Research Article

An Overview of Energy Recovery from Local Slaughterhouse-Based Gallus gallus domesticus Greasy Residues and Latest Applications

Zacharie Merlin Ayissi,1,2 Alain Fokoua Fongain,1,2 Leonel Tsafack Dongmo,1 Hossain Nazia,3 Rhiad Alloune,4 Innocent Ndoh Mbue,1,2 and Ruben Mouangue1,2

1National Higher Polytechnique School ENSPD, University of Douala, Douala, Cameroon
2Laboratory of Energy Materials Modeling and Method E3M, Douala, Cameroon
3School of Engineering, RMIT University, Melbourne VIC 3000, Australia
4Renewable Energy Developpement Center, Bioenergy and Environment Division, Bouzareah, Algeria

Correspondence should be addressed to Zacharie Merlin Ayissi; merlin.ayissi@gmail.com

Received 22 June 2022; Revised 13 September 2022; Accepted 2 October 2022; Published 25 October 2022

Copyright © 2022 Zacharie Merlin Ayissi et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Gallus domesticus is one of the world’s most consumed animals, with a significant presence in all parts of the planet. Chicken oil appears to be a credible raw material in the context of alternative energy research. This study focuses on a literature review to highlight the chicken’s energy potential and the application of energy recovery from local slaughterhouse-based Gallus gallus domesticus greasy residues and it is proposed to make biodiesel from the fatty residues of Gallus gallus domesticus. The transesterification reaction takes place at 60°C. Methanol is used in a 1 : 6 oil-to-alcohol mass ratio. Catalysis is carried out with 1% (m/m) potassium hydroxide (KOH). The accepted reaction time under light agitation is 120 minutes. The reaction yield is estimated to be 85.6%, and the biodiesel produced is characterized. The postcharacterization values are consistent with the EN14214 biodiesel standard. Gas chromatography coupled with mass spectrometry reveals the intrinsic composition of the acids derived from the developed biodiesel methyl esters. The latter reveals a predominance of oleic acids with a value of 29.47% and palmitic acids with a value of 29.21%. The viscosity of greasy residues appeared to be relatively high at 69.32 mm/s. The low calorific value is 38775.363 KJ/Kg and the cetane index is 50. It has been observed that, for 1000 g of fat waste, it is possible to extract by cooking 507.807 g of oil, or an extraction yield of 51%. Fatty chicken residues from tropical market areas can be used as a raw material for biofuel development.

1. Introduction

For more than a century, the global economy has relied on fossil fuels as energy sources, such as oil, natural gas, and coal. Furthermore, the transportation sector is expanding at an exponential rate, which will inevitably increase energy demand [1, 2]. Indeed, according to the most optimistic scenarios, peak oil will occur between the late 2020 and the late 2030[3]. According to the most pessimistic scenarios, we have already passed this peak and production is gradually declining [1, 2]. Petroleum products (petrol, diesel, and kerosene) currently meet 93 percent of the world’s transportation energy needs, but they face numerous criticisms. Oil is distributed unevenly across the globe and its sporadic oil shortage is resulting in conflicts over ownership of existing deposits [4]. In addition, the combustion of petroleum leaves out many polluting particles, including greenhouse gases, the main one being CO₂. It is for this reason that petroleum and its byproducts are accused of causing global warming.

Researchers interested in achieving sustainable societies are concerned about the transition to a noncarbon society. The need to reduce greenhouse gas emissions (GHGs) and avoid worst-case climate change scenarios, as well as anticipate the depletion of fossil fuels, motivates decarbonization efforts such as considering alternatives to petroleum
products in the transportation sector. The following three
approaches are questionable realities when considering al-
ternatives to petroleum products in the transportation
sector: (i) reducing the need for travel, (ii) lowering the
energy consumption of modes of transportation, and (iii)
changing the nature of the energy source. The latter ap-
proach entails optimizing the electric motor or substituting
natural gas, hydrogen, or biofuels for petroleum products.
Of all these solutions, biofuel is the one that least changes
the habits of users and manufacturers [5]. Biofuels are fuels
whose raw materials come from biomass [6]. They are
ecofriendly compared to fossil fuels [7]. Bioethanol from
whose raw materials come from biomass [6]. Their
habits of users and manufacturers [5]. Biofuels are fuels
Ofallthesesolutions,biofuelistheonethatleastchangesthe
natural gas, hydrogen, or biofuels for petroleum products.
energy consumption of modes of transportation, and (iii)
ternatives to petroleum products in the transportation
sector: (i) reducing the need for travel, (ii) lowering the
impact on air, soil, and biodiversity [6, 7, 9, 11].

Several studies have shown that biofuel is a viable al-
ternative to fossil fuels [1, 10]. Biodiesel is biodegradable,
and its exhaust gases contain fewer pollutants than diesel
fuel [4, 10]. Biodiesel can be produced from animal or plant
waste [7]. It is primarily made (95%) from edible oils such as
rapeseed (84%) sunflower oil (13%), palm oil (1%), and
soybean oil (2%). In some countries, this predilection has
negative consequences for food self-sufficiency. Famine,
hunger wars, food shortages, and rising food prices are thus
observed. This disruption is caused by the use of human-
consumed products as an energy source.

