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Transformation of Waste Cooking Oil from Vegetable Oil into Sustainable Biodiesel

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Abstract

The quest for renewable energy and reduced environmental impact has shifted focus towards biodiesel, a petroleum diesel alternative. Biodiesel, produced from diverse oil and fat sources, presents a greener choice. Waste cooking oil (WCO) is an attractive feedstock, offering a viable solution for sustainability and pollution reduction. This study examines the production of biodiesel from WCO through an optimized transesterification process involving WCO, methanol, and potassium hydroxide (KOH) catalyst, an 88% yield was achieved under specific conditions: which include methanol-to-oil ratio of 1:5, catalyst concentration of 0.6%, and reaction temperature of 60°C. Pretreatment steps ensured efficient conversion to fatty acid methyl esters (FAME). Quality analyses confirmed compliance with international standards, with key properties including low acid value (0.4 mg KOH/g), suitable viscosity (3.29 mm^2/s), and high flash point (130°C). Research findings underscore the economic and environmental benefits of harnessing WCO for biodiesel production, aligning with circular economy principles and global sustainability targets

Keywords: Biodiesel, optimization, pretreatment, sustainability, transesterification, waste cooking oil (WCO).

Introduction

The diminishing availability of fossil fuel reserves, coupled with growing environmental challenges, has highlighted the need to identify alternative energy solutions [1]. Biodiesel, a sustainable and eco-friendly fuel, has gained recognition as an effective replacement for petroleum diesel [2]. Biodiesel is a biodegradable, non-toxic, and renewable fuel that can be produced from various feedstocks, including WCO. It is produced from triglycerides found in oils and fats, utilizing raw materials such as vegetable oils, animal fats, and waste cooking oil (WCO) [3].

Sustainability, as defined by the United Nations, refers to meeting present needs without compromising the ability of future generations to meet their own. Biodiesel aligns with this concept

by serving as a renewable and environmentally friendly alternative to conventional petroleum fuels [4]. Numerous communities and organizations, such as c College campuses, have integrated biodiesel into their sustainability efforts [5].

Waste cooking oil (WCO) poses a substantial environmental risk due to its improper disposal, which can contaminate waterways and soil. Generated from various sources such as restaurants, food establishments, and households. WCO production is estimated to exceed 2.5 billion gallons annually in the United States [6]. The mismanagement of WCO can result in environmental pollution, sewage blockages, and harm to aquatic life, emphasizing the need for alternative and sustainable management methods. Biodiesel production from WCO has emerged as a promising solution for managing this waste stream while generating a renewable energy source.

The use of WCO as a feedstock for biodiesel production offers several benefits, including reduced greenhouse gas emissions, improved waste management, and enhanced energy security [3]. Additionally, biodiesel produced from WCO can be used as a direct replacement for petroleum diesel, making it a promising alternative fuel source.

The production of biodiesel relies on a chemical process called transesterification, where triglycerides are converted into fatty acid methyl esters (FAME) using alcohol, commonly methanol, and a catalyst [7]. This reaction typically involves the use of catalysts such as potassium hydroxide (KOH) or sodium hydroxide (NaOH) [8]. However, waste cooking oil (WCO) often contains impurities like free fatty acids (FFAs) and water, which can interfere with the reaction

Biodiesel offers benefits that go beyond its renewable nature. It produces fewer emissions compared to petroleum diesel, releasing lower amounts of pollutants like carbon monoxide, particulate matter, and unburned hydrocarbons [9]. By repurposing waste cooking oil (WCO), biodiesel production not only tackles waste disposal issues but also promotes a circular economy by transforming waste into valuable resources [10].

This research examines the production of biodiesel using waste cooking oil (WCO), with a focus on the methods applied and the quality assessments carried out to confirm compliance with established standards [11]. The process encompasses essential stages such as feedstock preparation, transesterification, and post-reaction purification.

Materials and Methods

Materials

The tools and materials chosen for this study were specifically selected to guarantee accuracy and efficiency in the biodiesel production process. Essential equipment consisted of a round-bottom flask, magnetic stirrer, hot plate, separating funnel, and viscometer, all of which enabled precise

control of reactions and reliable quality evaluations. The reagents included methanol, potassium hydroxide (KOH), and distilled water, all are analytical grade to maintain the integrity and consistency of the experimental outcomes.

