Ciencia Latina Revista Científica Multidisciplinar, Ciudad de México, México.
ISSN 2707-2207 / ISSN 2707-2215 (en línea), marzo-abril 2024,
Volumen 8, Número 2.

https://doi.org/10.37811/cl_rcm.v8i2

BIODIESEL PRODUCTION FROM REFINED PALM OIL THROUGH TRANSESTERIFICATION: EFFECT IN A PILOT THERMAL PLANT

PRODUCCIÓN DE BIODIESEL A PARTIR DE ACEITE DE PALMA REFINADO MEDIANTE TRANSESTERIFICACIÓN: EFECTO EN UNA PLANTA TÉRMICA PILOTO

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DOI: https://doi.org/10.37811/cl_rcm.v8i2.10967

Biodiesel production from refined palm oil through transesterification: effect in a pilot thermal plant

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ABSTRACT

This article presents the biodiesel production process from refined palm oil (RPO) through transesterification with ethanol and investigates its impact on a pilot thermal plant, encompassing both physical and environmental characterizations. The study adheres to the ASTM D 6751 standard, which delineates specifications for non-fossil origin fuels. The results indicate that biodiesel derived from RPO, when mixed with diesel in various proportions, exhibits significant potential, as its properties align with quality standards, particularly concerning power generation and gas emissions in the pilot thermal plant at ECCI University.

Keyword: biodiesel production, refined palm oil, transesterification, ethanol, pilot thermal plant

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Producción de biodiesel a partir de aceite de palma refinado mediante transesterificación: efecto en una planta térmica piloto

RESUMEN

Este artículo presenta el proceso de producción de biodiesel a partir de aceite de palma refinado (RPO) mediante transesterificación con etanol e investiga su impacto en una planta térmica piloto, abarcando caracterizaciones tanto físicas como ambientales. El estudio se adhiere a la norma ASTM D 6751, que delinea especificaciones para combustibles de origen no fósil. Los resultados indican que el biodiésel derivado de RPO, cuando se mezcla con diésel en diversas proporciones, presenta un potencial significativo, ya que sus propiedades se alinean con los estándares de calidad, particularmente en lo que respecta a la generación de energía y las emisiones de gases en la planta térmica piloto de la Universidad ECCI.

Palabra clave: producción de biodiesel, aceite refinado de palma, transesterificación, etanol, planta térmica piloto

Artículo recibido 15 marzo 2023

Aceptado para publicación: 15 abril 2023

INTRODUCTION

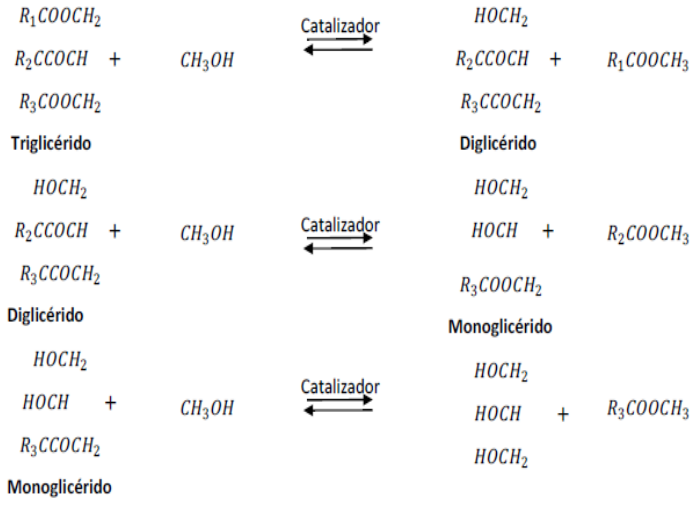
In Colombia, the renewable fuel industry is experiencing growth due to the increasing use of a 10% blend with diesel, a percentage expected to rise over time [1]. This necessitates the exploration of biodiesel production from conventional raw materials such as palm, soy, and corn [2].

