

# Optimization of Biodiesel Production from Fatty Residues of Cattle from Slaughterhouses

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## Abstract

This study optimizes biodiesel production from bovine fatty residues using a transesterification reaction with methanol and NaOH. A Box-Behnken response surface methodology is used to identify optimal process conditions (7.5:1 molar ratio, 1% catalyst, 45 min, 70°C), which achieved a 95% yield. The resulting biodiesel's physicochemical properties are characterized and compared against commercial diesel and ASTM standards to assess its viability as an alternative fuel. The Biodiesel obtained is characterized and the following property values are obtained: Density 0.875 g/cm<sup>3</sup> at 40°C; Water content (mg/kg): 0.048; Acid number (mg KOH/g): 0.34 ± 0.23; Saponification number (mg KOH/g): 161.28 ± 7.93; Iodine number (gI<sub>2</sub>/100 g): 28.55 ± 6.345; Peroxide number (meq O<sub>2</sub>/kg): 591.86 ± 0.19; Cetane number 59.45 (meq/kg), Fire point °C: 208; Pour point: -10; Smoke point 4°C; Flash point: 198°C; Viscosity at 40°C: 4.2 mm<sup>2</sup>/s; Viscosity at 100°C: 1.8 mm<sup>2</sup>/s.

## Keywords

Transesterification, Valorization, Optimization, Characterization, Biodiesel, Experimental Design

## 1. Introduction

The world's population is expanding rapidly. This means a high demand for energy to support the technological development that accompanies industries. The transportation sector is the most impacted, with the expansion of its networks, aerial, road, and rail. The major challenge today is to find alternatives to fossil fuels, the cost and depletion of which are becoming real, but also bio-additives that meet the requirements of sustainable development [1]. Beyond these aspects, criticism is in-

creasingly being made of fossil fuels due to their polluting nature. The criticisms made concern in particular CO<sub>2</sub> and greenhouse gases released into nature [2]. Hence, there is a need to resort to new, less polluting and renewable energies.

Among the alternatives to fossil fuels being considered is the production of biodiesel. It is a set of alkyl esters of long-chain fatty acids, produced from fatty acids from plants, animals, or recycled industrial residues. Biodiesel is produced by transesterification with an alcohol in the presence of a catalyst [3]-[6]. Compared to conventional diesels, biodiesel has chemical properties with few negative effects on engine performance. It emits few greenhouse gases and therefore pollutes the environment less [7].

To address the possibility of fossil fuel depletion and to address the fight against climate change and the reduction of polluting emissions, research is being undertaken. The main proposals include: (i) reducing travel, (ii) using energy efficiency (reducing energy consumption) in the transport sector, (iii) changing the nature of energy sources. The research work has led to the development of electric motors, natural gas engines and biofuels. Of all these solutions, the diversity of fuel sources occupies a prominent place [8].

Over the years, several research projects have led to the production of biodiesel from a wide variety of sources. Edible oils such as palm oil, soybean oil, sunflower oil, and coconut oil have been tested [9]-[12]. However, the problem of food security has arisen. Research has therefore focused on non-edible oils such as rubber seeds, jatropha, and algae [13]-[15]. This still poses a food security problem due to the arable land required. The other major obstacle to these vegetable oils is the high cost of refining raw materials, which accounts for around 70% of the production cost [16] [17]. To reduce the cost of biodiesel production, recourse is made to the recovery of fatty waste from chicken, pork, or beef, which is relatively available and inexpensive. However, the presence of impurities such as water and free fatty acids requires an alkaline catalyst in the production of inexpensive biodiesel with high energy potential.

Wyatt *et al.* [18] demonstrated that biodiesel produced from pork fat residues, bovine fat, and chicken fat in the presence of methanol is promising compared to soy-based biodiesel. Indeed, the latter has better lubricating power and oxidation stability and relatively low NO<sub>x</sub> emissions. This production was experimentally examined by Srinivasan *et al.* [19]. It appears that the maximum yield found is estimated at 94% under optimal conditions (M/O of 6:1, 0.5wt% catalyst 60°C, duration 2 h). This yield can be improved by factorial optimization.

Jambulingam *et al.* [20], in their work on the optimization of biodiesel production from bovine fatty residues, successfully carried out a transesterification reaction using methanol-ethanol as a co-solvent and KOH as a catalyst. The optimal conditions proposed a molar ratio of 1:6, catalyst concentration 0.55% at a temperature of 70°C for 30 min, which allowed obtaining a production yield estimated at 97.2 ± 1.08%. This work served as a basis for the work of Babatunde *et al.* [21], who experimented with the optimization and kinematic study of biodiesel production from bovine fatty residues using a solid catalyst, namely calcium oxide.

The factorial optimization of biodiesel production was determined by the RSM-CCD approach. The optimal conditions were as follows: free fatty acid of 0.60 at the operating conditions of the acid catalyst around 7.1%, molar ratio: 9:1 at the temperature of 60°C for 96 min. This allowed to obtain a yield of 72%. From this process, more wastewater comes out from the purification, resulting in a very high molar ratio and a high cost.

Furthermore, Hassan *et al.* [22] carried out the work of biodiesel production from fatty residues with sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) and potassium hydroxide (KOH) as catalyst, methanol is the alcohol used, the molar ratio is 5:1 at a temperature of 60°C for 120 min for sulfuric acid and a temperature of 55°C for 90 min for potassium hydroxide with a molar ratio of 5:1. In the first case, a yield of 65.7% is obtained and in the second case the yield is 48.8% but the physicochemical properties of the products obtained are in accordance with the ASTM standard in addition to being non-polluting. But with a low yield.

