

## Chapter 8 Obtaining Biodiesel from waste cooking oil using MOF-Zn-II as a heterogeneous acid catalyst

### Capítulo 8 Obtención de biodiésel a partir de aceite usado de cocina utilizando el MOF-Zn-II como catalizador ácido heterogéneo

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## Abstract

The metal-organic structure  $[\{Zn(O_2CCH_3)_2\}(m-bpe)]_n$ , MOF-Zn-II, was evaluated as a heterogeneous acid catalyst in the production of biodiesel by simultaneous esterification and transesterification of waste cooking oil from a hamburger restaurant. At reaction conditions of 140 °C, 7.5 h, molar ratio MeOH:Oil 24:1 and 1 % w/w catalyst, the yield of methyl esters reaches 94.31 %. The values of the parameters of the obtained biodiesel, such as acid number, viscosity, and density, were among those established in the ASTM D6751 and ASTM D1298 standards. In addition, MOF-Zn-II is a material that can be recovered and reused during three reaction cycles without significantly decreasing the performance of methyl esters. Consequently, MOF-Zn-II can be used as a catalyst in the production process of biodiesel from waste cooking oil, since the obtained biodiesel not only meets the specifications required to be sell, but is also obtained from waste raw materials, besides contributing to sustainability and the protection of the environment.

## Metal-Organic Framework, Heterogeneous catalyst, Waste cooking oil, Esterification

### Resumen

La estructura metal-orgánica  $[\{Zn(O_2CCH_3)_2\}(m-bpe)]_n$ , MOF-Zn-II, fue evaluada como catalizador ácido heterogéneo en la producción de biodiesel mediante la esterificación y transesterificación simultánea de aceite usado de cocina, proveniente de un restaurante de hamburguesas. Se encontró que, a condiciones de reacción de 140 °C, 7.5 h, relación molar MeOH: Aceite (24:1) y 1 % p/p de catalizador, el rendimiento de los ésteres metílicos alcanza el 94.31 %. Los valores de los parámetros del biodiesel obtenido, como índice de acidez, viscosidad y densidad se encontraron entre los establecidos en los estándares ASTM D6751 y ASTM D1298. Además, el MOF-Zn-II es un material que puede recuperarse y reutilizarse durante tres ciclos de reacción sin que disminuya de forma significativa el rendimiento de los ésteres metílicos. Por lo tanto, el MOF-Zn-II puede ser usado como catalizador en el proceso de producción de biodiesel a partir de aceite usado de cocina, dado que el biodiesel obtenido no solo cumple las especificaciones requeridas en el mercado para comercializarlo, sino también se obtiene de materias primas de desecho, contribuyendo a la sustentabilidad y al cuidado del medio ambiente.

## Estructura Metal-Orgánica, Catalizador heterogéneo, Aceite usado de cocina, Esterificación

### 1. Introduction

Edible vegetable oils are used for cooking and most of them are disposed of in landfills, drains or soil, creating different environmental problems (Monika et al., 2023). These are heated to temperatures between 160 and 190 °C for relatively long times, which causes them to undergo physical and chemical changes, such as an increase in viscosity and specific heat, changes in surface tension and color, as well as a decrease in the smoke point, i.e., the point at which the oil decomposes and loses its nutritional properties, generating an unpleasant odor and taste. Similarly, due to the high temperatures, the oil undergoes thermal oxidation, generating the formation of free radicals, causing damage at the cellular and molecular level, which makes it dangerous for human consumption (Lam et al., 2010). According to Profeco (2019), each Mexican consumes approximately 10 L of oil per year, with soybean oil being the most used (31%) and then canola oil (18%). In addition, it is in homes where the largest amount of vegetable oil is consumed (more than 80 %), the rest comes from food preparation establishments, such as restaurants and bars. If this oil is poured into drains or sewers, it can clog them and generate problems of bad odor, waterlogging and flooding, among others (Mandolesi De Araújo et al., 2013).

On the other hand, the high consumption of fossil fuels brings with it pollution problems, such as the emission of greenhouse gases, acid rain and global warming, which leads to the search for alternative fuels from renewable sources, such as biodiesel, which has gained great interest as a substitute for petroleum diesel due to the similarity between their properties. Therefore, an alternative for the production of third-generation biodiesel is used cooking oil, because it would overcome the problems faced by the raw materials of previous generations that influence the food chain, availability, flexibility with environmental parameters and economic viability. Coupled with this, the burden of waste management and water pollution would be decreased (Singh et al., 2020).

Homogeneous and heterogeneous catalysts are used in the transesterification process for biodiesel production. The traditional method uses basic homogeneous catalysts, mainly sodium hydroxide (NaOH) and potassium hydroxide (KOH), and requires high quality raw materials (free fatty acid content < 3 %), such as edible vegetable oils, the use of which can generate competition with the food sector. Likewise, although homogeneous alkaline catalysis allows the use of low-quality raw materials (free fatty acid content > 3 %), such as used cooking oil, this would require pretreatment (esterification) to reduce the percentage of free fatty acids, thus avoiding undesired secondary reactions (saponification).