The use of refined palm oil as an alternative fuel source has gained traction due to its ecological, biodegradable, and non-toxic attributes, among others, which were stipulated in the Kyoto Protocol [3].

Additionally, biodiesel is produced cleanly and, in the event of accidental spills, is less polluting than fossil fuels. Furthermore, it represents a 100% renewable and environmentally friendly source of energy [4,5].

This biofuel was produced using the transesterification method, the predominant technique in industrial production when vegetable oils are employed as raw materials. This method entails the reaction of esters (monoglycerides, diglycerides, and triglycerides) with alcohol (ethanol) and a catalyst, resulting in the conversion of triglycerides into biodiesel and glycerin. This transesterification process [6,7] is illustrated in Figure 1.

Figure 1. Chemical Reaction of Transesterification [8]



The physical and chemical characteristics of biodiesel produced from Refined Palm Oil (RPO) vary depending on the properties of the raw materials used in its production. As a result, it was imperative to subject the biodiesel to ASTM D 6751 standards, which are American standards established to regulate the

quality of non-fossil fuel production, specifically focusing on biodiesel [9].

These tests were conducted utilizing certified and calibrated equipment and instruments provided by ECCI University and the Uniagraria University Foundation of Colombia, ensuring the reliability of the obtained results. Initially, the physical properties of density and viscosity were determined. Viscosity is defined as a fluid's resistance to flow when subjected to an applied force. High-viscosity fluids exhibit resistance to flow, while low-viscosity fluids flow easily. Viscosity is influenced by factors such as temperature and pressure [10].

Subsequently, density was calculated, representing the mass contained within a specified volume. Density can be expressed in absolute terms, denoting mass per unit volume, or relative terms, indicating the relationship between a substance's density and a reference density. In the latter case, it results in a dimensionless magnitude without units [10]. Following these tests, the flash point was determined, serving as a descriptive parameter used to assess the flammability risk associated with biodiesel. The flash point was determined in accordance with the ASTM D 93 standard [9].

Additionally, the acid number was determined, which is expressed as the neutralization value. It represents the amount of potassium hydroxide (KOH) in milligrams required to neutralize the acids present in one gram of oil. This measure signifies the degree of degradation due to oxidation and bears a direct correlation with the thermal plant's operational lifespan and lubrication, in this context. Lastly, several parameters were calculated, including the consumption rate per minute for various biodiesel-diesel mixtures (B0, B10, B20, B30, B50, B70, and B100), gas emissions utilizing the BACHARAC model PCA-65 analyzer, and mechanical power using the digital dynamometer LUTRON reference FG-5100.

The primary objective of this study is to produce biodiesel from refined palm oil through the process of transesterification with ethanol, assessing its impact on a pilot thermal plant, and characterizing its physical and environmental properties.

