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BIODIESEL PRODUCTION FROM RECYCLED WASTE OIL IN CHAMISTRY CLASSES: AN APPROACH TO RECYCLINGAND SUSTAINABILITY

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ABSTRACT

The aim of this study was to produce biodiesel from recycled waste oils using an alkaline transesterification reaction, and to evaluate the most suitable experimental conditions, as well as its potential as a teaching resource for chemistry, whilst promoting recycling and sustainability. The research adopted an experimental approach using pre-treated waste cooking oil, which was subjected to different transesterification tests, varying the type of alcohol, the catalyst, the oil/alcohol molar ratio, the temperature and the reaction time. Nine tests were carried out and the biodiesel obtained was assessed in terms of visual appearance, combustibility and density. The results indicated that six trials produced biodiesel, whilst three resulted in a lack of phase separation and saponification. The best results were obtained using methanol as the solvent in combination with potassium hydroxide (KOH), which produced a biodiesel with a yellow colour, a clear appearance, efficient combustion and a density of between 0.863 and 0.872 g/mL, which is consistent with data in the literature. It is concluded that the efficiency of the process depends on the interaction between the reaction variables and the quality of the raw material, confirming the viability of waste oil recovery and its potential as an educational strategy in the teaching of chemistry and the promotion of sustainability.

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INTRODUCTION

The teaching of chemistry, as well as that of other sciences, aims to educate and prepare citizens to face global modernisation and work with technology, so as to enable them to use their knowledge of chemistry effectively in solving social problems. Thus, introducing pupils to the study of chemistry, with a view to acquiring knowledge relevant to their daily lives, should focus on aspects such as: the handling of chemical substances; understanding the chemical terminology found in food, medicines, drinks, fuels and various industrial products; and developing a critical perspective on social and environmental issues involving chemistry. All of this is of the utmost importance for the future citizen, who is expected to be prepared to serve society (Friedrich, 2019). According to Vechiatto (2020), the teaching of chemistry should be contextualised through social themes such as medicines, cleaning products, the environment, energy resources and food. The same author refers that, education for citizenship should not focus on the memorisation of formulas and nomenclature, but rather on teaching strategies that promote experimentation, contextualisation and the resolution of everyday problems (Vechiatto, 2020). In this process, the teacher plays a key role in developing experimental activities, defining procedures suited to pupils' needs, appropriate experimental methods and the attitudes to be adopted, thereby distinguishing this approach from traditional teaching practice (Friedrich, 2019; Lígia Bueno, 2013). In Angola, the lack of laboratories in most educational establishments has contributed significantly to the absence of experimental activities, which has a direct impact on the shortcomings in the teaching of this subject, compromising the effective delivery of teaching. For decades, there have been calls for the use of renewable sources to produce fuels, given that the use of oil has a negative impact on the environment. This urgency arose with climate change which has been proven to be one of the main causes of CO_2 emissions resulting from the combustion of petroleum-derived fuels and has led to a search for renewable fuel alternatives (Arthur Seidel; *et al.,*, 2021; Yeletsky *et al*., 2020). In order to directly reduce high greenhouse gas emissions and meet current and future energy needs, the development of sustainable alternatives derived from renewable energy sources and the associated technologies is the main focus today when it comes to replacing fossil fuels (Alexandra *et al*., 2022). In recent years, the production of biofuels from biomass has attracted enormous interest in various parts of the world, representing a highly attractive and promising key alternative (Alexandra *et al*., 2022; Yeletsky *et al*., 2020). Renewable sources for biodiesel production can be of many different types, whether of plant, animal or waste origin (Friedrich, 2019). Biodiesel can be used in engines without the need for any modifications and without any loss of performance, and it helps to extend the engine's service life, as it is a superior lubricant to petroleum-based diesel (Ferreira, 2009). In this context, this research will investigate the conversion of recycled waste oils into biodiesel via transesterification in a basic medium using alcohols, with a view to helping students understand that this is a viable alternative which maximises the use of waste resources for energy production, whilst simultaneously reducing operating costs and environmental pollution.