A solution to this problem would be the use of acid heterogeneous catalysts, with which it is possible to carry out the esterification and transesterification of the oil simultaneously, allowing the use of low quality raw materials. In addition, this type of catalysts can be easily separated from the reaction mixture, which allows their reuse and lowers production costs. An example of heterogeneous catalysts are metal organic frameworks (MOF), whose physicochemical properties (high surface area, pore size, high thermal stability, etc.) allow their use as catalysts.

Therefore, the capacity of MOF-Zn-II as a heterogeneous acid catalyst in the production of biodiesel from used cooking oil was evaluated. First, the used cooking oil was characterized to know its viability in obtaining biodiesel (acidity index, saponification index, kinematic viscosity, density, water content, free grade acids and molecular weight); and the effect of parameters such as temperature, amount of catalyst, methanol/oil ratio and reaction time in the production of biodiesel was evaluated: oil ratio and reaction time in the synthesis of biodiesel; the reuse of the catalyst in the simultaneous esterification and transesterification of used cooking oil; and finally, the physicochemical properties of the biodiesel obtained were determined.

## **2. Description of the method**

### **2.1 Materials**

Used cooking oil, originally canola oil, was provided by a hamburger restaurant. Prior to use, it was filtered and dried at 100 °C on a hot plate. The anhydrous reagent grade methanol, 99.8 %, was purchased from TECSIQUIM, S.A. de C.V. Zinc acetate and 4,4'-bipyridylethylene were from Sigma-Aldrich. For the autogenous pressure system, a Sigma-Aldrich glass ace pressure tube was used.

### **2.2. Obtaining the MOF-Zn-II catalyst**

4,4'-bipyridylethylene (0.182 g, 1 mmol) in DMF (2 mL) was added to  $\text{Zn}(\text{O}_2\text{CCH}_3)_2 \cdot 2\text{H}_2\text{O}$  (0.220 g, 1 mmol) in DMF (4 mL), the white precipitate obtained was immediately separated by filtration and redissolved in hot water. The clear solution was filtered and allowed to evaporate slowly in order to crystallize the material, obtaining yellow crystals, which were separated and washed with ether and left to dry in the oven at 105 °C for 1 h (0.140 g, 36 %). Subsequently, the crystals were crushed to obtain a crystalline powder which was analyzed by infrared spectroscopy to corroborate its obtaining (Toh et al., 2005).

### **2.3 Obtaining biodiesel**

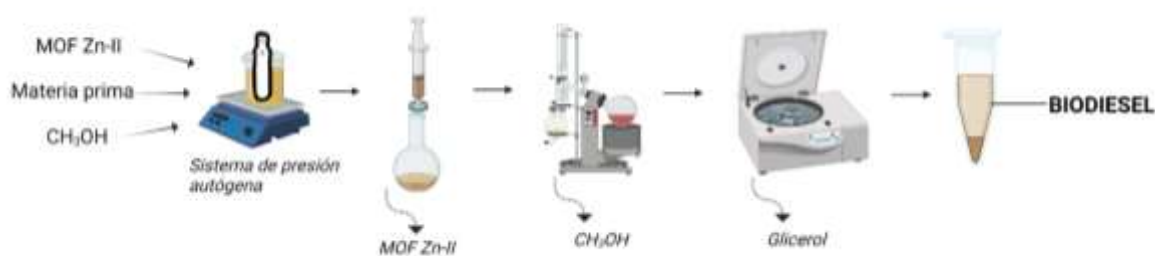
In order to obtain biodiesel from used cooking oil with MOF-Zn-II as catalyst, different reaction conditions were evaluated, varying the temperature, the molar ratio MeOH:oil, amount of catalyst and reaction times, in order to obtain the best conditions that would generate the best yields (Table 1). The optimal conditions previously found in the research group for the production of biodiesel from canola oil using MOF-Zn-II were taken as starting conditions, which were T = 150 °C; molar ratio MeOH:Oil, 12:1; amount of catalyst (% w/w) = 0.68 and reaction time = 4.5 h (Arceo-Ruiz, 2016).

**Table 1** Reaction conditions for the experiments conducted for the production of biodiesel with MOF

Variable parameter	No. Exp.	T (°C)	Molar ratio (MeOH:Oil)	Amount of catalyst (% w/w)	Reaction time (h)
Temperature	1	130	12:1	0.68	4.5
	2	140			
	3	150			
Molar ratio	4	140	12:1	0.68	4.5
	5		24:1		
	6		36:1		
	7		48:1		
Amount of catalyst	8	140	24:1	0.5	4.5
	9			0.68	
	10			1	
	11			1.2	
Reaction time	12	140	24:1	1	3
	13				4.5
	14				6
	15				7.5
	16				9

Source: Own Elaboration

For the transesterification reaction, a tube with an airtight lid fitted with a magnetic stirrer was used in duplicate, where 5 mL of the used cooking oil was placed and different amounts of anhydrous methanol and MOF-Zn-II were added, Table 1. To separate the biodiesel from the reaction mixture, first the catalyst was recovered by filtering the mixture obtained with a 20  $\mu\text{m}$  Millipore membrane. Subsequently, with the aid of a rotary evaporator, methanol was separated from the reaction mixture (50 °C at 150 rpm). The product obtained was centrifuged at 12,500 rpm for 8 minutes, with the biodiesel at the top and the glycerol at the bottom. The general scheme of the methodology for obtaining biodiesel is shown in Figure 1.

