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Used cooking oil as a renewable and cost-effective resource for biodiesel production in Algeria

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Abstract

Due to the awareness of the negative impact of conventional fuels on the environment and the frequent rise in crude oil prices, the need for sustainable and environmentally friendly alternative energy sources has become increasingly important in recent years. The aim of this study is to investigate the production of biodiesel from used cooking oil (UCO) as a sustainable and renewable fuel source. The study provides an overview of the biodiesel production process, including the transesterification method, which involves the reaction of UCO with alcohol and a catalyst to produce biodiesel. The properties and characteristics of biodiesel are also examined. Overall, this study aims to contribute to the growing body of knowledge on biodiesel production from UCO and provide valuable insights into its feasibility, benefits and potential applications.

Key words: Biodiesel, fuel, Glycerol, Transesterification, Used cooking oil, waste management.

Introduction

The 21st century faces many issues, such as energy sustainability, environmental problems and rising fuel prices. Conventional fuels are known to pollute the air with emissions of sulfur dioxides, carbon dioxide, particulate matter and other gases. This has led to increased research into alternative fuels and renewable energy sources (1). Renewable energies can be seen as alternatives to fossil fuels. They are already being used in many countries around the world. Biomass is the most widespread form of renewable energy and is the most important source of primary energy supply among the renewable forms of energy. Renewable resources account for around 10% of global energy consumption and can be converted into other usable forms of energy such as biofuels.Among biofuels, biodiesel is one of the possible alternatives in the field of transportation. Biodiesel is the name given to a variety of ester-based oxygenated fuels from renewable biological sources. Chemically, biodiesel is defined as a monoalkyl ester of long-chain fatty acids from renewable biolipids(2). Biodiesel can be produced from a variety of feedstocks. These feedstocks include the most common vegetable oils (e.g. soybean, cottonseed, palm, peanut, rapeseed, sunflower, safflower, coconut) and animal fats (usually tallow), as well as used cooking oils (UCO), also known as waste oil. Repeated frying for preparation of food makes the edible vegetable oil unsuitable for consumption due to high free fatty acid (FFA) content(3). UCO is associated with numerous disposal problems, such as water and soil pollution, human health concern and disturbance to the aquatic ecosystem(3; 4). Instead of discarding it and harming the environment, it can be used as an effective and cost-efficient feedstock for biodiesel production as it is readily available (5). The conversion of UCO into biodiesel through the transesterification process (Figure 1) reduces the molecular weight to one-third, reduces the viscosity by about one-seventh, reduces the flash point slightly, increases the volatility marginally and reduces pour point considerably (6). Then, the fuel produced has approximately the same property of petrodiesel and can be used in conventional diesel engines without any change in this last.

Furthermore, the production process yields a valuable byproduct, glycerol. This can be recovered and purified using a variety of practical techniques and methods such as centrifuging, bleaching and chemical treatment. Glycerol (Table 1) can be used in various industries such as food, cosmetics and pharmaceuticals. It has many valuable properties, including being a good moisturizer, emollient, plasticizer, thickener, solvent, dispersing medium, lubricant, sweetener and an antifreeze agent (7).