Biodiesel: From a chemical point of view, biodiesel can be defined as an alternative fuel consisting of esters of long-chain carboxylic acids, derived from renewable sources such as vegetable oils or animal fats, which can be used directly in compression-ignition engines (Ferreira, 2009). This biodiesel is obtained through the transesterification reaction (also considered a form of alcoholysis) of a vegetable oil in the presence of primary alcohols. Biodiesel is a liquid fuel obtained from entirely renewable sources, primarily of plant or animal origin, such as, oils and fats. It is a derivative of vegetable oils or animal fats, which undergo a transesterification reaction in the presence of a catalyst and alcohol to form alkyl esters (Oliveira Da Costa, 2017). This biofuel is biodegradable, non-toxic and virtually free from sulphur and aromatic compounds. Pure biodiesel, or biodiesel blended with conventional diesel in certain proportions, can be used in diesel engines without the need for any modifications (Demirbas, 2008). Biodiesel has emerged as a sustainable alternative to fossil fuels, whose environmental impacts and rising demand have accelerated the search for renewable energy sources (Nuno *et al*., 2015). Replacing fossil-based diesel with biodiesel significantly reduces emissions of pollutants into the atmosphere, in particular sulphur oxides (SOx), which are responsible for acid rain, and particulate matter (Angelkorte, 2019).

Biodiesel production: Biodiesel can be produced in the presence of a catalyst, which may be an acid, a base or an enzyme, and the reaction can take place in a homogeneous or heterogeneous medium (Ramos *et al*., 2011). The most commonly used catalysis is homogeneous alkaline catalysis, as it is the quickest and easiest method, although it is less environmentally sustainable. However, it is this that makes the process economically viable in our context. The catalyst, most commonly NaOH or KOH, can be added directly to the reaction medium or dissolved in the alcohol used as the transesterification agent (Fernandes Medeiros *et al*., 2014).

Transesterification: Currently, biodiesel is produced on a large scale using a chemical process known as transesterification or alcoholysis, which involves the chemical decomposition resulting from the interaction between a chemical compound and an alcohol (Sampaio José Fernandes, 2008). The transesterification reaction involves the reaction between a triglyceride (triacylglycerol) and an alcohol (usually methanol) to produce fatty acid esters (biodiesel), with glycerine also being obtained as a by-product (which can be utilised in the soap market) (Medeiros & Almeida, 2014). Figure 1 illustrates the transesterification reaction.

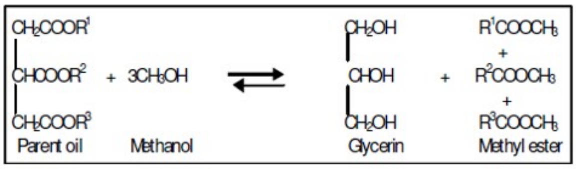


Image adapted from (Abdul Raqeeb, 2015)

Figure 1. Transesterification reaction

To produce biodiesel, the selected vegetable oil must be mixed with an alcohol (methanol, ethanol, propanol, butanol or amyl alcohol). However, the most commonly used alcohols are methanol and ethanol (Larcombe *et al*., 2015).

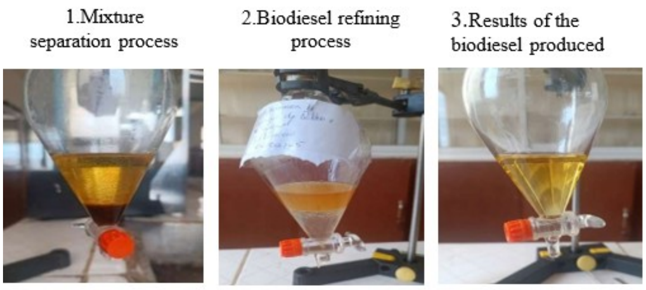
MATERIALS AND METHODS

Materials and reagents: The feedstock used in this study is recycled waste oil (frying oil). The waste oil used for biodiesel production was obtained from different sources: 350 ml from the author's home and 650 ml from a takeaway stall in the city of Uíge, making a total of 1 litre of waste oil. The reagents used (CH_4O, KOH and NaOH) were supplied by PanreacQuímica SAL, whilst C_2H_6O was supplied by AB Cosméticos. The recycled waste oil used is of the 'Soja' brand.

