

Estudio de la producción de biodiesel por procesos químicos y enzimáticos a partir de aceite de cocina usado.

Study of the production of biodiesel by enzymatic and chemical processes from used cooking oil.

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Resumen—Se analizó la producción de biodiesel por medios químicos y enzimáticos, a partir de aceite de cocina usado (ACU), evaluando la calidad y rendimiento del producto obtenido en cada método. Para el proceso químico se desarrolló una esterificación ácida seguida de una transesterificación básica (temperatura de reacción: 60 °C, relación molar aceite:metanol 1:6, concentración de catalizador KOH: 1% p/p), tiempos de reacción: 55 y 70 min; y la transesterificación enzimática (temperatura: 38 °C, relación molar aceite:metanol 1:3, concentración de catalizador enzima lipasa XX 25 split líquida: 5%), tiempos de reacción: 3 y 6 horas. Se determinó propiedades fisicoquímicas (i.e. densidad, viscosidad cinemática, contenido de humedad, perfil de ácidos grasos, índice de acidez, peróxidos y saponificación) de la materia prima, registrando presencia de ácido oleico (42.45%) y ácido palmítico (33.52%). El mejor rendimiento obtenido fue a partir de la transesterificación química bajo las condiciones de 60 °C, 1% KOH y 70 minutos, evidenciando un porcentaje de conversión del 96.15% y un número ácido de 1.33 mmKOH/g, en comparación con la transesterificación enzimática que registró un alto número ácido de 6.91 mmKOH/g y porcentaje de conversión de 48.8% bajo las condiciones de 38 °C, 5% de enzima lipasa y 3 horas.

Palabras clave: biodiesel, aceite de cocina usado, transesterificación enzimática, transesterificación química, metil ésteres de ácidos grasos.

Abstract—The biodiesel production was analyzed by chemical and enzymatic processes, from used cooking oil (UCO), evaluating the quality and yield of the product obtained in each method. For the chemical process, an acid esterification followed by a basic transesterification was developed, (reaction temperature: 60 °C, oil:methanol 1:6 molar ratio, concentration of KOH catalyst: 1% w/w reaction times: 55 and 70 min); and enzymatic transesterification (temperature: 38 °C, oil:methanol 1:3 molar ratio, enzyme concentration lipase XX 25 split liquid: 5%, reaction times: 3 and 6 hours). Physicochemical properties (i.e. density, kinematic viscosity, moisture content, fatty acid profile, percentage of acidity, peroxides index and saponification) of the raw material were determined. Results showed the presence of oleic acid (42.45%) and palmitic acid (33.52%). The highest yield obtained was from the chemical transesterification under the conditions of 60 °C, 1% KOH and 70 min with a conversion percentage of 96.15% and an acid number of 1.33 mmKOH/g, compared to the enzymatic transesterification which registered a high acid number of 6.91 mmKOH/g and conversion percentage of 48.81% under the conditions of 38 °C, 5% of enzyme lipase and 3 hours.

Keywords: Biodiesel, used cooking oil, enzymatic transesterification, chemical transesterification, fatty acid methyl ester.

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I. INTRODUCTION

The Paris Agreement carried out within the framework of the XXI Conference on Climate Change (COP 21), aimed to confront climate change by maintaining the increase in global average temperature below 2 °C [1]. Therefore, Colombia assumed the commitment to reduce greenhouse gas (GHG) emissions by 20%, although the national territory is only responsible for 0.4% of GHG emissions worldwide [1], [2]. The sector being forestry has the highest gross emissions in the country (36%), with deforestation as the primary source (98%), and the transport sector the fourth generator of emissions at the national level, of which more than 90% is due to the energy use of fossil fuels [2]. In 2017, the Colombian government increased its biodiesel-based palm oil by 3% compared to the previous year, amounting to 545 million liters. In Colombia, exist eight biodiesel production plants that use palm oil as raw material; however, only one of them has started to produce small amounts of biodiesel from used cooking oil (UCO) [3].

