Making Biodiesel from Recycled Cooking Oil Generated in Campus Dining Facilities

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Abstract

Made from vegetable oil, waste oil, or animal fats, biodiesel fuel is renewable and nearly carbon neutral; it requires little engine modification, and over time can reduce the United States' dependence on foreign oil. Over the past few decades, the production of biodiesel has increased significantly. Here at the University of Cincinnati (UC), biodiesel is being generated from fryer oil from campus dining halls to reduce diesel use and enhance sustainability on the campus. A secondary goal is to use this process as a real world classroom for students, K-12 teachers, and interested community members wishing to optimize conversion of waste cooking oil to biodiesel. The production of biodiesel at the UC is accomplished via transesterification, whereby waste fryer oil and methanol are converted, with the aid of the catalyst sodium hydroxide, to methyl esters, or biodiesel, and glycerol. The pretreatment, titration/pilot test, full-scale production, and purification processes are quantitatively described here, as are the estimated costs and potential uses of biodiesel on campus.

Introduction

Biodiesel has numerous advantages over petroleum diesel fuel. It is made from renewable sources (vegetable oil or animal fats) local to the United States, which may reduce our dependence on foreign oil, thus stimulating the U.S. economy. It is non-toxic and biodegradable, and contains no sulfur or carcinogenic compounds.[1] Compared to petroleum-based diesel, biodiesel has a more favorable combustion profile, such as lower emissions of carbon monoxide, particulate matter, and unburned hydrocarbons.[2] A joint study conducted by the U.S. Departments of Agriculture and Energy has shown soy-based biodiesel has a 78 percent carbon dioxide reduction over petroleum-based diesel.[3]

Compared to petroleum diesel, however, the cost of biodiesel is a major barrier to its commercialization.[2] Approximately 70 percent to 95 percent of the total biodiesel production cost arises from the cost of the raw materials.[3–7] A study in Spain showed that the cost of oil acquisition and preparation is 0.47 euro/kg of the total cost of 0.69 euro/kg when using Ethiopian mustard as the raw material, and the cost of the raw material alone is 0.15 euro/kg of the total cost of 0.37 euro/kg when using recycled olive oil (and before selling by-products).[8] Due to the high cost of raw materials, some researchers have concluded that the use of biodiesel from fresh oil is not profitable without tax exemptions or government subsidies.[9,10]

Currently, soybean oil is the most commonly used feedstock for making biodiesel in the United States. But several other feedstocks are being used or researched including rapeseed, jatropha, palm oil, mustard, and algae. An attractive feedstock is recycled cooking oil because it is inexpensive (oftentimes free), and is an excellent example of waste-to-energy conversion.

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The most widely used method for generating biodiesel from vegetable oil is *transesterification* (Fig. 1), which converts triglycerides (the oil fraction) into esters (biodiesel).[11] The chemical structure of

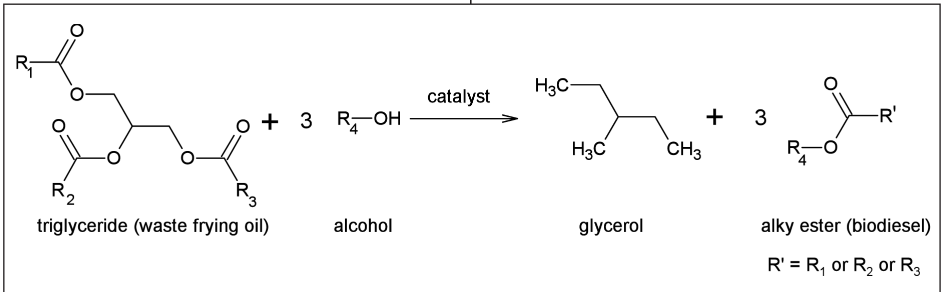

Fig. 1: Transesterification process.

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triglyceride can be viewed as three esters attached to a molecule of glycerin. During the transesterification process, an alcohol molecule replaces the glycerin molecule.[12,13] Many types of alcohols have been tested for biodiesel production, but methanol is typically used, especially in commercial operations, because of its low cost and ease of reaction.[14–16]

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A catalyst, either acid or base, is used to drive the transesterification reaction. The typical base catalysts used are sodium hydroxide or potassium hydroxide. If the waste oil is high in free fatty acids, an acid catalyst should be used to prevent the formation of soap.[17–19] The resulting products are biodiesel (i.e., methyl esters when produced using methanol) and glycerol.