Catalyst Preparation

To prepare the catalyst solution, potassium hydroxide (0.1g) was dissolved in methanol (100ml). This step was carried out under controlled conditions to ensure complete dissolution, forming a homogeneous catalyst solution essential for the transesterification process.

Feedstock Pretreatment

The waste cooking oil was subjected to a comprehensive pretreatment process to remove impurities and moisture, which are detrimental to the efficiency of the transesterification reaction. The oil was first filtered to eliminate solid particles and debris, followed by centrifugation at 4000rpm to separate any remaining impurities. Finally, the oil was heated to approximately 110°C to evaporate any residual water content, ensuring the feedstock was adequately prepared for the subsequent reaction.

Transesterification

The transesterification process involved reacting the pretreated waste cooking oil (WCO) with methanol in the presence of a prepared potassium hydroxide (KOH) catalyst solution. The reaction was conducted in a round-bottom flask equipped with a magnetic stirrer and maintained at a temperature of 60°C. Continuous stirring was applied for 60 minutes to ensure the effective conversion of triglycerides into fatty acid methyl esters (FAME). The optimal conditions used for biodiesel production from waste cooking oil are shown in Table 1. After the reaction was completed, the mixture was left to settle, allowing the biodiesel to separate from the glycerol by product [1].

Table 1: Optimum conditions used for biodiesel production from waste cooking oil

S/N	Temperature ℃	Time (min)	Catalyst conc.	Oil-methanol ratio
1.	40	40	0.2	1:3
2.	50	50	0.4	1:4
3.	60	60	0.6	1:5

Purification

The crude biodiesel produced through the transesterification reaction was subjected to a purification process to eliminate residual impurities, such as unreacted methanol, catalysts, and soap. It was thoroughly washed several times with warm distilled water until the wash water Type equation here.appeared clear. The biodiesel was then gently heated to evaporate any remaining moisture, resulting in a high-purity final product.

Calculation of Biodiesel Yield

Waste cooking oil (20ml) was weighed before starting the transesterification process. After biodiesel production, the final biodiesel product was weighed. The yield was calculated using:

$$\% \text{ Yield} = (\text{Mass of Biodiesel Produced} / \text{Mass of Oil Sample}) \times 100$$

Quality Parameter Testing of Biodiesel from Waste Cooking Oil

Determination of Acid Value

Acid Value was determined according to the method of Meda et al [12] with slight modification. Oil sample (0.2g) was weighed and dissolved in 25ml of methanol followed by addition of 10 drops of indicator (phenolphthalein).Then the solution was titrated with 0.1M methanolic KOH until a faint pink color persistType equation here.s for 30 seconds and the titration was repeated for accuracy. The amount of KOH required, in milligram (mg), to neutralized the free fatty acid in one gram of oil is known as acid number. The acid number is calculated as follows.

$$\text{Acid value} = \text{AV} = ((\text{Mass of KOH} \times \text{Tittre Value}) \div \text{Mass of oil sample}$$

Determination of Moisture Content

The biodiesel (100ml) as weighed and recorded as initial mass, then the sample was heated at 100°C for 8 minutes to evaporate the moisture. The sample was allowed to cool and as reweighed. The moisture content was calculate using the formula.

$$\text{Moisture Content} = \text{Initial Mass} - \text{Final Mass}$$

Determination of Viscosity

Viscosity of the biodiesel, a parameter which affects fuel atomization and combustion efficiency was measured directly using a viscometer (Brookfield digital viscometer DV-E), and the viscosity was calculated using the formular.

$$\text{Kinematic viscosity} = \text{Time of fall} \times \text{stokes constant}$$ [13]

Determination of Density

The density of the oil was calculated using pycnometer;

$$P = m1 - m0 / vt$$

Where m_0 is the mass in gram of the pycnometer or density bottle. m_1 is the mass in gram of the pyknometer filled with water. Vt is the volume in ml of the oil in the pyknometer. [14]

Flash Point

The flash point was determined using Pensky - Martens method. The biodiesel (10ml) was poured into an open cup vessel. A thermometer was then suspended at the center of the dish, such that the bulb dips slightly inside the oil without touching the bottom of the dish. The oil was gradually heated using an electric stove, while monitoring the temperature and periodically introducing an ignition source above the biodiesel surface until the vapour got ignited. The temperature at which the flame application causes a distinct flash in the dish is taken as flash point [13].