The intensification of monoculture and land grabbing by
certain lobbies in less developing countries has a significant
impact on air, soil, and biodiversity [6, 7, 9, 11]. The cost of
agricultural inputs accounts for 59 to 91 percent of the cost
of production, which explains why biodiesel is not yet
economically competitive with diesel [12]. This disparity is
most likely due to the cost of the raw materials. Indeed, the
use of farms and fields to grow energy plants or specific
animals incurs maintenance costs. The cost of converting
raw materials into biofuel is also determined by the tech-
nology used.

When economies of scale are considered, the ratio be-
tween quantities produced and those demanded by the
market remains relatively low, with an impact on the final
cost of the product. Specific tax provisions, as well as the
recovery of byproducts and industrial waste, allow the sector
to become profitable. Furthermore, in response to the
challenges posed by the conflict between food security and
energy deficit on the one hand, and plant occupation of
arable land on the other, the use of inedible raw materials
with no direct economic benefits for humans has grown in
importance [12].

Nonedible oils include Jatropha curcas, castor, and used
frying oils. Animal fats have also been discovered in the
category of nonedible materials: chicken, pork, and beef.
These fat residues, which have a low cost and a high energy
potential, are becoming more popular [8, 9, 10].

Mali et al. [13] studied the transesterification of fat
sheep residues into biodiesel. The findings showed an
intriguing biodiesel performance. Awad et al. [3] inves-
tigated the biodiesel transesterification of frying oil resi-
dues. Transesterification processes can be used to
transform these residues. The transesterification of tri-
glycerides primarily produces biodiesel. This
straightforward method involves substituting fat glycerin
for short-carbonated alcohols like methanol and ethanol
[10], with a catalyst to speed up the reaction. Figure 1
deicts Emaad’s [14] equation describing the tran-
sesterification reaction. In general, methanol outperforms
ethanol in the transesterification process.

When combined with basic catalysts such as KOH or
NaOH, methanol is a reactive product that adapts well to the
transesterification reaction. Many studies, however, note the
toxic nature of the vapours of this alcohol, as well as its
relatively high cost and not always obvious availability [14].
However, when ethanol is used, the efficiency of tran-
sesterification reactions is lower than when methanol is used
under the same experimental conditions. The results ob-
tained, however, are generally very close to those obtained
with methanol. As a result, given its availability and rela-
tively nontoxic nature, ethanol appears to be a low-cost
adjuvant. Depending on the alcohol used, two types of
biodiesels are commonly obtained. Ethyl ester when the
alcohol used is ethanol and methyl ester if it is methanol.
Generally, ethanol, methanol or diluted ethano-methanol
solution are commonly used. Although some authors sell the
merits of NaOH from the point of view of availability, KOH
is the most widely used catalyst in the literature. The method
of transesterification has evolved greatly thanks to scientific
investigations initiated by authors. Combinations are used,
as well as the introduction of new types of catalysers.

Zhang et al. [15] investigated the effect of in situ ul-
trasound on biodiesel production. The oleaginous yeast,
Trichosporon oleaginosus, was grown in waste water sludge
in order to produce lipids. The obtained biomass was used to
investigate the effects of ultrasonic treatment on trans-
esterification and lipid extraction. Water, hexane, and
methanol were among the solvents investigated. The ca-
capacity of various solvents in lipid extraction with ultrasonic
treatment was investigated. Within 20 minutes, the author
obtained maximum lipid evaluated to 11.8, 35.3, 62.0, and
95.3 percent (w/w) with water, hexane, methanol, and a
mixture of chloroform and methanol (1:1 v/v). Chloroform
and methanol performed relatively well. Transesterification:
biodiesel yield of 95% (w/w) was obtained in 60 min with
ultrasonication assistance, whereas 24 h was required to
achieve a similar experience without the assistance of
ultrasonication.