This study offers a commercial alternative to reduce the environmental impact caused by bovine residues from slaughterhouses, through the production of biodiesel, as shown in **Figure 1**, which presents an overview of the process. In order to minimize production costs, it seemed wise to require optimal conditions to avoid too low yields that would lead to losses of time and resources [23]. Design Expert 13.0.11 software was used for statistical analysis of the data. Thus, the Response Surface Methodology (RSM) under Box-Behnken by the conservation of four independent input factors that influence the transesterification reaction, namely: the amount of catalyst; the molar ratio; the reaction temperature and the reaction time, were brought into play.



**Figure 1.** Overview of the process for recovering value from slaughterhouse fat residues.

## 2. Materials and Methods

### 2.1. Materials and Reagents Used

**Figure 2** shows a sample of greasy waste in its packaging at the time of collection. Fatty waste collected in industrial cattle slaughterhouses in the cities of Yaoundé and Douala constitutes the raw material. It is the visceral fat taken from each animal unfit for human consumption intended for incineration when it is not thrown into

the wild. These disposal methods lead to environmental pollution, because these slaughterhouse residues contain a lot of BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) [19]. Also the odors due to the presence of microorganisms during decomposition and greenhouse gas emissions are all threats to the populations around the landfills and the environment. **Table 1** presents the different reagents used in for transesterification reaction in this study.



**Figure 2.** Fatty waste used as raw material.

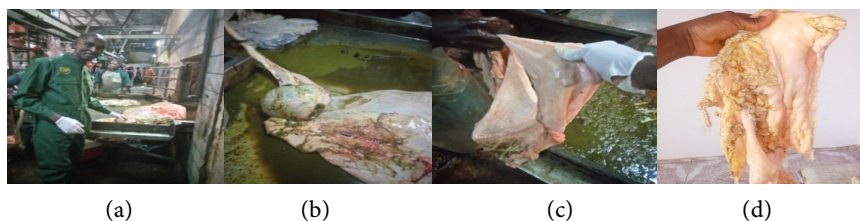
**Table 1.** reagents for transesterification.

Chemical names and formulas	Purity (%)	Origins	The material
Methanol: CH <sub>3</sub> OH	99.7	Louis Dreyfus commodities	1000 mL three-necked flask Flow refrigerant Separating funnel The beakers
Sodium Hydroxide: NaOH	88	Fisher Scientific	A scale (Sartorius) A magnetic stirrer Funnel Thermometer

## 2.2. Fat Extraction

### 2.2.1. Collection of Greasy Waste

**Figure 3** shows the removal of fatty waste during the slaughtering process. Fatty slaughterhouse waste was collected free of charge from modern slaughterhouses in Yaoundé and Douala. This consists of visceral fat removed from the outer walls of the intestines, stomach, and liver of each slaughtered animal. Each of these two slaughterhouses produces an average of between 350 and 400 kg of this waste per day. This waste was collected randomly directly at the time of slaughter and stored in a closed cooler away from light, water, and other contaminants, then taken directly to the fat extraction station.



**Figure 3.** Collection of fatty waste at the slaughterhouse. (a) Slaughterhouse chain; (b) intestine and liver; (c) extraction; (d) waste.

### 2.2.2. Extraction of Beef Fat

The waste was roughly chopped and blended to obtain a creamy paste. Heat this paste in a saucepan at a temperature of between 40 and 70°C until the oil appears. The fat was filtered to separate the non-greasy solid residues. The resulting oil was packaged in one or more jars, allowed to cool, and then stored away from light. The texture of this beef tallow at room temperature is as shown in **Figure 4**. The extraction yield was calculated using the formula:

$$R(\%) = \frac{m_g}{m_d} \times 100$$

with:

$m_g$ : mass of beef tallow;

$m_d$ : mass of fatt waste.



**Figure 4.** Sample of the fat obtained.

## 2.3. Biodiesel Production

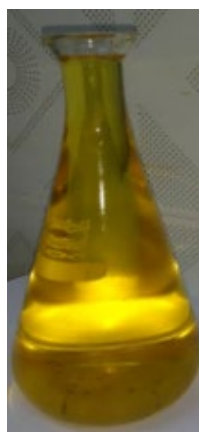
### 2.3.1. Analysis of the Value of the Fatty Acid Constituents of the Fat Obtained

A chromatography was carried out to obtain the value of the different constituents of fatty acids, a silica capillary column SLB-5ms, 30 mx 0.25 mm ID, 0.25 µm was used; with an oven temperature: constant and equal to 45°C for 3 min, then varying from 20 °C/min up to 360°C for 10 min; at an injector temperature: 275°C. Detector temperature: FID, set at 365°C. a carrier gas: helium, with a constant flow rate of 1.3 mL/min. an injection volume: 1.0 µL, 100:1 split. For a liner: 2 mm ID straight. The injection volume of the sample having a concentration of 1.0 µ/L in carbon disulfide solvent. It was sufficient to vaporize the sample to be analyzed before injecting it into the column. To do this, the sample was heated to 70°C. This assumes that the molecules of interest are not degraded at the temperature used to vaporize the sample. This made it possible to highlight the profile of fatty acids contained in our fat.

### 2.3.2. Description of Experimental Tests on Transesterification of Beef Fat

**Figure 1** gives the overview of the process adopted in this study. The fat is first brought to a constant temperature (60; 70 or 80°C) allowing the fat to melt. Methanol (CH<sub>3</sub>OH) is prepared at a molar ratio well calibrated with the quantity of fat

(6:1; 7.5:1 or 9:1) which is mixed with a catalyst Sodium Hydroxide (NaOH) at a suitable percentage proportional to the volume of the mixture (0.5%; 1% or 1.5%). This forms Sodium Methoxide ( $\text{CH}_3\text{NaO}$ ). The mixture is stirred in order to homogenize it and a constant time (30; 45 or 60 minutes) is allowed for the reaction to take place. Then it was left to settle in a funnel for 24 hours, then two phases are formed: the Methyl Ester on top and the glycerol, denser than the biodiesel, condenses in the lower part. The separating funnel is opened to remove the glycerol. Once these are eliminated, the methyl ester (EMHA) remains, which is purified with warm water to remove impurities such as residual glycerin, excess alcohol, traces of catalysts, soaps and salts formed by homogeneous catalysis. After washing the biodiesel with water, the drying operation removes the water present. It is carried out by heating in an oven at a temperature of  $105^\circ\text{C}$ . Finally, biodiesel is obtained and its appearance is shown in **Figure 5**.