Colombia is the largest Latin American producer of palm oil and the fourth in the world [4]. Hence, it is the primary source for the production of first generation biodiesel, although this affects the food supply since it compromises land extensions to provide cultivation areas that will be used in the generation of biofuel; which causes degradation of the soil and increases the prices of agricultural foods such as palm oil, by reducing the production of these [5]. As a result of this problem, the UCO has become in recent years an attractive raw material for the biodiesel production, due to its low cost and its capabilities for the reduction of the negative environmental impact caused by its inadequate disposal, which is already regulated by the Colombian government by the resolution 316 of 2018 [6]. Therefore, the production of biodiesel from UCO is a promising alternative. Considering the various investigations that have been carried out using the used cooking oil applying chemical transesterification for the production of biodiesel [7] - [11]. In this study, the production of biodiesel from used cooking oil was analyzed under chemical and enzymatic processes to determine the optimal operating conditions to produce a good quality biofuel that accomplish the standards of EN 14214 [12].

II. THEORETICAL FRAMEWORK

The production of biodiesel from used cooking oil happens in three stages: adequacy, transesterification and purification. In Figure 1, each of the stages is evidenced in the process of obtaining the biofuel from UCO.

Adequacy. One of the disadvantages of using the UCO in the production of biodiesel is the presence of unwanted material, mainly Free Fatty Acids (FFA), solid impurities and water. The UCO must undergo a process of degumming, refining, filtering, neutralizing and drying, to reduce the content of FFA and impurities that can cause breakdowns in the equipment and devices of the biodiesel production process [13] and also to comply with the quality parameters required in norm EN 14214 [12].

For the reduction of the FFA in the used oil, several techniques have been studied, such as esterification with methanol and sulfuric acid, as a catalyst; esterification with ion exchange resins; the neutralization with alkalis followed by the separation of soap; and extraction with polar liquids together with acid esterification and distillation of FFA [14].

In the case of water, its presence leads to hydrolysis, resulting in a high content of FFA leading to saponification [14], which adversely affects the conversion of biodiesel and can completely inhibit the transesterification reaction [15]. To remove the high-water content the sample is heated above 100 °C; at industrial scale, vacuum distillation (0.05 bar) is used. To remove solids in suspension, it is washed with

hot water or a centrifugation and filtration is carried out [14]. In addition, several pre-treatments have been implemented for oil purification before transesterification, such as: steam injection, column chromatography, neutralization, evaporation of film vacuum and vacuum filtration [16].

Transesterification. It is a catalyzed reaction of vegetable oils in the presence of alcohol to produce biodiesel and glycerol, as a by-product. The process consists of a sequence of three reversible reactions, where the triglycerides of the oil are converted into diglycerides, these in turn, into monoglycerides that are ultimately transformed into glycerol. At each stage of the reaction an ester is produced, such that three ester molecules of a triglyceride molecule are generated [15].

To achieve a complete reaction and a high conversion to methyl esters, a 3:1 molar ratio of alcohol to triglycerides is required, maintaining an excess of alcohol so that the reaction does not reverse, in addition to the presence of a catalyst to improve the reaction rate [16]. Homogeneous catalysts (e.g. acids and alkalis) and heterogeneous catalysts (e.g. acids, alkalis and enzymes) can be used. However, it has been shown that acid and alkaline transesterification processes are faster, and cost less than processes catalyzed by enzymes [14]. Using alkaline catalysts has certain advantages in the production process according to [13]: decreased complexity by requiring less demanding operating conditions than when acid catalysts are used, require low concentrations (0.5 to 1% w/w) to achieve high yields of alkyl esters (94 to 99%); short reaction times (less than 1 hour) and low excess alcohol and moderate temperature and pressure conditions (close to the boiling point of the alcohol used). Sodium and potassium hydroxide are the most commonly used alkaline catalysts on an industrial scale due to their greater availability, low cost and ease handling [15].

