

Biodiesel

Learning Objectives:

- Gained an understanding of what biodiesel is
- Gained an understanding of how biodiesel is made
- Gained an understanding of biodiesel properties
- Calculated yields and compared biodiesel sources
- Experienced the “hands-on” creation of a renewable biofuel
- Gain an understanding and appreciation for biodiesel's role in the emerging bioeconomy

Learning Outcomes:

- Define biodiesel
- Describe the inputs & process of making biodiesel (transesterification)
- Describe and compare diesel/biodiesel properties
- Explain the benefits and challenges of using biodiesel as a fuel
- Explain the factors that affect production costs
- Describe biodiesel blends

Pre-Lab

Background

Introduction

Fossil fuels (natural gas, coal, oil) are non-sustainable and non-renewable resources that our current society has become heavily dependent on. Petroleum (literally rock oil) is the source of gasoline and diesel gas, two common fuels that keep our automobiles running. Prices of these petroleum based fuel are rising due to their high demand and scarcity. In addition, the burning of these fuels increase society's ecological footprint and add to the greenhouse effect, which underlies global warming.

What is biodiesel?

Biodiesel is a fuel made from vegetable oil through a chemical reaction called *transesterification*. During transesterification, the **-O-R** group of an ester and the **-O-R'** group of an alcohol trade places, changing one *ester* (a chemical having the general structure R'COOR") into another. Vegetable oil is a triglyceride (also called a triacylglycerol), which is essentially a glycerin (or glycerol) molecule connected via ester bonds to three fatty acid molecules (R'COOH). During the reaction, the fatty acids of the triglyceride molecule are cleaved and attach to the alkyl group (the part made of carbon and hydrogen) of the alcohol to form fatty acid alkyl esters (in our case, fatty acid methyl esters or FAMES), which are biodiesel. To speed up the reaction, a base catalyst, typically sodium hydroxide (NaOH) or potassium hydroxide (KOH) is used. Animal fats are also triglycerides and therefore can also be made into biodiesel.

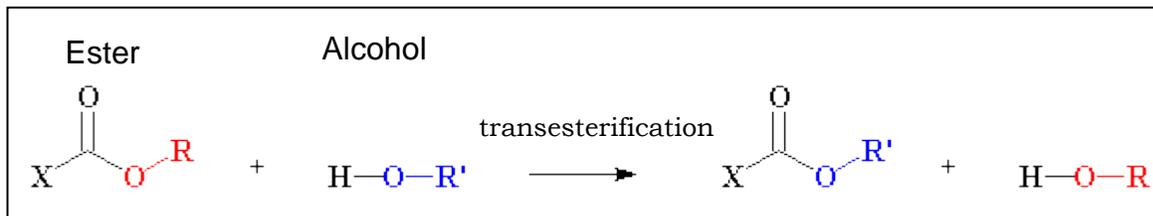


Figure 1: A general transesterification reaction.
Source: <http://pslc.ws/macrog/kidsmac/glossary.htm>

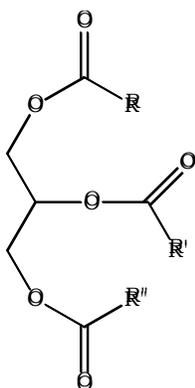


Figure 2:
Triglyceride structure: R, R' and R'' are long alkyl (hydrocarbon) chains ranging from 12-20 carbons in length

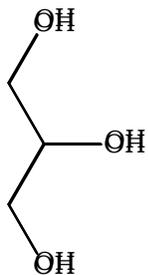


Figure 3:
Glycerol structure

The ester group in triglyceride will exchange places with the alcohol group in methanol or ethanol* to form biodiesel. Biodiesel is a methyl or ethyl ester (depending on whether methanol or ethanol is used) of a long chain fatty acid hydrolyzed from triglyceride.