**Figure 5.** Biodiesel obtained.

### 2.3.3. Study of the Experimental Model of the Transesterification Reaction

To achieve the transesterification of beef tallow, this study requires optimal conditions to avoid saponification or low yields that lead to losses of time and resources [19], Design Expert 13.0.11 software was used for statistical analysis of the data. Thus, the Response Surface Methodology (RSM) under Box-Behnken by the conservation of four independent input factors that influence the transesterification reaction including: the amount of catalyst (A); the molar ratio (B); the reaction temperature (C) and the reaction time (D), were used. While the yield of the Biolubricant obtained was considered as the response or output value. To optimize the results, 29 tests were proposed varying each factor, the experiment matrix is presented in the Appendix. The results obtained from these tests were analyzed using the quadratic model of response surfaces. **Table 2** below shows the minimum and maximum limits of each factor. Also, the analysis of variance (ANOVA) and the significance test were carried out to reassure the adjustment of the model corroborating with the regression equation of the response surface of the following polynomial:

$$+\varepsilon Y = \beta_0 + \sum_{i=1}^n \beta_i X_i + \sum_{i=1}^n \beta_{ii} X_i^2 + \sum_{ii>j}^n \sum_j \beta_{ij} X_i X_j$$

Or:

$Y$ : represents the response factor or the yield of the biolubricant;  $X_i$  represents the factor of level  $i$ ;  $X_j$  represents the factor of level  $j$ ; are coefficients of the polynomial;  $n$ : represents the number of factors of the experiment; and  $\varepsilon$  which represents the error attributed to  $Y$ .  $\beta_0; \beta_i; \beta_j; \beta_{ij}$ .

**Table 2.** The minimum and maximum limits of each factor of transesterification factors.

Experimental design: Box-Behnken Design (BBD)					
Number of independent variables: 4					
Number of attempts: 29					
Reaction parameters	unit	symbol	level		
			-1	0	1
Catalyst concentration	v/v'	HAS	0.5	1	1.5
Molar ratio	v/v	B	6	7.5	9
Reaction temperature	°C	C	60	70	80
Reaction time	min	D	30	45	60

The matrix of these tests is presented in the Appendix.

### 2.3.4. Coding of Factors

The experimental factors are codified in Box-Behnken Design as follows as presented in **Table 3** below:

**Table 3.** factor codification.

Factor	Name	Level	Low Level	High Level	Std. Dev.	Coding
A	NaOH	1,0000	0.5000	1.50	0.0000	Current
B	Ratio	7.50	6.00	9.00	0.0000	Current
C	Temperature	70.00	60.00	80.00	0.0000	Current
D	Time	45.00	30.00	60.00	0.0000	Current

## 2.4. Physicochemical Characterization of Biodiesel

### 2.4.1. Acid Number

A mass  $M$  of 1 g of oil is introduced into a 250 ml beaker, then 100 ml of 95°C ethanol were introduced. Two drops of 1% phenolphthalein solution are added to the contents of the beaker and the whole titrated with 0.1 N potassium hydroxide solution. The volume  $V1$  of KOH solution used to reach the indicator change (pink coloration of the phenolphthalein, persisting for 10 seconds is noted). This titration is also done with the blank test and the volume  $V0$  of KOH used is noted.

The acid index was calculated by the following formula:

$$Ia = [(V1 - V0)/m] \times 56.1T$$

$Ia$ : Acid number;

$V0$  (ml): Volume of KOH solution for the blank;

$V_1$  (ml): Volume of KOH solution for the sample;

$T(N)$ : Title of the ethanolic KOH solution used (0.1 N);

$m$  (g): Mass of the test sample (1 g).

The acidity in percentage of oleic acid was calculated using the formula:

$$I_a = (\% \text{ oleic acid}) = (I_a \ 282100) / m \times (56.11000) \times 1000$$

#### 2.4.2. Saponification Index

Saponification:  $R\text{-COO-R}' + \text{KOH} \rightarrow R\text{-COO-K}^+ + \text{HO-R}'$ .

A mass of 2 g of oil was dissolved in a potash solution ethanolic (0.5 N) in ethanol, the whole introduced into a ground-neck flask. The flask is connected to a reflux condenser and brought to a boil for at least 60 minutes, stirring from time to time.

The excess KOH is titrated with a hydrochloric acid solution (0.5 N), in the presence of phenolphthalein.

A blank test is prepared following the same procedure.

The saponification index (SI) is determined as follows:

$$IS = [(V_0 - V_1) / m] \times 56.1T \times$$

$V_0$  (ml): volume of hydrochloric acid required to titrate the blank;

$V_1$  (ml): volume of hydrochloric acid required to titrate the test;

$T(N)$ : Title of the hydrochloric acid solution used (0.5 N);

$m$  (g): Mass of the test sample (2 g).