However, the use of this type of catalysts is difficult when the content of FFA in the feedstock is very high [14]; although the high acidity of the oil can be counteracted by adding an excess of catalyst [15]. For all the above, to achieve high yields with this type of catalysts should be used raw materials with a moisture content less than 0.05% and FFA content less than 0.5% [15]. If these conditions are not met, transesterification in two stages is recommended, separately handling acidic and alkaline catalysts. The first stage consists of a catalysis with sulfuric acid or ferric sulfate to carry out the esterification of the fatty acids, while in the second stage an alkaline catalyst is used for the transesterification of the triglycerides, considering that the catalysts must be eliminated after each stage. In other investigations, alkaline catalysis followed by acid catalysis was first performed, obtaining a reduction in the time of the process and the concentration of the catalyst [14].

In the enzymatic catalysis, the use of biocatalysts has advantages over the mentioned catalysts, since they are more selective, biodegradable, less toxic and react at lower temperatures [15]. Lipases are the enzymes most used in the production of biodiesel from UCO since they convert all fatty acids into methyl esters of fatty acids. In addition, when used in the transesterification process, glycerol and biodiesel can be easily recovered and with a low level of impurities; in addition, the moisture content in the UCO is tolerated by the lipase, resulting in high biodiesel conversions at low temperature and pressure conditions in the reaction [14].

However, the biocatalyst has limitations when it comes into contact with a large amount of alcohol, since the active centers of lipases admit it as a substrate, causing loss in its catalytic activity. It has been reported that the presence of phospholipids in the feedstock and certain glycerin residues, formed as the process proceeds, are responsible for the inactivation of the enzyme [15]. Similarly, in enzymatic catalysis, high temperatures affect the process, to the point of denaturing the enzyme, with the recommended temperature range being between 35-50 °C [17]. The reaction time must be longer,

compared to chemical catalysis, in order to reach high yields of Fatty Acid Methyl Ester (FAME).

Purification. After the UCO conversion reaction, it is possible to find unreacted tri, di and monoglycerides, methanol, catalyst residues, glycerin, water and soap [13]. In most cases, the phases are separated by decantation. However, impurities in the raw material can cause the formation of emulsions that interfere in the separation, requiring the application of saturated salt (sodium chloride) or centrifugation to break such emulsions and achieve separation [16]. If the biodiesel is obtained by alkaline catalysis, the unreacted catalyst is neutralized using, in general, phosphoric acid, producing phosphate salts that are removed from the biodiesel and that can be used as fertilizers [4]; even so, biodiesel presents alcohol in excess, the process most used for its removal is evaporation, followed by vacuum distillation to eliminate other waste. The biodiesel is washed with water at different temperatures, ending when it is neutral, then the biodiesel is dried by

heating, being common to reach 110 °C in an open container, until no water vapor is detected [16]. Certain chemical products are also used, such as magnesium powder silicate (i.e. Magnesol®), dry cleaning with this product replaces the use of water and has the advantage of serving as an organic fertilizer after use [18]. This stage of dry washing uses 2% (w/w) magnesium silicate at a temperature of 100 °C, for 20 min, with a stirring speed of 160 rpm [4]

After the purification of the biodiesel, the conditioning of the obtained glycerol is carried out, using phosphoric acid, which reacts with the residual alkaline catalyst and the soaps that were formed during the transesterification process. As a result, fatty acids, phosphates or salts and glycerin are generated that must be purified before being commercialized. During this process water and alcohol are removed by means of vacuum distillation to obtain concentrated glycerol at 85% or higher [13].

