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Oil Extracted from Coffee Grounds to Obtain Biodiesel as Renewable Energy

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Biodiesel is one of several alternative fuels as it reduces the amount of greenhouse gases that cause global warming in the world. Coffee consumption produces a by-product called ground coffee, raw material for the oil used in the production of biodiesel. In the investigation, the conversion efficiency of the oil extracted from the coffee grounds into biodiesel was determined, from the obtaining and characterization of the oil extracted from the coffee grounds, which presented a density of 0.875 g/mL, viscosity of 44.7 mm²/s, free fatty acids of 2.729%, acid value of 5.722 mg KOH/g, iodine value 111.672 g I_2/100 g and saponification value of 31.422 mg KOH/g. With the extracted oil, biodiesel was obtained by the transesterification process through a completely randomized design analysis, the stirring speed significantly influenced the conversion of the oil to biodiesel, the results obtained under a stirring speed of 100 rpm the conversion was 77.78 % while the biodiesel produced at a stirring speed of 400 rpm the conversion was 92.48 % and presented a density of 0.88 g/mL, viscosity of 5.47 mm²/s, free fatty acids of 0.1605 %, acid value of 0.3366 mg KOH/g and iodine value of 83.754 g I_2/100 g. Biodiesel was obtained with good efficiency as an environmentally friendly fuel.

1. Introduction

Biodiesel is one of the environmentally friendly liquid fuel alternatives, it reduces the amount of greenhouse gases that cause global warming. Biodiesel as a liquid fuel shows a constant upward trend until 2030 in global energy consumption, which in the industrial sector represents a large part of the demand for this fuel (Ganev et al., 2022). In addition, biodiesels are non-toxic, biodegradable and do not contain sulfur, the disadvantage of industrial biodiesels is that they are not economically competitive with petroleum-derived fuels (Mueanmas et al., 2019).
Worldwide, coffee is one of the most consumed beverages, in 2017 its consumption was estimated at 9.3 million tons (Pettinato et al., 2019), which generated approximately 6 million tons of discarded coffee grounds (Mata et al., 2018). Among the components of coffee grounds are cellulose, hemicellulose and lignin. In addition, they contain compounds of high added value such as fatty acids, tocopherol (vitamin E), kahweol and cafestol, these last compounds could be extracted from coffee grounds and used for cosmetic, food and bioenergy purposes (Batista et al., 2020b). Coffee grounds, presenting a high concentration of triglycerides and long fatty acids, are suitable substrates for the production of biodiesel, it is stable, remains viscous and does not freeze easily, therefore it is only comparable to conventional first-generation biomass (Al-Hakam et al., 2012, Efthymiopoulos et al., 2018). These properties make coffee grounds oil a promising raw material for the production of biodiesel, an alternative and economical fuel (Van Gerpen, 2005). In biodiesel production, the variables that influence yield are: molar ratio of methanol to oils, temperature, reaction time and catalyst concentration measured as FAME analysis (Goh et al., 2020, Oliveira et al., 2008). Increasing the ratio of solvent to oils affects transesterification in two opposite directions: a) increased efficiency, because higher solvent concentrations favor biodiesel production (direct reaction) or, b) less efficiency, because low concentrations of oils favor the production of triglycerides (inverse reaction) (Najdanovic-Visak et al., 2017). Therefore, an optimal methanol/coffee grounds oil ratio represents a prerequisite for efficient biodiesel production.

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Coffee grounds are the waste product of coffee preparation, oil is extracted from this biomass for the production of biodiesel. The conversion of ground coffee oil to biodiesel can be carried out by transesterification of coffee oils catalyzed by acids, alkalis or enzymes, generally using methanol as a reactive substance for the production of fatty acid methyl esters (Batista et al., 2020a). To improve the efficiency of the transesterification process, the agitation speed was increased and to obtain a better conversion of oil into biodiesel.
In the city of Huancayo-Peru there is a large consumption of coffee, so in this context the research used coffee grounds for the extraction of oil and subsequent production of biodiesel.