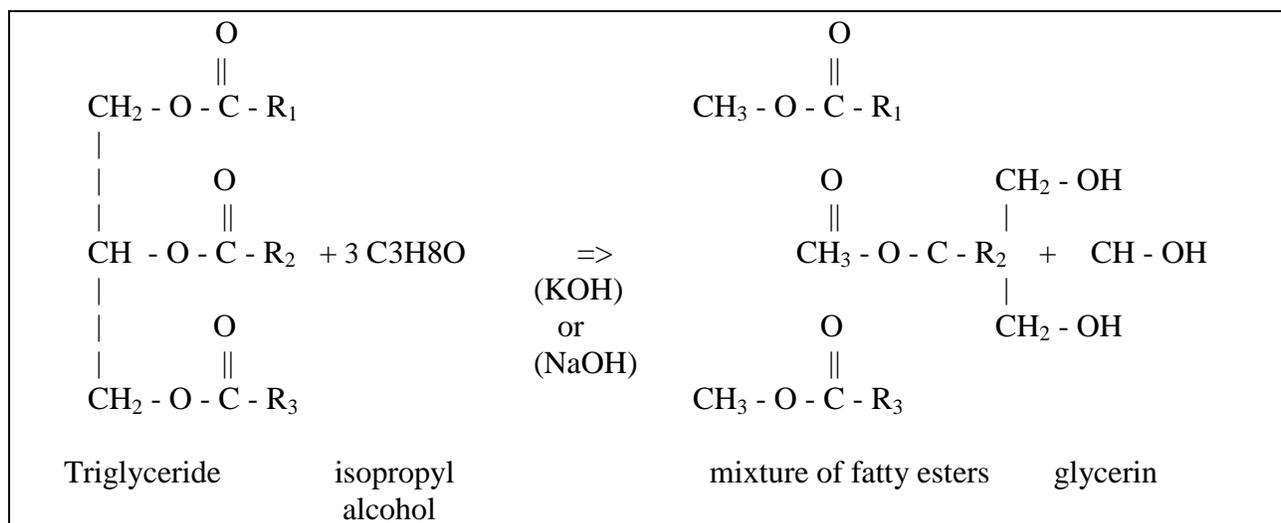
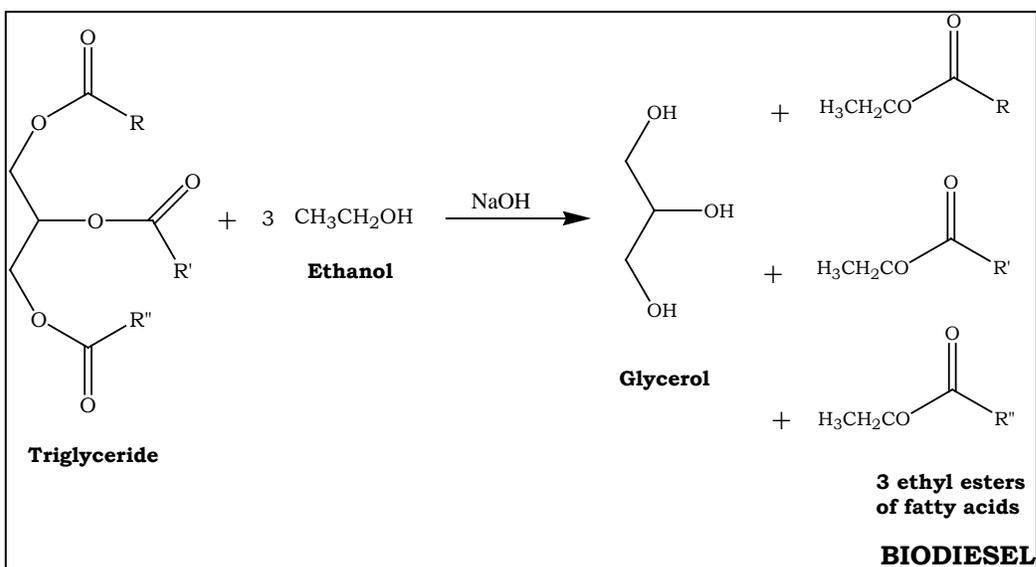


Figure 4: The transesterification reaction in the synthesis of biodiesel

The chemical composition of diesel is about 75% saturated hydrocarbons (primarily paraffins including n, iso, and cycloparaffins), and 25% aromatic hydrocarbons (including naphthalenes and alkylbenzenes). The average chemical formula for common diesel fuel is $\text{C}_{12}\text{H}_{23}$, ranging from approx. $\text{C}_{10}\text{H}_{20}$ to $\text{C}_{15}\text{H}_{28}$. The heat of combustion of diesel = 10,700 cal/g.

Biodiesel is produced from renewable sources such as new and used vegetable oils and animal fats and is a cleaner-burning replacement for petroleum-based diesel fuel. It is nontoxic and biodegradable. Biodiesel has physical properties similar to those of petroleum diesel.

Average Density and Heating Value of Biodiesel and Diesel Fuel

Fuel	Density, g/cm³	Net Heating Value Avg., Btu/gal.	% Difference vs. No. 2 Diesel Avg.
No. 2 Diesel	0.850	129,500	
Biodiesel (B100)	0.880	118,296	8.65 %
B20 Blend (B20)	0.856*	127,259*	1.73 %*
B2 Blend (B2)	0.851*	129,276*	0.17 %*

