

Sustainable Generation of Biodiesel using a Locally Available Bio-Based Substance as Non-Edible Feedstock

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Abstract

Feedstock for biodiesel production as fuel is made up of mono-alkyl esters of long-chain fatty acids obtained from renewable sources such as vegetable oils and animal fats via a transesterification reaction with short-chain alcohol in the presence of a catalyst, which results in the washing water as a residue and glycerine as a co-product). The properties of the biodiesel produced are determined by the raw material characteristics and the alcohol used in the reaction. This research aims to make biodiesel from used cooking oil (Sunflowerbased) from a local restaurant in Baghdad city, Iraq. This will be accomplished using a transesterification reaction involving methanol as the alcohol and a basic catalyst, specifically potassium hydroxide. Various experiments will be carried out, with temperature and reaction time parameters varied to find the best fit. Even though this is a quick reaction, it still takes several hours, so some way to speed it up is required. As a result, it will be carried out in an ultrasonic bath to obtain faster reaction times. The use of ultrasound helps to speed up this process by causing cavitation bubbles to form.

Keywords: Waste cooking oil, Biodieselgeneration,ultrasound, Characterization

1.0 Introduction

The significant worldwide use of diesel and rapidly depleting crude oil reserves have sparked interest in biofuel alternatives [1]. Kyoto Protocol limits fossil fuel emissions. 2025 CO₂ emissions are projected to reach 415 to 421 ppm [2]. Biodiesel is an alternative fuel that emits less CO₂ than non-renewable petrochemical fuels. Biodiesel can be used safely in compression-ignition engines and is renewable, biodegradable, and environmentally friendly. Biodiesel reduces unburned hydrocarbons, CO, and NO_x emissions in diesel engines. Biodiesel's density and cetane number are similar to automotive diesel. Still, it has a higher flashpoint. It can be blended with diesel in compression-ignition internal combustion engines (MCI-EC) and even replaced with some engine modifications. Biodiesel can reduce dependence on imported oil, becoming scarcer and more expensive. Transesterification is a catalysed chemical reaction involving vegetable oil and alcohol to produce biodiesel and glycerol. Transesterification uses homogeneous, heterogeneous, or enzymatic catalysts.

Biodiesel is made by trans esterifying used cooking oil. Used cooking oil's a free fatty acid and water content determines the process. Biodiesel is made from waste materials for sustainability and environmental reasons [3]. Second-generation biodiesel is produced from waste plant materials from food crops that have served their food purposes, such as oils already used in home and restaurant kitchens. This type of biodiesel is still very small, but it's more sustainable than the first generation because farmland isn't used and waste is

repurposed. Using vegetable fuel in diesel engines requires no major modifications. It allows agricultural producers to be fuel self-sufficient and agricultural countries to be oil independent. Its lubrication reduces engine wear. Compared to diesel fuel, it reduces carbon monoxide (CO), hydrocarbons, sulphur dioxide (SO₂), polycyclic aromatic hydrocarbons (PAH), and particulate matter (PM). Diesel-like performance in engines. Mixes with diesel in any proportion. Reduces start-up fumes. Biodegradable. It's 10x less toxic than table salt. High flash point makes transport and storage safer. Non-sulphur and catalyst-friendly. It's safe for people, plants, animals, and monuments/buildings. Combustion smells like frying, not diesel [4].

This work uses transesterification, the most common and best method for making biodiesel. Four main methods are used to make biodiesel: mixing oils with mineral diesel, micro-emulsions, thermal cracking, and transesterification. Unsaturated hydrocarbons are more viscous, less volatile, and reactive. After use tests, engines develop coke in the injectors, larger deposits, and lubricating oil gelling. Biodiesel has fewer calories per litre than diesel (7.795 vs. 8.74). Its kinematic viscosity is between 1.9 and 6.0 cSt, similar to diesel (1.3-4.1 cSt). Its density is 0.878 kg/L at 15°C, and its flash point is 130°C, making it a safer fuel than diesel. It doubles diesel's lubricating power and has a higher cetane number than diesel. There are many studies on biodiesel production and the ultrasound transesterification method [8]. We can confirm a good diversity of works, including some theses [5]. Recently, ultrasound has been used to produce biodiesel [6]. We also found studies [7] on our topic, using cooking oil. All these works served as a theoretical basis for this work, which combines ultrasound with used oil to make biodiesel.

2.1 Methodology of the experiences

2.1.1 method

The method chosen was basic transesterification with used oil from Baghdad City's local food restaurants. It was carried out in an ultrasonic bath to shorten the reaction time. Although using an ultrasound probe would increase the speed significantly (the reaction would be completed in a matter of minutes), we could not use such a probe due to material constraints, so we proceeded with the bath. With a 1:7 oil-alcohol molar ratio, methanol was used as the transesterification alcohol. Furthermore, two previous experiments were conducted to determine the preferred catalyst. Sulfuric acid (H₂SO₄) was used as a catalyst in both of these experiments, but the reactions were not completed correctly. Longer reaction times are expected when an acid is used as a catalyst [8]. As a result, a basic catalyst was chosen, specifically potassium hydroxide (KOH), which we see was used in [9] using the same method.

