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Sustainable Energy Outlook: Biodiesel from Used Cooking Oil in Palestine

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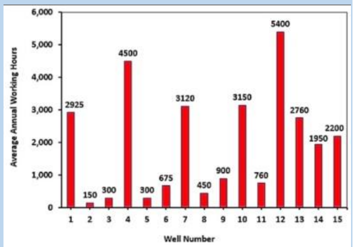
Ahmad Ashqar[1], Fihme Hantoli[1], Maher Abdulkareem[1], Ihab H. Alsurakji[1,*]

Abstract: Developing alternatives to fossil fuels has become increasingly essential due to the ongoing depletion of non-renewable energy sources worldwide. Biodiesel, a promising substitute for fossil fuels, is not only environmentally friendly but also compatible with diesel engines. The process of converting used vegetable oils or animal fats into biodiesel is known as transesterification. In order to increase Palestine's potential for renewable energy and attain energy independence, biodiesel could be used as a renewable resource. This study focuses on the viability of developing a home appliance that can transform used cooking oil into biodiesel appropriate for domestic usage. Currently, used cooking oil is disposed of inappropriately in Palestine, causing serious environmental harm. Palestine stands to gain by addressing this environmental problem and making it simpler to use used cooking oil as a renewable energy source. Therefore, the main objective of this study is to create a machine that is simple to operate, affordable in comparison to other devices on the market, and needs minimal maintenance. An in-house prototype was built at An-Najah National University's workshop for 4,500 NIS (or roughly $1,320). In addition, a number of lab tests were performed to assess the characteristics of the cooking oil and the required reaction conditions, such as temperature, mixing rate, and the right catalyst. According to the findings, the created machine has a production cost that is 25% lower than that of conventional diesel while maintaining a comparable level of performance in diesel engines. This study opens the door for a long-term solution to Palestine's energy problems and environmental problems.



Keywords: Energy Independence, Biodiesel, Transesterification, Renewable resource, Used Cooking Oil.

Introduction

A. *What is Biodiesel?*

Biodiesel is a renewable fuel option that has a minimal environmental impact, and it's derived from sustainable resources such as animal fats and vegetable oil, as well as domestic waste cooking oil (1). Biodiesel, while not a pure petroleum fuel, can be mixed with petroleum diesel to form a blend at any level. Pure biodiesel and/or blend can be used in compression-ignition diesel engines with little or no modifications (2). Biodiesel is an easy-to-use, nontoxic fuel, biodegradable, and ultimately free of sulfur and aromatics. Furthermore, it considerably decreases the number of hazardous pollutants and greenhouse gases (3).

Biodiesel can be produced from used cooking oil by a chemical reaction using methanol or ethanol using the catalysts for the transesterification of triglycerides and may be classified as basic acid or enzymatic (4). According to (5), several base catalysts have been used including sodium hydroxide (NaOH), potassium hydroxide (KOH), carbonates, and their corresponding alkoxides, for instance, sodium methoxide or ethoxide. Also, acidic catalysts have been utilized such as; sulfuric acid, sulfonic acid, and hydrochloric acid.

B. *Why Biodiesel?*

Biodiesel has been extensively investigated earlier as an alternative fuel because of several reasons which are related to its physical properties, its accessibility for domestic use, and its tested safety for human use.

To begin with, engines can use biodiesel without requiring any modifications to engine parts, and it can be handled, burned, and pumped in the same manner as petroleum diesel fuel (6). It is also safe to use in its pure form or in blends. Biodiesel provides similar fuel economy as petroleum fuel and can be used throughout the year (7). In addition, biodiesel blends and pure biodiesel have been found to exhibit similar fuel efficiency, horsepower, and torque characteristics as traditional petroleum diesel fuel (7-8). Although typical biodiesel has 5% – 10% lower energy content than typical petroleum diesel in its pure form (6), it's worth noting that petroleum diesel fuel energy content may vary up to 15% between different suppliers. While using biodiesel in its pure form may slightly reduce performance, users generally report little noticeable change in mileage or performance (8). When blended with petroleum diesel at B20, which involves blending 80% diesel with 20% biodiesel, there is less than a 2% change in fuel energy content, and users typically report no noticeable change in mileage or economy (8).