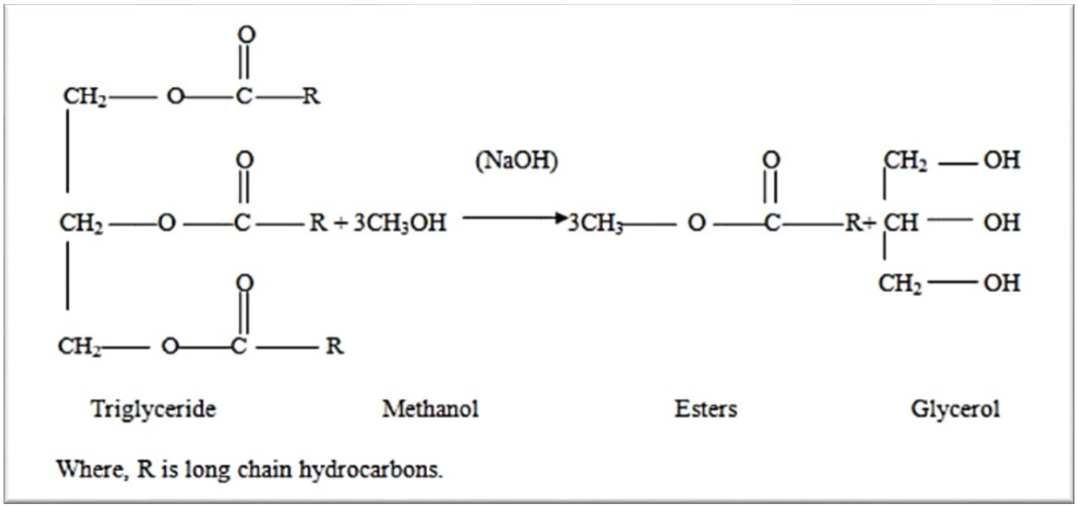

Figure 1. A schematic representation of the transesterification reaction (8).

Table 1. Glycerol properties (7).

Description value	Description value
Molecular formula	C3H5(OH)3
Molecular weight (g)	92
Melting point (°C)	17.8
Boiling point (°C)	290
Viscosity (Pa s^{-1})	1.5
Vapour pressure at 20°C (mmHg)	<1
Density at 20°C (g mL^{-1})	1.261
Flash point (°C)	160 (closed cup)

Biodiesel can be used directly as a fuel in diesel engines -in cars, busses, trucks and boats - without the need for engine modifications. Its physical properties are similar to those of petroleum diesel.Biodiesel can be used alone (B100) or blended with petroleum diesel in many different concentrations, e.g. B100 (pure biodiesel), B20 (20% biodiesel, 80% petroleum diesel), B5 (5% biodiesel, 95% petroleum diesel) and B2 (2% biodiesel, 98% petroleum diesel). The advantages of biodiesel as a diesel fuel are its higher biodegradability, higher combustion efficiency and lower emissions compared to petrodiesel. Biodiesel is non-toxic and degrades about four times faster than petrodiesel. Its oxygen content improves the biodegradation process. In comparison with petrodiesel, biodiesel shows better emission parameters. It improves the environmental performance of road transport and reduces greenhouse emissions (mainly of carbon dioxide) (2).

The use of biodiesel in a conventional diesel engine dramatically reduces the emissions of unburned hydrocarbons, carbon dioxide (CO2), carbon monoxide (CO), sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, ozone-forming hydrocarbons, and particulate matter (2). Oxygen content of biodiesel improves the combustion process and decreases its oxidation potential. Structural oxygen content of a fuel improves combustion efficiency due to the increase of the homogeneity of oxygen with the fuel during combustion. Because of this the combustion efficiency of biodiesel is higher than petrodiesel. Additionally,the use of biodiesel can extend the service life of diesel engines, as it is more lubricious than mineral diesel. Biodiesel has better lubricating properties than petrodiesel. The higher heating values (HHV) of biodiesel are relatively high. The HHVs of biodiesel (39–41 MJ/kg) are slightly lower than those of gasoline (46 MJ/kg), petrodiesel (43 MJ/kg) or petroleum (42 MJ/kg), but higher than those of coal (32–37 MJ/kg) (9).

Material and methods

The experimental procedures in this study were carried out according to the protocol established by(10), with specific modifications made to adapt the methodology to the current research objectives. Transesterification is our method of choice for the production of biodiesel. Vegetable oil is mixed with an alcohol (ethanol or methanol) in the presence of a catalyst (sodium or potassium hydroxide) in a process.

During transesterification, the oil molecule is chemically split into methyl ester, producing glycerol as a by-product. The used cooking oil was collected free of charge from a local restaurant in Saida. Methanol was used as the alcohol for the transesterification reaction and sodium hydroxide (NaOH) served as the basic catalyst. Both were obtained from the biology laboratory of the University of Saida, and the water used was pure distilled deionized.