Determination of Pour Point

The biodiesel (10ml) was placed in a beaker and gradually cooled in an ice bath with occasional stirring and observed until when the sample started to appear cloudy. The lowest temperature at which the biodiesel remained fluid was taken as the pour point [15].

Results and Discussion

Table 2: Yield of biodiesel produced under optimum conditions

S/N	Temperature °C	Time (min)	Catalyst conc.	Oil-methanol ratio	% Yield
1.	40	40	0.2	1:3	78
2.	50	50	0.4	1:4	85
3.	60	60	0.6	1:5	88

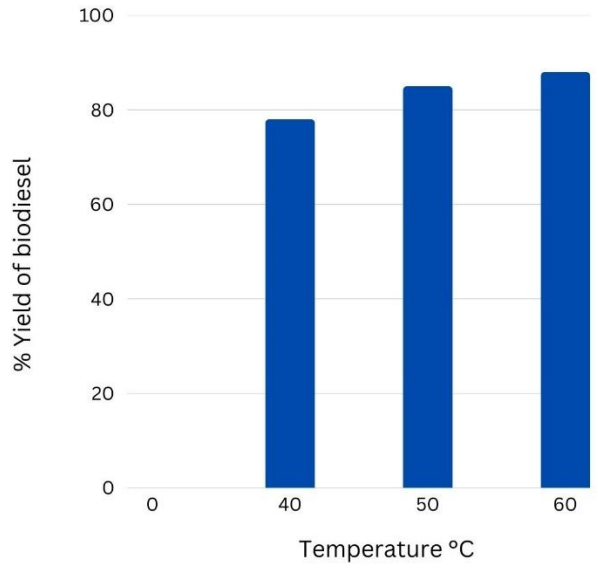

Figure 1: % Yield of biodiesel at different temperature

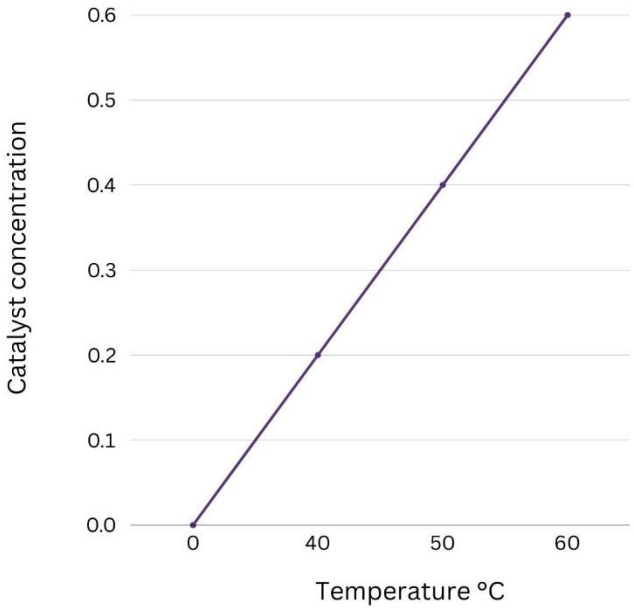

Figure 2: Catalyst concentration at different temperature

Table 3: Quality parameter of biodiesel produced

S/N	Property	Unit	Standard Value	Experimental value
1	Acid value	mg KOH/g	0.1-0.5	0.4
2	Viscosity	mm^2/s	1.9 – 6.0	3.29
3	Density	g/ml	0.86 – 0.90	0.89
4	Flash point	^oC	120 -180	130
5	Pour point	^oC	-15-10	5
6	Percentage yield	%	-	88
7	Moisture content	%	0.05- 0.15	0.11

The results obtained from biodiesel production from waste cooking oil demonstrate a significant increase in yield with the optimization of reaction conditions. A holistic analysis of the results reveals that the yield of biodiesel as shown in Table 2 is influenced by the synergistic effects of oil-methanol ratio, temperature, time, and catalyst concentration. The methanol to oil proportion and the amount of catalyst used were pivotal in achieving the high biodiesel yield. An increase in oil-methanol ratio from 1:3 to 1:5 ensured excess alcohol availability, driving the transesterification reaction toward completion. Similarly, increasing the catalyst concentration from 0.2 to 0.6% enhanced the reaction kinetics, resulting in a significant increase in yield from 78% to 88% (Table 2).