Oil recycling: After collection, the oil was subjected to an initial filtration through a sieve. It was then heated to 120 °C, the temperature required to evaporate any traces of residual water. To ensure the purity of the product, the oil was left to stand in a plastic container for 24 hours, allowing solid residues to settle at the bottom of the container. After this period, the oil was filtered again, this time using a cotton cloth to retain smaller particles, and was subsequently stored in a 1.5-litre bottle.

Biodiesel Production Trials: To produce biodiesel, more than 10 trials were carried out in order to identify the most optimised and viable reaction, by varying the operational factors. The procedures used to produce the biodiesel were adapted to the methodology proposed by(Friedrich, 2019). Once the standard reaction had been identified, the procedure for subsequent experiments remained the same, with the sole difference being that the quantities of the reagents (solvent, catalyst) and the oil were altered. The model protocol for the optimised reaction, suggested for adaptation by the students, is described below:

Initially, 100 ml of pre-treated waste oil, 50 ml of ethanol and 0.5 g of potassium hydroxide (KOH) were used. The catalyst was dissolved in ethanol, with stirring, to promote the formation of potassium ethoxide (C_2H_5OK), which acted as the catalyst for the transesterification reaction. The waste oil was first heated to 80 °C to dry it, and then cooled to 50 °C to initiate the transesterification reaction. The potassium ethoxide solution was then slowly added to the heated oil, whilst maintaining continuous stirring throughout the process. The transesterification reaction took place for 30 minutes at a temperature of 50 °C. Once the reaction had finished, the reaction mixture was transferred to a separating funnel and left to stand for 15 hours to allow the phases to separate by gravity. After this period, two distinct phases were observed: the upper phase is the biodiesel and the lower phase consists mainly of glycerine, residual catalyst, soaps and other impurities. The biodiesel obtained was subjected to a washing step using 30 ml of distilled water containing 10 g of sodium chloride (NaCl), in order to remove any remaining impurities. After separation from the aqueous phase, 25 ml of purified biodiesel was collected and stored in sealed glass vials for basic physico-chemical analysis. All these processes can be seen in the images in Figure 2.



Source: Adapted by the authors

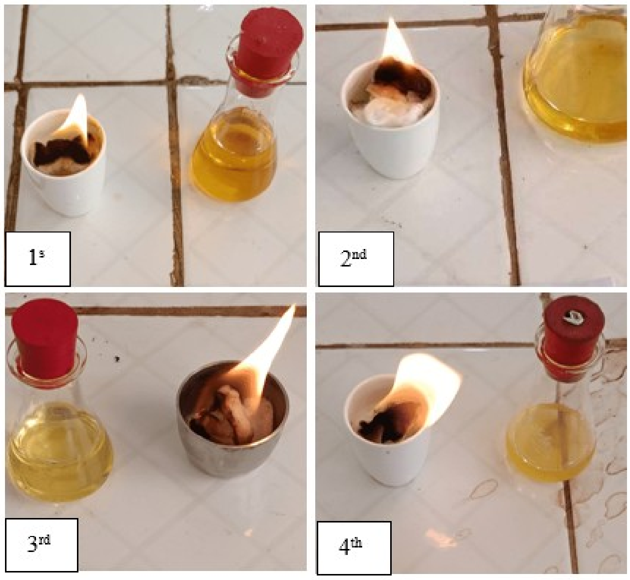
Figure 2. Stages in biodiesel production

Tests for the identification of biodiesel

Visual assessment (colour and appearance): Once the biodiesel had been obtained, a qualitative visual assessment was carried out to analyse its physical characteristics, namely its colour, turbidity, homogeneity and the possible presence of impurities. The appearance of biodiesel is a parameter used in preliminary analysis, which aims to detect the presence of impurities that can be identified visually, such as suspended matter, sediment or even cloudiness in the biodiesel sample, which may be due to the presence of water. In the absence of these contaminants, the biodiesel is classified as clear and free from impurities (Lobo *et al*., 2009). To test the colour and appearance of the biodiesel, the same procedures were carried out to assess these aspects in the biodiesel produced, and the results were similar to those of this study. Therefore, by observing and comparing the images in Figure 2, which resulted from this study, it can be concluded that they comply with the characteristics recommended by the literature, as no particles were detected either in suspension or deposited at the bottom of the container (Arthur Seidel; *et al.,*, 2021).