Table 2. Selected Properties of Typical No. 2 Diesel and Biodiesel Fuels

Fuel Property	Diesel	Biodiesel (B100)	Units
Fuel Standard	ASTM D975	ASTM D6751	
Higher Heating Value	129,500	118,296	Btu/gal
Kinematic Viscosity @ 40° C	1.3 - 4.1	1.9 - 6.0	mm ² /s
Specific Gravity @ 60° C	0.85	0.88	kg/l
Density	7.079	7.328	lb/gal
Water and Sediment	0.05 max	0.05 max	% volume
Carbon	87	77	wt. %
Hydrogen	13	12	wt. %
Oxygen	0	11	
Sulfur	0.0015 max	0.0 to 0.0024	wt. %
Boiling Point	180 to 340	315 to 350	° C
Flash Point	60 to 80	130 to 170	° C
Cloud Point	-15 to 5	-3 to 12	° C
Pour Point	-35 to -15	-15 to 10	° C
Cetane Number	40 to 55	47 to 65	
Lubricity SLBOCLE	2,000 to 5,000	>7,000	grams
Lubricity HFRR	300 to 600	<300	microns

Source: U.S. Department of Energy, Biodiesel Handling and Use Guidelines (2nd Edition, March 2006)

Like petroleum diesel, biodiesel is used to fuel compression-ignition (diesel) engines. Low-level blends of biodiesel with petroleum diesel also provide benefits.

B20 and B100: Alternative Fuels

The interest in biodiesel as an alternative transportation fuel stems mainly from its renewable, domestic production; it's safe, clean-burning properties; and its compatibility with existing diesel engines. Biodiesel can be legally blended with petroleum diesel in

any percentage. The percentages are designated as B20 for a blend containing 20% biodiesel and 80% petroleum diesel, B100 for 100% biodiesel, and so forth. B100 and blends of B20 or higher qualify for alternative fuel credits under the Energy Policy Act of 1992.

B20

Twenty percent biodiesel and 80% petroleum diesel—B20—is the most common biodiesel blend in the United States. Using B20 provides substantial benefits but avoids many of the cold-weather performance and material compatibility concerns associated with B100. B20 can be used in nearly all diesel equipment and is compatible with most storage and distribution equipment. B20 and lower-level blends generally do not require engine modifications. Because diesel engines are expensive, users should consult their vehicle and engine warranty statements before using biodiesel. Biodiesel contains about 8% less energy per gallon than petroleum diesel. For B20, this could mean a 1 to 2% difference, but most B20 users report no noticeable difference in performance or fuel economy. Greenhouse gas and air-quality benefits of biodiesel are roughly commensurate with the blend; B20 use provides about 20% of the benefit of B100 use and so forth. Low-level biodiesel blends also provide benefits.

B100

B100 or other high-level biodiesel blends can be used in some engines built since 1994 with biodiesel-compatible material for parts such as hoses and gaskets. However, as biodiesel blend levels increase significantly beyond B20, a number of concerns come into play. Users must be aware of lower energy content per gallon and potential issues with impact on engine warranties, low-temperature gelling, solvency/cleaning effect if regular diesel was previously used, and microbial contamination. To avoid engine operational problems, pure biodiesel (B100) must meet the requirements of ASTM D6751-09, Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels. B100 use could also increase nitrogen oxides emissions, although it greatly reduces other toxic emissions. All these issues can be handled, but currently B100 use might be best for professional fleets with maintenance departments prepared to deal with this fuel.

Why biodiesel?

Environmental Benefits

In 2000, biodiesel became the only alternative fuel in the country to have successfully completed the EPA-required Tier I and Tier II health effects testing under the Clean Air Act. These independent tests conclusively demonstrated biodiesel's significant reduction of virtually all regulated emissions, and showed biodiesel does not pose a threat to human health. Biodiesel contains virtually no sulfur or aromatics, and use of biodiesel in a conventional diesel engine results in substantial reduction of unburned hydrocarbons, carbon monoxide and particulate matter. A U.S. Department of Energy study showed that the production and use of biodiesel, compared to petroleum diesel, resulted in a 78.5% reduction in carbon dioxide emissions. Moreover, biodiesel has a positive energy

balance. For every unit of energy needed to produce a gallon of biodiesel, at least 4.5 units of energy are gained.

Energy Security Benefits

With agricultural commodity prices approaching record lows, and petroleum prices approaching record highs, it is clear that more can be done to utilize domestic surpluses of vegetable oils while enhancing our energy security. Because biodiesel can be manufactured using existing industrial production capacity, and used with conventional equipment, it provides substantial opportunity for *immediately* addressing our energy security issues. If the true cost of using foreign oil were imposed on the price of imported fuel, renewable fuels, such as biodiesel, probably would be the most viable option. For instance, in 1996, it was estimated that the military costs of securing foreign oil was \$57 billion annually. Foreign tax credits accounted for another estimated \$4 billion annually and environmental costs were estimated at \$45 per barrel. For every billion dollars spent on foreign oil, America lost 10,000 – 25,000 jobs.