In conclusion, among alternative fuels, biodiesel has successfully passed the Environmental Protection Agency's (EPA) extensive emissions and health effects study under the Clean Air Act (9). It greatly decreases emissions of carbon monoxide, unburned hydrocarbons, particulate matter, and sulfates compared to petroleum diesel fuel (6). Moreover, compared to petroleum diesel, biodiesel can reduce the number of carcinogenic compounds emitted by up to 85% (10). These reductions in emissions are generally proportionate to the quantity of biodiesel blended with petroleum diesel fuel (10).

1 Department of Mechanical Engineering, Faculty of Engineering, An-Najah National University, Nablus, Palestine.

* Corresponding author: isurakji@najah.edu

According to (1), the usage of Biodiesel has many advantages, including its renewability as a fuel source, which is derived from vegetable oils or animal fats. Biodiesel is less toxic compared to diesel fuel, degrades more quickly than diesel fuel, and minimizes the environmental impacts of biofuel spills. In addition, it emits fewer contaminants such as carbon monoxide, particulate matter, polycyclic aromatic hydrocarbons, and aldehydes, thus reducing health risks associated with exposure to carcinogenic substances. Moreover, biodiesel does not produce sulfur dioxide emissions and has a higher flash point.

On the other hand, there are several disadvantages associated with the use of biodiesel, including:

- The lower calorific value of biodiesel results in slightly higher fuel consumption.
- Biodiesel exhibits slightly higher nitrous oxide emissions compared to diesel fuel.
- Biodiesel has a higher freezing point than diesel fuel, which can pose challenges in colder climates.
- Biodiesel is less stable than diesel fuel, which means it is not recommended to store it for more than six months.
- Using pure biodiesel can cause damage to plastic and natural rubber components, necessitating the replacement of these parts with Teflon components.
- Biodiesel has the ability to dissolve sediment and other contaminants present in diesel fuel storage tanks and lines. If these contaminants are not cleaned before filling the tanks with biodiesel, they can cause problems in the valves and injection systems of the engine. Thus, it is recommended to clean the tanks before filling them with biodiesel.

It is worth noting that the drawbacks of biodiesel are considerably mitigated when it is used in blends with diesel fuel.

C. *Sources of Biodiesel*

In addition to other sources, soybean oil, which has an oil content of about 18% and is a significant feedstock for biodiesel production, can be utilized to make the fuel (11). Another common source is rapeseed oil, which is widely used for biodiesel production in Europe and produces biodiesel that gels at a lower temperature, making it a suitable fuel for colder regions (12). Palm oil is also a key source of raw material for biodiesel production despite having a high fossil energy balance (13). Other sources such as sunflower oil and animal fats, including used cooking oil, are also increasingly being used as feedstocks for biodiesel production. Although the main feedstock for biodiesel is food crops like soybeans, rapeseed, and palm oil, Kim S. et al. (14) observed that the use of animal fats and used cooking oil is growing. A thorough analysis of current developments in the production of biodiesel from Used Cooking Oil (UCO) may be found in the article by Rocha-Meneses et al. (15). The writers talk about many elements that affect the synthesis of biodiesel, such as different types of reactors, catalysts, and optimization methods. Their analysis offers insightful information for increasing the productivity and affordability of UCO's biodiesel production.

D. *Why Cooking Oil?*

Using waste cooking oil as the feedstock for biodiesel production benefits both humans and the environment. For humans, it lowers the cost of waste cooking oil disposal as it requires different treatments before disposed. Regarding the environment, it prevents pollution from waste cooking oil disposal. Additionally, waste cooking oil is widely available, it can be collected from restaurants or through domestic usage.

The properties of used cooking oil are different from those of mineral diesel. Specifically, the kinematic viscosity of used cooking oil is about ten times higher, and its density is about 10% greater than that of mineral diesel, as per (2). As a result, before it can be used in engines, biodiesel derived from used cooking oil must undergo modifications. Several techniques have been developed to modify the kinematic viscosity and density of used cooking oil, including pyrolysis, emulsification, leaning, and transesterification, as mentioned in (4).