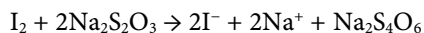
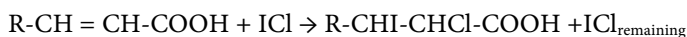
#### 2.4.3. Ester Index

The ester index (EI) is used to determine the molar mass of glycerides. It is equal to the saponification index for pure glycerides. This index is not measured, it is calculated:

**Ester index** = saponification index – acid index.

#### 2.4.4. Iodine Index

Add to the fatty substance, in solution in carbon tetrachloride and an excess of iodine monochloride (Wijs reagent). After a reaction time (1 hour), the determination of the excess halogen (iodine) by addition of a potassium iodide (KI) substance is carried out by titration of the liberated iodine with a sodium thiosulfate solution.



A mass of 0.2 g of oil was weighed into a flask into which 15 ml of carbon tetrachloride ( $\text{CCl}_4$ ) solution and 25 ml of Wijs' reagent were introduced. The tightly closed flask was shaken gently and placed in a dark place for 1 hour, then 20 ml of aqueous potassium iodide (KI) solution (10%), 15 ml of distilled water and 5 drops of 1% starch paste were added. The solution in the flask was titrated with 0.1 N sodium thiosulfate ( $\text{Na}_2\text{S}_2\text{O}_3$ ) solution and the volume  $V_1$  of sodium thiosulfate used to turn the solution (disappearance of the blue color) in the flask was noted. This titration was also done with the blank test and the volume  $V_0$  of sodium

thiosulfate used was noted.

The iodine index is calculated using the formula:

$$II = [(V0 - V1)/m] \times 12.69T \times$$

$V0$  (ml): volume of  $\text{Na}_2\text{S}_2\text{O}_3$  necessary to titrate the white;

$V1$  (ml): volume of  $\text{Na}_2\text{S}_2\text{O}_3$  necessary to titrate the test;

$T(N)$ : Title of the hydrochloric acid solution used (0.1 N);

$m$  (g): Mass of the test sample (0.2 g).

#### 2.4.5. Peroxide Index

The method is based on the spectrophotometric determination of ferric ions ( $\text{Fe}^{3+}$ ) formed following the oxidation of ferrous ions ( $\text{Fe}^{2+}$ ) by hydroperoxides in the presence of ammonium thiocyanate. Thiocyanate ions ( $\text{SCN}^-$ ) react with ferric ions to form a red-colored complex that absorbs strongly around 500 nm.

In a 10 ml glass test tube containing 50-100 mg of oil sample, 9.8 ml of a chloroform-methanol mixture (7:3) is added, and the mixture is vortexed for 2 - 4 seconds. Then, 50  $\mu\text{l}$  of a 30% aqueous solution of ammonium thiocyanate is added and the mixture is again vortexed for 2 - 4 seconds, followed by the addition of 50  $\mu\text{l}$  of an aqueous solution of iron II chloride. The mixture is again vortexed for 2 - 4 seconds. After 5 minutes of incubation at room temperature, the absorbance of the reaction mixture is read at 500 nm against a blank containing all reagents except the oil, using a spectrophotometer (PERKIN ELMER, LAMBDA 35). The manipulation took place in a dimly lit enclosure and was completed within a maximum of 8 minutes per test. The samples were measured in triplicate. The peroxide index expressed in ppm was calculated from the Fe III calibration curve using the formula:

$$IP = [(As - Ab)k] \times (55.84m) \times$$

PI = Peroxide value;  $k$  = Slope, obtained from the calibration curve (38.40); AS = Absorbance of the sample;  $m$  = mass of the sample in g; Ab = Absorbance of the blank; 55.84 = Molar mass of iron.

#### 2.4.6. Cetane Index

The cetane number represents the saponification number for producing biodiesel or beef tallow. It is determined by an empirical equation:

$$Ic = 46.3 + \frac{5458}{Is} - 0.225 * Iiode$$

#### 2.4.7. Density

The density of a substance is equal to the density of the substance multiplied by the density of the reference body at the same temperature. For liquids and solids, water is used as a reference; for gases, the measurement is relative to air. We measured the masses of a known volume of oil and biodiesel. Knowing the mass and volume allows us to calculate the density and deduce the density of the sample using the following relationships:

$$\text{And } \rho = \frac{m}{v} d = \frac{\rho}{\rho_e}$$

$m$ : mass of the sample;

$v$ : sample volume;

$\rho$ : density of the sample;

$\rho_e$ : density of water.

In this case, the density was taken at different temperatures: 40°C; 60°C; 80°C and 100°C.

#### 2.4.8. Water Content

The oil was initially weighed before being heated to 105°C and exposed for 24 hours and weighed again. This operation was repeated three times and the values recorded. The value was found by the following equation:

$$\% \text{humidity} = \times 100 \frac{w_i - w_f}{w_i}$$

$W_i$ : initial weight;

$W_f$ : final weight.

#### 2.4.9. Dynamic Viscosity and Kinematic Viscosity

Viscosity is defined as the resistance to uniform, turbulence-free flow occurring in the mass of a material. The viscosity of oil is determined using a rotational viscometer. This instrument acts by rotating a rod (cylinder) that is immersed in the material to be analyzed and measures the resistance of this substance at a selected speed. The resulting resistance is the measure of the viscosity flow, dependent on the rod; the device calculates the result and the direct reading of the viscosity is reflected in cP (1cP = 1mPa.S) (SI).

Dynamic viscosity is related to kinematic viscosity by the formula  $\mu = \nu \cdot \rho$

$$\nu = \frac{\mu}{\rho} \gamma \nu = \mu \rho$$

with:

$\mu$ : is the dynamic viscosity of the fluid in pascal-seconds (Pa s) or kg m<sup>-1</sup> s<sup>-1</sup>;

$\nu$  is the kinematic viscosity of the fluid, expressed in 104 $\gamma$  stor in m<sup>2</sup>/s;

$\rho$ : is the density of the fluid, in kg/m<sup>3</sup>.