In a study conducted by Mohadese, lipase from Rhizos-
mucor miehei (RML) and lipase B from Candida Antarctica
(CALB) were covalently immobilized into epoxy-function-
alized silica in a study conducted by Mohadese et al. [16]. A
multienzyme system was developed in this study to produce
biodiesel from waste cooking oil and methanol. To increase
biodiesel production yield, the author used a mixture of 1,3-
specific lipase (RML) and nonspecific lipase (CALB). The
response surface methodology (RSM) and a central com-
posite rotatable design (CCRD) were used to investigate the
effects of four factors on fatty acid methyl ester (FAME)
yield: CALB : RML ratio, t-butanol to oil (wt. percent), water
adsorbent content (wt. percent), and reaction time. FAME
yield of 91.5%, relatively close to the predicted value of
95.6%, was obtained.
Singh et al. [17] used coprecipitation to create a heterogeneous catalyst, magnesium zirconate (Mg$_2$Zr$_5$O$_{12}$). Transesterification was used to produce biodiesel from the obtained product. As a feedstock, kusum oil was used. TGA, XRD, ATR FTIR, SEM, and EDX were used to characterize the catalyst. The parameters of the catalyst were determined, including particle size, zeta potential, BET surface area, and basicity. The catalyst catalyzed the transesterification reaction, allowing for economically viable biodiesel production. Response surface methodology (RSM) based on Box–Behnken design was used to optimize various reaction parameters such as molar ratio (methanol: oil), catalyst concentration, and reaction time in the presence of Mg$_2$Zr$_5$O$_{12}$. The catalyst was reusable for up to seven runs, with a 75% conversion rate in the seventh. The author obtained a maximum conversion of 97.98% FAME at 18:1M ratio (methanol: oil), 2.5 wt% of catalyst at 65°C temperature for 150 min.

Bayat et al. [18] carried out an experiment. An optimized method for preparing Fe$_3$O$_4$Al$_2$O$_3$ as an efficient nano-catalyst for waste cooking oil transesterification to biodiesels was presented in this study. The catalyst with an Al$_2$O$_3$/Fe$_3$O$_4$ mass ratio of 0.5 produced the highest oil conversion. XRD, SEM, TEM, DLS, FTIR, TPD, and VSM analysis were used to characterize it. The XRD pattern appears to agree with the standard cubic Fe$_3$O$_4$ XRD pattern. Temperature programmed desorption (TPD) of NH$_3$ revealed a broad peak in the 400–450°C temperature range. An analysis of variance (ANOVA) revealed that the effects of time and temperature were far more significant than the M/O ratio. On August 1, 2010, this entry was published. The interaction between temperature and time was more important than the other experimental interactions. The recovery of the catalyst was successfully performed at 400°C, and the performance of the catalyst was acceptable after four cycles of recovery. These different methods are of proven effectiveness but require specific and specialized instrumentation. The exploitation of animal fats and fatty residues is widely reported in the literature. The use of chicken fats in the biofuel manufacturing process has been experimented with by the authors. Table 1 provides a summary of the work on obtaining biodiesel by transesterification of chicken fats.

The use of biodiesel as a fuel for compression ignition engines has generated a lot of interest. Metin et al. [21] looked into using chicken fat biodiesel in a diesel engine. The performance of a typical B10 blend fuel was compared to that of traditional diesel. The tests were carried out at speeds ranging from 1800 to 3000 revolutions per minute. The use of B10 fuel increases engine torque by 10% while increasing specific consumption by 5.2 percent over B0. The authors attribute the rise in specific consumption to the cut’s low calorific value. There was also an increase in cylinder pressure peak and an advance in ignition time. CO emissions and sooty needed decrease by 13% and 9%, respectively, in terms of the environment. Observation causes a 5% increase in NO.

Sierra-Vargas et al. [22] investigated the effect of chicken oil use on the performance of a generator powered by a 13.45-kWe diesel engine. Under laboratory conditions, biodiesel was developed and introduced into the thermal engine. Total electrical efficiency, heat release, fuel consumption, and the polluting content of exhaust gases are all factors to consider. The author discovered that the genset’s yield increased to 38.79 percent, which is 22.5 higher than the 35.08 percent obtained for fossil diesel. This performance is justified by the addition of a sustainable biofuel, such as biodiesel based on chicken fat. Under the same conditions, the released CO$_2$ level decreases by approximately 2.9 kg-CO$_2$·h$^{-1}$.

These studies show that chicken fat is a potential fuel with energy and environmental benefits. There is a definite interest in the value of chicken fats. Chicken is edible. It is an animal of the subspecies Gallus gallus domesticus, generally bred for its flesh, making it a comestible animal [23, 24]. The production conditions of broilers differ from those of laying hens that are raised for their eggs. Chicken farming is done with large numbers of animals in closed buildings for an average of 35 days, which gives it an intensive character (approximately one to three million chickens). However, next to this modern breeding is grafted small-scale breeders whose herds are between 100 and 1000 chickens.

Some other types of food by their composition make it possible to obtain fatter chickens with faster growth. As a percentage of mass, chicken meat contains two to three times more polyunsaturated fats than most red meats. Chickens are considered to be, of all the most numerous land animals, being bred. The fat in the chicken is located in the abdomen and skin. This lipid reserve is a potential raw material for the biofuels sector and an energy source for thermal engines. Unlike formal slaughterhouses in safe and organized environments, informal slaughterhouses end up in marginal locations. These identifiable places in African markets in general are reserved for the skinning of chickens purchased by private individuals to facilitate culinary operations. About

![Figure 1: Transesterification reaction of chicken fatty acids by [14].](image-url)
100 chickens can be gutted in these places, and the residues stored in barrels without special care. This abundant raw material is likely to be converted into biodiesel [25, 26].