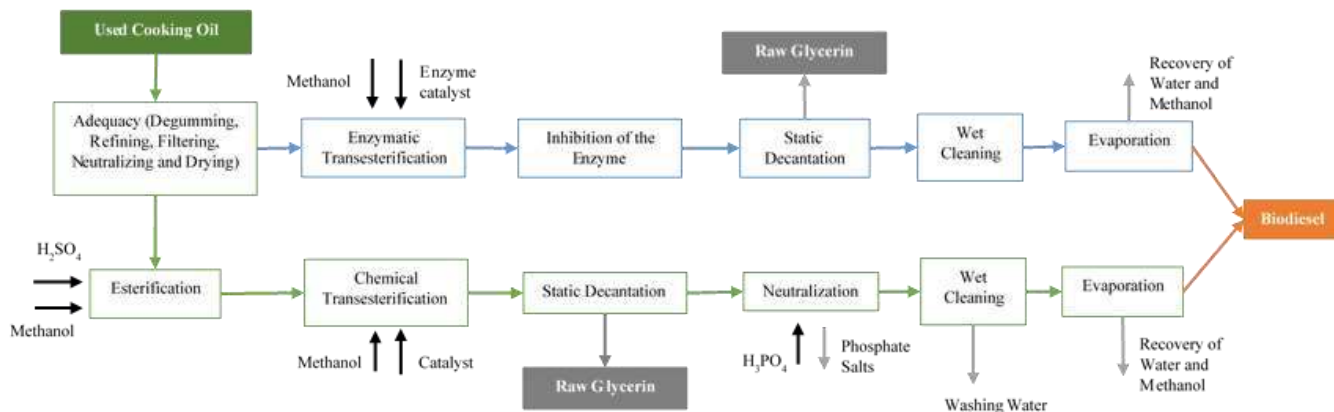


Figure 1: Diagram of chemical and enzymatic production process of biodiesel from UCO.

Source: Self-elaboration

III. METHODOLOGY

Physicochemical properties of the feedstock. UCO was collected in a restaurant in the city of Cúcuta. The oil was filtered in order to remove sediments (i.e. food residues, emulsions) which could interfere with the development of transesterification reactions. Analyses were developed to determine the quality of the UCO such as density, refraction index, moisture content [19], kinematic viscosity, the percentage of acidity [20], peroxide index [21], saponification value [22] and fatty acid profile [23].

Production of biodiesel from UCO

Chemical transesterification. The chemical conversion of the UCO to biodiesel was developed at lab-scale with an oil volume of 500 ml. As a primary step, the amount of free fatty acids (FFA) were reduced. In order to achieve the latter, the oil volume was mixed with methanol (molar ratio 1:6, oil:alcohol) and sulfuric acid (H_2SO_4 , 1% w/w). The reaction took place under 60 °C and 200 rpm for 60 min. The obtained sample was subjected to a chemical transesterification for conversion to methyl esters of fatty acids. The sample was mixed with methanol (molar ratio 1:6, oil:alcohol) in the presence of 1% (w/w) potassium hydroxide (KOH) at 60°C and 200 rpm. The influence of reaction time on the yield of biodiesel was evaluated with two different experiments: 55 and 70 min (Q1 and Q2).

Enzymatic Transesterification. Due to the ability of enzymatic transesterification to not be affected by the presence of FFA, there was no need to reduce its concentration on the oil sample. 500 ml of oil was mixed with methanol (molar ratio 1:3, oil:alcohol) and 5% of lipase XX 25 split (enzymatic catalyst), the process was carried out at 38 °C to prevent the inactivation of the enzyme. After adding the

enzyme, the mixture was homogenized for 15 min prior to adding the alcohol. The reaction times of 3 and 6 hours (E1 and E2) were applied to evaluate the most favourable condition in the production of methyl esters of fatty acids. After complete reaction time, the product obtained was subjected to a process of heating to a temperature of 70 °C for 15 min in order to inactivate the enzyme, taking advantage that its inhibition occurs at temperatures over 35-50 °C [24].