Biodiesel combustion test: To check whether the biodiesel produced was suitable for use as fuel, a simple test was carried out based on the procedure described by (Arthur Seidel *et al.,*, 2021). In accordance with the procedure described by these authors, the following steps were taken:

A small piece of string was dipped in the stored biodiesel and placed inside a crucible. Next, taking great care, the string soaked in biodiesel was ignited using a source of ignition (a match), and the flames produced by the biodiesel on the string inside the crucible were observed, as shown in Figure 3.



Source: Adapted by the authors

Figure 3. Combustion tests on the biodiesel produced

Determination of the density of biodiesel: The density of the biodiesel was determined by the ratio of its mass to its volume. First, the mass of the empty 100 ml beaker was determined using an analytical balance. A known volume of biodiesel, previously measured using a graduated cylinder, was then transferred to the beaker, after which the beaker was weighed again. The mass of the biodiesel was calculated as the difference between the mass of the beaker containing the sample and the mass of the empty beaker, as shown in the equations below:

Eq.1 $m_{bio} = m(becker + biodiesel) - m(becker)$

To calculate the density of biodiesel, the following applies:

Eq. 2 $\boldsymbol{d_{bio} = \frac{m_{biodiesel\,(g)}}{V_{biodiesel\,(mL)}}}$

All the measurements were taken at room temperature (25 ºC). All calculations were carried out in triplicate to ensure the reliability of the calculations and the results.

RESULTS AND DISCUSSION

Results regarding the methodology used in biodiesel production: The results presented in Table 1 show that variations in the oil/alcohol ratio, the type of alcohol, the catalyst, the temperature and the reaction time significantly influenced the yield and quality of the biodiesel obtained. Of the nine trials carried out, only trials 1, 2, 4, 5, 8 and 9 resulted in the production of biodiesel, whilst trials 3, 6 and 7 did not produce the expected product; trial 3 resulted in saponification.

Table 1. Results obtained from biodiesel production in different trials

Essay	*V_{oil} (mL)*	*Base*	*m_{base} (g)*	*Type of alcohol*	*V_{Al} (mL)*	*Temp. (ºC)*	*Reaction time*	*V_{bio} (mL)*
1st	100	KOH	0.5	Ethanol	50	50	30 min.	25
2nd	100	KOH	0.3	Ethanol	30	55	1h	45
3rd	100	NaOH	0.3	Ethanol	30	55	1h:30 min.	N/D
4th	100	NaOH	0.2	Ethanol	20	40	45 min.	40
5th	50	KOH	0.3	Methanol	10	50	50 min.	38
6th	50	KOH	0.3	Ethanol	10	50	50 min.	N/D
7th	50	KOH	0.35	Ethanol	20	50	1h:30 min.	N/D
8th	50	NaOH	0.3	Et./Met.	10	50	1h	25
9th	50	NaOH	0.5	Methanol	15	50	1h:15 min	36

Table 2. Results of the assessment of the colour and appearance of biodiesel

Essay	*Colour of biodiesel*	*Aspect*	*State of aggregation of the product(s)*
1st	Brown	Cloudy	Liquid/liquid
2nd	Brown	Cloudy	Liquid/liquid
3rd	N/D	N/D	Solid
4th	Brown	Semi-cloudy	Liquid/liquid
5th	Yellow	Crystal-clear	Liquid
6th	N/D	N/D	Liquid
7th	N/D	N/D	Liquid
8th	Brown	Semi-cloudy	Liquid/liquid
9th	Yellow	Crystal-clear	Liquid/liquid

Table 3. Results of the combustion test

Essays	*Combustion test results*		
1st	Moderate	6th	N/D
2nd	Moderate	7th	N/D
3rd	N/D	8th	Moderate
4th	Moderate	9th	Effective
5th	Effective		

Table 4. Results of the calculations for mass, volume and density obtained at 25 ºC