Chicken-based biodiesel has been mentioned in the literature. The raw material is generally derived from informal settings. The raw material in these environments is well preserved following the requirements of the sector [27, 28]. Fats and oils from these environments have proven their effectiveness as the raw material for biodiesel. In informal slaughterhouses, storage and handling conditions do not meet prescriptive requirements. It is essential to characterize these residues to develop the required technical data for the energy recovery of this abundant raw material and the less expensive production of biodiesel [29, 30]. The purpose of this study is to recover slaughterhouse fatty residues by formulating a chicken oil methyl ester using the transesterification method.

The transformation of fatty residues of *Galus galus domesticus* from informal slaughterhouses into biodiesel is carried out in this study. The characterization to highlight the physical properties of fatty residues is carried out to produce low-cost biodiesel and because of the availability of the primary material and the relative operational simplicity of the transesterification method.

### 2. Materials and Methods

An average of 150 chickens, with a mass varying from 1.5 kg to 3 kg, are slaughtered per day. A mass of 10.5 g of fat, on average, was extracted from a 100 g chicken. The average fat recovered in similar studies presented in the literature is estimated between 11 and 14 g by specialized means of extraction.

Male and female chickens of 60 days on average are bought by housewives. A group of volunteers is responsible for disemboweling the poultry, extracting the viscera, and storing them in plastic drums. The collection of greasy residues is done at the end of the day. The oil is extracted immediately after the recovery of the fat residues. It is cooled and stored in sanitized and hermetically sealed glass boxes.

#### 2.1. Materials

Methanol was used as alcohol and KOH as a catalyst in the transesterification reaction. The Marie bath was used to ensure the transesterification reaction at a temperature of 60°C. A gas-phase chromatograph coupled with thermo-scientific trace 1300 GC mass spectrometry was used to determine the methyl ester composition of fatty acids from the developed biodiesel.

#### 2.2. Oil Extraction

In this study, fat chicken residues were collected from PK14 market slaughterhouses in Douala, Cameroon. The humid climate, the high heat (approximately 27°C in the shade), and flies’ permanent presence are potentially detrimental to preserving fats. The first step in extracting chicken oil was to clean up greasy residues with drinking water to remove solid particles, blood, and protein residues. The grease was then placed in a steel container for cooking at a temperature of 90°C to extract the oil and avoid degrading the raw material. Once the first traces of oil were observed, freshwater was added to ensure the complete extraction of the oil. The oil was extracted by evaporation of the

### Table 1: Summary work on obtaining biodiesel by transesterification of chicken fats.

<table>
<thead>
<tr>
<th>Operating conditions</th>
<th>Experimental results</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol and lipids in a molar ratio of 6:1 and a methanol-ethanol-lipids mixture in a molar ratio of 3:3:1 reacted with 1% KOH catalyst ethanol-lipids molar ratio of 6:1; 1% sodium ethoxide.</td>
<td>Amounts of biodiesel were 771.54 mg/mL ± 15.28, 722.98 mg/mL ± 37.38 and 714.86 mg/mL ± 29.99 from methanol, ethanol, and a mixture of methanol/ethanol (3:3)</td>
<td>[10]</td>
</tr>
<tr>
<td>140°C, 4 h of reaction time and a molar ratio of transesterification reactions of chicken fat/methanol 1:31. Enzymatic transesterification reactions of residual chicken fat with ethanol without cosolvents. Ten lipases tested.</td>
<td>The yield was of 98% under of 140°C, 4 h of reaction time, and a molar ratio of chicken fat and methanol of 1:31. Viscosity: 6.3 mm²/s; density: 895.9 kg/m³. CALB provided a 96% yield of ethyl biodiesel with 20 mg of the enzyme. After 10 h, the yield: 90%. Temperatures up to 50°C tolerated by the enzyme, reused.</td>
<td>[19]</td>
</tr>
<tr>
<td>Chicken fats/oil or WCO, methanol or ethanol (50 ml), n-hexane (50 ml), and HCl (2 ml) taken in a flask fitted with a condenser and refluxed at water bath at 100°C for 24 hours separately. Synthetic Mg additive studied in a single-cylinder, direct injection (DI) diesel engine and its effects on engine performance. A two-step catalytic process was chosen for the synthesis of the biodiesel. Organic-based synthetic magnesium additive doped into the biodiesel blend by 12 ppmol Mg. Acid-base and base-catalyzed transesterification. Hydrochloric acid and potassium hydroxide with methanol used. Transesterification of fried chicken oil monitored by TLC technique. Blending with petrodiesel using three volume percentages (10, 30, and 50% v/v).</td>
<td>The significant yields of fats and oils obtained from waste chicken fats and WCO were 38% and 80%, respectively.</td>
<td>[20]</td>
</tr>
<tr>
<td>2.1. Materials.</td>
<td>The engine torque was not changed significantly with 10% chicken fat biodiesel. The specific fuel consumption increased by 5.2%. In-cylinder peak pressure slightly rose, and the start of combustion was earlier. CO and smoke emissions decreased by 13% and 9%, respectively, but NOx emissions increased by 5%. Two-step base-catalyzed transesterification was better. The average molecular weight of FCO 878, the acid value of CFO was 2.80 mg; KOH/g oil. Density and KV of FCO 0.9222 g/mL and 29.99 ± 0.15 mL/g. Density and KV of CFO 37.38 ± 0.15 and 714.86 ± 0.15 mL/g.</td>
<td>[21]</td>
</tr>
<tr>
<td>2.2. Oil Extraction. In this study, fat chicken residues were collected from PK14 market slaughterhouses in Douala, Cameroon. The humid climate, the high heat (approximately 27°C in the shade), and flies’ permanent presence are potentially detrimental to preserving fats. The first step in extracting chicken oil was to clean up greasy residues with drinking water to remove solid particles, blood, and protein residues. The grease was then placed in a steel container for cooking at a temperature of 90°C to extract the oil and avoid degrading the raw material. Once the first traces of oil were observed, freshwater was added to ensure the complete extraction of the oil. The oil was extracted by evaporation of the</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
water. It was later filtered. This method is laborious, and its performance depends on the quality of the instrumentation. Figure 2 presents the protocol for extracting chicken oil.