E. *Biodiesel Production*

The production of biodiesel around the world is limited, as shown in Fig. 1. For instance, the United States produced 5.5 billion liters in 2016, while in the same year India and Singapore barely produced any Biodiesel. In Palestine, there is still no production of Biodiesel on a domestic or commercial scale.

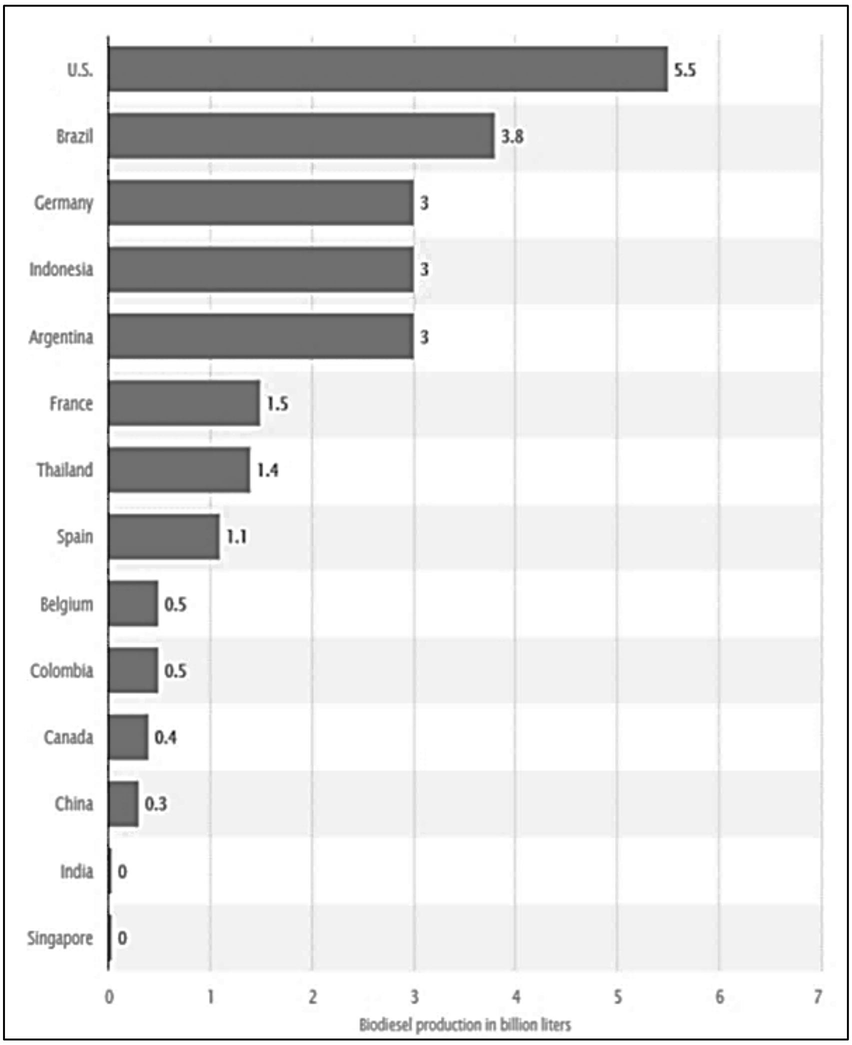


Figure (1): Countries that produced the largest quantities of biodiesel in 2016, measured in billion liters (16).

Methodology

A sample of the Used Cooking Oil (UCO) was tested in the lab to determine the most suitable conditions for the reaction to be applied on the machine. The factors that needed to be determined were:

temperature, stirring time, and mixing speed. catalyst type and its concentration, and oil to methanol ratio.

The Chemicals brought from the central chemical store at An-Najah National University and other substances used throughout this experiment can be addressed as follows:

- UCO stands for Used Cooking Oil, which is obtained from vegetable oil that has been used for cooking food. The oil becomes unsuitable for consumption due to high levels of free fatty acids (FFA) resulting from repeated frying.
- Methanol: Used as alcohol as it is less expensive compared with other types of alcohol.
- Sodium hydroxide: Used over other catalysts due to its low cost and high yield obtained.
- Potassium hydroxide: Used for comparison with NaOH. Phenolphthalein: Used in titration (pH 8.2-9.8).
- Isopropyl alcohol: used in titration as a standard to reduce the error, which could occur due to the potential of existing contaminants.
- Sulfuric Acid: Used for the esterification process to reduce water content and to prevent soup formation.
- Distilled water: Used to prepare solutions and for washing the product from excess methanol and sulfuric acid.