2.1.2 Procedure and assembly

As has been said, we have used frying oil as raw material. Specifically, sunflower oil has been used, from the kitchen of the selected restaurants in Baghdad. As seen above, an oil-alcohol molar ratio of 1:7 was used for the reaction, with 0.5% by weight of the catalyst. Therefore, the quantities used in each experience are:

- Waste cooking oil: 135g
- Potassium hydroxide (KOH): 0.675g
- Methanol (CH₃OH): 43ml

The set-up used is the same in all the experiences, except a control one that was carried out without ultrasound. It consists of a reactor (of different capacity depending on experience) immersed in an ultrasonic bath, with the help of a clamp, and covering the entire reaction with said bath, as shown in the following image:

A thermometer is inserted in said reactor, with which the temperature of the reaction is controlled at each instant.

For the ultrasonic bath, an Elmasonic S300H ultrasonic cleaning device has been used, which has the following specifications:

- Ultrasound frequency: 37kHz
- Total rated power: 1500W
- Effective ultrasound power: 300W
- Maximum ultrasound power: 1200W
- Bath capacity: 28l

Below is a simplified scheme of said assembly:

For the experiments, oil was heated in a water bath in a reactor (Fig. 1). When the oil reached the desired temperature, potassium hydroxide and methanol were added. Then, they were gently stirred with a stirrer until thoroughly mixed. The reactor was then placed in the ultrasonic bath and started. Uninterrupted ultrasound was used until reaction time elapsed. The ultrasonic bath's thermostat keeps the water at a temperature similar to when the experience began. Variations occurred due to the ultrasounds.



Figure 1: Reactor detail, reaction reaction decanting and Detail of stored biodiesel sample

After the reaction, the esters (biodiesel) were separated from the glycerine in a decanter. Biodiesel was washed with warm water in the decanter to remove methanol and catalyst. Next, glycerine, methanol, and catalyst were extracted as waste. The remaining biodiesel was stored for testing. The control experience assembly is simpler without ultrasound. The reactor is clamped on a stirrer to maintain temperature and agitation in this experiment. The thermometer monitors the temperature.

2.2 Programming of experiences

9 valid experiences were used to determine the best process parameters. Temperature and reaction time were varied. Observing other authors' experiences [8,9], we varied the time between 15 and 90 minutes and the temperature between 30°C and 40°C. Four experiments

were conducted at 30°C and four at 40°C. 15, 30, 60, and 90 minutes of reaction time each. The ninth test involved 4 hours at 40°C without ultrasound. Below is a table of the matrix's numbered experiences.

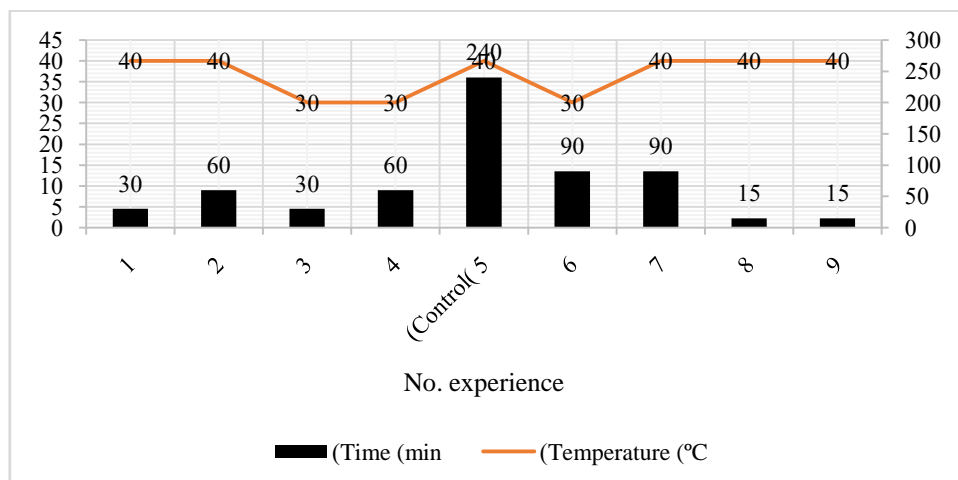


Figure 2: Matrix of experiences

2.3 Tests carried out

This section explains how biodiesel from different experiences was tested. Some tests were done on all samples, while others were only done on the best. For these tests and values, UNE-EN 14214 [10] was used. The standard also specifies the method standard for each property.