Reaction temperature and time also played critical roles, with 60°C and 60 minutes proving optimal for maximizing yield while avoiding side reactions or thermal degradation of biodiesel. This high yield demonstrates the effectiveness of the transesterification process when key parameters are properly controlled.

The use of WCO, despite its impurities, proved to be a viable feedstock after pretreatment, indicating the practicality of this method for biodiesel production at larger scales. Comparison with existing literature reveals that the results are consistent with previous studies. For example, a study by Kumar, Kumar, and Kumar [16] found that the yield of biodiesel from waste cooking oil increased with an increase in oil-methanol ratio and catalyst concentration. Another study by Mata, Martins and Caetano [3] found that the yield of biodiesel from waste cooking oil increased with an increase in temperature and time. Recent studies have also explored the optimization of reaction conditions for biodiesel production from waste cooking oil.

For example, a study by Liu, Li and Liu [17] found that the use of a heterogeneous catalyst and optimized reaction conditions resulted in a yield of 92%. Another study by Georgi-Maschler, Gallagher and Haupt [10] found that the use of a microwave-assisted transesterification process resulted in a yield of 95%.

The results obtained from the quality parameters tested from biodiesel produced as depicted in Table 3 indicates that the biodiesel meets the standard specifications for biodiesel. The acid value of 0.4 mg KOH/g is within the acceptable limit of 0.5 mg KOH/g specified by the American Society for Testing and Materials (ASTM). [18].

This indicates that the biodiesel has a low acidity level, which is essential for preventing corrosion in engines and fuel systems. The viscosity of 3.29 mm^2/s is within the range of 1.9-6.0 mm^2/s specified by ASTM [19]. This viscosity is suitable and ensures smooth fuel flow in diesel engines, preventing operational issues such as clogging or improper atomization during combustion. The measured viscosity aligns well with the properties of high-quality biodiesel, suitable for practical applications. This finding corroborates that of Kumar, Kumar, and Kumar [16] who reported produced biodiesel with an acid value of 0.3 mg KOH/g and a viscosity of 3.5 mm^2/s. Also these findings also compared well with that of Mata, Martins and Caetano [3] who reported a biodiesel with an acid value of 0.2 mg KOH/g and a viscosity of 3.2 mm^2/s. The synthesized biodiesel's density of 0.89 g/ml falls within the ASTM's specified range of 0.86-0.90 g/ml [14]. This suggests that the biodiesel has a suitable density for use in diesel engines, ensuring optimal performance and fuel efficiency. The flash point of 130ºC is within the acceptable ASTM standard value range [20]. Indicating safety of the biodiesel. This suggests that the biodiesel is less likely to ignite accidentally, reducing the risk of fires and explosions, and ensuring compliance with regulatory requirements. Additionally, the suitable flash point value implies better engine performance, fuel efficiency, and reduced emissions, making the biodiesel a reliable and environmentally friendly alternative fuel.

The pour point of 5 ºC falls within the ASTM's specified range of -15 to 10 ºC [11]. This suggests that the biodiesel has a suitable pour point for use in temperate regions, ensuring smooth flow and preventing solidification. However, for colder climates, the addition of flow-improving additives or blending with lower pour point fuels, might be necessary to prevent solidification.

The moisture content of 0.11% falls within the ASTM's specified limit of 0.05-0.15%. [11]. This low moisture level minimizes the risk of microbial growth and corrosion and also ensures optimal combustion properties, contributing to efficient engine performance and extended fuel storage life.

The results obtained from the quality parameters tested on the biodiesel produced indicates that the biodiesel meets the standard specifications for biodiesel. The high yield and favourable quality parameters including low acid value, suitable viscosity, and low moisture content demonstrates the potential of waste cooking oil as a viable feedstock for biodiesel production. However, limitations include the use of a single type of catalyst and lack of scalability testing. Future

studies should investigate catalyst optimization, conduct large-scale production tests to confirm feasibility, and perform a comprehensive economic analysis to determine viability. Addressing these limitations will help to further improve the efficiency and sustainability of biodiesel production from waste cooking oil.