**Figure 1** Scheme of the methodology for obtaining biodiesel

Source of consultation: Own elaboration. Created with BioRender.com

## 2.4 Catalyst recovery

The catalyst recovered by membrane filtration of the reaction mixture was washed with hexane (10 mL) to remove traces of oil and biodiesel. Then, it was dried in the oven at 105 °C for 24 h.

## 2.5 Characterization of the biodiesel

### 2.5.1 Thin Layer Chromatography (TLC)

The reaction product was qualitatively analyzed by thin layer chromatography using silica gel plates. This procedure was carried out in order to determine if there was any conversion in the raw material (oil) to proceed with the quantitative analysis. For this purpose, a mixture of hexane, ethyl acetate and acetic acid in a 90:10:1 ratio was used as mobile phase; and a 50 % v/v solution of sulfuric acid with water was used as developer (Shah et al., 2004).

### 2.5.2 $^1\text{H}$ Nuclear Magnetic Resonance ( $^1\text{H}$ NMR)

One way to express the yield of biodiesel is as the percentage of fatty acid methyl esters, % MS, (Yang et al., 2016). So the yield was expressed as the percentage of methyl esters obtained from the triglycerides present in the oil, equation (1).

Triglycerides +  $\text{MeOH} \rightleftharpoons$  methyl esters + glycerol

$$\% EM = \frac{\text{methyl esters (mol)}}{\text{triglycerides (mol)}} \quad (1)$$

The quantification of the methyl esters was performed using a Varian/Agilent 600 MHz spectrometer and  $\text{CDCl}_3$  as solvent. The percentage was calculated using a ratio between the integration of the signal corresponding to the protons of triglycerides,  $I_{\text{TG}}$  (4.07-4.35 ppm) and methyl esters,  $I_{\text{ME}}$  (3.67 ppm); following equation (2) (Alegría et al., 2014).

$$X (\%) = \frac{4 \times I_{\text{ME}}}{4 \times I_{\text{ME}} + 9 \times I_{\text{TG}}} \times 100 \quad (2)$$

Where the factor 4 refers to the four hydrogen atoms present in the two C-H bonds of the methylene groups in the triglycerides and the factor 9 comes from the hydrogen atoms in the three C-H bonds in each of the three methoxy groups, resulting from the transesterification of each triglyceride molecule.

### 2.5.3 Gas chromatography (GC)

The determination and quantification of methyl esters was performed using an Agilent gas chromatograph with mass detector, equipped with an SP-2560 column of 100 m length, 250  $\mu\text{m}$  thickness and an internal diameter of 0.2  $\mu\text{m}$ . Nitrogen was used as carrier gas, at a constant flow rate of 1 mL/min. Injections of the reaction products were 0.2  $\mu\text{L}$  of sample. The oven temperature was set at an initial 150  $^\circ\text{C}$ , increasing 5  $^\circ\text{C}/\text{min}$  to 180  $^\circ\text{C}$  and remaining at this temperature for 10 min. Subsequently, the temperature was increased 5  $^\circ\text{C}/\text{min}$  until 240  $^\circ\text{C}$  was reached. The total time of the sample analysis was 38.2 min.

## 3. Results

### 3.1 Characterization of the raw material

The residual cooking oil used as raw material for the simultaneous esterification and transesterification reactions was characterized to determine its properties and quality (Table 2). It presented a percentage of free fatty acids (FFA) of 3.82 %. Alkaline catalysis requires an oil with a fatty acid percentage lower than 3 % (Sharma & Singh, 2009), so it is deduced that acid catalysis is the most viable method to carry out the transesterification of the oil.

**Table 2** Characterization and composition of used cooking oil used as raw material

Parameter	Unit	Cooking oil used in this study	Blending of used soybean, canola and palm oils(Nadeem et al., 2014)
Acid value	mg KOH/g	6.70 $\pm$ 0.07	1.25
Saponification index	mg KOH/g	203.67 $\pm$ 2.31	200
Kinematic viscosity (40 $^\circ\text{C}$ )	$\text{mm}^2/\text{s}$	42.09 $\pm$ 0.01	42.5
Density (15 $^\circ\text{C}$ )	$\text{g}/\text{cm}^3$	0.93 $\pm$ 0.00	0.898
Water content	ppm	41.47 $\pm$ 0.45	-
AGL	%	3.82	2.5
Molecular weight	$\text{g}/\text{mol}$	854.44	835

Source: Own Elaboration

The values of the parameters obtained presented values similar to those found in a study of a mixture of used oils (soybean, canola and palm) from various types of restaurants (Nadeem et al., 2014), except for the value of the acid value, which is approximately five times higher than that reported. Whereas, Mexican Standard NMX-F-101-SCFI-2012, defines the acid number or acid value as the milligrams of KOH needed to neutralize one gram of sample and is related to the amount of free fatty acids in the oil (FFA). In addition, the high temperatures of food cooking processes accelerate the hydrolysis of triglycerides and increase the amount of FFA (Vázquez-Garrido et al., 2023), therefore, the difference in the acid value of the samples could be attributed to the difference in the use of the oils, the one in this study comes only from a hamburger store. The average molecular weight (MPW) of the oil was calculated using equation (3), considering the saponification index (SI) and acidity index (AI) (Zhu et al., 2006).

$$PMP = (56.1) (1000) \left( \frac{3}{SI-AI} \right) \quad (3)$$

The fatty acid profile of the used cooking oil obtained in this study is presented in Table 3. It is observed that oleic acid predominates, i.e., there is a greater presence of monounsaturated fatty acids, comparing with the literature, a similar composition of a used cooking oil was found (Foroutan et al., 2019). This composition is preferably important to select an oil for biodiesel production (Aransiola et al., 2014).

