

WASTE TO ENERGY APPROACH OF TRANSFORMING USED COOKING OIL INTO BIODIESEL FOR COMPRESSION IGNITION ENGINES

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Abstract

Waste vegetable oil (WVO) is a byproduct of food processing and cooking practices that is unfit for human consumption. The existence of edible Waste Vegetable Oils (WVO), which are hazardous to water quality and show resistance to conventional filtration, causes major operational challenges for community water treatment plants. The International Energy Agency (IEA) has reported that inappropriate disposal of these fuels significantly worsens the state of the environment. In order to successfully prevent water pollution and meet the expanding worldwide fuel demand, this study uses the transesterification process to convert WVO into biodiesel utilizing methanol and ethanol. The generated biodiesel underwent standard fuel testing, and the results closely met the ASTM standards. This study has successfully achieved the reduction in the specific gravity and chemical viscosity of vegetable oils, making them suitable alternatives to mineral diesel. Tests in the field demonstrated the fuel's effectiveness, and the recovery of glycerol as a by-product significantly increased its economic value. This study concluded that both the formations of biodiesel has shown properties in terms of calorific value and flow characteristics. In addition, both the fuels have shown optimal flash points, making it the fuel of choice for the commercial utilization. However, Methyl ester has comparatively good flow properties besides this it is also less volatile in nature, due to which it has better characteristics of storage and transit safety.

1. Introduction

The necessity of the energy has grown in a large scale. Most importantly the source of the energy not only needs to be sustainable but it should also be environmental friendly with the perspective of usage [1]. Biodiesel is one of the sustainable fuels, that has excellent potential to replace conventional crude oil-based fuels [2]. Bio-diesel is generated from the transesterification method serving a variety of different oils [3].

Used cooking oil possesses adequate capacity to power CIE [4, 5]. It is readily accessible in the super markets at a low price due to its seldom usage [6]. A substantial volume of used cooking oil can be sourced from domestic and from food junctions [7]. Its density is roughly 10 % higher than that of mineral fuels [8, 9]. These qualities are essential for combustion; thus, they must be altered before utilizing bio-diesel in the engine [10].

Waste vegetable oils collected from different restaurants, fried potato chips, and similar outlets serve as an excellent raw material for biodiesel production [11]. Unwanted fatty acids development can potentially reduce the production [12]. Edible vegetable oils become persistent waste after usage, which is dangerous because they can contaminate land and water [13]. Making use of garbage and turning it into a useful resource, like producing biodiesel, is an quite innovative approach [14].

Vegetable waste oils undergo esterification with methanol or ethanol in the presence of a lye catalyst to yield fatty acid, methyl ester or ethyl ester, along with byproducts of glycerin and soap [15]. Biodiesel has specific qualities that make it advantageous as a fuel for internal combustion engines. Biodiesel fuels are non-toxic, biodegradable, and virtually devoid of sulfur and carcinogenic benzene [16]. Biodiesel fuels do not substantially contribute to the accumulation of greenhouse gases typically linked to petroleum-derived fuels. Biogenic fuels achieve a 60% reduction in soot emissions [17]. The molecular structures of biodiesel are oxygenated and possess a higher flash point. This characteristic renders biodiesel fuel (BDF) as cleaner combustion fuel.

Mostly transesterification is the process that is for the biodiesel production. Transesterification is described as the displacement of alcohol from an ester by another alcohol, similar to hydrolysis but with alcohol instead of water. This reaction is frequently catalyzed by a strong acid or base and is regularly used to lower the viscosity of triglycerides. When compared to acid catalysis, alkaline transesterification produced better results. Methanol, Ethanol and sodium hydroxide has justified their utilization due to their economical nature. The optimum settings is a catalyst concentration of Sodium Hydroxide at 6.25 g/L of Waste Vegetable Oil, Methanol and ethanol at 25% volume by volume of Waste Vegetable Oil, and a temperature of 60°C. Bio-diesel fuel (BDF) is chemically characterized as mono-alkyl fatty acid ester. It is obtained from vegetable oils and animal fats.

In this study transesterification method was applied on leftover cooking, for optimizing the required chemical process parameters. Waste vegetable oil (WVO) from UOL cafés was collected for the experimental scheme and then it was blended with other chemical proportions for the production of optimized biodiesel for the practical applications.