A. Effect of KOH concentration

To study the effect of KOH concentration, the following experiments have been conducted:

- 400 mL of used cooking oil was filtered with refinery and gauze.
- The process of titration was done to understand the required amount of potassium hydroxide to complete the reaction. In this process, distilled water, ethanol, isopropyl alcohol, phenolphthalein and potassium hydroxide were used. A solution of 1 ml of distilled water with 1 g of potassium hydroxide was used for titration.
- 10 mL of ISO-propane as well as 3 drops of phenolphthalein were added to a sample of 1 mL of used cooking oil. Then, a gradual addition of potassium hydroxide solution until the color changes to pink.
- After measuring the needed amount of KOH and Methanol from titration, a 400 mL sample of used cooking oil was heated to 105 °C. After a while, a reaction was done at 65 °C with 3.2 g of KOH dissolved in 80 mL of methanol. As a result, 360 mL of biodiesel was produced.

During the process, it was found that KOH doesn't dissolve easily in water which is why the reaction was incomplete, and using cooled distilled water creates a very low yield of biodiesel.

B. Effect of NaOH concentration

The following procedure was followed to study the effect of NaOH concentration:

- Waste cooking oil was heated to (55-60 ºC).
- 23.1 g NaOH was weighted for 3L samples, which obtained from titration to have 0.1%.
- Methanol was put in a beaker for 3.0 L samples. Then, NaOH was added to methanol with continuous stirring to make sure that all amounts of NaOH dissolved in methanol to have Methoxide.
- Pure methoxide was added to heated oil step by step with stirring. The speed of impeller = 350 rpm, and the time of reaction = 2 h
- A settlement overnight in the separatory funnel is allowed.
- After ensuring that the separation happens, stopcock of separatory funnel is opened to allow bottom brown layer of glycerin to flow out.

The purification process was carried out on all parts as follows:

- Sample was washed with heated 1000 ml tap water in the funnel.
- Air was pumped into the sample for 3 minutes.
- Sample was left to settle, then the bottom soapy layer was drained.
- Repeat until the bottom water layer is clear.

It was discovered that NaOH is a better catalyst for this project since it dissolves more quickly in methanol and is more readily available and affordable.

C. Mechanical Design and Manufacturing

To ensure compatibility with the transforming process, a specific shape was developed for the machine and particular materials were chosen for the tanks. The suggested machine was made to be less expensive, simpler to produce, and easier to use than the current UCO transformation machine in order to compete with it (See Fig. 2). The actions that can be taken to justify the manufacturing process are as follows:

– Stainless steel material was chosen for the tanks to prevent corrosion and reaction with chemical materials.
– Three motors were selected, each having a 0.25 horsepower output and a maximum speed of 1400 revolutions per minute (rpm).
– Two heaters were chosen with a power of 2000 watts and a max temperature of 110 ˚C.
– The stainless-steel boards were rolled and welded to make cylindrical shapes for the three tanks. The chemical tank with 25 liters of volume and the mixing and washing tanks with 50 liters of volume. Fig. 3 shows the three tanks with the chemical tank on top, followed by the mixing tank, and finally followed by the washing tank.
– In the final stage, heaters and motors were connected to the control panel to control the speed and heat of the machine.