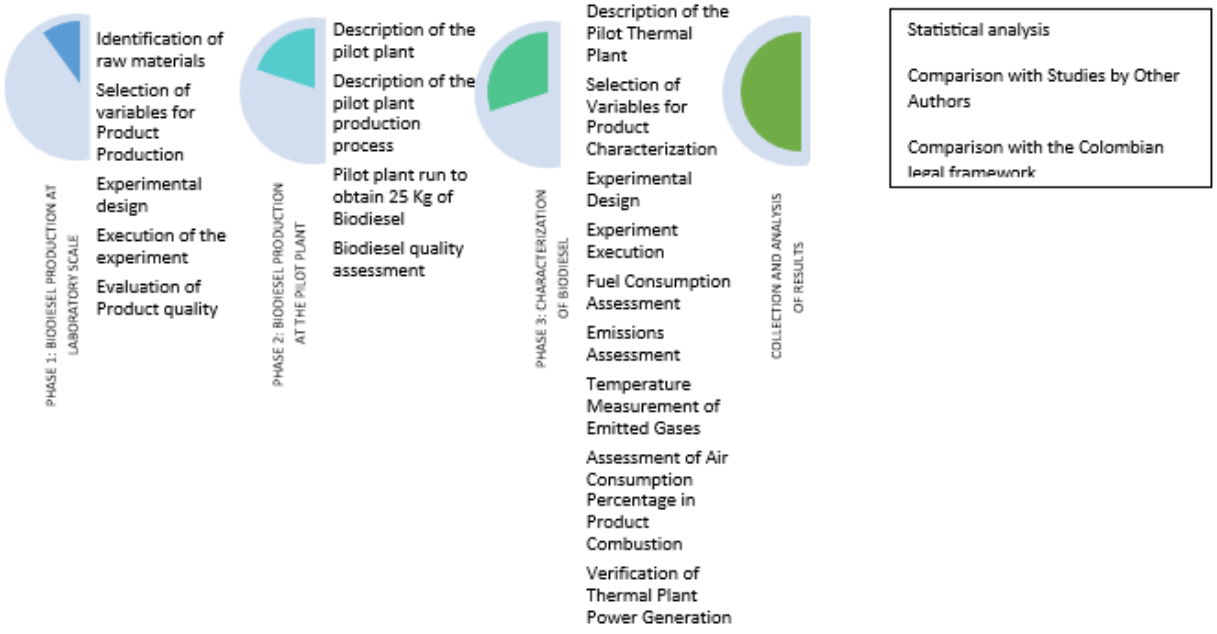
METHODOLOGY

This research falls into multiple categories, including exploratory, descriptive, correlational, and

explanatory types. It encompasses the establishment of causal relationships between variables and measurements to comprehend the resulting effects [11].

The procedural framework was designed in four distinct phases with the primary objective of producing a high-quality product that adheres to the environmental emission standards outlined in the ASTM standard. These sequential phases are visually depicted in Figure 2.

Figure 2. Methodological Phases [23]



The laboratory-scale production of biodiesel (Phase 1) was conducted as follows:

Initially, palm oil was subjected to heating at 110°C for a duration of 5 minutes. This step was aimed at eliminating moisture content from the raw material. The palm oil was placed in a beaker on a heating plate for this purpose. Subsequently, 150 ml of ethanol and 3.754 g of catalyst (KOH) were precisely measured and added to an Erlenmeyer flask. A magnetic stirrer was introduced, and the solution was promptly covered with aluminum foil to facilitate the dissolution of the catalyst flakes.

Following the dissolution, the catalyst-ethanol solution was combined with the vegetable oil in a 1000 ml four-neck glass reactor. The reaction mixture was brought to a state of ebullition while ensuring the connection of water supply hoses to the full reflux condenser to maintain the necessary cooling. The

reaction proceeded for a duration of 90 minutes.

Upon completion of this period, any excess ethanol was distilled or removed from the reaction mixture until it became turbid. Subsequently, the mixture was transferred to a separating funnel and allowed to stand for a period of 24 hours. This duration allowed the formation of two distinct layers, as depicted in Figure 3: one consisting of glycerin and the other of biodiesel.

Figure 3. Separation of biodiesel from glycerin [23]

Density

The measurement of density, denoted as mass per unit volume, is conducted in grams per milliliter at ambient room temperature, as prescribed by the formula outlined in standard NTC 336 [13]. The procedure encompasses the following sequential steps:

1. Preliminary calibration of the pycnometer at the ambient room temperature.
2. Computation of the pycnometer's precise volume.
3. Determination of the cubic expansion coefficient inherent to the pycnometer.
4. Subsequent utilization of these derived values in the aforementioned formula.