Purification of the obtained biodiesel. The resulting mixture was separated by decantation (12 hours) in which the formation of two phases was identified: the upper one, which was biodiesel and the lower one corresponding to glycerol. The biodiesel obtained by the chemical process was subjected to neutralization to counteract the excess of the catalyst that did not react; this process was carried out using phosphoric acid (H_3PO_4) at 60 °C for 15 min. Then, five spray washes were carried out with 100 ml of distilled water, applying decantation times of 15 min for each wash and 12 hours for the last wash, this protocol allowed the dragging off particles to the bottom (remains of catalyst) contributing to the biodiesel conforming to the quality standards required by EN 14214 standard [12]. Finally, the obtained product was taken to an R-210/215 rotavapor to recover the water and the residual methanol from the process.

Characterization of the obtained product. In order to compare the properties and quality of the obtained biodiesel, the samples were compared according to standard EN 14214 [12]. In the physicochemical characterization, some previously evaluated parameters were taken into account in the raw material (i.e. density, kinematic viscosity, moisture content and refraction index), additional parameters were also studied (i.e. flash point [25], acid number [26], copper strip corrosion [27], and ester content [28]).

IV. IV RESULTADOS

Physicochemical properties of the feedstock. The UCO presented characteristic organoleptic properties of a burned oil such as dark colour and strong odour; also, a dense and viscous phase with a lighter colour was identified. The oil presented a percentage of acidity of 2.572%, which is below to those used by [7] and [29] (with 3.243% and 9.193%, respectively). This is an important parameter to define if the production process takes place in two stages (esterification and transesterification) [9], which for the enzymatic process is not necessary to consider since the high content of FFA in the oil does not promote the formation of soap and are immediately converted into methyl esters of fatty acids [17]. The oil sample presented low moisture content (0.055%), is lower than that reported in other investigations such as [30] and [29] that obtained 1.34% and 0.1046%, respectively. This low moisture content makes it an optimal parameter for the performance of chemical transesterification as shown by [14], who recommends working with a moisture percentage lower than 0.5% in the production of biodiesel.

The oil has a density (0.962 g/cm^3) similar to that reported by the investigations of [31] and [30] with 0.924 g/cm^3 and 0.93 g/cm^3 respectively. However, the value obtained is high taking into account the density reported by [32] of 0.887 g/cm^3 for used vegetable oil. The studies of [33] and [34] report values of kinematic viscosity, below that obtained in the present investigation being $52.892 \text{ mm}^2/\text{s}$, with an average value of $9.12 \text{ mm}^2/\text{s}$ and $49.04 \text{ mm}^2/\text{s}$, respectively. However, the viscosity is lower compared to the $131.5934 \text{ mm}^2/\text{s}$ reported by [9]. The peroxide value obtained was $12.505 \text{ meqO}_2/\text{g}$, which is higher than $10.448 \text{ meqO}_2/\text{g}$ reported by [35] and with $2.561 \text{ meqO}_2/\text{g}$ obtained by [36] for fat chicken residues. The saponification index found was 174.686 mgKOH/g , being below the 201.5 mgKOH/g obtained by [29] and higher than 172.65 mgKOH/g reported by [30]. Concerning the refraction index of 1.462 [7] reported a similar value of 1.461 for frying oil; this property is characteristic for each type of oil because it indicates the degree of unsaturation of the fatty acids by the oxidation action of the oils [8].

The sample of UCO showed a high concentration of oleic and palmitic acid (42.45% and 33.52%). In addition, there was a small percentage of stearic acid (7.44%), being the main fatty acids that represent 83.41% of all the sample; 16.59% of the remaining percentage is distributed in small contents of various acids such as myristic, palmitoleic and lauric acids. This profile of fatty acids is similar to the mixture of palm oil and soybean characterized by [37], where the predominant acids are oleic acid and palmitic acid with a content of 39.9% and 35.8%, respectively.