2.3.1 Moisture and volatile percentage

The original oil was tested for moisture and volatiles. In a beaker, 50g is sampled for the test. It's been weighed and baked at 100°C. Every 5 minutes, it was weighed to ensure that all water and volatiles had been removed. The percentage was found using the following formula:

$$\% \text{ Moisture} = \frac{m_{\text{initial}} - m_{\text{Final}}}{m_{\text{initial}}} \times 100$$

It is important that this value is as low as possible since a moisture content that is too high can cause problems, such as corrosion in the engine components, corrosion in the tank, or the appearance of microorganisms that clog the filter.

2.3.2 Density at 15°C

This property is important because fuel injection systems must measure fuel precisely for proper combustion. Density was measured using UNE-EN ISO 3838 [11]. A 50ml sample in a volumetric flask was refrigerated for a few minutes until it reached the desired temperature. When it reached 15°C again, the 50ml was adjusted with a pipette due to volume loss. After weighing the sample, the result was calculated using the following formula.

$$\rho = m/v$$

2.3.3 Acid value: The acid number indicates the amount of free fatty acids present in the fuel. If this ratio is too high, too many deposits will be produced, negatively affecting the fuel

pump, injectors and filters. The acidity index is useful to find the conversion percentage, explained in the next section. We have proceeded in accordance with the UNE-EN 14104[12] standard. For each of the tests the following products and amounts have been used:

- Biodiesel sample: approx. 8g
- Ether ($\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3$): 25ml
- Ethanol ($\text{CH}_3\text{CH}_2\text{OH}$): 25ml
- Phenolphthalein ($\text{C}_{20}\text{H}_{14}\text{O}_4$): 0.15ml
- 0.05M solution of potassium hydroxide (KOH) in ethanol

First, 50ml of ether and ethanol were mixed and added to 8g of biodiesel with 0.15ml of phenolphthalein. Erlenmeyer flask held the final mixture. Then, potassium hydroxide in ethanol was added. Drop by drop; potassium hydroxide was added to the previous mixture while stirring. The potassium hydroxide consumed until the mixture turned pink was noted. The acidity index was calculated with the following formula.

$$\text{Acid Value} = \frac{V_{\text{KOH dissolved}} \times N(\text{KOH}) \times M_{\text{KOH}}}{m_{\text{sample}}}$$

Since $N(\text{KOH})=0.05\text{M}$ and $M_{\text{KOH}}=56.1056$, the formula is as follows:

$$\text{Acid Value} = \frac{V_{\text{KOH dissolved}} \times 2.80528}{m_{\text{sample}}}$$

2.3.4 Conversion rate: This percentage derives from the acid number, and gives us an idea of what percentage of the transesterification reaction has been completed correctly. It is a relationship between the acidity indexes of the original oil and the biofuel obtained. It has been calculated with the following formula:

$$\% \text{ of Conversion} = \frac{\text{Acid Value}_{\text{oil}} - \text{Acid Value}_{\text{Biodiesel}}}{\text{Acid Value}_{\text{oil}}} \times 100$$

For this, the acidity index of the original oil has been calculated, giving a result of 0.25566mg KOH/g sample.

2.3.5 Iodine value: The iodine number is defined as the amount in grams of iodine adsorbed per 100g of sample. It gives us an idea of the level of unsaturation present in the fuel, since the higher this index, the higher the unsaturation content. Unsaturated fatty acids can lead to polymerization of glycerides, causing deposits or even deterioration of the lubricating oil. Therefore, it is important to limit the iodine value.

This index has been calculated in accordance with the UNE-EN 14111[13] standard, and the following products and quantities have been used for each of the samples:

- Biodiesel sample: approx. 0.25g
- Cyclohexane (C_6H_{12}): 10ml
- Acetic acid (CH_3COOH): 10ml
- Wijs reagent: 25ml
- Potassium iodide solution (KI): 20ml
- Distilled water (H_2O): 150ml
- 0.1M sodium thiosulfate solution ($\text{Na}_2\text{S}_2\text{O}_3$)

- Starch (C₆H₁₀O₅)_n

To carry out this determination, first, the sample was introduced into a 500ml flask, to which the solvent, composed of cyclohexane and acetic acid, was added (under a hood). Next, the 25 ml of Wijs reagent were added, covered, shaken and allowed to stand for one hour protected from light.

After this hour, the potassium iodide solution and distilled water were added, and titration began with the sodium thiosulfate solution. Using a burette, said solution was dropped drop by drop into the previous mixture, while it was kept continuously stirred. Later, when the characteristic yellow color of iodine began to disappear, a few drops of starch were added. Finally, the titration was continued with intense stirring until the bluish-gray color disappeared and the color remained colorless, noting the amount of thiosulfate used. The first test was carried out blank, without a biodiesel sample to take as a reference.