**Table 3** Fatty acid profile of cooking oil used as feedstock

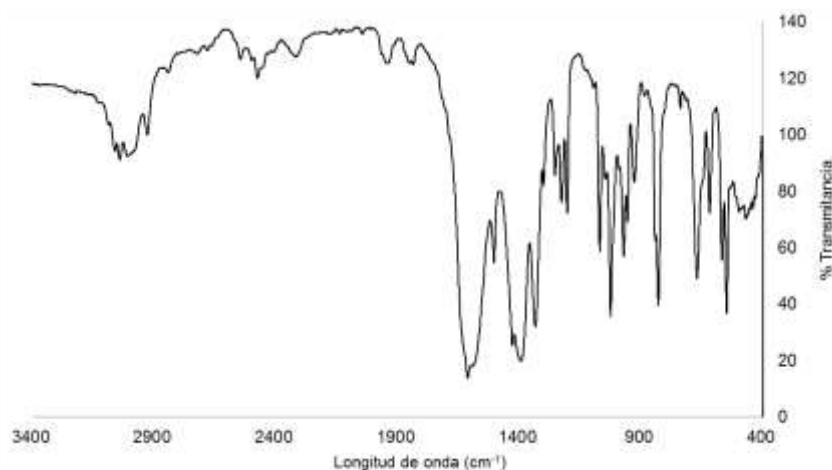
Fatty acid profile (%)	Oil used in this study (%)	Used cooking oil (Foroutan et al., 2019)
C 16:0 - Palmitic	8.48 ± 0.16	31.88
C 18:0 - Stearic	2.73 ± 0.04	6.45
C 18:1 - Oleic	66.79 ± 1.68	41.04
C 18:2 - Linoleic	20.14 ± 0.83	17.98
C:18:3 - Linolenic	1.86 ± 2.64	0.43

Source: Own Elaboration

### 3.2 Infrared (IR) spectroscopy of MOF-Zn-II

The IR spectrum of MOF-Zn-II is presented in Figure 2. The characteristic bands of pyridine C-H bond stretching were observed between 3000-3100 cm<sup>-1</sup>, as well as CH<sub>2</sub> stretching of methylene groups between 2915 and 2935 cm<sup>-1</sup>; at 1846 and 1948 cm<sup>-1</sup> the bands corresponding to C-H stretching of aromatics are found. At approximately 1587 and 1359 cm<sup>-1</sup> the bands corresponding to the asymmetric and symmetric stretching of the C-O bond of the carboxylate group attached to Zn are observed, respectively. Between 1274 and 1473 cm<sup>-1</sup> is the C=N stretching band corresponding to pyridine, whose signal overlaps with the band corresponding to the symmetric C-O stretching (Toh et al., 2005).

**Figure 2** Infrared spectrum of the MOF-Zn-II synthesized for the present study



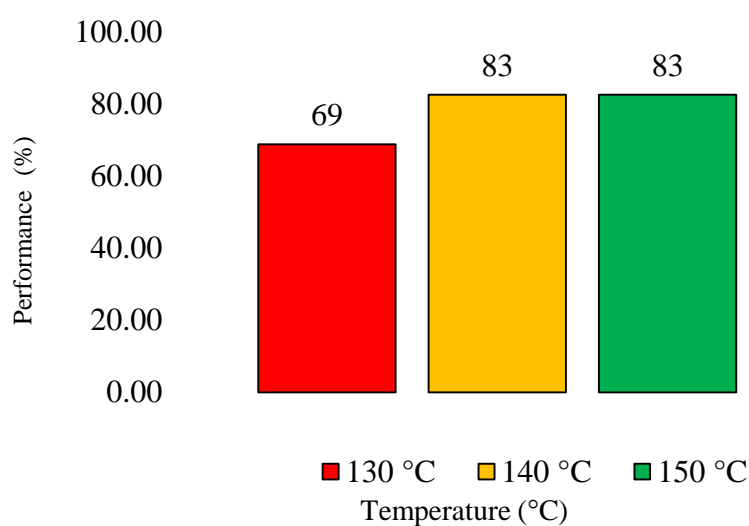
Source: Own Elaboration

### 3.3 Synthesis of biodiesel from used cooking oil using MOF-Zn-II

#### 3.3.1. Temperature study

Reactions were carried out at 130, 140 and 150 °C, maintaining the optimum conditions reported in the previous study (4.5 h, molar ratio MeOH:Oil 12:1 and 0.68 % w/w of catalyst). The yields obtained for each temperature are shown in Graph 1. The yield at temperatures of 140 and 150 °C had similar values (82.65 and 82.68 %, respectively). A high reaction temperature facilitates mass transfer in the reactor and dispersion of the catalyst particles. However, a low temperature is considered economically more favorable since a lower amount of energy is required (Olutoye et al., 2016). Because of the above, the temperature of 140 °C was chosen to perform the reaction, due to the fact that it is the minimum temperature at which the maximum yield is also obtained.