Physicochemical properties of the product obtained

Biodiesel obtained by chemical process. In Table 1, the parameters of density, kinematic viscosity and refraction index of the product obtained are presented. Data showed a decrease in their value compared to the results obtained in the physicochemical characterization of the UCO. This behaviour is consistently similar to the results presented by [38], which obtained a density lower than 0.899 g/cm^3 and a similar viscosity of $9.5 \text{ mm}^2/\text{s}$. As stated by [10] and [24], variations in these parameters indicate the conversion of Free Fatty acids into methyl esters, which is confirmed by the change in properties after the transesterification reaction. The moisture content in the sample increased in comparison to the UCO, which indicates that the water used in the washing process was not entirely removed from the product. Something similar happened in the research carried out by [29], where the biodiesel obtained had an increase in water content, reporting 0.516%, a value slightly higher than that obtained in this study. In [16] a flashpoint of $171 \text{ }^\circ\text{C}$ was found, being below the value determined in the two biodiesel samples of the present work, which comply with the minimum quantity established by the quality standards. Concerning the acid number, the best value obtained was that of the biodiesel produced in the Q2 treatment. However, the two

samples produced do not comply with the standards required by the European standard. The result reported in this study is greater than the acid number found in other investigations that used the same raw material from chemical processes [14], [31], [32]. However, the acid number value obtained by [10] of 1.7 mgKOH/g is more significant than calculated in this study. This result can be attributed to the incorrect neutralization stage, or the type of washing agent used, as shown [8] who obtained the best values when performing the washing of biodiesel with acetic acid. In the characterization of the product, only the flash point and copper strip corrosion comply the quality standards of EN 14214 [12].

Biodiesel production by enzymatic process. The biodiesels obtained did not show changes in its properties compared to those that had been registered for the UCO. As shown in Table 1, the density and refraction index were similar to those of the raw material, indicating that the conversion in methyl esters of fatty acids was not carried out under the operating conditions developed (E1 and E2). A difference of what reports [39] where the density value of the biodiesel obtained by cooking oil used from the immobilization of the *Rhizopus Oryzae* lipase was 0.89 g/cm^3 . The kinematic viscosity showed no change after the reaction, similar to the study carried out by [32] with oil used in an acid-base process, where FFA and triglycerides were found that did not change. Copper strip corrosion is below the maximum value required by the quality standards for biodiesel, which leads to this property along with the flashpoint are the only ones that comply the standards of EN 14214 [12]. A high acid number was obtained, which indicates that there was an increase in FFA in the sample because the enzyme developed three reactions in parallel (e.g. hydrolysis, esterification and transesterification). The enzyme at the time of the esterification of the FFA caused that small amounts of methyl esters were produced together with water, this reacted with the triglycerides that had not yet been transformed in the oil generating more FFA and glycerol. Which in turn produced a slow process and less effective, since in some cases excess water acts as a competitive inhibitor of lipase [40].

In Table 1, the ester content of the biodiesel samples obtained for each developed process is presented. The chemical transesterification test that showed the highest ester content was Q2 (Temperature: $60 \text{ }^\circ\text{C}$, 1% KOH, molar ratio 1:6 oil-methanol, 70 min) with 96.15%, obtaining the best performance in comparison with the values obtained for biodiesel produced by enzymatic transesterification which were 48.81% and 47.53%. However, the two samples of biodiesel produced by chemical catalysis do not reach the minimum percentage of esters established by the standard EN 14214 [12].

Table 1: Characterization of the biodiesel obtained.

Parameter	Treatment				EN 14214 [12]
	Q ₁	Q ₂	E ₁	E ₂	
Density at 25 °C (g/cm^3)	0.918	0.920	0.963	0.964	0.86-0.9
Moisture content (%)	0.449	0.387	0.421	0.359	500 mg/kg
Refraction index	1.4462	1.4425	1.4631	1.4632	-
Kinematic viscosity (mm^2/s)	9.303	9.483	50.538	50.710	3,5 – 5
Flashpoint ($^\circ\text{C}$)	178.4	174.1	> 200	> 200	101 Min.
Copper strip corrosion	1a	1a	1a	1a	N° 1 Min.
Acid number (mgKOH/g)	1.582	1.327	7.453	7.645	0.5 Max.
Ester content (%)	94.21	96.15	48.81	47.53	96.5 Min

Source: Self-elaboration.