To determine the iodine value, the following formula was used:

$$\text{Iodine Value} = \frac{12.69 \times C_{\text{Thiousulf}} \left(\frac{\text{mol}}{\text{l}} \right) \times \left(V_{\text{Thiousulf (ml)}} - C_{\text{Thiousulf .oil (ml)}} \right)}{m_{\text{sample}} \text{ (g)}}$$

This test was performed on the biodiesel obtained in experiences 1, 4 and 5.

2.3.6 Color: This test was also carried out on samples 1, 4 and 5. They have been sent to the Arsenal de Ferrol laboratory for analysis, where they have been carried out in accordance with the ASTM D1500 standard [14].

2.3.7 Viscosity at 40°C: Viscosity measures the internal friction between molecules, that is, the resistance to flow of a liquid. This must be low. Otherwise it can cause problems in the engine and the injection system. In addition, a high viscosity can also lead to power losses due to leaks in the said injection system. This test has also been carried out in the Arsenal de Ferrol laboratory, according to the ASTM D445 standard [15]. This has also been done to samples 1, 4 and 5.

2.3.8 Content of fatty acid methyl esters (FAMES): This test measures the percentage of fatty acid methyl esters, which is the biodiesel itself. Therefore, this test gives us a good idea of the richness of the biodiesel obtained, so it must have a high FAMES content. This test has been carried out in accordance with the UNE-EN 14103 [16] and UNE-EN ISO 5508 [17] standards at the Center for Scientific and Technological Research Support in Iraq, and it has been done on the experiences 1, 4 and 5. The contents obtained in the different FAMES have been compared with the UNE-EN 14214 standard [18]. Said norm regulates three different values of esters content: linolenic acid esters, polyunsaturated esters, and total esters content. The method used was gas chromatography, using nonanoic acid methyl ester as internal standard. The gas chromatograph used is a Thermo Trace GC Ultra, from Thermo Scientific. First, the sample is weighed, hexane is added and it is homogenized, to then add the nonanoic acid methyl ester. At this time the sample is ready to be injected into the chromatograph. A ZB-WAX column of 60m x 0.25mm internal diameter x 0.25µm is used for this analysis. To carry out the analysis in the gas chromatograph, the temperature in the oven is programmed as follows: initially, the temperature is set at 50°C, maintained for 2

minutes, and then raising it at a rate of 10°C/min until reaching 240°C, keeping them for 30 minutes. Therefore, the total duration of the test is 51 minutes.

For FAMES analysis, the injector must be at a temperature of 250°C. To perform these analyses, a Trace DSQ detector has been used.

Helium is used as carrier gas at a 1 ml/min constant flow rate. To determine FAMES, 0.5µl of the solution to be analyzed is injected into the chromatograph's injector, using a microsyringe.

Finally, the content of each ester is found, expressed as a mass percent, using the following formula:

$$C = \frac{(\sum A') - A_{EI}}{A_{EI}} \times \frac{C_{EI} \times V_{EI}}{g'_{sample}} \times 100$$

Where,

- $\sum A'$: Total area of the peaks from the methyl ester C14 to C24.
- A_{EI} : Peak area corresponding to methyl heptadecanoate.
- C_{EI} : Concentration of the methyl heptadecanoate solution in mg/ml.
- V_{EI} : Volume of the methyl heptadecanoate solution used, in ml.
- g'_{sample} : Amount of sample, in mg.

In the case of the methyl ester of linolenic acid, expressed in the same way as a percentage of mass, the following formula is used:

$$L = \frac{A_L}{(\sum A) - A_{EI}} \times 100$$

Where:

- $\sum A$: Total area of the peaks from the methyl ester C14 to C24-1.
- A_{EI} : Peak area corresponding to methyl heptadecanoate.
- A_L : Area of the peak corresponding to the methyl ester of linolenic acid.

2.3.9 Cetane number (CN)

This index measures a fuel's ignition quality and influences smoke emissions and combustion quality. Interestingly, this number is high because if it is too low, it will cause noise in the engine, ignition delays, and increase emissions.

The calculation is reflected in the UNE-EN ISO 4264 standard. Said standard establishes a method according to the temperatures at 10%, 50% and 90% of distillate but allows an estimate to be made using only that of 50% of distillate. It has been calculated for samples 1, 4 and 5, and has proceeded using the 50% distillate temperature, as follows:

- To determine the temperature at 50% distillate, we proceeded according to the UNE-EN ISO 3405 standard [19]. In the first place, 80ml of the sample was taken and introduced into a distillation flask. Next, a distillation apparatus at atmospheric pressure has been assembled with this flask, a distillation head with its corresponding thermometer, and a cooling tube (condenser) distilled directly in a cylinder. In figure 3, we can observe this

assembly. When it began to distill, the temperature was taken every 10% until reaching 50%.