2. Methodology

To obtain biodiesel, a completely randomized design analysis was carried out with the following procedure.

2.1 Collection and drying of coffee grounds

The coffee grounds were collected as a residual product in the coffee drink, from different cafeterias in the city of Huancayo, in plastic containers with hermetic lids (Figure 1) and were dried at a temperature of 80 °C for 3 days., to eliminate moisture and prevent the growth of fungi that can alter the composition of the coffee grounds.

2.2 Extraction of oil from coffee grounds

A soxhlet system was used, in the following process:

- 50 g of the dried coffee grounds were weighed and wrapped in filter paper, so that the biomass does not mix with the solvent, this package was placed in the extractor chamber.
- 400 mL of hexane was added to the round bottom flask as process solvent.
- The system was put into operation, the temperature was controlled at 70 °C, because it is higher than the boiling point of the solvent, this process was carried out for 6 hours to ensure maximum oil yield.
- Once the process was finished, a simple distillation was performed to separate the solvent from the oil obtained, this process was carried out by heating the oil and hexane mixture up to 70 °C in a steam entrained system, which helped to evaporate the solvent and recover it.
- The oil obtained was heated for 1 hour at a temperature of 100 °C to remove any trace of solvent (Figure 2).

Figure 1. Receptacles for coffee grounds

Figure 2. Heating of the obtained oil

2.3 Characterization of coffee grounds oil

The laboratory results of the physical analysis (density and viscosity) and the chemical analysis (percentage of free fatty acids, acid value, iodine value and saponification value), were compared with the American Standard for Testing Materials (ASTM D 6751) and the European Standard EN 14214:2012+A2:2019 to assess the quality of the oil.

2.4 Procedure for obtaining biodiesel

- The extracted oil was heated to 54 °C to homogenize it.
- Then 100 mL of the oil, heated together with methanol and the catalyst (NaOH) was added to a batch reactor (250 mL flat-bottomed balloon), the molar ratio of methanol and oil was 6:1; and as for NaOH, 1 wt.% was added (Figure 3).

- The mixture of oil, methanol and catalyst was stirred at the speed of: 100 rpm and 400 rpm, at a process temperature of 60 °C.
- The reaction time to obtain biodiesel was 90 minutes.
- After the reaction, the mixture was subjected to centrifugation at 2500 rpm for 5 minutes.
- Next, the mixture was placed in a separator funnel, letting it settle for 12 h, this helped to separate the two phases, the bottom phase was the glycerine formed, and the upper phase was biodiesel (Figure 4).
- Finally, the biodiesel obtained was measured for: pH, acidity index. This procedure was carried out until the pH of the biodiesel was neutral.
- The conversion efficiency of the oil in the biodiesel was determined with the acidity index of the oil and the acidity index of the biodiesel.

Figure 3. Mixture of oil, methanol and catalyst

Figure 4. Separation of biodiesel and glycerin

3. Resulted and discussion

3.1 Physicochemical characterization of the oils extracted from coffee grounds

Table 1 presents the results of the physicochemical characterization of the oil extracted from the coffee grounds used, with respect to that established in standard EN 14214, it is observed that the oil density of 0. 875 g/mL complies with the standard by being between the limits of 0.86 and 0.90 g/mL, in terms of viscosity the oil presents a kinematic viscosity of 44.7 mm2/s, exceeding limits of 1.9 to 6 mm2/s; It is recommended that this value be close to that stipulated in the standard to favor the fluidity of the oil.
The acidity index exceeds the 0.8 mg KOH/g established by the standard presenting a value of 5.722 mg KOH/g and regarding the iodine index if it complies with the provisions of the standard by presenting a value of 111.672 g I2/100 g, lower than the maximum value of 120 g I2/100 g. Likewise, by presenting fatty acids of 2.729% relatively low value compared to other studies such as Haile (2014) which mentions for the transesterification process to use an alkaline catalyst such as NaOH, the same which is substantially beneficial because it exhibits a higher reaction rate and requires less amount of methanol than an acid catalyst.