#### 2.4.10. The Pour Point

This is the temperature below which an oil loses its ability to flow. More specifically, the pour point is the best reference for predicting an oil's performance at low temperatures. To determine this value, an oil sample was cooled rapidly, up to 20°C per hour. The sample was tilted on its side every 3°C to determine the oil's fluidity. The lowest temperature at which fluid movement is noticeable is the pour point.

#### 2.4.11. The Flash Point

The flash point is the temperature to which the sample must be heated for the vapors emitted to combust spontaneously in the presence of a flame. The flash point test involves gently heating a sample at a constant rate of temperature rise

and with continuous stirring. For each degree of temperature increase, a flame is introduced into the vapor produced above the sample. The lowest temperature at which the vapors ignite is the flash point.

#### 2.4.12. The Smoke Point

This is the maximum flame temperature at which the sample burns without smoke. The smoke point is related to the fatty acid content of beef tallow and is inversely proportional to the acid content. It is used to determine smoking tendency and is calculated by the following equation:

$$\text{Smoking tendency} = 320/\text{smoke point.}$$

### 3. Results and Discussion

#### 3.1. Performance

##### 3.1.1. Yield after Fat Extraction

The experiment was repeated five times with different masses. The average of these experiments will be considered as the extraction yield value. **Table 4** shows the average yield after extraction operations.

**Table 4.** Yield of the extraction phase.

Order number	Initial mass (g)	Extraction yield
1	750	89.50%
2	700	93.50%
3	750	88.60%
4	600	85.40%
5	700	87.30%
<b>Average</b>		<b>88.86%</b>

##### 3.1.2. Overall Performance

The yield of 88.86% had already been retained from the exploitation of fatty waste to obtain beef tallow. The series of experimental design was launched for the realization of the transesterification fixing at each test a sample of identical mass of 50 g of starting product (beef tallow). With the optimal parameters obtained thanks to the Design Expert software we arrive at the final product (methyl ester or biodiesel) of mass 47.5 g applying the formula of the yield cited above we find a yield of 95%.

##### 3.1.3. Biodiesel Density Yield

Depending on the temperature, as shown in **Table 5**, the volumetric mass and density of beef tallow and biodiesel can be defined. From the density and volumetric mass of the obtained beef fat and those of the biobiodiesel we can estimate the quantity of biodiesel that can be obtained from the mass of waste.

The experiment carried out above enabled us to evaluate the average yield of oil extraction from waste, which is approximately 88.86%. Therefore, 100 kg of fatty waste produces approximately 88.86 kg of tallow. Using the density formula and the optimal biodiesel yield of 95%, the volume of biodiesel extracted is 74.01 litres.

**Table 5.** Volumetric mass and Density of grease and biodiesel depending on the temperature.

Temperature °C	Mass volumetric		Density	
	raw	biodiesel	raw	biodiesel
40	0.888	0.850	0.897	0.875
60	0.858	0.828	0.872	0.841
80	0.816	0.808	0.845	0.837
100	0.792	0.784	0.843	0.833

### 3.2. Chemical Composition of Beef Fat

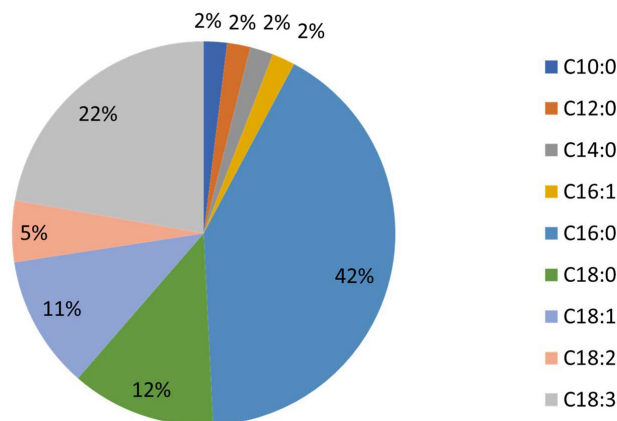
The results of the chromatography of our sample allowed us to know its internal structure, and are presented in **Table 6** below, where they are first compared to the standard and subsequently analyzed.

**Table 6.** Comparison between the composition of fatty acids and the sample and that published by NF EN14331.

Fatty acids	Chemical composition	Sample values (%)	Values* Standards (%)
Capric acid	C10:0	1 to 3.02	< 0.5
Lauric acid	C12:0	1 to 3.02	< 0.5
myristic acid	C 14:0	1 to 3.02	2 to 6
Palmitoleic acid	C16:1	1 to 3.02	1 to 5
Palmitic acid	C 16:0	38 to 47	20 to 30
Stearic acid	C 18:0	2 to 23	15 to 30
Oleic acid	C18:1	2 to 21	30 to 45
Linoleic acid	C18:2	0.6 to 10	1 to 6
Linolenic acid	C18:3	0.7 to 45	< 1.5

\*Codex Standard for named Animal Fats (Codex-STAN 211-1999), FAO/WHO.