- To find the exact value, the following formula [20] has been used, which has been deduced to find it with the same values :

$$CN = -420.34 + 0.016 \times G^2 + 0.192 \times G \times (\log T_{50}) + 65.01 \times (\log T_{50})^2 - 0.0001809 \times T_{50}^2$$

Being:

- T_{50} : distillate temperature at 50%, in °F
- G: API relative density
- $G_{API} = (141.5/GE) - 131.5$

Where:

- $GE = \text{ensity of biodiesel at } 15^\circ\text{C} / \text{Density of at } 15^\circ\text{C} (999.19\text{kg/m}^3)$



Figure 3: Distillation apparatus

3 RESULTS

This section presents the results obtained in all the experiences, referring to everything explained in the previous chapter. It will also be checked if the properties regulated in the UNE-EN 14214 standard for biodiesel are fulfilled in our case.

3.1 Percentage of humidity and volatile: Here, we will see the result of the calculation of the moisture and volatile content and a graph of the moisture curve. Our raw material has obtained moisture and volatile value of 0.22%, which is a low value, and, therefore acceptable for the use we want to give it.

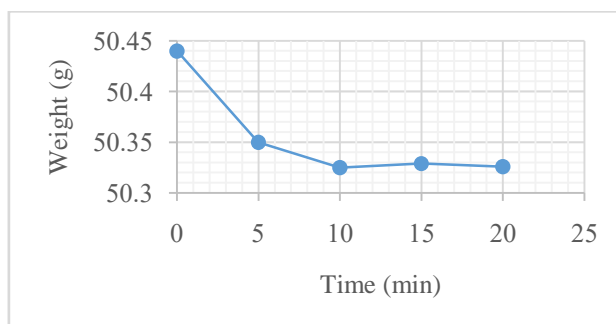


Figure 4: Humidity curve

3.2 Time-temperature relationship: It shows how the temperature has changed over time due to ultrasound in each experience. The temperature drops at some point due to the ultrasound machine's thermostat, which keeps the bathwater constant. Because No. 5 is a control experience, ultrasound was not used. For illustration, the temperature variation graph from experience 1 has been included. As shown later, experience 1, 4, and the control were chosen for further analysis. Ultrasound causes the temperature in the bathroom to rise even when the thermostat is turned on. The temperature does not stabilise in 15 minutes, and it raises the most in the first six minutes, rising less than 10°C. After 15 minutes, the temperature stabilised. The temperature remains around 10°C higher than it was at the start of the test in the second half.

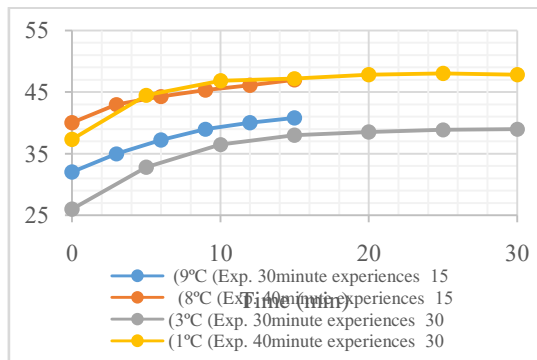


Figure 5: Time-temperature, 15min experiments & 30min experiences

Below is, as an example, the graph mentioned above from experience number 1:

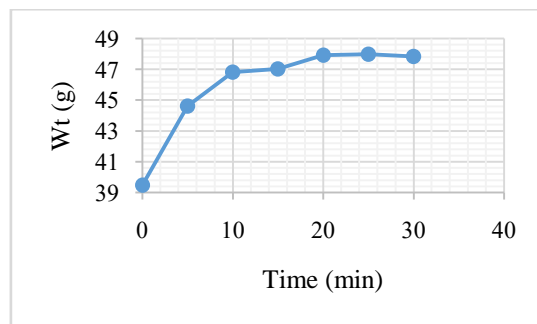


Figure 6: Time-temperature, experiment no.1

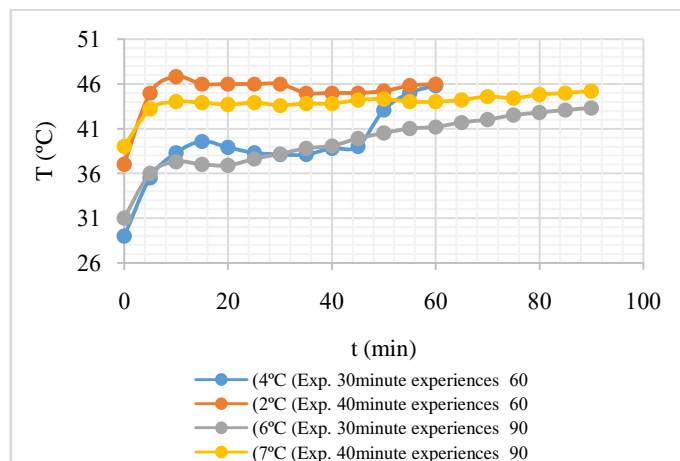


Figure 7: Time-temperature, 60min experiences & 90min experiences

The first half-hour, in this case, is the same as before, but the last ten minutes are warmer. In the 30°C case, it has risen above 40°C, indicating that the reaction has reached 45°C as a result of ultrasound. Finally, 90-minute experiences start out in the same way as the others. The temperature returns to normal after 20 to 50 minutes. The same pattern emerges from minute 50 to minute 90: the 30°C temperature rises to around 45°C, while the 40°C temperature rises only slightly because it was already close. Ultrasound raises the temperature of the reaction to around 45°C once more.