2. Materials and Methods

2.1 Materials

(Raw Oil): UOL Cafés were the sources of WCO, the main raw ingredient. To guarantee a sanitary processing quality, the oil was filtered before usage to eliminate large particulate impurities. ASTM D 6751 standards were used in order to ensure complete deliverance of the objectives. After filtering, the oil was kept in plastic containers with covers.

2.2 Equipment

Essential lab equipment, such as an electric or magnetic stirrer with a temperature control sensor was used to maintain proper reaction conditions, was the part of the experimental setup. Phase separation was done using funnel, and fine purification was done by applying the filter paper of size less than five microns in regard to the EN

14214 standard. To ensure uniform chemical reactions, mixtures were homogenized using a blender.

2.3 Chemicals and Regents

In the transesterification process, methanol and ethanol are important reagents. sodium hydroxide (NaOH) was used as catalysts to speeds up the chemical process. In the post-reaction stage, distilled water was also utilized to remove any remaining contaminants and purified the biodiesel. By using simple laboratory techniques and easily accessible ingredients, this methodology guarantees an effective and methodical conversion of used cooking oil into biodiesel.

In figure 1, the whole process for the development of biodiesel is explained. Waste cooking oil (WCO) was collected from UOL cafés to start the biodiesel production process. To get rid of big contaminants and solid particles, the collected oil was first filtered. After that, it was heated to remove any remaining moisture, preventing water from interfering with the chemical reactions. Following heating, the oil was further purified by removing tiny particles with filter paper. Once cleaned, the oil was subjected to the transesterification process, where it reacts with alcohol (methanol or ethanol) in the presence of acid and base catalysts. This chemical reaction results in the production of biodiesel and glycerol as a by-product.

The collected waste cooking oil (WCO) subjected to preliminary filtration using fine mesh sieves or vacuum filtration to remove suspended particles and food residues. The filtered oil was allowed to settle for 24 hours to separate any remaining water. In cases of increased water or free fatty acid (FFA) concentrations, the oil was subjected to heating at 110–120°C for 30 minutes to promote moisture evaporation. The FFA concentration was evaluated using acid-base titration, and if it surpassed acceptable limits (>2%), pre-treatment through acid esterification was considered.

Two liters of wasted or used cooking was taken and filtered with the help of filter paper of 5 micron which was carried out in chemistry lab at UOL. After filtering the waste cooking oil, it was heated up to 100 degrees of centigrade,

so the moisturizer present in the oil was evaporated and was cleaned by contaminant or food particles. 400 ml (20% of methanol) 600 ml (25% of ethanol) and 20 grams of sodium hydroxide NaOH for methanol and 20 grams sodium hydroxide for ethanol poured into the flask and then mixed them separately with help to magnetic stirrer. This mixture is also known as sodium methoxide and sodium ethoxide. After getting this mixture the filtered oil was poured into sodium methoxide and sodium ethoxide. The mixture was left for two hours for complete mixing. The mixture was then dipped in the water container which having the temperature up to 67 degrees centigrade. The mixture then poured into another flask for separating and cool it down. The pale yellowish color fluid is biodiesel and thick dark brown was glycerol or glycerin. 20% methanol and 25% ethanol were utilized, but only 11.3% was stoichiometrically necessary. Consequently, an excess quantity of methanol and ethanol was present in the remaining solution.

UCOME, which was extracted through distillation for subsequent utilization. NaOH utilized in the transesterification reaction was present in the UCOME, resulting in a pH value of 7.8. Medium. Hot water was introduced into the UCOME and agitated briskly to achieve a homogeneous mixture. The mixture was subsequently permitted to settle. In this mixture, NaOH was absorbed by the water, resulting in soap that was accumulated at the bottom of the container in a foamy state, which was subsequently extracted. Although UCOME's pH was drop to 7.8, still it was a high number. After four rounds of washing, the pH was 7.98 and crystal-clear water was deposited, signifying that all of the NaOH has been removed. Ethanol utilized in the transesterification reaction was present in the UCOMEE, resulting in an alkaline medium. Hot water was introduced into the UCOMEE and agitated briskly to achieve a homogeneous mixture, allowing the excess ethanol to be separated during subsequent washing steps.