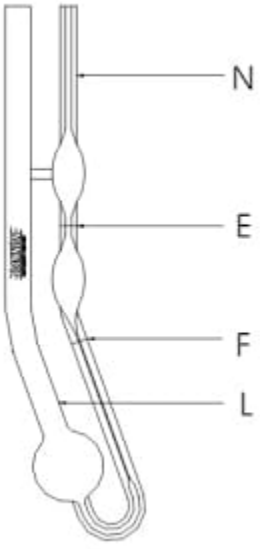
Viscosity (Kinematic At 40 °C)

Viscosity, in the kinematic sense, is evaluated in adherence to the ASTM D 445-06 [14] standard. This involves the utilization of an Oswald viscometer. The operational steps are as follows:

1. Loading the specified sample into the Oswald viscometer.

2. Inverting the viscometer instrument and subsequently applying suction to tube L.
3. Immersing tube N within the liquid sample and withdrawing the liquid until it reaches the designated mark F.
4. Ensuring the drying of arm N and returning the viscometer to its upright vertical position.
5. Placement of the viscometer within a specialized receptacle affixed to the equipment, followed by immersion into a controlled-temperature bath, with meticulous alignment to maintain verticality.
6. Allowing the liquid sample to attain a precisely regulated temperature of 40 °C, followed by a stipulated 10-minute stabilization period.
7. Application of suction to tube N, accompanied by gentle agitation to ensure the liquid rises slightly above the demarcation at point E.
8. Accurate measurement of the flow time, as the liquid traverses freely from the designated point E to the F mark.
9. Repeating this measurement thrice and subsequently computing the average value to ensure robust experimental results.

Figure 4 Cannon Fenske Viscometer [14]



Acid Number

The determination of the ACID NUMBER adheres to the ASTM 664-07 standard [15], which involves quantifying the quantity of milligrams of potassium hydroxide necessary to neutralize the free fatty acids present within 1 gram of the sample, expressed in milligrams per gram (mg/g). The procedure begins by selecting a sample size proportionate to the anticipated acidity percentage, as detailed in Table 1. Subsequently, the potassium hydroxide solution is dissolved in 125 mL of titration solvent that has been previously neutralized. To serve as a pH indicator, four (4) drops of phenolphthalein are introduced into the solution. Simultaneously, the solution is stirred, and titration is performed with the potassium hydroxide solution until reaching the endpoint, characterized by the emergence of a clear solution. This method allows for the accurate determination of the ACID NUMBER, a vital parameter in the characterization of sample acidity.

Table 1 Mass of test proportion

Percentage of acidity expected	**Mass of test portion g**	**Concentration of alkali solution**	**Accuracy in weighing**
<1	28,0	0,05	0,0200
1 a 4	7,0	0,10	0,0200
4 a 15	2,5	0,25	0,0100
15 a 75	0,5	0,50	0,0010
>75	0,1	0,50	

The Flame Point

Determination follows the guidelines outlined in the ASTM D 93-07 standard. This test employs a dynamic methodology that relies on specific heating rates, and its accuracy is contingent upon precise measurement techniques.

The procedure entails filling the equipment container up to a predetermined mark, which is subsequently sealed with a lid of precise dimensions. The sample within the container is subjected to heating at a specific stirring rate. At regular intervals, the sample is exposed to an ignition source while agitation is

momentarily interrupted. The flame point is determined when a flame becomes apparent, and the corresponding temperature reading on the thermometer is recorded as the flame point value.

This method provides a reliable means of assessing the flame point, a critical parameter, while adhering to standardized protocols in accordance with ASTM D 93-07.

Figure 5 Flame point reading [12]

Table 2 presents the physical and chemical criteria that biodiesel must conform to, as specified by ASTM 664-0, ASTM D 93-07, NTC 336, and ASTM D 445-06 standards. The table includes the respective units of measurement and outlines the minimum requirements for each characteristic.