3.3 Density at 15°C: This section reflects the density at 15°C of each of the experiences and the original oil. According to the UNE-EN 14214 standard, this density must be between 860 and 900 kg/m³. As we can see, all the experiences comply without any problem with the values established by the UNE-EN 14214 standard. We also observe that the experiences of 60 and 90 minutes have less density than those of 15 and 30, and the control experience has the least; therefore, it can be concluded that the longer the reaction time, the more the density will decrease. Although it is not a problem since they all comply with what is established in our case.

3.4 Acid number: Here, the results corresponding to the acidity index of the experiences and the original oil will be indicated. It must have a maximum value of 0.5 mg KOH/g, according to the UNE-EN 14214 standard. As we can see, the values obtained for the acidity index in the different experiences are below the maximum value established in the UNE-EN 14214 standard. As can be seen, although they all comply, the worst indices are shown by the 15-minute experiences, so it follows that a longer reaction time is necessary. Although the others have similar values, we see that 90 minutes at 40°C has it slightly high. Therefore it can be deduced that if the reaction is left for too long and at too high a temperature, the acidity index may increase, which would not be appropriate.

3.5 Conversion rate: We have based ourselves on this percentage, together with the temperature and reaction time, to determine which have been the best experiences of the 8 that have been carried out with ultrasound and a comparison with the control. The percentages obtained are shown below:

Table1: Density at 15°C Acid number and Percent Conversion

Experience No.	Density (kg/m ³)	Acid number (mg KOH/g sample)	Conversion (%)
original oil	902.2	0.256	
1	894.2	0.017	93.22
2	888	0.018	93.12
3	894.6	0.021	91.85
4	891.6	0.018	93.13
5 (Control)	885	0.018	93.15
6	889.6	0.018	93.14
7	889.8	0.021	91.81
8	892.4	0.038	84.95
9	893.4	0.032	87.64

Below is a comparative graph of these conversion percentages as a function of temperature and time:

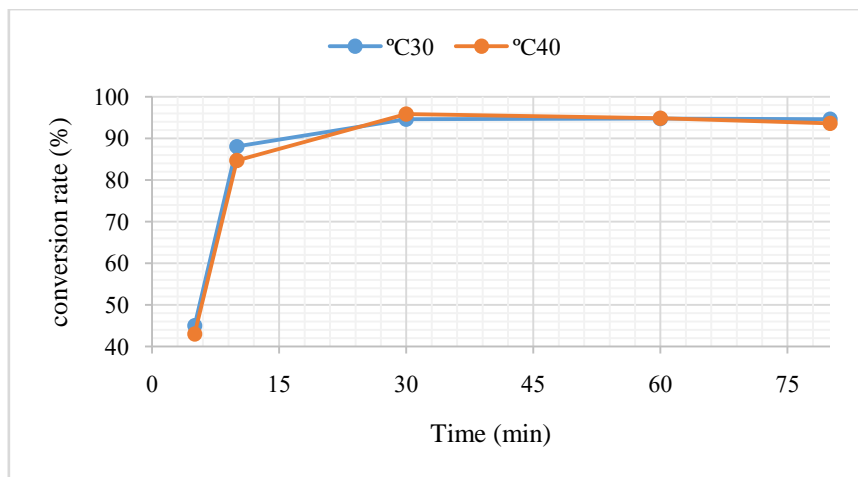


Figure 8: Conversion rate

As we can see, they are all quite high and similar, although the last two are notably lower since they are both 15-minute experiences. Therefore, experiences 1 and 4 have been selected as the best for subsequent analyses, together with control 5. It should be mentioned that even though the percentage of 6 is higher, 4 has been chosen since it has been 60min, while 6 has been 90min, and the difference in the percentage is not so great as to compensate for the use of the 90min.

3.6 Iodine value: The iodine index must have a value lower than 120g of iodine/100g, according to the UNE-EN 14214 standard. The results obtained are shown in Figure 9. As can be seen, all the experiences comply with the established values with good protection and similar values. In this case, the best value would be that of experience number 1, corresponding to 30 minutes at 40°C.

3.7 Color: The following figure 9 shows the data obtained from the color analysis:

In this section, we see the values obtained for viscosity at 40°C. According to the UNE-EN 14214 standard, these must be between 3.5 and 5.0 mm²/s. None of the samples complies with the regulations, as they give higher viscosity values. This could cause various engine problems, especially in the injection system, if this biodiesel is used without blending. Here what we observe is that experience 1 (30min, 40°C) is the one that offers us the worst value, with the control being the best. From this, it can be deduced that, relative to viscosity, it is better than the reaction time to be longer since it decreases as it increases.