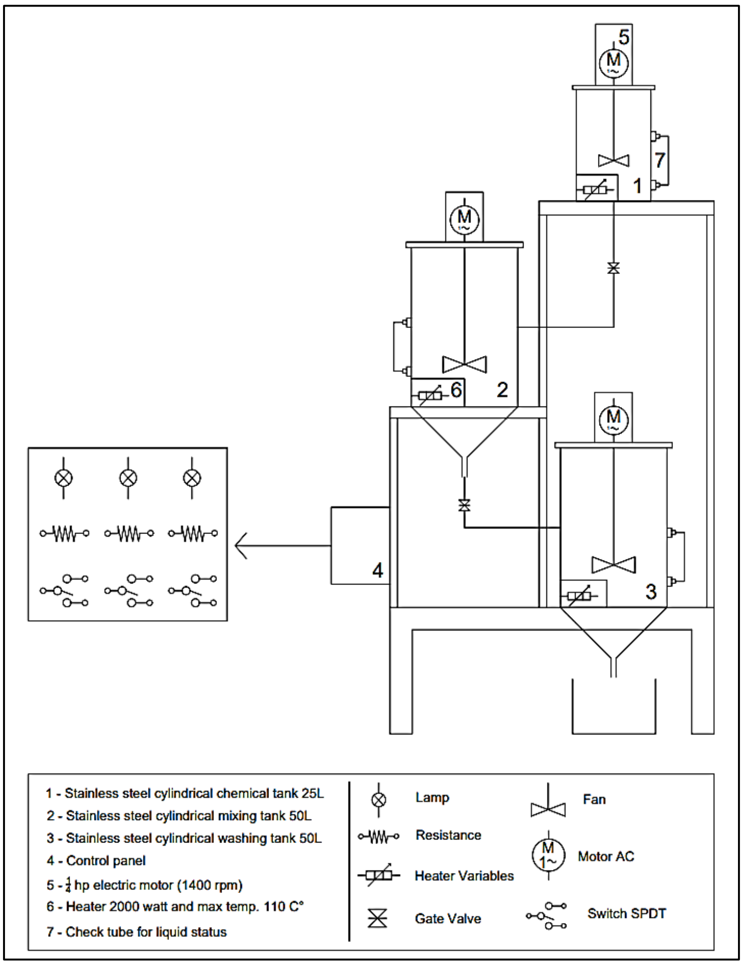


Figure (2): The proposed machine design.

Figure (3): The manufactured device with three tanks namely, a chemical tank on top, followed by the mixing tank, and the washing tank at the bottom.

Result

It was found that using NaOH as a catalyst leads to a higher yield of biodiesel production around 90%, whereas using KOH leads to 85%. In addition to that, KOH doesn't dissolve completely during the reaction.

As shown in Table 1, the total cost of the machine is $1,320.0 while the price of a similar machine varies between $4,000.0 – $5,000 (17).

The payback period may be computed as follows:

- If 1.0 liter of used cooking oil is converted and 0.9 biodiesel is produced.
- The cost of converting 1.0 liter of used cooking oil is 0.9155 $ (3.0 NIS).
- Production rate is 180 L/24h.

If the price of a liter of biodiesel is 4 NIS the payback period is 25days.

Table (1): Cost of materials

Material	Cost ($)
Stainless steel $\mathbf{2mm\ thikness\ (2 * 3)\ m}$	350
Control panel $\mathbf{40cm * 50cm * 25cm}$	120
Motor quarter hp one phase $\mathbf{1,400\ rpm}$	180
Electrical heater and thermostat 2000 watt	60
Push button and emergency	60
Pipe and valve	120
Solid state relay	130
Labour	300
Total	1,320

Conclusion

Despite the existing knowledge of how to convert UCO to Biodiesel, doing so for household quantities of oil and with low costs has remained a challenge. In this study, we tackled these specific challenges and managed to build a prototype of a machine that converts domestic quantities of oil into biodiesel at a relatively low cost.

This machine is both environmentally safe and economical for domestic use and potentially could be used for large-scale usage. Environmentally, rather than UCO being dumped directly into the soil, which is very hazardous to the environment, it can be reused as a result reducing short and long-term environmental damage and providing an alternative energy source. Economically, manufacturing such a machine that produces biodiesel at a lower cost than diesel would have eventually minimized the fuel monthly bill for the customer. Importantly, converting UCO to biodiesel using transesterification with NaOH as catalyst is much better than using KOH as catalyst. Additionally, using hot distilled water creates a higher yield than using cooled distilled water.