Materials and Methods

Source of recycled cooking oil

Located on the campus of the University of Cincinnati is the buffet-style restaurant known as Center Court. During the school year, the restaurant serves approximately 5,500 diners per day. The oil for the fryer is supplied by Frywise. Typically waste fryer oil is removed by Frywise, with the cost of removal included in the price of new oil. Approximately 12 to14 gallons of waste oil are generated at Center Court per week. At this rate, about 36 to 42 gallons of biodiesel (Freedom Fueler®) can be produced in the 55 gallon biodiesel reactor every three weeks. By recycling the cooking oil and converting it to biodiesel to be used by campus vehicles or generators, the campus can reduce operations costs.

An inventory assessing the amount of waste fryer oil generated on UC's main campus has been developed. The results are given in Table 1.

Fig 2. The biodiesel reactor at the UC power plant

Titration and small-scale test

An acid-base titration is applied to the waste frying oil to measure the acid value and determine the amount of catalyst needed.[20] A mixture of 5 mL waste oil, 50 mL ethyl alcohol, and 2 drops of 0.5 percent phenolphthalein is titrated by a 0.05 percent sodium hydroxide (NaOH) solution. The free fatty acid content in the waste frying oil from UC dining facilities ranges from 0.2 percent to 0.5 percent, which corresponds to an acid value of 0.27 to 0.68 mg of KOH/g of oil. Comparably, the free fatty acid content in a virgin vegetable oil is as low as 0.05 percent, which corresponds to an acid value of 0.07 mg of KOH/g of oil. Thus, the quality of waste frying oil from UC's dining facilities is better than that of most waste oils reported in the literature, whose acid values range from 0.42 to 75.92 mg of KOH/g of oil, or contain roughly 0.3 percent to 6 percent free fatty acid.[11,21,22] The higher content of free fatty acids compared to fresh oil is due to the hydrolysis of triglycerides during heating.[23] Free fatty acids may also be generated after long-term storage in the presence of oxygen.[24]

The first step in converting recycled cooking oil to biodiesel is to filter the oil, as it may contain food debris. Then the oil can be poured into the biodiesel reactor, as shown in Figure 2. The reactor is equipped with a hot water heater and a circulation system. A temperature of 140°F must be achieved for transesterification to occur. Once the hot water heater and circulation system are turned on, the oil temperature of 140°F is reached in approximately four hours. During this time, the amount of sodium hydroxide required is established by two methods: titration and a small-scale pilot test using 100 mL of oil. The recommended ratio of recycled frying oil to methanol is 5:1. For example, 40 gallons of frying oil requires eight gallons of methanol.

Table 1. UC Main Campus Waste Fryer Oil Inventory

Restaurant	Diners (no.)	Waste oil (gal/week) Summer	Other	Price	Supplier	Current Disposal Method	Disposal Cost
Center Court	5,500	Closed	12-14	$0.88/lb	Frywise	Supplier pickup	Included
MarketPointe	5,500	12	16	$1.09/lb	RTI	Supplier pickup	Included
Mick&Mack's	100	8	10	$0.88/lb	Frywise	Supplier pickup	Included
Catering	100	8	10	$0.88/lb	Frywise	Supplier pickup	Included
Gold Star Chili		6	8			Griffin Industry	
Burger King		Not open, estimate a little more than Gold Star Chili		n/a		n/a	n/a

Previous research suggests that the amount of base catalyst required is approximately 00.5 percent to 1 percent of the weight of the oil.[10,15,25,26] The optimal amount is affected by other parameters, such as the use of methanol. The amount of NaOH applied in this study was typically 0.35 g/100 mL of pure vegetable oil. Because recycled cooking oil is more acidic than pure vegetable oil, more catalyst is needed. The additional catalyst is necessary to eliminate the free fatty acids from the oil, which are the result of frying the vegetable oil; they also increase the gelling temperature of the oil.

To determine the amount of required catalyst experimentally, varying amounts of NaOH, in 0.05 g increments ranging from 0.40 to 0.65 g, are dissolved in 20 mL of methanol. This takes place by mixing NaOH (in crystal form) and methanol together in a covered flask (to prevent evaporation of the methanol). Next, 100 mL of recycled frying oil are added and heated in a microwave until the temperature reaches 140ºF. This mixture is shaken vigorously for one minute, then allowed to settle for at least five minutes. When two distinct layers (biodiesel and glycerin) develop, the reaction has taken place. The glycerol will appear as a very dark layer of liquid at the bottom of the flask (Fig. 3). Glycerol has a density of about 1.25 g/cc, and biodiesel has a density of about 0.87 g/cc. The smallest amount of NaOH required for the reaction to occur is used as a basis for producing additional batches with the corresponding amount of recycled frying oil. Each batch of recycled fryer oil requires the performance of a new pilot test since recycled oil can vary by source. When oil from multiple sources is used, the oils may be mixed in the proper proportions and tested for the required amount of catalyst.