As shown in Figure 2, the biodiesel obtained by [8], who worked an alkaline transesterification with sodium hydroxide (NaOH) reported 96.41% of ester content, being a value similar to the best percentage obtained in the present study. The study carried out by [9] reports the lowest content of 77.6% when using cooking oil used in an alkaline transesterification with KOH and methanol. The work developed by [38] with a content of esters between 91-92% when using methanol and 0.75% KOH in an alkaline transesterification. The biodiesel produced by [7] obtained the highest content of esters in a 99.16% exceeding the quality standards when working with residual oil from an alkaline transesterification with NaOH and methanol, under a subcritical reaction temperature range (160-200 °C). The product obtained by [10] complied with the ester content, reporting a percentage of 98.82% when working with domestic oil residues through a chemical transesterification using KOH and ethanol. For the production of biodiesel from enzymatic transesterification is the work carried out by [39], which used *Rhizopus Oryzae* immobilized lipase from used cooking oil, obtaining an ester content between 88-90%. Only biodiesel obtained from a mixture of residual frying oil with canola oil complies with the standard, reporting 97.8%, using 15% of immobilized enzyme Novozym 435 and applying long reaction periods that exceed 48 hours [40].

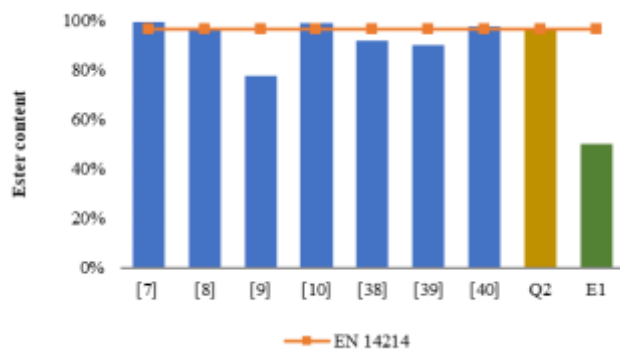


Figure 2: Analysis of ester content

Source: Self-elaboration based on contributions from [7], [8], [9], [10] [38], [39], [40].

V. SOLUTION PROPOSAL

The production of biodiesel is a viable alternative for reducing the dependence on fossil fuels in the transport sector, minimizing air pollution caused by greenhouse gas emissions. Additionally, it is positioned as a favorable option for the sustainable use of the UCO, proposing a solution to the environmental problems generated by the incorrect final disposition of this agroindustrial waste in the environment; it has been estimated that each liter of UCO that is thrown into the water sources causes the contamination of 1000 liters of water [41]. Considering the UCO volumes generated in the country (60 million liters per year), the negative environmental impact is of great proportions and to avoid it as much as possible constitutes a mitigating action.

Regarding the environmental benefits of the use of biofuels, such as ethanol and biodiesel, there is a reduction of GHG emissions by 12 and 41%, respectively, in relation to fuels [42], [43]. Thus, [44] and [45] they obtain that the emissions of carbon monoxide (CO) and carbon dioxide (CO₂) decrease when using biodiesel-diesel mixtures, due to the oxygen content in the biodiesel (11%) and the increase of the engine speed during combustion. Similarly, [46] show that CO emissions decrease by 30% when using a B25 mixture (i.e. 25% biodiesel-75% diesel, w/w), related to the increase in the amount of methyl esters in it biofuel.