2.3. Characterization of Extracted Chicken Oil and Biodiesel. The purpose of the characterization is to determine the chemo-physical property of the methyl ester and the chicken oil from which it derives.

2.3.1. Acid Index. The acid index was evaluated experimentally and deduced by (1) according to Tsai’s method [10].

\[
I_a = \frac{5.611 \times V \times F}{m_{HP}}.
\]  

(1)

The constant 5.611 represents the product of the molar mass of the KOH and the concentration of the solution (0.1 N); \( V \) volume in ml of consumed KOH solution needed to transfer the mixture; \( F \) 0.1 MOL potency of KOH solution, which has a value of 1 because the KOH is a monobase; \( m_{HP} \): g mass of chicken oil used.

2.3.2. Iodine Index. The iodine index was also subsequently determined following the WIJS method. This index was deduced by the following equation:

\[
\text{Iodine} = \frac{M' \times 100}{M}.
\]

(2)

\( M' \) represents the formed diode mass; \( M \) represents the mass of the fat waste.

The biodiesel iodine index was empirically determined by the approved formula (4) proposed by Kalayasiri et al. in 1996 [31]:

\[
\text{Iiode} = \frac{\sum (254 \times D \times Ai)}{M_{wi}}.
\]

(3)

\( Ai \) represents the percentage of methyl fatty acid ester (I) found in biodiesel; \( M_{wi} \) represents the molar mass of methyl fatty acid ester (I) present in biodiesel; \( D \) denotes the number of double bonds contained in methyl fatty acid ester (I).

2.3.3. Lower Calorific Value (LCV). The low calorific value is determined by the high calorific value (HCV) and the hydrogen content of the oil or biodiesel. (4) calculates ICH after the experimental phase on a PARR-type calorimetric bomb.

\[
LCV = HCV - 50.45 \times (\% H),
\]

(4)

\( \% H = 26 \times 15 \times d. \)

\( \% H \) represents the hydrogen mass content of the oil or EMHPB developed; \( (d) \) represents the density of crude oil or EMHPB (g/cm\(^3\)).

2.3.4. Biodiesel Saponification Index. The biodiesel saponification index is determined by an empirical formulation based on the molar mass and the percentage of fatty acid esters present in biodiesel.

\[
Is = \frac{\sum (560 \times Ai)}{M_{wi}}.
\]

(5)

\( Ai \) represents the percentage of the fatty acid methyl ester present in biodiesel; \( M_{wi} \) represents the molar mass of the fatty acid methyl ester present in biodiesel.

2.3.5. Indice de Cétane. The cetane index was determined by the empirical equation:

\[
Ic = 46.3 + \frac{5458}{Is} - 0.225 \times \text{Iiode}.
\]

(6)

It represents the saponification index of elaborate biodiesel or chicken oil; \( \text{Iiode} \) means the diode index of biodiesel or chicken waste fat.

2.3.6. The Density of Oil or Biodiesel. The density of biodiesel or oil from fat waste is obtained from a densimeter.

2.4. Transesterification of Chicken Fat Waste. The transesterification reaction is achieved using the Tsai method [10]. Methyl fatty acid esters were synthesized from a methanol and oil substrate in a mass ratio of 6:1, with 1% (m/m) KOH as a catalyst. A mass of 80.041 g of chicken oil, for 13.32 g of methanol and 0.803 g of KOH, was measured. At first, the catalyst is dissolved in alcohol using a magnetic agitator. When the catalyst is wholly dissolved, one gets a mixture of alkoxide. The resulting alkoxide is poured into a conical vial with the chicken oil preheated to a light temperature. The mixture was placed in a double boiler and heated to a temperature of 60°C and for 120 minutes under light agitation. At the end of the reaction, the vial contents are poured into a decanting light bulb and left to rest for 1 hour. Glycerol, which is not miscible with esters, settles at the bottom of the bulb, retaining a large part of the catalyst. The upper phase containing methyl ester of organic chicken oil (EMHPB) with excess alcohol, glycerol, and catalyst is recovered and washed with water heated at 70°C to avoid emulsions that may lower yield. After washing and decanting, the resulting biodiesel was heated to a temperature of 100°C in a Marie bath for a few minutes to remove the remaining water particles and recover purified biodiesel. Figure 3 presents the protocol for the transesterification of chicken oil.