Large-scale production

After titration and the small-scale test, the amount of NaOH required for an entire batch is calculated. Five-gallon pickle buckets are used for dissolving the NaOH into the methanol. First, the methanol is added to the bucket. Next, a drill with a paint mixer attachment is used to stir the methanol as the NaOH is slowly poured into the bucket. The mixture should be stirred for at least three minutes until the NaOH is dissolved. Next, the NaOH/methanol solution is poured into the smaller tank of the reactor. The circulation system will mix the NaOH/methanol solution with the heated fryer oil. Mixing continues for approximately one hour to ensure completion of the reaction.

The biodiesel/glycerin mixture is allowed to settle for eight hours after mixing. A distinct separation between biodiesel and glycerin can be seen through the semi-transparent tank. Since glycerin is about 1.5 times denser than biodiesel, about 75 percent of the glycerin settles after just one hour. First, the glycerol is drained through the tubing at the bottom of the large tank. Next the biodiesel is drained into five gallon pickle buckets. At this point, there are still trace amounts of glycerol in the biodiesel. To speed up the settling process, the biodiesel may be placed in a cold room (≤40ºF). Because glycerol has a higher gelling point than biodiesel, the low temperature causes the glycerol to begin to gel before the biodiesel, thus causing the glycerol to settle at a higher rate.

In order to remove the sodium hydroxide from the biodiesel and thus lower the pH, the biodiesel must be washed with water. Water washing also helps remove any unreacted alcohol and glycerol. To start a water wash, the biodiesel is transferred to one of two 30 gallon washing tanks (Fig. 4). Using plastic tubing, water from the tap is distributed into the tank. The water should be sprayed evenly over the surface of the biodiesel. A low velocity spray should be used to prevent turbulence, which may result in an undesired emulsion. Since water is denser than biodiesel, it sinks to the bottom of the tank. After 24 hours, the water is drained from the bottom of the washing tank. The biodiesel should be washed in this manner at least three times. A 1:1 ratio of wash water to biodiesel is recommended. After the first wash, the biodiesel can be washed as frequently as every two hours. The pH value of the effluent wash water after the first wash is approximately twelve, decreasing to seven after the third wash.

The last step in the biodiesel production process is filtration. The washed biodiesel is filtered into clean dry containers. Hair nets, when placed over a strainer or colander, are inexpensive and efficient for filtering the biodiesel. Finally the biodiesel is ready for use in a diesel engine.

Regarding engine modification, biodiesel has been shown to degrade rubber. Diesel engines manufactured before 1992 may contain rubber hosing, which should be replaced before using biodiesel fuel.

Results and Discussion

The estimated costs for making biodiesel from recycled cooking oil are listed in Table 2.

Since 2007, hundreds of gallons of biodiesel have been produced at UC. The biodiesel has been successfully used by one student in her diesel Jeep. The UC utility plant plans to use B2 (2 percent biodiesel) in their diesel turbine as part of its commitment to climate, a statement signed by UC's previous president, Nancy Zimpher. Our energy renewal efforts have become known within the community, and as a result, we have been asked to provide technical guidance to the Cincinnati Zoo and Botanical Gardens in converting its waste oil into biodiesel.

The biodiesel operation at UC has also contributed to education here on campus and out in the commu-

Fig. 3. Biodiesel and glycerol separation in a flask.

When two distinct layers (biodiesel and glycerin) develop, the reaction has taken place. The glycerol will appear as a very dark layer of liquid at the bottom of the flask.

Fig. 4. Washing tank at the UC power plant.

Table 2. Breakdown of Biodiesel Production Costs in Dollars per Gallon

	Costs for 35 Gallons of Biodiesel	Unit Cost ($/gal)
Waste oil	$ 0	
Methanol	$30.29	
Sodium hydroxide	$ 5.46	
Filtration	$ 2.69	
Electricity	$ 8.74	
Purification (water)	$ 0.14	
Total	*$47.32*	*$1.35*

nity. It has become part of a laboratory class to more than 30 undergrad seniors and graduate students since 2008, and has served as a research project to many K-12 math and science teachers.

Currently we are in the process of promoting the use of biodiesel by the UC delivery fleets (six diesel vehicles) and the UC shuttle service. A key barrier to accomplishing this goal is the lack of a filling station for our biodiesel. In addition we are researching more cost-effective and efficient methods of glycerin separation in the future.

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