**Graph 1** Effect of temperature for obtaining biodiesel at 130, 140 and 150 °C

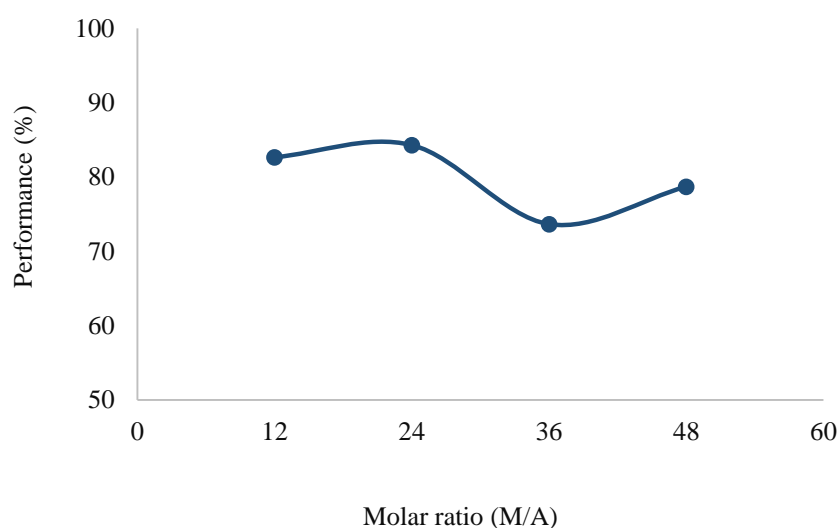


*Source: Own Elaboration*

#### 3.3.2 MeOH: oil molar ratio study

With the temperature already established, the effect of the MeOH:Oil ratio on the transesterification of used cooking oil was evaluated. Reactions were carried out at molar ratios of 12:1, 24:1, 36:1 and 48:1, with 0.68 % w/w of catalyst, at 140 °C with reaction times of 4.5 h, Graph 2. The highest yield for this evaluation (84.28 %) was obtained when using the MeOH:Oil molar ratio of 24:1; increasing it (36:1) decreases the yield.

**Graph 2** Evaluation of the molar ratio at 140 °C, 4.5 h with 0.68 % w/w catalyst



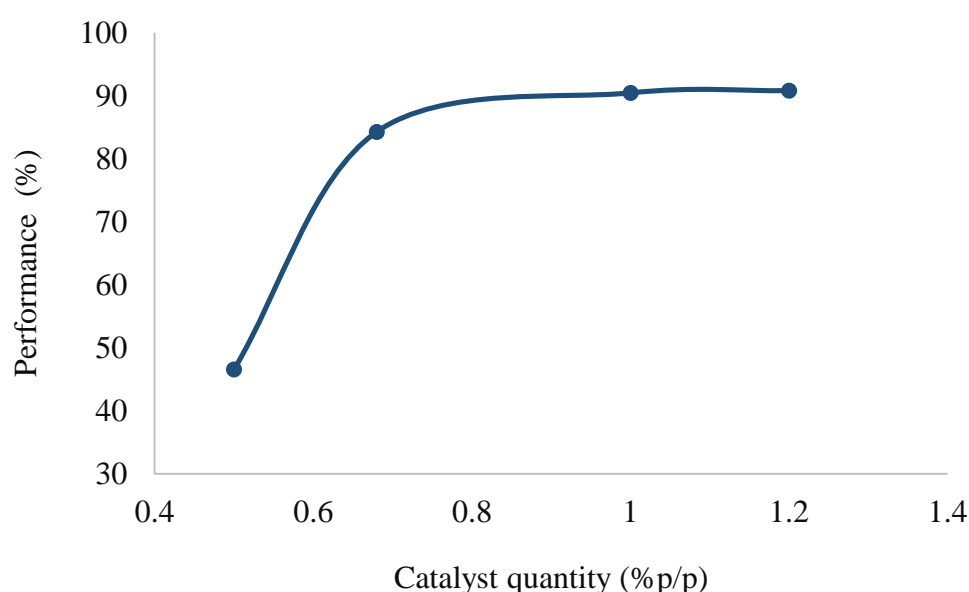
*Source: Own Elaboration*

In this study, the MeOH: Oil molar ratio of 24:1 was chosen as the best condition, although the difference in yield compared to the 12:1 ratio was 1.93 %, it was considered because having a higher amount of methanol in the solution could favor the displacement of the reaction towards the products, producing more methyl esters and, therefore, increasing the yield of the reaction (Olutoye et al., 2016). Although, also the solvent in excess can be conducive to the solubility of glycerol, which would lead to decrease its conversion to methyl esters (Narkhede et al., 2014). Which would explain the decrease in yield as the MeOH:Oil molar ratio increases from 24:1 to 36:1.