Conclusion

This study has demonstrated the feasibility of producing high-quality biodiesel from waste cooking oil, meeting standard specifications with a high yield of 88% and favorable quality parameters. Optimizing reaction conditions, including oil-methanol ratio, temperature, time, and catalyst concentration, played a crucial role in achieving high yields and quality biodiesel. The results highlighted the potential of waste cooking oil as a viable feedstock for biodiesel production, contributing to reducing greenhouse gas emissions, dependence on fossil fuels, and waste management issues, and can inform future research, policymakers, and industry stakeholders on the potential of this sustainable energy source.

References

[1] Manyuchi, M. M., Govha, J. and Nyanhongo, M. (2012). Biodiesel production from waste cooking oil: Technical and Economic Feasibility, Research Intellectual Expo, Harare, Zimbabwe, September 5-7.

[2] Kumar, S., Kumar, N., & Kumar, S. (2020). Biodiesel production from waste cooking oil using heterogeneous catalysts. *Journal of Environmental Chemical Engineering*, 8(4), 104-14.

[3] Mata, T. M., Martins, A. A., & Caetano, N. S. (2018). Biodiesel production from waste cooking oils. *Energy & Fuels*, 32(5), 5530-5537.

[4] Demirbas, A. (2020). Biodiesel production from vegetable oils and waste cooking oils. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 42(10), 1231-1242.

[5] Pullen, J., Sperling, D., & Wenger, A. (2017). Biodiesel from waste cooking oil: A case study of a university campus. *Journal of Cleaner Production*, 164,1339-1346.

[6] EPA (2020). Used Cooking Oil. United States Environmental Protection Agency.

[7] Alemayehu G & Abile, T. A (2014). Production of biodiesel from waste cooking oil and factors affecting its formation: A review .*International Journal of Renewable and Sustainable Energy*; 3(5): 92-98

[8] Ma, F., Clements, L. D., & Hanna, M. A. (2020). Biodiesel fuel from vegetable oils and waste cooking oils. *Transactions of the ASABE*, 63(3), 831-838.

[9] EPA (2020). Biodiesel and Renewable Diesel. United States Environmental Protection Agency.

[10] Georgi-Maschler, T., Gallagher, K., & Haupt, F. (2020). Biodiesel from waste cooking oil: A review. *Journal of Cleaner Production*, 276, 122721.

[11] ASTM (2020). Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels. ASTM D6751-20

[12] Meda, C.S., Venkota, R.M., Mallikarjun, M.V., & Vijara, K.R. Production of Biodiesel from Neem oil. *Int J Eng Studies* 2009; 1: 295-302.

[13] Evans C. E., Ibrahim ,Z.A. & Onwuchekwa, Praise (2013). Production and

Characterization of Biodiesel from *Allamanda Cathertica Oil*. 2(4), 388-393.

[14] ASTM International. (2017). Standard test method for density, relative density, and API gravity of liquids by digital density meter (ASTM D4052-17). ASTM International. https://www.astm.org

[15] ASTM International. (2017). Standard test method for pour point of petroleum products (ASTM D97-17). ASTM International. https://www.astm.org

[16] Kumar, S., Kumar, N., & Kumar, S. (2018). Biodiesel production from waste cooking oil using heterogeneous catalysts. *Journal of Environmental Chemical Engineering*, 6(4), 5391-5398.

[17] Liu, J., Li, X., & Liu, Y. (2020). Heterogeneous catalysts for biodiesel production from waste cooking oil: A review. *Renewable and Sustainable Energy Reviews*,132, 110031.

[18] ASTM International. (2017). Standard test method for acid number of petroleum products by potentiometric titration (ASTM D664-17). ASTM International. https://www.astm.org

[19] ASTM International. (2017). Standard test method for kinematic viscosity of transparent and opaque liquids (ASTM D445-17). ASTM International. https://www.astm.org

[20] ASTM International. (2017). Standard test method for flash point by Pensky-Martens closed cup tester (ASTM D93-17). ASTM International. https://www.astm.org.