Table 1. Physicochemical characterization of the oils extracted from coffee grounds.

	Parameters	Unit	Results	Norma ASTM D6751	Norma EN 14214
Physics	Density	g/mL	0.875	-----	0.86 – 0.90
	Viscosity	mm^2/s	44.7	1.90-6.00	3.50 – 5.00
Chemistry	Free fatty acids (FFA)	%	2.729		
	Acidity index	mg KOH/g	5.722	0.50 max	0.50 max
	Iodine index	$g\ I_2/100\ g$	111.672	-----	120 max
	Saponification Index	mg KOH/g	31.422		

Considering other studies on the extraction of oil from coffee grounds, according to Dang and Nguyen (2019) they extracted oil from coffee grounds that presented an acid value of 6.13 mg KOH/g, free fatty acids (FFA) 3, 07% value close to the result of the investigation and, according to Bendall et al. (2015) consider the amount of oil obtained from coffee depends on the source and varies from 11 to 20% in dry weight.

3.2. Influence of Agitation Speed

The transesterification process to convert the oil extracted from coffee grounds into biodiesel, was carried out at agitation speeds of 100 and 400 rpm. The acidity index and the conversion percentage were determined for three samples. The results are presented in Table 2.

Table 2. Agitation speed in the biodiesel production process.

Samples	100 rpm		400 rpm	
	Acidity index (mg KOH/g)	Conversion (%)	Acidity index (mg KOH/g)	Conversion (%)
Sample 1	1.234	78.43	0.449	92.16
Sample 2	1.403	75.49	0.337	94.12
Sample 3	1.178	79.41	0.505	91.18

In Table 2, it can be observed that the biodiesel obtained at an agitation speed of 400 rpm complies with the ASTM standard by presenting acidity levels lower than 0.5 mg KOH/g. The lowest acidity index is 0.337 mg KOH/g, obtained in sample 2. At 100 rpm, values exceeding 1 mg KOH/g were recorded, with the highest value being 1.234 mg KOH/g in sample 1. Regarding conversion, at an agitation speed of 400 rpm, conversion percentages greater than 90% were achieved, with the highest conversion percentage being 94.12% in sample 2. Meanwhile, at 100 rpm, the conversion percentage of oil into biodiesel reached a maximum of 78.43% in sample 1.

3.3. Physicochemical characterization of biodiesel

Table 3 indicates that the biodiesel produced at a stirring speed of 400 rpm complies with the ASTM D6751 standard in terms of viscosity and acid index, and with respect to the EN 14214 standard, it complies with all except for viscosity, this biodiesel being the most optimal in comparison with the biodiesel produced at a stirring speed of 100 rpm that only complies with the density and iodine value established in the EN 14214 standard.

Table 3. Physicochemical characteristics of biodiesel obtained from oil extracted from coffee grounds.

Parameters	Unit	Biodiesel (100 rpm)	Conversion (%)	Biodiesel (400 rpm)	Conversion (%)
Density	g/mL	0.86	77.78	0.88	92.48
Viscosity	mm^2/s	6.01		5.47	
Free fatty acids (FFA)	%	0.5618		0.1605	
Acidity index	mg KOH/g	1.1781		0.3366	
Iodine index	g I_2/100 g	60.912		83.754	

Comparing with other similar works, according to Tuntiwiwattanapun et al. (2017) the biodiesel obtained from worn coffee beans presented a viscosity of 4.18 mm^2/s, acidity index of 1.4 mg KOH/g result superior to our research, ASTM D6751 and EN 14214 Standards. According to dos Santos et al. (2022) in the study of prediction of kinematic viscosity in biodiesel from vegetable and algae oils, its viscosity turned out to be higher than that of fossil diesel, therefore, it is important to comply with the specifications defined by the regulatory agencies for the final blends of diesel and biodiesel. In the research of Urribarrí et al. (2014) analyzed the increase of agitation speed in the production of biodiesel with ground coffee fats, a higher concentration of methyl esters was obtained, and these results indicate that coffee grounds fats have great potential as a raw material for biodiesel production.