3. Results and Discussion

3.1. Characterization of Chicken Oil. The experimental results, the acid indices obtained from the literature as well as the properties of chicken fat-based biodiesels are presented in Table 2.

The chicken oil acid index studied is 0.44 mgKOH/g, which is relatively lower than that of 5.72 mgKOH/g and 26.89 mgKOH/g [5, 32]. However, this result is similar to that of Lin and Tsai [10]. This observation would reflect that the fatty residues of chicken from informal slaughtering houses do not suffer significant degradation concerning acidity during the stay in the storage places. The viscosity of chicken
oil determined at 25°C has a value of 94.32 mm²/s. The chicken oil extracted has a relatively high tendency to solidify. The observed pasty form of the oil after extraction could be a consequence of its high viscosity.

3.2. Characterization of Developed EMHPB (Biodiesel)

3.2.1. Characteristic Indices. Methyl oil esters of Gallus gallus domesticus EMHPB were subject to characterization to determine their physical-chemical properties. Table 3 shows the results obtained and compared to the values required by EN14214 and the physical and chemical properties of diesel (D100). The yield on the transesterification reaction is 85.6%. This resulted in a biodiesel mass valued at 63.522 g.

The acid index is 0.44 mgKOH/g, 12% below the upper limit value set (0.5 mgKOH/g) by the EN14214 standard. The acid index of the developed EMHPB is similar to that of the oil from which it derives. This similarity in the oil acid index with biodiesel developed was observed by Lin and Tsai [10]. The oxidation stability of biodiesel is related to its free fatty acid content, which is measured by the acid index. The experimental results of this study reveal a low acid value of the elaborate methyl ester. This predisposition is likely to facilitate the long-term operation of an engine powered by biofuel based on fatty chicken residues from informal slaughterhouses. The iodine index of the EMHPB was determined and estimated at 68.2 gI₂/100 g or 43% lower than the value set by the standard EN14214 (120 gI₂/100 g). The value found is similar to that found by Panneerselvam [33] and Lopes [32]. The density of the EMHPB obtained is 0.860 g/cm³. This value is 3.13% higher than that of diesel. This value found is close to Haq and Mohammad [7] and is within the range set by the EN14214 standard. The kinematic viscosity at 40°C, the kinematic viscosity of EMHPB is estimated at 4.96 mm²/s, 10.22% higher than that of diesel. This viscosity is consistent with the value required by EN14214. The EMHPB cetane index, determined by the saponification index and the EMHPB cetane index, is estimated at 60.483, or about 8% and 26% higher, respectively, than the lower and upper limits of the diesel cetane index. The values found in this study are similar to those of Haq and Mohammad [7].

Gas chromatographic analysis and mass spectrometry determined the methyl ester composition of fatty acids from the developed biodiesel. This analysis indicates that the chemical structure contains carbon, hydrogen, and oxygen, respectively. This presence of oxygen, combined with the absence of sulfur, and the aromatic compound, is potentially
Figure 3: Biodiesel production protocol from fatty chicken residues.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid index (mgKOH/g)</td>
<td>0.44</td>
<td>5.72</td>
<td>0.13</td>
<td>26.89</td>
<td>1.72</td>
<td>6.6</td>
</tr>
<tr>
<td>Saponification index (mgKOH/g)</td>
<td>255.816</td>
<td>—</td>
<td>148.62</td>
<td>—</td>
<td>—</td>
<td>203</td>
</tr>
<tr>
<td>Iodine index (gI₂/100 g)</td>
<td>77.4</td>
<td>—</td>
<td>6.18</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Cinematic viscosity at 25°C (mm²/s)</td>
<td>94.32</td>
<td>—</td>
<td>59.2</td>
<td>38.10</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Density (g.cm⁻³)</td>
<td>0.916</td>
<td>—</td>
<td>—</td>
<td>0.932</td>
<td>0.926</td>
<td>0.9074</td>
</tr>
<tr>
<td>Cetane index</td>
<td>50.22</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Lower calorific value (KJ/Kg)</td>
<td>36789.18</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
interesting. Indeed, this predisposition would offer the developed biodiesel the advantage from the point of view of reducing emissions of unburned hydrocarbons, particulate matter, and sulfur oxides when burning in a diesel engine. The absence of sulfur in biodiesel is essential for the life of the biofuel user engine. Figure 4 presents the spectra of methyl esters identified in the chicken fat waste biodiesel sample. Figure 4 presents the physical-chemical properties of chicken fat waste methyl ester.