### 3.3.3 Study of the amount of catalyst.

Tests were carried out using MOF-Zn-II at a percentage of 0.5, 0.68, 1.0 and 1.2 % based on the weight of used cooking oil, using a MeOH:Oil ratio of 24:1, at 140 °C and 4.5 h of reaction. Graph 3 shows the data obtained, it is observed that the yield of methyl esters increases with increasing weight percentage of the MOF-Zn-II catalyst and stabilizes after the addition of 1 % w/w of catalyst, reaching a maximum yield of 90.82 %.

**Graph 3** Effect of the catalyst on biodiesel production [MeOH:Oil (24:1), 140 °C, 4.5 h].



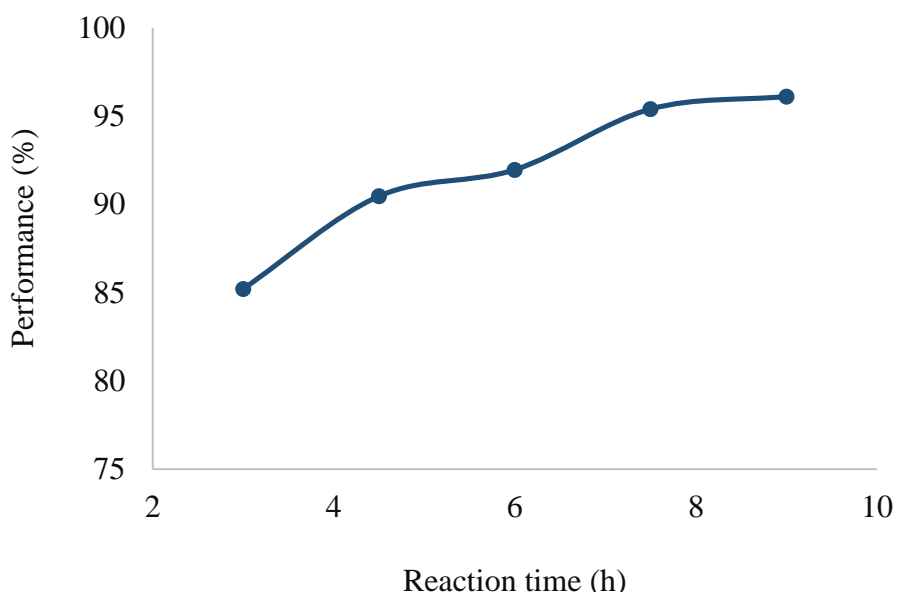
*Source: Own Elaboration*

The behavior of MOF-Zn-II in the production of biodiesel was similar to the transesterification of dimethyl carbonate using MOF as catalyst, where the reaction yield increased as the amount of catalyst increased, as long as the catalyst was not in excess (Zhou et al., 2009). Furthermore, this is attributed to the fact that there is a greater availability of active sites as the catalyst used in the reaction increases, thus increasing the reaction yield (Alhassan et al., 2013). However, an excess of catalyst no longer promotes product formation, because this behavior only occurs until the reaction reaches equilibrium (Zhou et al., 2009), which could explain the small difference in yield between 1 and 1.2 % catalyst. Therefore, the amount of 1 % w/w was chosen as the best condition, considering that the lower the amount of MOF Zn-II, the greater the economic savings in the process.

### 3.3.4 Reaction time study

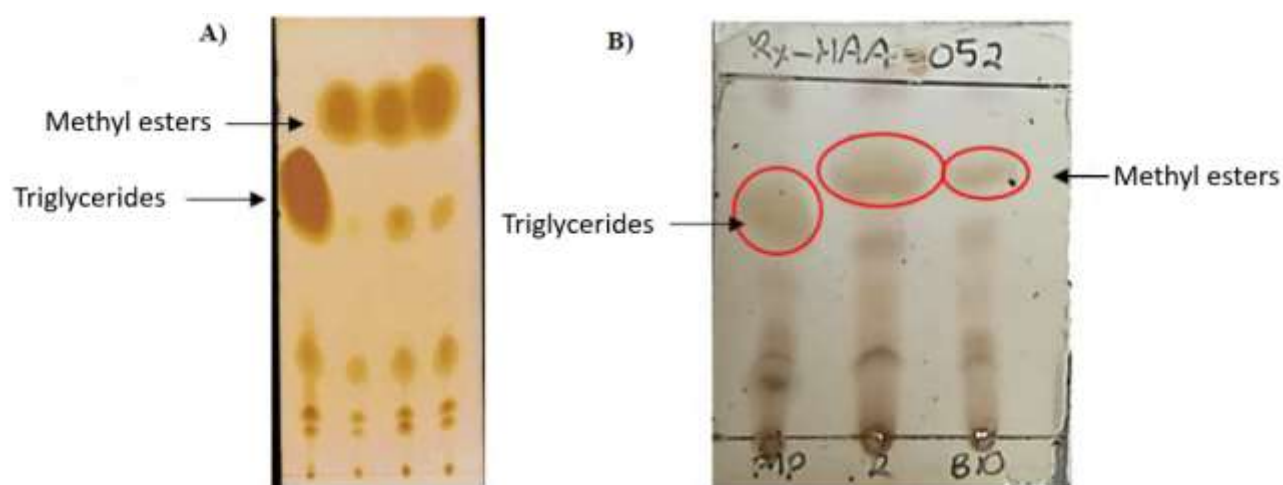
Finally, for the study of the effect of reaction time, reactions were carried out at 3, 4.5, 6, 7.5 and 9 h, at the previously selected conditions (140 °C, molar ratio MeOH:Oil (24:1) and 1 % w/w catalyst), Graph 4. At 7.5 h of reaction time, a maximum yield of 94.31 % was reached and no significant change was observed if the time was increased to 9 h. In a study where the reaction time was varied between 5 and 9 h, it found that at 8 h of reaction, a maximum yield of 86 % was obtained, with no significant change with further increase in time (Narkhede et al., 2014). Furthermore, an excess in reaction time can lead to a decrease in yield due to hydrolysis of esters (Eevera et al., 2009). Therefore, 7.5 h was chosen as the best reaction time for this study.



