42.53    | 74.06     | 2.65            | 0.93          | 31.11 ± 0.34           | 157.0 ± 1.01      |
| RD/H₂/350 °C  | 42.39    | 72.96     | 2.47            | 0.92          | 33.70 ± 0.39           | 159.4 ± 1.11      |
| RD/H₂/400 °C  | 41.45    | 69.04     | 2.24            | 0.99          | 31.33 ± 7.39           | 183.2 ± 0.87      |
| RD/C/H₂/300 °C| 42.16    | 72.4      | 2.61            | 0.92          | 29.77 ± 0.33           | 166.4 ± 1.11      |
| RD/C/H₂/350 °C| 41.96    | 72.81     | 2.20            | 1.05          | 25.53 ± 0.24           | 169.2 ± 0.47      |
| RD/C/H₂/400 °C| 41.43    | 71.16     | 2.01            | 0.94          | 20.57 ± 0.20           | 185.1 ± 3.96      |

RD = Renewable diesel, C = Catalyst, H₂ = Hydrogen.
375 °C (Bambang et al., 2014) and slightly above the minimum range (40) set by ASTM-D975.

Similarly, from Table 6, it shows that renewable diesel obtained at C/H₂/400 °C has an appreciable certain number of 71.16 which is higher than the values 60.01 and 53 as reported by Sokoto et al. (2011a) and Farooq et al. (2013) respectively. In general, all the products produced have a favorable cetane number as they all fall above the minimum limit set by ASTM-D975.

Iodine value is used as an indicator of the level of saturation present in a particular fuel (Freedom Biofuelers, 2012). It is the amount of iodine required to iodize all the double bonds in the fuel expressed in grams of iodine per 100 g. From these analyses, it is observed that the iodine value decreases with increase in temperature when other conditions (H₂ and catalyst) are kept constant. From Table 6, Iodine value of RD (C/H₂/400 °C) (20.57 ± 0.20) is by far less than the value (52.17) reported by Huseyn et al. (2011). This might be due to cracking and hydrogenation of unsaturated double bonds. The European standard limit of biodiesel iodine value is set to be 120 gI₂/100 g (UNE-EN 14214, 2003). From these analyses, it can be seen that the iodine values of renewable diesels produced (20.57–56.03) are appreciably within the standard limit.

High viscosity value is the major hindrance preventing the use of vegetable oil and animal fats directly in diesel engines (Yunus et al., 2011; Surachai, 2015). From these results (Table 6), lower viscosity (2.01 mm²/s) is observed in renewable diesel (C/H₂/300 °C) and the higher value was recorded by renewable diesel (H₂/400 °C). The viscosity of renewable diesel (C/H₂/400 °C) is (2.61 mm²/s) which is in congruence to the 2.46 mm²/s when pd/zeolite was used at 400 °C as reported by Bambang et al. (2014). The value (2.61 mm²/s) is also lower than 8.01 mm²/s when Ru/SiO₂ was used as catalyst at 350 °C and 3.69 mm²/s for normal diesel (Yanyong et al., 2012). However, all the values recorded (2.04–2.65 mm²/s) were within the stipulated range ASTM D-975 (1.9–4.1 mm²/s).

From the results obtained in Table 6, it was observed that RD (C/H₂/350 °C) has a higher density (1.05 g/cm³) than all the other renewable diesels produced. However, the density of all the other renewable diesels produced (0.90 g/cm³–1.05 g/cm³) were greater than the value (0.865 g/cm³) reported by Bambang et al. (2014) when pd/zeolite was used as a catalyst at 400 °C, and 0.75 g/cm³ when Ru/SiO₂ catalyst was used at 300 °C (Yanyong et al., 2012). This is an indication that the produced renewable diesels contain more energy and less energy is required to transport each unit of energy. The good density of the renewable diesels might be because it does not contain aromatic or asphalting compounds that cause poor combustion performance (Almustapha et al., 2009).
4. Conclusion

Hydrotreatment of waste cooking oil to produce hydrocarbon-based diesel fuel will be a promising future technology in solving the menace of waste cooking oil disposal into the environment. It also provides an alternative route in producing a renewable diesel that is more environmentally friendly due to its stability and feedstock flexibility over ester-based biodiesel and compatibility with the petroleum distribution system and diesel engine.

Declarations

Author contribution statement

Jamilu Sani: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

A. M. Sokoto: Conceived and designed the experiments; Analyzed and interpreted the data.

A. D. Tambuwal, N. A. Garba: Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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