This research has many avenues for future development as this was only the first prototype of this type of machine. The final goal of this research would be to create a fully automated machine. A simpler next step would be to write a clear and concise user manual. Another potential development would be to create a simpler test kit and manual to address the complexity of the titration step before conversion. Nevertheless, in order for these developments to occur, more funding is needed as this research was self-funded by three undergraduate students thus far.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The raw data required to reproduce these findings are available in the body and illustrations of this manuscript.

Author's contribution

The first version of the document was written by Ashqar and Alsurakji. Alsurakji was in charge of overseeing the organization of research activities and the primary conceptual ideas. Hantoli, Ashqar, and Abdulkareem were the ones who carried out the experiment. Explanation of the data, experimental design, and outcomes Hantoli and Alsurakji. Data curation and manuscript editing were done by Ashqar and Abdulkareem. The final draft of the work was reviewed by all authors, who also gave their approval.

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Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this article

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References

1) Ma F, Hanna MA. Biodiesel production: a review. Bioresource technology. **1999** Oct 1;70(1):1-5.

2) Phan AN, Phan TM. Biodiesel production from waste cooking oils. Fuel. **2008** Dec 1;87(17-18):3490-6.

3) Knothe G. Dependence of biodiesel fuel properties on the structure of fatty acid alkyl esters. Fuel processing technology. **2005** Jun 25;86(10):1059-70.

4) Demirbaş A. Biodiesel from vegetable oils via transesterification in supercritical methanol. Energy conversion and management. **2002** Nov 1;43(17):2349-56.

5) Bilgin A, Gülüm M, Koyuncuoglu İ, Nac E, Cakmak A. Determination of transesterification reaction parameters giving the lowest viscosity waste cooking oil biodiesel. Procedia-Social and Behavioral Sciences. **2015** Jul 3;195:2492-500.

6) Bala BK. Studies on biodiesels from transformation of vegetable oils for diesel engines. Energy Education Science and Technology. **2005**;15(1/2):1.

7) Adaileh WM, AlQdah KS. Performance of diesel engine fuelled by a biodiesel extracted from a waste cocking oil. Energy Procedia. **2012** Jan 1;18:1317-34.

8) Srithar K, Balasubramanian KA, Pavendan V, Kumar BA. Experimental investigations on mixing of two biodiesels blended with diesel as alternative fuel for diesel engines. Journal of King Saud University-Engineering Sciences. **2017** Jan 1;29(1):50-6.

9) USEPA. “Biofuels and the Environment: First Triennial Report to Congress. EPA/600/R-10/183F.” U.S. Environmental Protection Agency, Washington, DC. **2011**.

10) US Department of Energy. **2017**. Alternative Fuels Data Center: Fuels and Vehicles / Biodiesel. Accessed 20.02.2023. Website Available: http://www.afdc.energy.gov/fuels/biodiesel_blends.html.

11) Peterson CL. Vegetable oil as a diesel fuel: status and research priorities. Transactions of the ASAE. **1986**; 29(5):1413-22.

12) Balaji G, Cheralathan M. Potential of various sources for biodiesel production. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. **2013** May 1;35(9):831-9.

13) Schuchardt U, Sercheli R, Vargas RM. Transesterification of vegetable oils: a review. Journal of the Brazilian Chemical Society. **1998**; 9:199-210.

14) Kim DS, Hanifzadeh M, Kumar A. Trend of biodiesel feedstock and its impact on biodiesel emission characteristics. Environmental Progress & Sustainable Energy. **2018** Jan;37(1):7-19.

15) Rocha-Meneses L, Hari A, Inayat A, Yousef LA, Alarab S, Abdallah M, Shanableh A, Ghenai C, Shanmugam S, Kikas T. Recent advances on biodiesel production from waste cooking oil (WCO): A review of reactors, catalysts, and optimization techniques impacting the production. Fuel. **2023** Sep 15;348:128514.

16) Meher LC, Sagar DV, Naik SN. Technical aspects of biodiesel production by transesterification—a review. Renewable and sustainable energy reviews. **2006** Jun 1;10(3):248-68.

17) Prabodh Illukpitiya and Jason P. de Kof. Economics of Small-Scale Biodiesel Production. **2014**.