Essay	*Volume of biodiesel (ml)*	*Mass of biodiesel (g)*	*Molar ratio of oil to alcohol*	*Density (g/ml)*
1st	25	17	1:8	0.68
2nd	45	39	1:5	0.866
3rd	N/D	N/D	1:5	N/D
4th	44	38	1:4	0.863
5th	38	33	1:5	0.868
6th	N/D	N/D	1:4	N/D
7th	N/D	N/D	1:7	N/D
8th	25	21.6	1:4	0.864
9th	36	31.4	1:7	0.872

The results obtained show that transesterification in an alkaline medium depends to a large extent on the rigour and optimisation of the reaction conditions. The results show that the largest volumes of biodiesel obtained, in trials 2 and 4 both using 100 ml of waste oil were produced using different catalysts and reaction conditions. These results suggest that the combination of the oil/alcohol ratio, the catalyst concentration and the reaction time favoured a more efficient conversion of triglycerides into alkyl esters. These factors can be compared with those of the study in question(Larcombe *et al*., 2015),it can be stated that the efficiency of transesterification depends on effective contact between the reacting phases, an adequate amount of catalyst, and the shifting of the chemical equilibrium through the use of an excess of alcohol. The effect of the oil/alcohol ratio can be observed by comparing the different experiments. In the experiments where molar ratios of 1:4 and 1:5 were used (see Table 4), good experimental results were obtained. On the other hand, higher ratios did not result in a higher yield, with the exception of experiment 9, which was influenced by the type of alcohol used. This observed behaviour is consistent with the results of studies done by(Atabani *et al*., 2013; Atadashi *et al*., 2010; Meher *et al*., 2006) demonstrated that there is an optimal alcohol concentration capable of increasing conversion without compromising phase separation. A key factor to be taken into account in this study was the type of alcohol used in the reactions. Trials 5 and 9, carried out using methanol, produced a biodiesel with a better visual appearance and which achieved better results in the combustion test, compared with the trials carried out using ethanol. This difference can be attributed to the physicochemical properties of methanol, which has higher polarity, lower steric hindrance and greater chemical reactivity, thereby favouring higher reaction rates and greater conversion of triglycerides into methyl esters (Sharif Hossain *et al*., 2010). In contrast, ethanol tends to promote the formation of emulsions, particularly when it contains small amounts of water. Similar results were reported by (Atabani *et al*., 2013; Gui *et al*., 2008; Muhammad Idris1, 2024; Patel & Singh, 2024) which found higher yields for methanol-based catalyst systems compared with ethanol-based ones. The comparative efficiency of the catalysts is one of the key aspects observed in this study. Potassium hydroxide (KOH) performed better in several tests, particularly when combined with methanol. On the other hand, some tests carried out with sodium hydroxide (NaOH) yielded no results, whilst in others saponification occurred. According to the studies carried out by (Encinar *et al*., 2020; Moser, 2009),) , both catalysts can achieve high conversion rates, provided that raw materials with low acidity and low moisture content are used. Finally, tests 3, 6 and 7 did not produce biodiesel; instead, solid material formed because no phase separation occurred between the materials. This behaviour can be explained by the occurrence of the saponification reaction, a secondary process that competes with alkaline transesterification, a factor that was highlighted in the studies carried out by (Atadashi *et al*., 2010; Helwani *et al*., 2009; Larcombe *et al*., 2015) and as can be seen in Figure 4 of this paper.

Adapted by the authors

Figure 4. Saponification results for the product from test number 3

Colour, appearance and quality of biodiesel: The results presented in Table 2 show that tests 5 and 9 produced a biodiesel with a yellow colour and a clear appearance, indicating a high conversion of triglycerides and a low presence of glycerol, soaps and other impurities. On the other hand, trials 1, 2, 4 and 8 produced brown and cloudy or semi-cloudy biodiesel, suggesting incomplete phase separation or the occurrence of secondary reactions, such as saponification. Trials 3, 6 and 7 did not produce the expected biodiesel. These results are consistent withMonika *et al*., (2023)**,** indicating that the turbidity of biodiesel produced from waste cooking oils is often associated with the presence of free fatty acids, water, soaps and residual glycerol. SimilarlySaputro *et al*., (2022) state that biodiesels with a clear appearance and a pale yellow colour are normally obtained when the waste oil is properly pre-treated and the transesterification conditions are optimised(Monika *et al*., 2023; Saputro *et al*., 2022).