1. Transesterification process

400 ml of the used oil is first poured into an Erlenmeyer flask with a capacity of 500 ml, and the oil is heated to 50°C, which is the optimum temperature for the transesterification process. A sodium methoxide solution is then prepared in a 500 ml beaker using 1.95 g NaOH pellets in 75 ml methanol. The solution is then stirred thoroughly to completely dissolve the hydroxide pellet and the solution is kept in the oven at 60 °C for 5 minutes. Once the solution is ready, it is poured into the preheated oil and placed on a hot plate.The mixture is heated and stirred vigorously using a magnetic stirrer for 1 hour, as shown in Figure 2. To accelerate the reaction, the reaction mixture is kept close to the boiling point of the alcohol (64.7 °C for methanol and 78.4 °C for ethanol). Finally, the mixture is poured into a separatory funnel attached to a beaker and left to cool overnight so that the fractions can settle well. The biodiesel forms the upper layer, while the lower layer consists of glycerol and soap.

Figure2. Mixture of Sodium methoxide solution with used cooking oil.

2. Separation the reaction products

The different densities of glycerol and biodiesel play a decisive role in the separation of the reaction products. As the density of glycerol is greater than that of biodiesel, the biodiesel naturally rises to the top. A settling vessel or separating funnel is used for the separation, which uses gravity to clearly separate the two products.In this method, the glycerol is easily drawn off from the bottom of the vessel or funnel, while the biodiesel is drawn off from the top, ensuring a clear and efficient separation of the components.

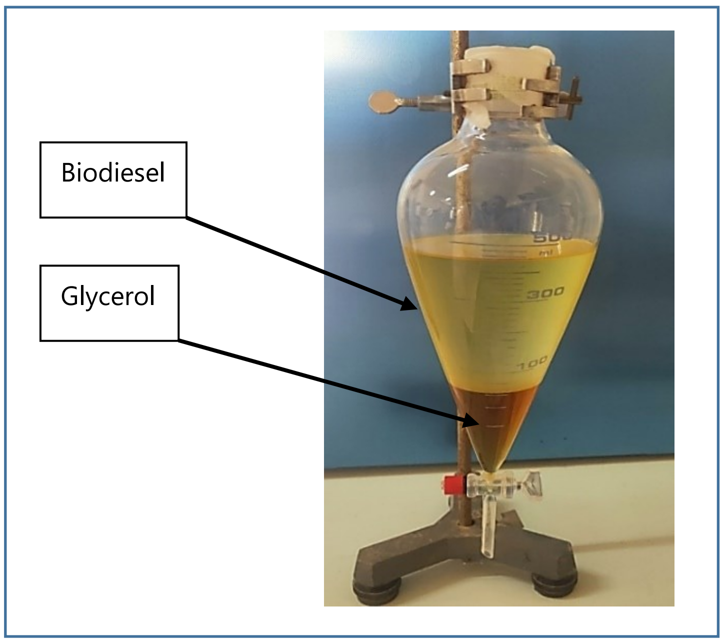

Figure3. Separation of glycerol from biodiesel.

3. Biodiesel purification

In this process, heated (50°C) deionized water is added to crude biodiesel and gently stirred to allow maximum contact with the impurities. The method is based on the affinity of the polar components to water. The process is usually repeated until the initial milky bottom layer becomes clear, as shown in Figure 4. Care must be taken as vigorous stirring of crude biodiesel with water can lead to emulsification. After the washing process, the biodiesel may still contain traces of water, which is why it is heated to 115 °C to remove all water molecules.

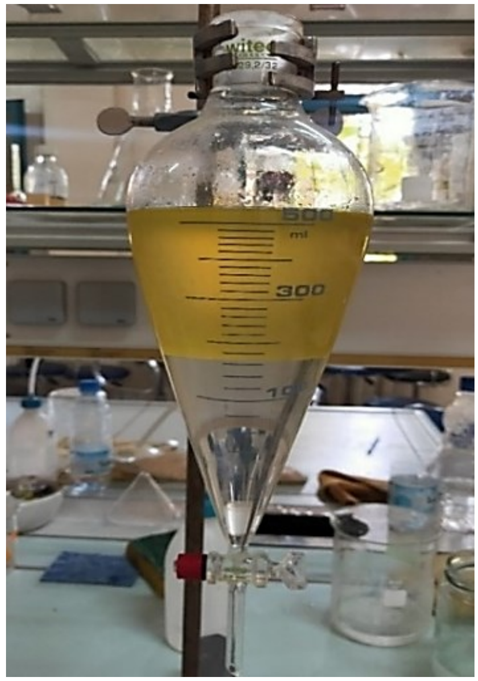

Figure 4. Biodiesel purification.