**Graph 4** Effect of reaction time in obtaining biodiesel [MeOH:Oil (24:1), 140 °C, 1 % w/w catalyst]

Source: Own Elaboration

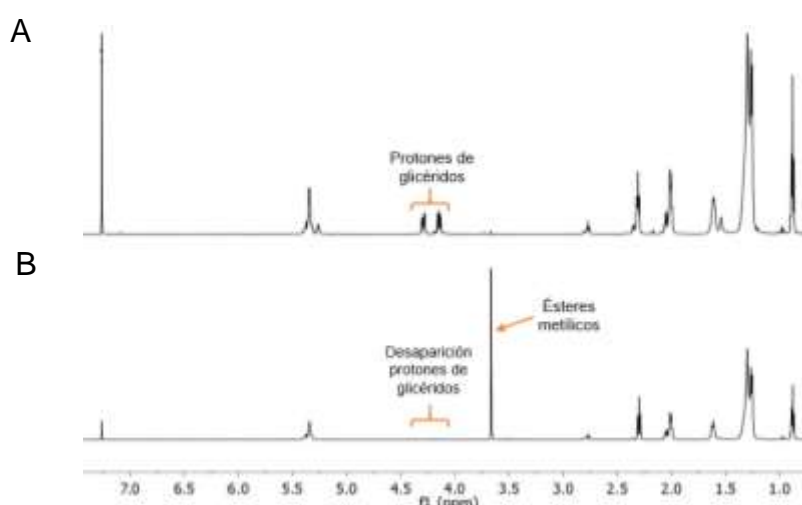
The biodiesel obtained was qualitatively analyzed by TLC following a methodology (Shah et al., 2004), where the difference between the adsorption on the chromatographic plate of triglycerides and methyl esters is indicated, Figure 3A. Figure 3B shows the chromatographic analysis of the reaction prepared with the best conditions, whose yield was 94.31 %. The difference between the appearance of the triglyceride signal and that corresponding to the methyl esters is observed, above the former.

**Figure 3** TLC of methyl esters. A) Analysis previously reported (Shah et al., 2004) and B) Reaction at 140 °C, 7.5 h, MeOH:Oil (24:1) and 1 % MOF-Zn-II; MP: Used cooking oil, R: Reaction, Bio: Biodiesel

Source: Own Elaboration

In Figure 4A, the appearance of the signal corresponding to the protons of the glycerides was observed between 4.07 and 4.35 ppm; in Figure 4B the disappearance of these can be seen, as well as the appearance of a signal at 3.67 ppm, which corresponds to the protons of the methyl esters. This behavior coincides with that reported by Savaliya et al. (2023), who obtained biodiesel from inedible castor oil and proved, through the appearance of the peak of the protons of the methoxy group, at 3.54 - 3.60 ppm, the conversion of the oil to biodiesel.

**Figure 4**  $^1\text{H}$  NMR spectra of A) used cooking oil; B) reaction at  $140\text{ }^\circ\text{C}$ , 7.5 h, MeOH:Oil (24:1) and 1 % MOF-Zn-II

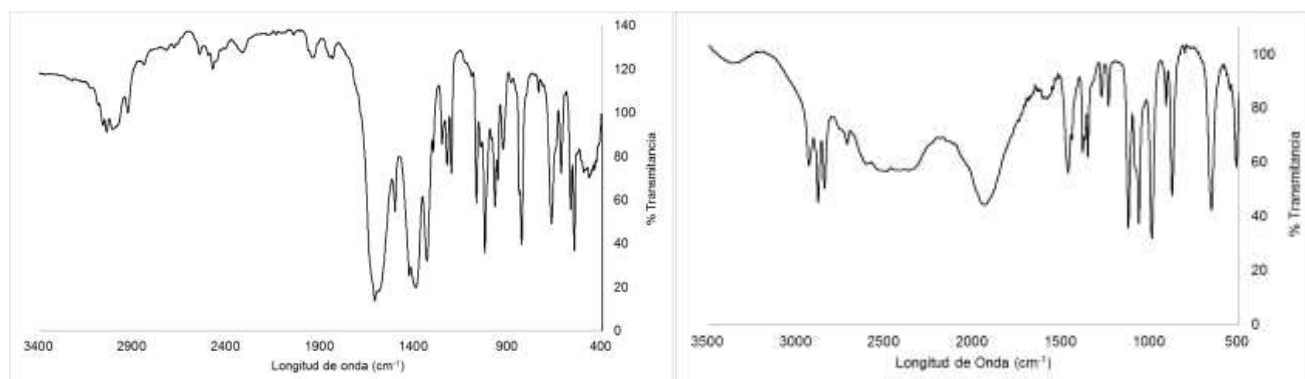


Source: Own Elaboration

### 3.4 Reuse of the catalyst

To check the reuse of MOF-Zn-II in biodiesel synthesis, the structure of the material was analyzed by infrared spectroscopy, before and after the transesterification reaction, Figure 5.