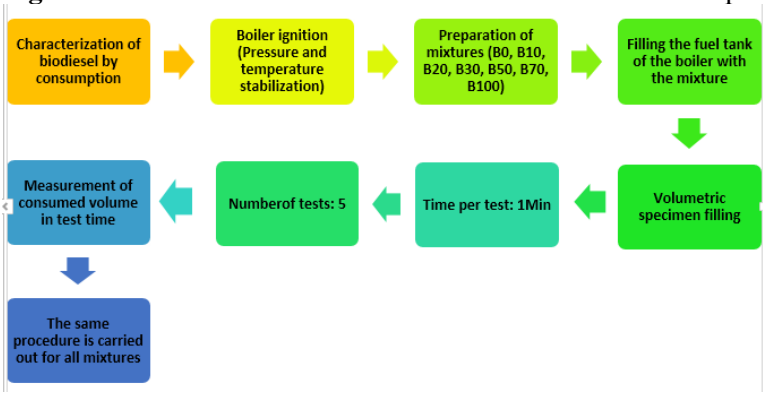
Table 2. Biodiesel characterization [16]

PROPERTY	UNIT	REQUIREMENT	TESTING METHOD
Density at 15 ° C	kg/m^3	860-900	ASTM D4052
Viscosity (kinematic at 40 ° C)	mm^2/s	1,9 – 6,0	ASTM D445
Acid Number	mg KOH / g	0,5 Maximum	ASTM D664
Flash point	° C	120 Minimum	ASTM D93

Consumption

Fuel consumption testing is conducted within the pilot thermal facility at ECCI University. This testing occurs subsequent to the successful production of 25 kilograms of biodiesel with the optimal laboratory-level characteristics. Figure 6 illustrates the methodology employed during the characterization process, providing insights into the testing procedure.

Figure 6. Procedure for characterization of Biodiesel consumption [23]



Environmental

For the assessment of gases discharged from the boiler utilizing various biodiesel-diesel blend ratios, a portable BUCHARAC model PCA-65 apparatus was employed. A total of five (5) readings were recorded for each biofuel mixture, with adherence to the parameters delineated in Table 3 [17]. This evaluation was conducted as part of the environmental assessment.

Table 3. Gas Analyzer Measurement Parameters

PARAMETER	SENSORS ACCURACY	MEASUREMENT RANGE
O2 oxygen	+/− 0,3%	0 -20,9%°C Auto calibration
Ambient temperature ° C	+/− 1%	0 -537°C
Chimney gas temperature ° C	+/- 15,5 in 0 -123°C +/- 14,5 in 124 -249°C +/- 13,5 in 250 -1093°C	0 -1093°C
Carbon monoxide	+/− 5%	0 -2000 ppm
Draft pressure in the	+/- 1%	-8¨- +8 in w.c.

The environmental operating conditions must be:	Room temperature 0-40°C Relative humidity 20 - 80%
versatility	Integrated dot printer

RESULTS AND DISCUSSION

The results obtained from the characterization of biodiesel at the pilot plant and laboratory level are shown in table number 4.

Table 4. Results obtained from the characterization of biodiesel [23]

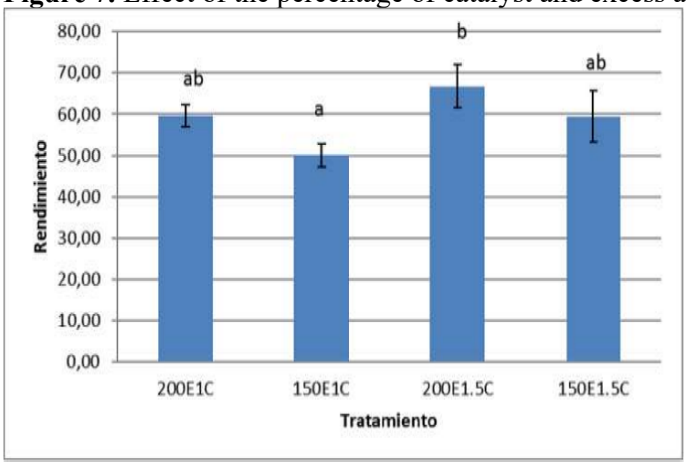
PROPERTY	UNIT	REQUIREMENT	RESULTS (LABORATORY)	RESULTS (PLANT)
Density at 15 ° C	kg/m^3	860-900	875	876
Viscosity (kinematic at 40 ° C)	mm^2/s	1,9 – 6,0	4,8	4,81
Acid Number	mg KOH / g	0,5 Maximum	0,42	0,44
Flash point	° C	120 Minimum	183,5	185