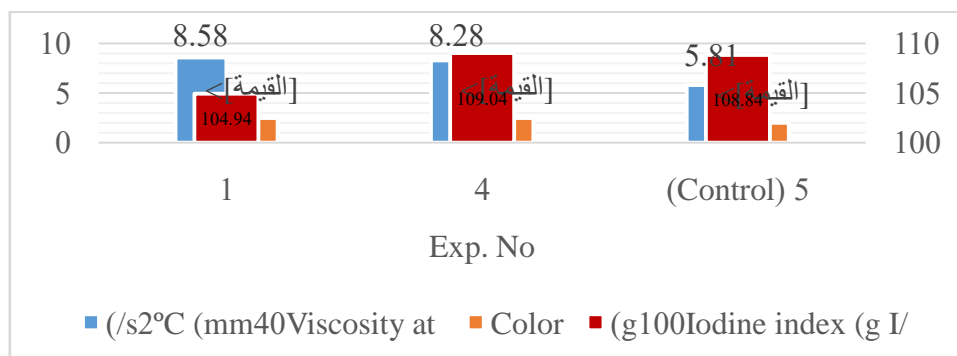


Figure 9: Number of experiences Vs Iodine index (g I/100g), Colour, Viscosity at 40°C

3.8 Content of fatty acid methyl esters (FAMES)

In this section we will see the results of the FAMES content analysis carried out on samples 1, 4, and 5 at the Center for Scientific and Technological Research Support in Baghdad. As has already been said, we will compare these values with the UNE-EN 14214 standard. This standard establishes a maximum value of linolenic acid esters at 12.0%, a maximum content value of polyunsaturated esters of 1.0%, and, most important, a minimum content of total esters of 96.5%.

Table 2: Content in FAMES

Compound (%)	Exp. No. 1	Exp. no. 4	Exp. no. 5
Stearic acid methyl ester	13.4	13.3	13.7
Palmitic acid methyl ester	3.9	3.9	4.4
Oleic acid methyl ester	42.9	41.5	41.2
Linoleic acid methyl ester	39.8	41.3	40.7
TOTAL FAMES	63.2	51.6	62.3

We can see that none of the three polyunsaturated or linolenic acid esters have been found, indicating that this part complies with the standard. However, the total of FAMES is the most important value of this test, and none of the three samples meet the standard's minimum requirement. This means that this biodiesel does not meet the minimum richness requirements for use without mixing, and if used, it could result in a loss of performance and even deposits in injection systems. It's also worth noting that number 4 has the lowest value. This was completed in 60 minutes at 30°C, while the other two were completed at 40°C (number 1 for 30 minutes, and number 5 is the control, without ultrasound). We can deduce that low-temperature results in a lack of FAMES in the final product; thus, the best option for this parameter would be to use the 40°C reactions. The characterization of biodiesel of livestock origin was achieved in this article using the gas chromatography technique with methanol at a 6:1 alcohol/oil ratio, as shown in the chromatograms below (Figure 10). Below are the chromatograms obtained during the test (two per sample have been made to find the mean, but here we will only put one of each). From the preceding, it can be deduced that most of the fatty acids present in biodiesel are unsaturated. Oleic acid contributes the most to both, implying a low cetane number and lower stability, resulting in residues during cooking. Oxidation reactions that deposit in injectors result in incomplete combustion, though they won't cause fluidity issues at low temperatures.

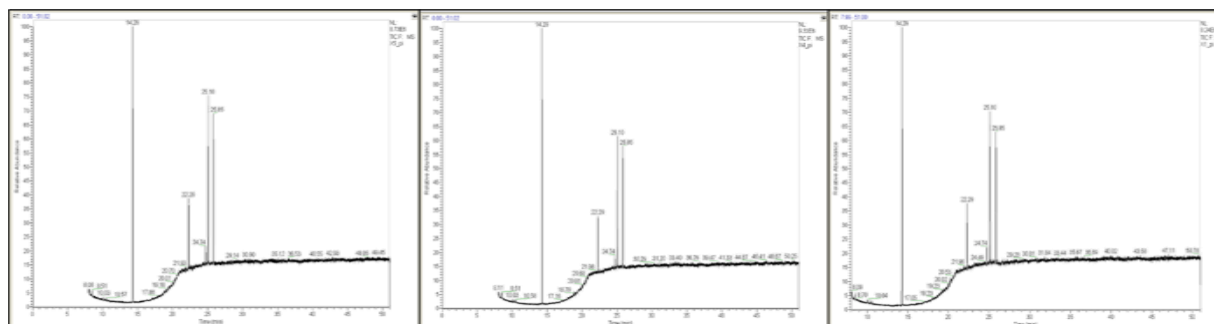


Figure 10: Chromatogram experiences No. 1, No. 4, and No. 5

3.9 Cetane Number

This section shows the result of the calculation of the cetane index for samples 1, 4 and 5. According to the UNE-EN 14214 standard, this value must be greater than 51.0.