The values thus found are close to those found in the previous work of C. Limmatvapirat *et al.* [24] or Chizo *et al.* [25]. This can attest to the reliability of the method and the tool used. From the average of the values present in this table above, we obtain the following graph (**Figure 6**):



**Figure 6.** Experimental estimation of the mass composition of beef tallow acids.

The graph shows minor acids Capric acid (C10:0), Lauric acid (C12:0), Myristic acid (C14:0) and Palmitoleic acid (C16:1); can we notice a peak on Palmitic acid (C16:0), which like Oleic acid (C18:1) has a low degree of instauration. We can hope to obtain an acceptable viscosity because the properties of the final product depend on the chemical composition of the material on the one hand and the main fatty acid has a long carbon chain and a low degree of instauration. For the same reason a high density cannot be considered because, the density increases with the decrease in the length of the chain and the increase in the number of double bonds [26]. Since the problem of oxidation of mechanical parts in engines is one of the major challenges that a lubricant must solve, studies have found a close relationship between oxidation stability and unsaturated fatty acids. Oxidation stability decreases with increasing linoleic and linolenic acid content. The equation below shows the correlation between oxidation stability and fatty acid content [27].

$$Y = \frac{117.9295}{X} + 2.5905 (0 < X < 100)$$

Where X represents the linoleic and linoleic acid content (%) and Y represents the oxidative stability. From this equation we can deduce that the oxidative stability is inversely proportional to the linoleic and linoleic acid content. Oxidizability (OX) can be calculated when the fatty acid composition is known by the equation [28]:

$$OX = [0.02(\%O) + 2(\%Ln)/100]$$

Where O represents oleic acid, L represents linoleic acid and Ln represents linoleic acid. From these equations we find for our sample: Y = 6.56 and OX = 0.51. It has been proven in other studies [29] [30] that palmitic acid and oleic acid significantly affect oxidative stability. These studies show a close relationship between oxidative stability and unsaturated fatty acid content.

### 3.3. Statistical Analysis Using Response Surface Methodology

#### 3.3.1. Regression Analysis and Analysis of Variance

**Table 7** below shows the results of the analysis of variances (ANOVA) for the quadratic model.

**Table 7.** Results of the analysis of variances (ANOVA) for the quadratic model.

Source	Sum of Square	df	Mean Square	F-value	p-value
<b>Model</b>	1932.81	11	175.71	32.51	< 0.0001
A-NaOH	36.75	1	36.75	6.80	0.0184
B-molar ratio	114.08	1	114.08	21.11	0.0003
C-Temperature	560.33	1	560.33	103.67	< 0.0001
D-Time	85.33	1	85.33	15.79	0.0010
AB	16.00	1	16.00	2.96	0.1035
AC	36.00	1	36.00	6.66	0.0194
BC	16.00	1	16.00	2.96	0.1035

## Continued

A <sup>2</sup>	757.75	1	757.75	140.20	< 0.0001
B <sup>2</sup>	346.45	1	346.45	64.10	< 0.0001
C <sup>2</sup>	142.27	1	142.27	26.32	< 0.0001
D <sup>2</sup>	311.81	1	311.81	57.69	< 0.0001
<b>Residual</b>	91.88	17	5.40		
Lack of Fit	87.08	13	6.70	5.58	0.0548
Pure Error	4.80	4	1.20		
<b>Total Horn</b>	2024.69	28			

The model's F-value of 32.51 implies that the model is significant. There is only a 0.01% chance that such a high F-value could occur due to noise. P-value less than 0.0500 indicates that the model terms are significant. In this case, A, B, C, D, AC, A<sup>2</sup>, B<sup>2</sup>, C<sup>2</sup>, D<sup>2</sup> are significant model terms. Values greater than 0.1000, *i.e.*, AB and BC, indicate that these model interactions are not significant. **Table 8** below shows that the predicted R<sup>2</sup> of 0.8406 is in reasonable agreement with the adjusted R<sup>2</sup> of 0.9253; *i.e.*, the difference is less than 0.2. Adeq Precision measures the signal-to-noise ratio. A ratio greater than 4 is desirable. Your ratio of 16,683 indicates an adequate signal. This model can be used to navigate the design space.

**Table 8.** Adjustment statistics.

<b>Std. Dev.</b>	2.32	<b>R<sup>2</sup></b>	0.9546
<b>Mean</b>	80.90	<b>Adjusted R<sup>2</sup></b>	0.9253
<b>RESUME %</b>	2.87	<b>Predicted R<sup>2</sup></b>	0.8406
		<b>Adeq Precision</b>	16,683

### 3.3.2. Development of the Regression Equation

The statistical analysis conducted was summarized by the regression equation, the development of which is presented as follows:

$$\begin{aligned} \text{Rendement}\% = & -407.37 + 67.96A + 44.11B + 5.64C + 2.95D - 2.66AB \\ & + 0.6AC + 0.13BC - 43.23A^2 - 3.24B^2 - 0.04C^2 - 0.03D^2 \end{aligned}$$

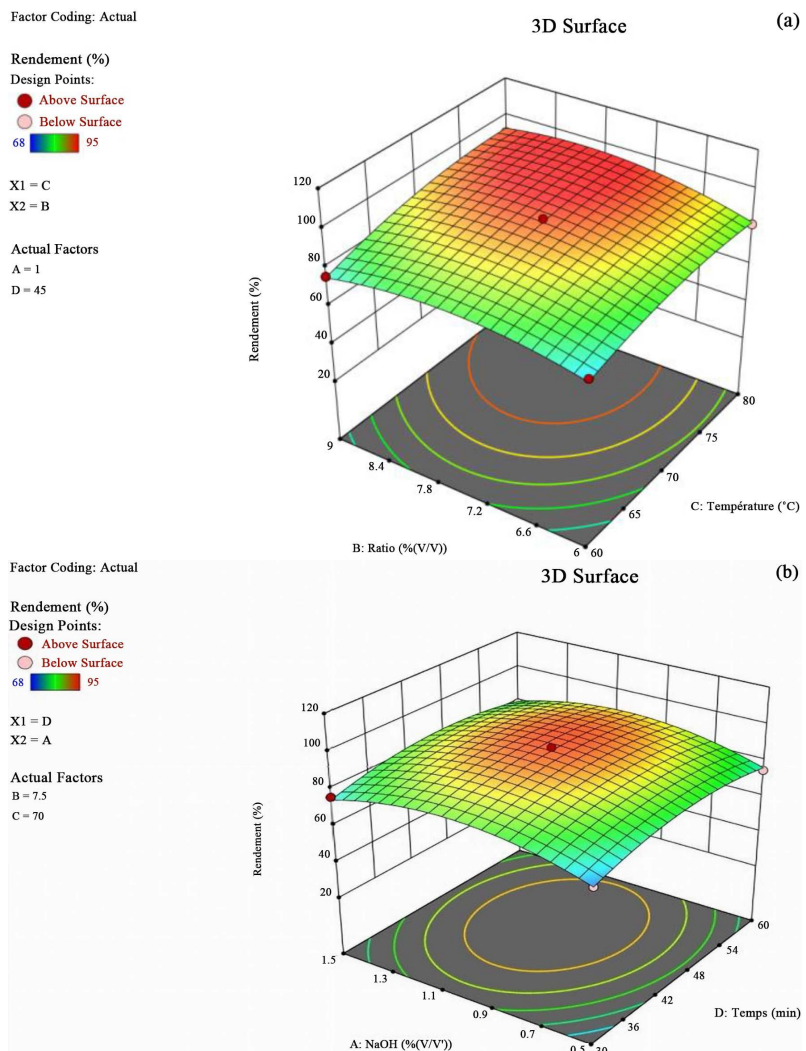
The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels must be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to fit the units of each factor and the intercept is not at the center of the design space.