The characterization of the biodiesel reveals its compliance with the stipulated requirements outlined in the ASTM standard. This compliance extends to the density measurement conducted at 15°C, both at the laboratory scale and during plant production. In fact, the density values obtained not only fall within the specified range but also demonstrate negligible differences between them (875.876), indicating the attainment of a higher thermal energy output [18].

Furthermore, the kinematic viscosity, determined to be 1.9 mm^2/s, aligns comfortably within the bounds set by the ASTM standard. This is a noteworthy achievement as it enhances engine combustion, affording optimal lubrication properties, and mitigating environmental damage in the event of spillage [19, 20].

The acid number results obtained (0.42 and 0.44) closely approximate the values mandated by the ASTM standard. This observation underscores the favorable quality of the biodiesel, a characteristic attributed to the catalyst, alcohol, and recommended distillation purification processes employed during production [20]. In terms of the flame point result (183°C), it signifies the production of a biodiesel that is 50% safer than conventional diesel, surpassing the minimum requirement as stipulated in the standard [21]. Figure 7 illustrates the outcomes of the experimental evaluation of biodiesel yield under various treatment conditions, involving the excess alcohol-to-catalyst ratio.

Figure 7. Effect of the percentage of catalyst and excess alcohol on biodiesel yield. [2. 3]

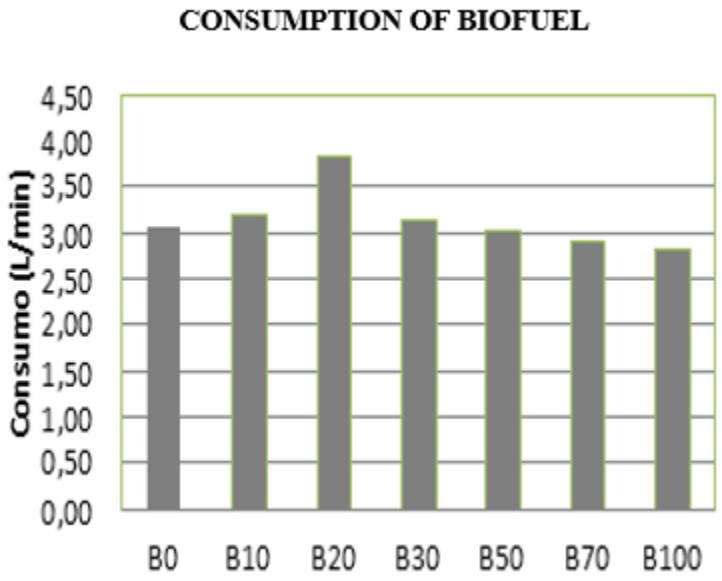


Statistical analysis revealed significant differences ($p = 0.013$, 95% significance) among the treatments, specifically between 150E1C (150% molar excess and 1% catalyst) and 200E1.5C, while no significant differences were found between 200E1C and 150E1.5C in terms of yield percentage.

The highest yield, 66.7 ± 5.24%, was obtained from the 200E1.5C treatment (200% alcohol excess and 1.5% catalyst), while the 200E1C and 150E1.5C treatments yielded 59.6 ± 2.75% and 59.5 ± 6.15%, respectively. The 150E1C treatment yielded the lowest at 50.7 ± 2.81%.