The absciss axis represents the retention time of the compounds, and the axis of the order is that of the predominance of the compound present in the EMHPB. The blue coloration in the spectrum makes it possible to differentiate the surfaces of the spectra of the different

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid index (mgKOH/g)</td>
<td>0.44</td>
<td>5.72</td>
<td>0.13</td>
<td>26.89</td>
<td>1.72</td>
<td>6.6</td>
</tr>
<tr>
<td>Saponification index (mgKOH/g)</td>
<td>255.816</td>
<td>—</td>
<td>148.62</td>
<td>—</td>
<td>—</td>
<td>203</td>
</tr>
<tr>
<td>Iodine index (gl/100 g)</td>
<td>77.4</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>65.9</td>
</tr>
<tr>
<td>Cinematic viscosity at 25°C (mm²/s)</td>
<td>94.322</td>
<td>—</td>
<td>59.2</td>
<td>38.10</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Density (g.cm⁻³)</td>
<td>0.916</td>
<td>—</td>
<td>0.932</td>
<td>0.926</td>
<td>0.9074</td>
<td>—</td>
</tr>
<tr>
<td>Cetane index</td>
<td>50.22</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Low calorific value (kJ/Kg)</td>
<td>36789.18</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Table 3: Physical-chemical property of chicken fat waste compared to those obtained in the literature.

Table 4: Methyl fatty acid esters identified in biodiesel sample.

<table>
<thead>
<tr>
<th>Common names</th>
<th>Fatty acyl ester</th>
<th>Formula</th>
<th>Retention time (min)</th>
<th>Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmitoléic</td>
<td>C16:0 methyl</td>
<td>C₁₇H₃₂O₂</td>
<td>8.96</td>
<td>11.96</td>
</tr>
<tr>
<td>Palmitic</td>
<td>C16:0 methyl</td>
<td>C₁₇H₃₄O₂</td>
<td>9.20</td>
<td>29.21</td>
</tr>
<tr>
<td>Linoléic</td>
<td>C18:2 methyl</td>
<td>C₁₉H₃₄O₂</td>
<td>11.25</td>
<td>9.57</td>
</tr>
<tr>
<td>Oléic</td>
<td>C18:1 methyl</td>
<td>C₁₉H₃₆O₂</td>
<td>11.39</td>
<td>29.47</td>
</tr>
<tr>
<td>Stéaric</td>
<td>C18:0 methyl</td>
<td>C₁₉H₃₈O₂</td>
<td>11.62</td>
<td>13.46</td>
</tr>
<tr>
<td>Myristic</td>
<td>C14:0 methyl</td>
<td>C₁₅H₂₆O₂</td>
<td>7.20</td>
<td>2.62</td>
</tr>
<tr>
<td>Myristoléic</td>
<td>C14:1 methyl</td>
<td>C₁₅H₂₈O₂</td>
<td>7.12</td>
<td>0.58</td>
</tr>
<tr>
<td>Lauric</td>
<td>C12:0 methyl</td>
<td>C₁₃H₂₂O₂</td>
<td>5.76</td>
<td>1.48</td>
</tr>
<tr>
<td>cis-13-Octadécanoic</td>
<td>C18:1 methyl</td>
<td>C₁₈H₃₄O₂</td>
<td>14.01</td>
<td>1.63</td>
</tr>
</tbody>
</table>
The results of Table 4 indicate the dominant presence of oleic acid (C18:1), followed by palmitic acid (C16:0) in the developed biodiesel. His high content of oleic and palmitic acid is noted by Lin and Tsai [10], Haq and Mohammad [7], and Jorge and Merced [11].

The literature indicates that saturated esters are predisposed to higher calorific and cetane indexes than unsaturated esters [1, 2]. On the other hand, the double bonds intrinsic to unsaturated esters are more sensitive to chemical deterioration such as self-oxidation and polymerization [3, 34, 35]. Investigations by Mittelbach [36] reveal that soy oil-based biodiesel containing a high level of unsaturated fatty esters can lead to the formation of deposits in the engine and the deterioration of lubrication oil. However, the developed EMHPB has an ester content of unsaturated fatty acids of 53.21% and a saturated fatty acid content of 46.77%. His biodiesel could be exposed to chemical damage. Awad et al. [3] advise adding antioxidants to this type of biodiesel and bringing it to a temperature of 60°C before its possible introduction into the engine to avoid the formation of deposits in the engine. The comparative presentation between the methyl ester composition of fatty acid from the developed biodiesel and the results from the literature are contained in Table 5.

Usually, the fat will be with a higher FFA. The reason for the decline in FFA in this study can be attributed to the transformation of recovered fats into biofuel about four hours after the hens have been slaughtered. The use of appropriate tanks for fat recovery probably limited their contact with oxidizing agents that could increase the rate of FFA. Physical-chemical properties of chicken fat waste methyl ester are shown in Table 6.