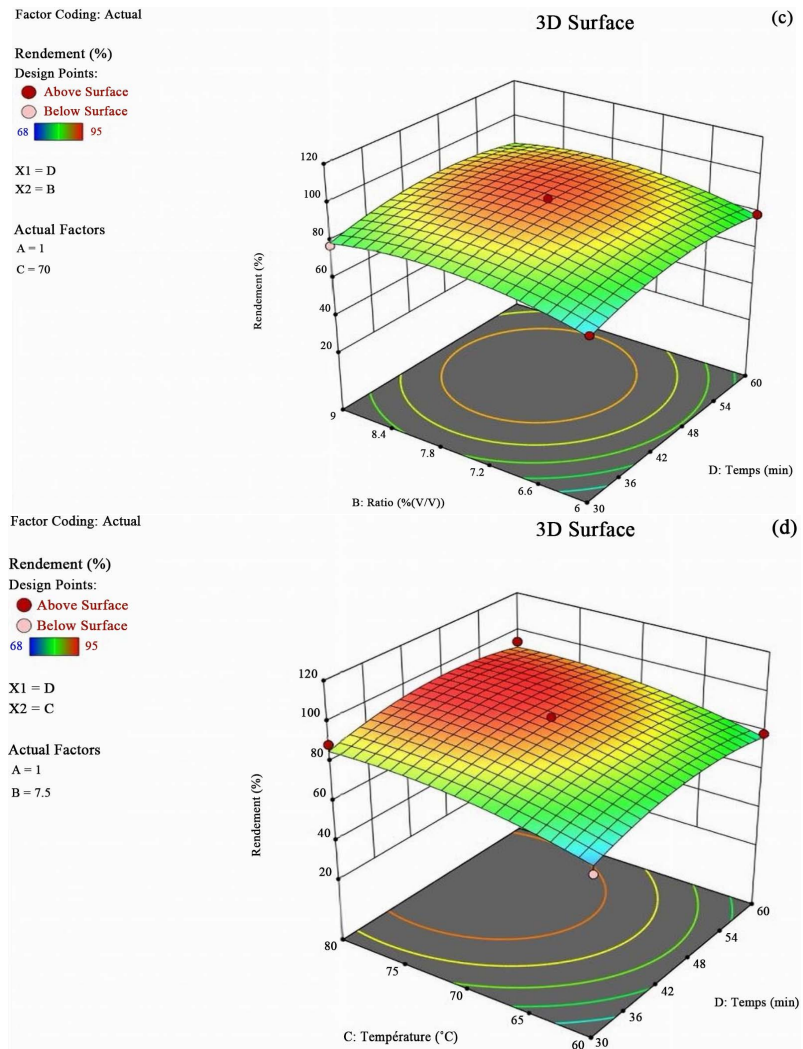
### 3.3.3. Effect of Processing Parameters on Biodiesel Yield

**Figure 7** shows that the molar ratio of methanol/fat, NaOH catalyst, reaction temperature; and reaction time are significant and influence the yield of biodiesel production. The yield increases with temperature and can rise above 95% yield.

The graphs representing the molar ratio and catalyst concentration in **Figure 7** clearly show that the biodiesel yield increases up to a molar ratio of 7.5:1, which corresponds to the stoichiometry of the reaction mixture, while a further increase in the molar ratio increases the availability of alcohol, leading to ester-glycerol

recombination. Similarly, a steady increase in biodiesel yield was observed up to a catalyst concentration of 1% due to increased catalytic activity, but it decreased with a further increase in concentration due to soap formation. According to the temperature-time graph (Figure 7(d)), the reaction was found to be reciprocal up to 70°C; however, a further increase in temperature resulted in a slight reduction in yields due to solvent evaporation. Similarly, the transesterification reaction responded well and produced higher biodiesel yields up to the first 70 minutes of reaction time; meanwhile, continuing the reaction time resulted in the formation of monoglycerides. Contrary to the ideal molar ratio of 3, an excess molar ratio of 7.5/1 was used in the reaction due to the presence of long-chain fatty acids in the triglyceride molecule, while the increase in saturation content resulted in a higher reaction temperature. In addition, it was recognised that increasing the reaction time overcame the mass transfer barrier, followed by the time required for the bonds to break and reconfigure into ester molecules. The maximum reaction yield of 95% made it possible to determine the optimal values of the reaction parameters suitable for the transesterification of melted tallow.