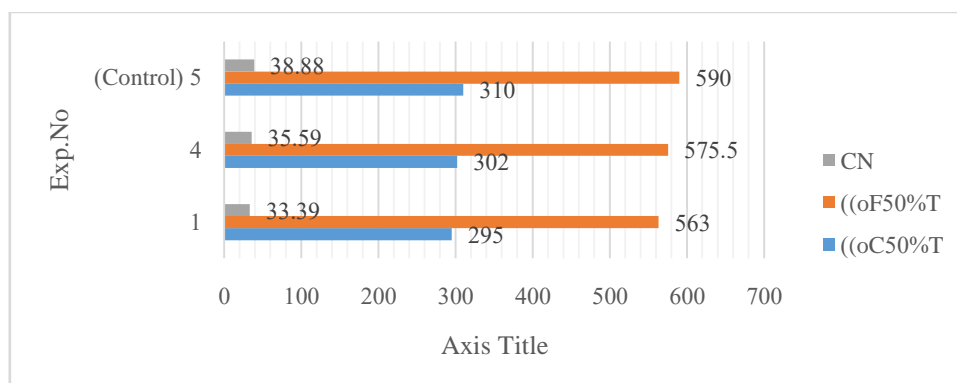


Figure 11: Cetane Number

As we can see, the values are below the minimum required; that is, it does not have the necessary ignition quality; Therefore, according to this parameter, this biodiesel could not be used by itself. Doing so would cause problems such as excessively high emissions, ignition retardation, or engine noise. We can also verify that the one with the highest value is the control. Therefore, we can conclude that time directly affects this value and that the longer the reaction reaction lasts, the better the cetane index it will have.

4 CONCLUSIONS AND FUTURE LINES

4.1 Conclusions

The best reaction times and temperatures are 60 minutes and 40 degrees Celsius. The second experience, which corresponds to these values, has not been thoroughly tested. Because 4 has a similar conversion percentage but a lower temperature, this is the case. We now know that this temperature was insufficient because 40°C met other biodiesel-related parameters better, such as fatty acid methyl ester content (FAMES). Because none of the expected characteristics were present in the 15-minute reactions, we can conclude that this time is insufficient for the method. The acidity index and conversion percentage worsened as time passed, reaching 90 minutes. Excessive reaction time can have negative consequences. The best reaction times have been found to be 30 and 60 minutes. We can conclude that the 60-minute option is preferable because the 30-minute option had an insufficient cetane index, which is one of the most important properties: biodiesel with a lower cetane index would cause ignition delays and excessive emissions. It is simpler to select the operating temperature. Despite the fact that some began at 30°C and others at 40°C, they all ended at 45°C. The steps leading up to that temperature are crucial, and those at 40°C had better properties than those at 30°C because the higher temperature improves reaction kinetics. Cavitation bubbles form, and the mixture's viscosity decreases as the reaction temperature rises, improving transfer. As a result, a temperature of 40°C is ideal. Because the biodiesel obtained does not meet several of the UNE-EN 14214 standards, it is not suitable for engines on its own. This isn't an issue because biofuels are frequently blended with conventional fuels (around 10%). This can be done with biodiesel. As we've seen, biodiesel has a wide range of applications beyond motor fuel. Among other things, it can be used as a lubricant, cleaner, or

solvent. Cooking oil that has been used is also a waste issue. For many businesses, this entails costly and time-consuming procedures. This problem could be solved by making biodiesel from all used oil. In most organisations or businesses with a kitchen and a lot of used oil, biodiesel production is highly recommended. The elimination of residual treatment costs and the biodiesel itself, whether as fuel or for any of the other uses mentioned, will result in significant savings when this oil is used for biodiesel production.

4.2 Recommendations

Some future lines that would be a good addition to this work are listed below.

As we've seen, 60 minutes is the ideal amount of time. Too much time was spent comparing experiences due to the wide range of times covered (30 minutes between those of 60 and those of 30 and 90, respectively). This was required in order to cover all possible parameter values. Now that we know that better results can be obtained when the reaction time is 60 minutes, it would be interesting to conduct new experiments at 45, 60, and 75 minutes to fine-tune the reaction time. This would aid in determining the best way to dispose of a waste product such as used oil.

The method used in this study is faster because it uses direct ultrasound instead of a bath. We were unable to verify this due to a lack of resources. Using an ultrasound probe to study this process would be fascinating. This would improve efficiency by speeding up the reactions. Used cooking oil would be a more profitable and desirable raw material for biodiesel in any company or organisation that uses it if this goal could be met.

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