To evaluate the effect of the speeds and the biodiesel conversion efficiency, a graph was made as shown in Figure 5, the transesterification process was carried out at 100 rpm, the percentage of oil conversion into biodiesel was 77.78 %, a value that increases to 92.48 % when the transesterification process is carried out at 400 rpm. Finally, determining that the biodiesel obtained from the oil extracted from coffee grounds is of good efficiency.

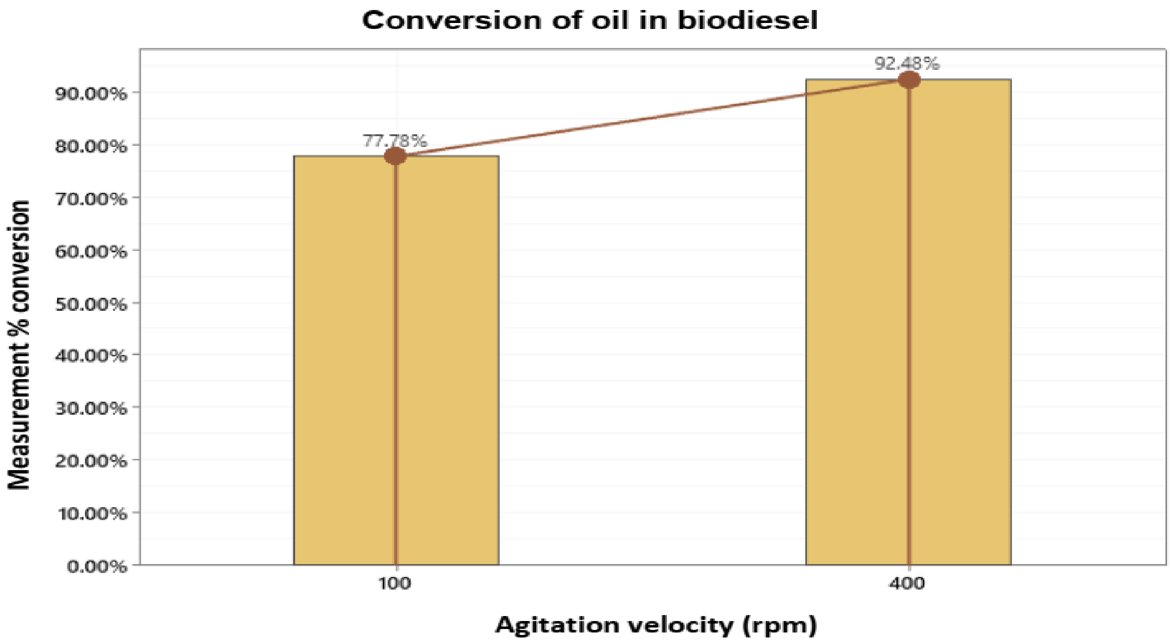

Figure 5. Conversion of oil extracted from coffee grounds into biodiesel.

4. Conclusions

In the process of obtaining biodiesel from the oil extracted from the coffee grounds, it was determined that the stirring speed significantly influenced the conversion of the oil extracted from the coffee grounds into biodiesel, considering that the biodiesel produced under a stirring speed at 100 rpm it presented a conversion efficiency of 77.78% while at 400 rpm it was 92.48%. The results of the investigation indicate that it is possible to produce biodiesel from the oil extracted from coffee grounds with physicochemical parameters of: density of 0.88 g/mL, viscosity of 5.47 mm^2/s, percentage of fatty acids. free of 0.1605 %, acid value of 0.3366 mg KOH/g and iodine value 83.754 g I_2/100 g results that comply with ASTM D6751 and EN 14214 Standards. This emerging technology is viable for alternative energy generation in cities with high production and consumption of coffee and improve the use of energy quality in the population.

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