In the investigation of [47] it is found that the specific consumption of the fuel is reduced by using biodiesel mixtures from vegetable sources other than palm oil, with conventional diesel,

reporting a lower consumption of this in D80/H20 mixtures (80% diesel with 20% biodiesel from castor oil) and D80/P10/AFU10 (80% diesel with 10% biodiesel from palm oil and 10% biodiesel from used frying oil). Regarding the composition of the combustion gases, [48] showed that the mixture of diesel by 70% together with biodiesel produced by palm oil (7.5%), castor oil (7.5%) and used frying oil (15%) has a better combustion than the B30 mixture (70% Diesel, 30% Palm oil biodiesel) since it shows an increase in CO₂ production and a large decrease in CO. Finally, several studies indicate that the use of biofuels significantly reduces the emissions of particulate matter (PM), hydrocarbons (HC) and nitrogen oxides (NO_x), compared to conventional diesel [42], [49], [50].

In order to identify the impact of biodiesel from UCO in air, Figure 3 shows Ramírez's study [51], which evaluated the emissions of CO, NO_x and sulfur dioxide (SO₂) generated when using different biodiesel-diesel blends, in a 1600 cc four-cylinder diesel engine operating at a speed of 2000 rpm and with the biodiesel obtained from the UCO. As for the CO, it can be seen that its concentration decreases by 14 ppm when using a B100 mixture (ie 100% biodiesel) with respect to the B0 mixture (ie 0% biodiesel - 100% diesel), which is due to the quality of biodiesel, since a high content of esters ensures a decrease in CO generation [52].

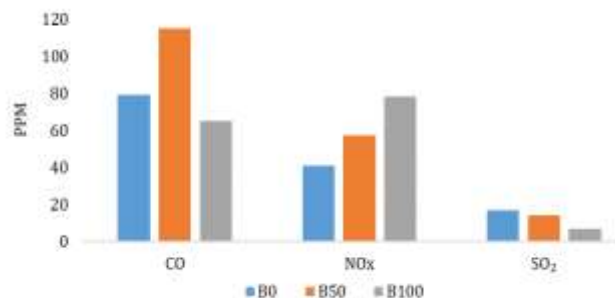


Figure 3: Emission of gases by biodiesel-diesel mixture
Source: Adapted from [53].

On the other hand, NO_x emissions increase with the use of biodiesel (B100) compared to pure diesel (B0). This result is consistent with the literature, which indicates that the use of biodiesel generates higher NO_x emissions, despite its high cetane index [53], [54], because the NO_x emissions in fuels are due to the presence of oxygen in its molecular structure or to a high degree of instauration in biodiesel [45]. This oxygen improves the oxidation of the fuel during combustion, which results in higher local temperatures, generating an increase in NO_x emissions by a thermal formation mechanism [53], [55], [56].

Regarding SO₂ emissions, they decrease when the percentage of biodiesel in the mixture increases, with a minimum value (i.e. 7 ppm) for pure biodiesel (B100), unlike the pure diesel that generated 17 ppm. However, Ramírez [51] assures that the presence of SO₂ in these mixtures is not to be expected, since it is assumed that biodiesel has a low sulfur content but could be affected by the frying of food in the oil.

VI. CONCLUSIONS

The biodiesel obtained by the chemical process presented the highest conversion percentages (96.15%) without complying with the quality standard (96.5%). This is probably due to the quality of the sample of oil collected and that the residues of FFA were not removed in the biodiesel purification, which led to a decrease in the yield of the product obtained. It was evidenced that enzymatic transesterification was incompletely developed, the enzyme presented an interruption of its catalytic activity, so the operating variables studied are not optimal to work with this type of raw material. Therefore, it is necessary that

the UCO be subjected to a more efficient pre-treatment, establishing a better filtering process and optimizing the biodiesel purification process applying a better drying system. Biodiesel obtained by not complying with quality standard cannot be used as a biofuel in the automotive sector, however, its application in another sector such as electricity can be studied, where it can be adapted for its implementation as a fuel for power plants in the generation of energy in some areas not interconnected to the national electricity system.

VII. ACKNOWLEDGMENTS

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VIII. REFERENCES

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