The results for biodiesel-diesel mixture consumption are illustrated in Figure 8

Figure 8. Biodiesel consumption in a pilot thermal plant. [2. 3]



The data reveals that the B20 mixture exhibits the highest consumption at 3.83 L/min, while the B100 mixture demonstrates the best performance with the lowest consumption at 2.82 L/min. Examining the data dispersion for each sample, it becomes evident that biodiesel consumption increases from the B0 mixture to the B20 mixture, after which it improves (decreases) from the B30 mixture to the B100 mixture. Moreover, the data dispersion for each sample is adjusted, indicating the statistical significance of the results.

Table 5 presents a summary of gas emissions obtained from the gas analyzer installed in the chimney of the pilot plant at ECCI University, along with biodiesel consumption and emissions test details [23].

VARIABLE	B0	B10	B20	B30	B50	B70	B100
Consumo (1/min)	3,05	3,19	3,83	3,13	3,02	2,89	2,82
O2(%	5,34	3,36	4,08	3,72	4	5,02	4,16
CO2 (%)	12,38	13,04	12,78	12,78	12,66	11,80	12,58
CO (ppm)	6,92	6,53	6,75	6,54	6,56	6,57	6,52
NO (ppm)	55,60	55,20	52.80	54,00	43,60	42,20	43,80
NOx (ppm)	58,40	57,40	55,40	56,4	46	44,40	45,80
XS (%)	27,73	27,11	26,27	26,69	22,56	22,00	22,57
T (c°)	337,8	360	352,4	353,20	359,40	328,20	351,20

The most fuel-efficient biodiesel-diesel blend in terms of consumption is B100, surpassing the B20 mixture, which proved to be the least efficient. In percentage terms, the B100 mixture exhibits a remarkable 26.45% greater efficiency compared to the B20 blend.

Regarding the measurements conducted in the thermal plant, it is evident that the B0 mixture emits the highest percentage of O2 into the environment, at 5.34%, while the B10 mixture emits the lowest O2 percentage at 3.36%. On average, the other mixtures hover around 4%, slightly lower than conventional diesel.

In terms of CO2 emissions, the least environmentally favorable mixture is B10, emitting 13.04%, whereas the B70 mixture emits the lowest amount of CO2 at 11.8%. The other mixtures show minimal variation, averaging around 12.5%. This suggests that the biofuel produced is of good quality, as reduced CO2 emissions contribute to improved boiler combustion [22].

No emissions (in ppm) range from 55.6 ppm for the B0 mixture to 42.2 ppm for the B70 mixture. The remaining mixtures fall within this range, with an average of 55 ppm. The results exhibit low dispersion, and emissions are not statistically significant.

Illustrations, Tables, Figures

Figures

Figure 1. Chemical Reaction of Transesterification [8]

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CONCLUSIONS

The biodiesel produced in this study exhibits several environmental advantages compared to fossil diesel. It has a higher flash point (130°C) in contrast to petroleum-based diesel (52°C) [28], making it less prone to combustion. Biodiesel is biologically active and biodegradable, unlike diesel, which is challenging to break down. Additionally, it leads to lower carbon monoxide (CO) emissions due to reduced ignition delay. Furthermore, its compatibility with international markets offers promising avenues for commercialization.

A biodiesel was successfully manufactured through transesterification of refined palm oil using ethanol as a catalyst. This biodiesel possesses properties that closely resemble those of traditional fossil diesel and adheres to ASTM D 6751 standards.

In terms of fuel efficiency, B100 emerges as the most efficient biodiesel-diesel mixture, while the B20 blend proves to be the least efficient. The B100 mixture demonstrates an impressive 26.45% increase in efficiency compared to the B20 blend.

These conclusions highlight the promising environmental and efficiency advantages of the biodiesel produced in this study. The findings underscore its potential as a sustainable and eco-friendly alternative to conventional diesel, with particular merit for B100 as a highly efficient fuel blend. Further research and application in real-world contexts could further validate its viability and benefits.

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