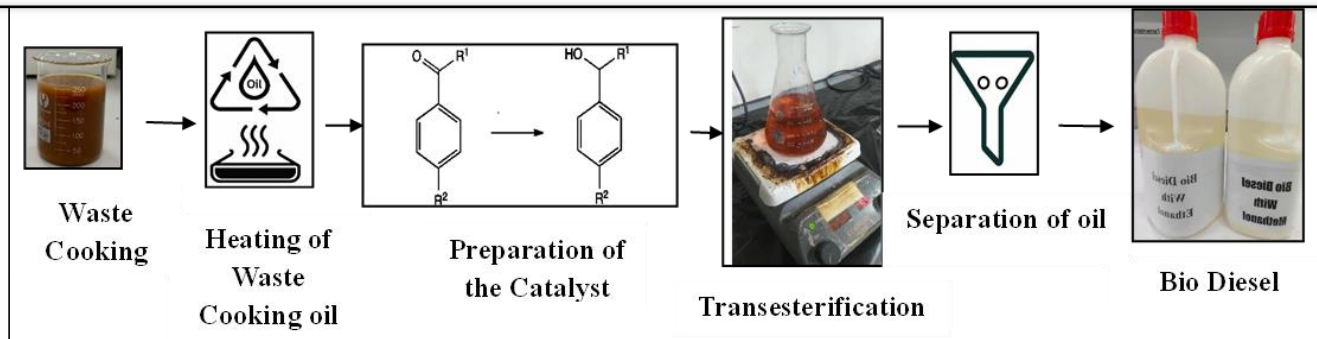


Figure 1 : Development of Bio Diesel

3.Results and Discussions

The fuel characteristics of biodiesel made from ethanol (ethyl esters) and methanol (methyl esters) were compared in Table.1. Methyl esters showed a kinematic viscosity of 4–5 mm²/s at 40 °C, whereas ethyl esters have shown a slightly greater viscosity of around 5–6 mm²/s. This suggests that methyl ester biodiesel has superior flow

Table 1: Comparative Analysis Of Methyl Ester And Ethyl Ester-Based Biodiesel

Properties Methanol vs Ethanol	Unit	Methyl Esters (Methanol)	Ethyl Esters (Ethanol)
Kinematic Viscosity at 40°C	(N. s/m ²)	4–5 mm ² /s at 40°C	Slightly high (5–6 mm ² /s)
Flash Point	(°C)	145°C	135°C
Density at 20°	(kg/m ³)	0.86–0.90 g/cm ³	0.85–0.88 g/cm ³
Pour Point	(°C)	-4°C	-6°C
Specific Gravity 15°C	No unit	0.86 – 0.90	0.87 – 0.91
Calorific Value	MJ/kg	37 MJ/kg	38 MJ/kg

Additionally, methyl esters had density values between 0.86 and 0.90 g/cm³, but ethyl esters had somewhat lower or similar values. This resemblance suggests that both fuels would act similarly in combustion and fuel injection systems. According to the pour point data, ethyl esters have a lower pour point (–6 °C) than methyl esters (–4 °C), indicating that ethyl ester biodiesel may function better in cold weather because of its increased fluidity. With methyl esters ranging from 0.86–0.90 and ethyl esters from 0.87–0.91, the specific gravity values at 15 °C were also similar, suggesting relatively slight change in the fuel mass-to-volume ratio. Ethyl esters showed a little greater calorific value (38 MJ/kg) than methyl esters (37 MJ/kg) in terms of

properties, which can increase combustion efficiency and fuel atomization during injection. Methyl esters had a flash point of about 145 °C, but ethyl esters had a somewhat lower value of 135 °C. Because methyl esters are less volatile, their higher flash point indicates better storage and transit safety.

energy content, which might result in a slightly higher energy output during burning.

Overall, the findings show that the physicochemical characteristics of methyl ester and ethyl ester biodiesel are similar, with minor differences in viscosity, flash point, cold-flow characteristics, and calorific value. These variations imply that ethyl esters may provide better cold-flow behavior and a little larger energy content, which might affect their appropriateness under various operating and environmental situations, whereas methyl esters give advantages in terms of fuel flow and safety.

Both methyl ester and ethyl ester biodiesel exhibit similar physicochemical properties, with only minor differences.

Methyl esters improve fuel atomization, combustion efficiency, and storage safety by providing improved flow characteristics and higher flash points. Conversely, ethyl esters have better cold-flow behavior and a marginally greater calorific value, which may make them more appropriate for low temperatures and a marginally higher energy output. All things considered, both varieties of biodiesel are feasible fuels, and the choice between them can be influenced by particular operational or environmental needs.