**Figure 5** IR spectra of biodiesel: before the transesterification reaction (left) and after the transesterification reaction (right).



Source: Own Elaboration

It can be observed that in the spectrum of the MOF-Zn-II recovered from the reaction (right), the bands did not coincide completely with the spectrum of the newly synthesized MOF (left). Possibly due to the remnants of biodiesel and/or glycerol from the reaction because the presence of the  $\text{CH}_3$ ,  $\text{CH}_2$  and  $\text{CH}$  stretching signals of biodiesel was observed at  $2843$ ,  $2879$  and  $2932\text{ cm}^{-1}$ , respectively (Tariq et al., 2011). It could even be due to the restructuring of MOF-Zn-II, since zinc-containing MOFs have exhibited instability in aqueous solution (Rivera et al., 2016). In another study,  $\text{Zn}_4\text{O}(\text{BDC})_3$ , known as MOF-5, presented stability when the water content is low, but at percentages  $\geq 4\%$  water there is an opening of the structure (Greathouse & Allendorf, 2006).

On the other hand, it was found that MOF-Zn-II maintains its catalytic activity during three reaction cycles, with yields ranging from 92 to 94 %, so it can be reused in simultaneous esterification and transesterification reactions for biodiesel production.

### 3.5 Biodiesel characterization

The biodiesel obtained was characterized to compare its viscosity, density and acid number properties with the specifications established in the ASTM D6751 and ASTM D1298 standards (Sakthivel et al., 2018), Table 4. It can be observed that the biodiesel obtained in this work complied with the parameters established in the standards. Likewise, the reduction of the acid number evidenced that MOF-Zn-II carried out the transesterification of triglycerides, as well as the esterification of free fatty acids simultaneously, since the latter was significantly reduced, from 6.70 to 0.840 mg KOH/g.

**Table 4** Comparison of parameters of biodiesel obtained from used cooking oil with those established in the biodiesel standards

Property	Unit	Biodiesel obtained	Theoretical value	Standard (Sakthivel et al., 2018)
Density at 15 °C	kg/m <sup>3</sup>	853	880	ASTM D1298
Viscosity at 40 °C	mm <sup>2</sup> /s	5.85	1.9 – 6.0	ASTM D6751
Acid number	mg KOH/g	0.840	0.5	ASTM D6751

*Source: Own Elaboration*

On the other hand, in the detection and quantification of fatty acid methyl esters (FAME) carried out by gas chromatography, Table 5. It was observed that the product consisted of methyl esters of oleic acid (50.96 %), linoleic (20.20 %), palmitic (6.79 %), linolenic (4.27 %), stearic (2.60 %) and others (2.0 %).

**Table 5** Composition of the methyl esters of the biodiesel obtained.

FAME	Concentration
C 16:0 - Palmitic	6.79
C 18:0 - Stearic	2.60
C 18:1 - Oleic	50.96
C 18:2 - Linoleic	20.20
C:18:3 - Linolenic	4.27
Other	2.0

*Source: Own Elaboration*

The product obtained is mainly composed of monounsaturated fatty acid methyl esters (50.96 %), followed by polyunsaturated (24.47 %) and saturated (9.39 %). The properties of biodiesel depend on the fatty acid composition, these being comparable to petroleum diesel when the biofuel contains a large amount of mono-unsaturated FAME, a controlled amount of polyunsaturated FAME and low concentrations of saturated FAME. (Wang et al., 2011) From the above, the effectiveness of using MOF-Zn-II in obtaining biodiesel from used cooking oil can be attributed.

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### Conclusions

The used cooking oil, coming from a store, presented the quantity of free fatty acids of 3.82 %, which catalogs it as a raw material of low quality. Its initially calculated acid number was reduced from 6.70 mg KOH/g to 0.840 mg KOH/g without pretreatment, thus proving that MOF-Zn-II carried out esterification and transesterification simultaneously. Through the evaluation of the reaction parameters, the conditions at which the highest yield of methyl esters was obtained were determined, which was 94.31 % at a temperature of 140 °C, in a reaction time of 7.5 h, MeOH:Oil ratio of 24:1 and a catalyst amount of 1 % w/w. In addition, it can be recovered and reused for up to three reaction cycles with a minimal decrease in conversion to methyl esters, which can promote a reduction in biodiesel production costs.

Finally, the parameters of acidity index, viscosity and density of the biodiesel obtained were found to be within the values established in ASTM D6751 and ASTM D1298 standards.

Therefore, MOF-Zn-II can be used as a catalyst in the production process of biodiesel from used cooking oil, since the biodiesel obtained not only meets the specifications required in the market to be marketed, but is also obtained from waste raw materials, contributing to sustainability and environmental care.

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