**Figure 7.** Effect of processing parameters on biodiesel performance, Individual effect of parameters; (a) Effect of molar ratio temperature interaction; (b) Effect of molar ratio time interaction; (c) Effect of catalyst time interaction; (d) Effect of temperature time interaction.

### 3.4. Physicochemical Characterization of Biodiesel Based on Fatty Waste

To better appreciate the quality of the biodiesel in this study, the following **Table 9** presents a comparison of the physicochemical characteristics of biodiesel based on fatty slaughterhouse waste with those of a commercial diesel, and the ASTM standard values.

**Table 9.** Comparison of physicochemical characteristics of biodiesel based on slaughterhouse fat waste with ASTM standards.

Properties	Diesel [22]	Biodiesel	Standard and test method ASTM D6751-DIESEL
color	-	transparent	-
Density (g/cm <sup>3</sup> ) at 40 °C	0.850	0.858	0.840- 0.9 (D1298)
Density (g/cm <sup>3</sup> )	0.845	0.850	-

**Continued**

Water content (mg/kg)	0.01	0.048	0.05 (max) (D2709)
Acid number (mg KOH/g)	0.35	0.34 ± 0.23	0.5max (D664)
Saponification index (mg KOH/g)	-	161.28 ± 7.93	5 min
Iodine index (gI <sub>2</sub> /100 g)	34	28.55 ± 6.345	120 max
Peroxide index (meq O <sub>2</sub> /kg)	4.5	1.86 ± 0.19	-
Cetane index	52.25	65.35	47 min (D613)
Fire point °C	74	208	93 (min) (D93)
Smoke point °C	-9	4	-3 to 12 (D2500)
Flash point °C	167	198	93(minimum) (D93)
Pour point °C	-13	-10	-15 to 10 (D97)
*Viscosity at 40°C	5.7	4.2	1.90- 6 max (D445)
*Viscosity at 60°C	-	3.2	-
*Viscosity at 80°C	-	2.0	-
Viscosity at 100°C	-	1.8	-

\*represents the viscosity index (ISO VG 32).

If the color of biodiesel and its density which is a function of the raw material, the water content and the water content are satisfactory 0.048 higher than the value of commercial diesel but within the margin of the specification standard ASTM D2709. The other properties will be examined by comparison with a commercial diesel on the one hand and the standard values on the other hand. Regarding the water content, the acid number and the saponification number respectively 0.048; 1.54 ± 0.53; 161.28 ± 7.93 The values, although within the acceptable range of the standard, it should be noted that these are considerably lower than the values of commercial diesel. These values are closer to biodiesel obtained from chicken oil synthesized with methanol at a relatively mild temperature of 280 °C. The work of Mandale *et al.* [31] states that its values are a function of the reaction time. He suggests that the product obtained be subjected to post-treatment such as distillation or flash drum to reduce the water content. Other properties Cetane index, Cetane number, Fire point, Smoke point, Flash point respectively: 65.35; 208; 4; 198; show satisfactory values compared to the specification standard, which clearly shows that the biodiesel obtained can be an alternative to fossil fuel.

#### 4. Conclusion

Fatty slaughterhouse waste, which is a low-cost raw material, has a high fatty acid potential. By a Transesterification guided by the optimal parameters are: methanol as alcohol, sodium hydroxide as catalyst, molar ratio of 7.5:1 reaction time 45 min at a temperature of 70 °C, it was possible to separate these triesters from glycerols to produce a biodiesel at a yield of 95% whose properties are as follows: Density 0.875 g/cm<sup>3</sup>; Water content (mg/kg): 0.048; Acid number (mg KOH/g): 0.34 ± 0.23; Saponification number (mg KOH/g): 161.28 ± 7.93; Iodine number

(gI<sub>2</sub>/100 g): 28.55 ± 6.345; Peroxide number (meq O<sub>2</sub>/kg): 591.86 ± 0.19; Cetane number 59.45 (meq/kg), Fire point °C: 208; Pour point: -10; Smoke point: 4°C; Flash point: 198°C; Viscosity at 40°C: 4.2 mm<sup>2</sup>/s; Viscosity at 100°C: 1.8 mm<sup>2</sup>/s. The physicochemical characteristics of this biodiesel already present it as viable alternative warranting further investigation into its emissions profile. This opens the way for tests on an engine to evaluate consumption, and the composition of emissions in order to make improvements.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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## Appendix: Experience Matrix

Std	Run	Factor 1	Factor 2	Factor 3	Factor 4	Response 1
		A: NaOH	B: Ratio	C: Temperature	D: Time	Yield
		%(V/V')	%(V/V)	(°C)	min	%
15	1	1	6	80	45	82
26	2	1	7.5	70	45	95
16	3	1	9	80	45	91
13	4	1	6	60	45	75
8	5	1	7.5	80	60	94
17	6	0.5	7.5	60	45	72
24	7	1	9	70	60	82
18	8	1.5	7.5	60	45	70
22	9	1	9	70	30	78
28	10	1	7.5	70	45	93
12	11	1.5	7.5	70	60	79
9	12	0.5	7.5	70	30	71
1	13	0.5	6	70	45	68
21	14	1	6	70	30	74
14	15	1	9	60	45	76
27	16	1	7.5	70	45	93
3	17	0.5	9	70	45	82
23	18	1	6	70	60	79
6	19	1	7.5	80	30	89
10	20	1.5	7.5	70	30	76
4	21	1.5	9	70	45	80
5	22	1	7.5	60	30	68
2	23	1.5	6	70	45	74
19	24	0.5	7.5	80	45	78
25	25	1	7.5	70	45	92
20	26	1.5	7.5	80	45	88
7	27	1	7.5	60	60	79
29	28	1	7.5	70	45	93
11	29	0.5	7.5	70	60	75