Table 2 clearly shows that the tests carried out with methanol (5th and 9th) exhibited cleaner combustion and densities within the expected ranges, whilst those carried out with ethanol showed greater difficulty in ignition and a cloudier appearance. The trend in these results can be compared with those presented by Monika *et al*, (2023), these researchers identified methanol as the most efficient alcohol in the alkaline transesterification of waste cooking oils, due to its high chemical reactivity. Another study states that, although ethanol is a renewable and more environmentally favourable alcohol, its greater affinity for glycerine promotes the formation of emulsions, which reduces yield and hinders the purification of biodiesel (Monika *et al*., 2023; Silitonga *et al*., 2025). The quantitative results revealed significant differences between the trials. The highest volume of biodiesel obtained was 45 mL in trial 2, followed by trials 4 (44 mL), 5 (38 mL) and 9 (36 mL). Conversely, trials 3, 6 and 7 did not produce any biodiesel. The literature indicates that the oil/alcohol molar ratio is one of the most important factors in the transesterification process. Although the stoichiometry of the reaction is 1:3, higher ratios are typically used to shift the chemical equilibrium towards biodiesel formation (Larcombe *et al*., 2015; Meher *et al*., 2006). According to Monika, et. Al (2023) the optimum molar ratio for biodiesel production using methanol and alkaline catalysts lies between 1:5 and 1:6, enabling conversions in excess of 95% (Monika *et al*., 2023). E Silitonga *et al* (2025)**,** add that very high molar ratios hinder glycerine recovery, whilst lower ratios significantly reduce triglyceride conversion (Silitonga *et al*., 2025). In this study, it was found that molar ratios of 1:5 and 1:4 produced the highest volumes of biodiesel. On the other hand, certain experimental conditions associated with the ratios 1:5, 1:4 and 1:7 did not result in the formation of the desired product, which indicates that the molar ratio, on its own, does not determine the success of the reaction. Efficiency also depends on the type of alcohol, the catalyst used, the quality of the waste oil, the temperature and the reaction time, as shown in Table 2. The biodiesels produced in tests 2, 4, 5, 8 and 9 had densities ranging from 0.863 to 0.872 g/mL, values consistent with the generally accepted limits for good-quality biodiesel. Test 1 showed a density of 0.680 g/mL, which may indicate the presence of residual alcohol, low conversion or difficulties with phase separation. Similar results were found by Saputro (2022), who obtained densities between 0.86 and 0.88 g/mL in biodiesel produced from waste cooking oil using methanol(Saputro *et al*., 2022). Other authors suggest that density values outside this range may be associated with the presence of impurities, excess residual alcohol or inadequate washing of the biodiesel (Silitonga *et al*., 2025)

CONCLUSION

The results obtained demonstrated that the production of biodiesel from recycled waste oil constitutes a technically viable alternative for the recovery of waste and a valuable teaching resource for chemistry education. The experimental analysis showed that the efficiency of transesterification depends directly on the interaction, reaction time and the quality of the feedstock. Among the conditions tested, methanol performed better than ethanol, resulting in biodiesel with a better visual appearance, more efficient combustion and densities between 0.863 and 0.872 g/mL values consistent with those reported in the literature for high-quality fuels. It was also observed that inappropriate conditions favour the formation of soaps, highlighting the need for rigorous optimisation of the reaction parameters. The assessment of simple properties, such as colour, combustion and density, proved effective for a preliminary analysis of biodiesel quality, and was particularly useful in educational contexts with limited laboratory resources. From a pedagogical perspective, the study reinforces the potential of biodiesel production as a teaching strategy to integrate content from organic chemistry, renewable energy and environmental education, promoting contextualised learning and sustainability awareness. In future studies, it is recommended that the reaction yield be determined and that more detailed physico-chemical analyses be carried out, such as viscosity, acid number and even characterisation by chromatography where equipment is available, to ensure a more complete characterisation of the biodiesel obtained.

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