Results and discussion

380 ml of biodiesel and about 60 ml of glycerol were producedin the current study. In our investigation, we assessed the density and viscosity of the produced biodiesel.Density is a very important property of any fuel as it directly affects the performance characteristics of the engine. Density is the mass per unit volume of a liquid at a given temperature. Specific gravity is the ratio of the density of a liquid to the density of water. Density has importance in diesel-engine performance since fuel injection operates on a volume metering system(11). The density value of biodiesel should be between 860-900 kg/m^3. Fuel that exceeds the density limitspecification causes the fuel pump to inject a greater amount of biodiesel, which will affect the air-fuel ratio, engine performance and combustion characteristics of the fuel(12; 13). Biodiesel fuel is denser than petrodiesel, but less compressible due to its higher molecular weight(14; 15).One common method for measuring the density of biodiesel is by using a pycnometer. The Pycnometer was weighed empty and then weighted full of Biodiesel. The difference between the two weights was divided by 10 ml to determine the density. The determined density of the biodiesel was 0.8708 g/cm^3 (870.8 kg/m^3). Based on

the results of the analysis, it can be seen that the biodiesel density obtained meets EN 14214, which is in the range of 860-900 kg/m^3. According to BUDIMAN et all(16), the density values within the EN 14214 limit can produce perfect combustion. Biodiesel with a density above the standard leads to incomplete combustion reactions, which can increase engine emissions and wear. This observation is similar to that of (17), who found that the biodiesel they produced had a density of 0.87 g/cm^3 using the same method as the one we used (NaOH and methanol).

Viscosity is another important property of biodiesel as it affects the operation of the injection system. The viscosity of a fuel refers to its resistance to flow or its internal friction. It is a measure of the fuel's thickness or fluidity, affecting its ability to move through pipes, injectors, and other components in an engine or heating system. A high viscosity will result in poorer atomization of the fuel spray and inaccurate operation of the fuel injectors. The lower the viscosity of the biodiesel, the easier it is to pump and atomize and achieve finer droplets (18).Acceptable limits of kinematic viscosity at 40C° for biodiesel are 1.9to 6.0 and 3.5to 5.0 mm^2/s, based on American and European standards respectively.

The upper limit ensures a smooth flow in cold weather conditions, while the lower limit prevents a potential loss of power in the engine (19). The kinematic viscosity value of biodiesel is higher by a factor of about 1.6 compared to petrodiesel, and this value is higher at low temperatures (20). An increase in temperature reduces the viscosity of biodiesel samples because weak intermolecular forces allow the molecules to flow more freely (13). In this study, the absolute viscosity of biodiesel was determined using the Ostwald viscometer and was found to be 6.314 mm^2/s (6.314 cSt) at 30°C just out of the standard range of 1.9-6.0 mm^2/s. The kinematic viscosity was calculated using the ratio of absolute viscosity to density and was found to be 7.25 mm^2/s. This value is higher than the viscosity of 5.89 cSt given by (21).

Decreased cooking oil viscosity indicates a certain amount of triglyceride molecules have been successfully converted into shorter or simpler molecules, namely methyl esters. According to the results obtained, it can be concluded that the biodiesel produced from the used cooking oil in the laboratory has approximately the same characteristics as petroleum diesel, particularly in terms of density and viscosity.

Conclusion

Biodiesel is a better fuel than petro-diesel and meets most of the chemical/physical standards of petrodiesel. It has the potential to offer a number of benefits, such as economic, agricultural, environmental (due to its biodegradability, lower toxicity, renewability) and health (greenhouse gas savings, less harmful exhaust emissions). Biodiesel can be considered as the best option that has immense potential to fulfill the fuel requirements and secure a sustainable fuel supply in the future. In large-scale production plants, glycerin is usually recovered and purified, as it is a valuable substance that has numerous applications in the pharmaceutical, cosmetic and chemical industries. Future research could focus on optimizing the production process, investigating new feedstock sources, and exploring emerging markets for biodiesel.

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