### 4. Conclusion

The oil extracted has been characterized, revealing that it has physical and chemical properties of interest for energy application. A transesterification reaction to basal catalysis with methanol at specific proportions (alcohol/oil mass ratio of 6:1, 1% (m/m) KOH) was achieved. The transesterification reaction took place over 120 minutes. The conversion of the oil to biodiesel was assured with a yield of 85.6%. Biodiesel has been characterized and has properties following EN14214:

(i) The density of the EMHPB obtained is 0.860 g/cm$^{-3}$, 3% higher than that of diesel.

### Table 5: Comparison of methyl fatty acid esters in biodiesel developed with those obtained in the literature.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(%)</td>
<td>(%)</td>
<td>(%)</td>
<td>(%)</td>
<td>(%)</td>
<td>(%)</td>
</tr>
<tr>
<td>Caprylic methyl ester (C8:0)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Capric methyl ester</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Lauric methyl ester (C12:0)</td>
<td>1.48</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Tridecanoic methyl ester</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Myristic methyl ester (C14:0)</td>
<td>2.62</td>
<td>0.28</td>
<td>—</td>
<td>0.2286</td>
<td>6.1</td>
</tr>
<tr>
<td>Myristoleic methyl ester (C14:1)</td>
<td>0.58</td>
<td>—</td>
<td>—</td>
<td>0.0827</td>
<td>—</td>
</tr>
<tr>
<td>Palmitic methyl ester (C16:0)</td>
<td>29.21</td>
<td>24.85</td>
<td>7.97</td>
<td>24.654</td>
<td>29.6</td>
</tr>
<tr>
<td>Palmitoleic methyl ester (C16:1)</td>
<td>11.96</td>
<td>6.13</td>
<td>—</td>
<td>6.9231</td>
<td>—</td>
</tr>
<tr>
<td>Heptadecanoic methyl ester</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.1419</td>
<td>0.4</td>
</tr>
<tr>
<td>Margaric methyl ester (C17:0)</td>
<td>13.46</td>
<td>6.23</td>
<td>6.19</td>
<td>6.2515</td>
<td>4.6</td>
</tr>
<tr>
<td>Stearic methyl ester (C18:0)</td>
<td>29.47</td>
<td>41.19</td>
<td>36.21</td>
<td>45.1812</td>
<td>42.1</td>
</tr>
<tr>
<td>Oleic methyl ester (C18:1)</td>
<td>9.57</td>
<td>20.94</td>
<td>16.11</td>
<td>12.5832</td>
<td>15.9</td>
</tr>
<tr>
<td>Linoleic methyl ester (C18:2)</td>
<td>—</td>
<td>&lt;LD*</td>
<td>80</td>
<td>0.3832</td>
<td>1.3</td>
</tr>
<tr>
<td>Linolenic methyl ester (C18:3)</td>
<td>1.63</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

* Below the detection limit.

### Table 6: Physical-chemical properties of chicken fat waste methyl ester.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid index (mgKOH/g)</td>
<td>0.44</td>
<td>0.144</td>
<td>0.183</td>
<td>0.301</td>
<td>0.15</td>
<td>—</td>
<td>0.5 max</td>
</tr>
<tr>
<td>Iodine index (gI$_2$/100g)</td>
<td>68.2</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>80</td>
<td>—</td>
<td>120 max</td>
</tr>
<tr>
<td>Cinematic viscosity</td>
<td>4.96 (à 40°C)</td>
<td>4.469</td>
<td>4.594</td>
<td>4.822</td>
<td>4.24</td>
<td>4.50 (à 40°C)</td>
<td>3.5–5.0</td>
</tr>
<tr>
<td>Density (g.cm$^{-3}$)</td>
<td>0.860</td>
<td>879.6</td>
<td>874.7</td>
<td>879.6</td>
<td>874</td>
<td>870</td>
<td>0.83</td>
</tr>
<tr>
<td>Cetane index</td>
<td>60.483</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>48–56</td>
<td>51 min</td>
</tr>
<tr>
<td>LCV (KJ/Kg)</td>
<td>38775.363</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
Chromatographic analysis coupled with mass spectrometry indicates the fatty residues of Gallus gallus domesticus have an oleic and palmitic dominant composition, 29.49% and 29.21, respectively.

The cetane index of the fatty residues of Gallus gallus domesticus is estimated at 60.483.

The fundamental analysis of the biodiesel obtained would make it possible to formulate the biofuel chemically obtained.

Experimenting with other thermochemical treatment methods could improve performance. Conservation and conservation methods do not irreversibly alter the properties of the raw material.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

The authors thank the Laboratory of Applied Chemistry of the Faculty of Science and the Applied Science Research Laboratory of the University Institute of Technology of University of Douala for the technical facilities.

References


[24] M. Kehani, H. Esmaeili, and P. Roohi, “Biodiesel production from chicken fat using nano-calcium oxide catalyst and...