4. Conclusions

The findings of this research on the synthesis of biodiesel from WVO lead to the following key conclusions:

- Transesterification process was successful in producing the fuel, that was a high quality and suitable to be used as biofuel per ASTM D 6751 and EN 14214. The process worked well and neutralized FFA and reduced specific gravity to be compatible with the standard CIE.
 - Both alcohols were effective, but Methyl Esters (UCOME) had better flow properties (4–5 mm²/s), and overall better storage safety (flash point 145°C). However, for low-temperature climates, Ethyl Esters (UCOME) have a more renewable profile, and better cold-flow (-6°C pour point) properties.
 - The transition from mineral diesel to biodiesel using WVO results in a reduction of soot emissions of 60%. The fuel is not poisonous, it doesn't contain any sulfur and is environmentally friendly as it is biodegradable, thus reducing environmental risks due to cooking oil disposal.
 - Glycerol is recovered as a valuable byproduct, making waste management a valuable economic system. Reduces the overall carbon footprint of the food and energy sector, supports the 'Waste-to-Energy' model.
- This research gives a scalable approach to use local waste streams to improve energy security. The findings indicate that WVO-based biodiesel is a very good and economical alternative to liquid petroleum-based fuel which is also in line with the global sustainable development goals.

References

1. Kiamansouri, M.J.E.J.o.C., Medicinal and P. Research, *Integration of renewable energy sources in oil and gas operations a sustainable future*. 2025. **4**(1): p. 63-87.
2. Kuang, W., et al., *Cost-effective, environmentally-sustainable and scale-up synthesis of vertically oriented graphenes from waste oil and its supercapacitor applications*. 2021. **3**(1): p. 31-39.
3. Mishra, A. and B.J.F. Meikap, *Optimization of process parameters for waste motor oil pyrolysis towards sustainable waste-to-energy utilizing a combinatorial approach of response surface methodology and desirability criteria*. 2023. **353**: p. 129226.
4. Qi, Z., et al., *The future of waste cooking oil and its carbon and economic benefits—An automotive energy perspective*. 2024. **184**: p. 107204.
5. Asmoro, P.T.J.I.J.o.E., *Efficiency and Electrical Power Consumption Analysis of Gasification Stove Fueled by Used Cooking Oil as A Renewable Energy Alternative*. 2025. **8**(2): p. 118-128.
6. Mahaputra, M.R. and F.J.I.J.o.A.M. Saputra, *Determination of public purchasing power and brand image of cooking oil scarcity and price increases of essential commodities*. 2022. **1**(1): p. 36-46.
7. Sigurdson, J.L., *THE GOOD FOOD JUNCTION INTERVENTION: A LONGITUDINAL STUDY OF FOOD INSECURITY AND VEGETABLE AND FRUIT CONSUMPTION*. 2022, University of Saskatchewan.
8. Putra, M.I.R. and A.N.J.A. Yunisya, *Street Culinary Food Development Study With Case Study of Food Junction Surabaya*. 2021. **1**(1): p. 21-27.
9. Wirawan, S.S., et al., *Biodiesel implementation in Indonesia: Experiences and future perspectives*. 2024. **189**: p. 113911.
10. Suzihaque, M., et al., *Biodiesel production from waste cooking oil: A brief review*. 2022. **63**: p. S490-S495.
11. Melikoglu, M.J.B. and Bioenergy, *Sustainable biodiesel production: Forecasting agricultural waste utilization in Türkiye's oilseed industry*. 2025. **199**: p. 107953.

12. Budiarto, A. and A. Surjosatyo. *Indonesia's road to fulfill national renewable energy plan target in 2025 and 2050: current progress, challenges, and management recommendations—a small review*. in *IOP Conference Series: Earth and Environmental Science*. 2021. IOP Publishing.
13. Kay, M., et al., *The state of the world's land and water resources for food and agriculture 2021. Systems at breaking point*. 2022, FAO.
14. Kalfas, D., et al., *Assessing the connection between land use planning, water resources, and global climate change*. 2024. **16**(2): p. 333.
15. Nisbar, N.D., et al., *Determination of ethanol, isopropyl alcohol and methanol in alcohol-based hand sanitiser to ensure product quality, safety and efficacy*. 2023. **13**(1): p. 9478.
16. Mukhopadhyay, P., R. Chakraborty, and S.J.E.C.L. Singh, *Triacetin additive in biodiesel to reduce air pollution: a review*. 2022. **20**(2): p. 1193-1224.
17. Ogunkunle, O. and N.A.J.S. Ahmed, *Overview of biodiesel combustion in mitigating the adverse impacts of engine emissions on the sustainable human-environment scenario*. 2021. **13**(10): p. 5465.