Economic Benefits

The biodiesel industry has contributed significantly to the domestic economy. The 51,893 jobs that are currently supported by the US biodiesel industry reflect the beginning of the industry's potential to create jobs and economic growth in the US economy. Biodiesel has added \$4.287 billion to the Gross Domestic Product (GDP). Biodiesel has the potential to support more than 78,000 jobs by 2012. A stable, thriving biodiesel industry is necessary if the U.S. is to eventually benefit from the commercial scale production of algal-based biofuels. The NBB estimates that for every 100 million gallons of biodiesel that is produced from algae, 16,455 jobs will be created and \$1.461 billion will be added to the GDP.

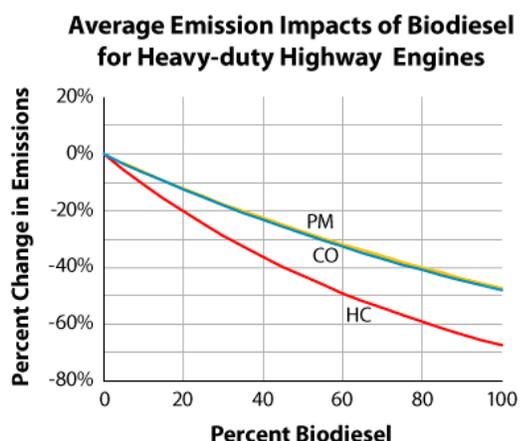
Quality Benefits

Biodiesel is registered as a fuel and fuel additive with the EPA and meets clean diesel standards established by the California Air Resources Board (CARB). B100 (100 percent biodiesel) has been designated as an alternative fuel by the U.S. Department of Energy and the U.S. Department of Transportation. Moreover, in December 2001, the American Society of Testing and Materials (ASTM) approved a specification (D675) for biodiesel fuel. This development was crucial in standardizing fuel quality for biodiesel in the U.S. market. The biodiesel industry also utilizes a voluntary quality management certification program for biodiesel producers, marketers, and laboratories called the BQ-9000 Program. The BQ-9000 Program combines internationally accepted quality management principles with the ASTM biodiesel fuel specification to help ensure that customers and end users get the highest quality fuel possible. The National Biodiesel Accreditation Commissions issues 'BQ-9000 Marketer,' 'BQ-9000 Producer' and 'BQ-9000 lab' certifications for biodiesel marketers and/or producers and biodiesel testing laboratories that have met all requirements of quality management system certification program.

EPAct Benefits

Effective November 1998, Congress approved the use of biodiesel as an Energy Policy

Act (EPA) compliance strategy. The legislation allows EPA-covered fleets (federal, state and public utility fleets) to meet their alternative fuel vehicle purchase requirements simply by buying 450 gallons of pure biodiesel and burning it in new or existing diesel vehicles in at least a 20% blend with diesel fuel. The Congressional Budget Office and the U.S. Department of Agriculture have confirmed that the biodiesel option is the least-cost alternative fuel option for meeting the Federal government's EPA compliance requirements. Because it works with existing diesel engines, biodiesel offers an immediate and seamless way to transition existing diesel vehicles into a cleaner burning fleet.



Using biodiesel also reduces greenhouse gas emissions because carbon dioxide released from biodiesel combustion is offset by the carbon dioxide sequestered while growing the soybeans or other feedstock. B100 use reduces carbon dioxide emissions by more than 75% compared with petroleum diesel. Using B20 reduces carbon dioxide emissions by 15%.

Biodiesel Improves Engine Operation

Biodiesel improves fuel lubricity and raises the cetane number (performance rating) of the fuel. Diesel engines depend on the lubricity of the fuel to keep moving parts from wearing prematurely. Federal regulations reduced sulfur in diesel fuel to 15 ppm a few years ago, which resulted in reduced lubricity of petroleum diesel. Diesel specification ASTM D975 was modified to require lubricity; biodiesel provides adequate lubricity to meet this requirement at blends as low as 1%.

Safety Benefits

Biodiesel is nontoxic, so it causes far less damage than petroleum diesel if spilled or otherwise released to the environment. It is also safer than petroleum diesel because it is less combustible. The flashpoint for biodiesel is higher than 150°C, compared with about 52°C for petroleum diesel. Biodiesel is safe to handle, store, and transport.

Biodiesel has about 93 percent of the energy content of petroleum diesel, on a per gallon basis, and a cetane number between 50 and 60. The chemical composition of biodiesel, especially its higher cetane number, translates to better engine performance and lubrication. However, its lower energy density results in a small decrease in fuel economy in terms of miles per gallon (2-8 percent). Since biodiesel's combustion

properties are similar to that of petroleum-based diesel fuel; biodiesel can be legally blended with conventional diesel in any fraction. As opposed to ethanol, the use of biodiesel does not require many significant engine modifications. Individual engine manufacturers determine which blends can be used in their engines. The most common blend of biodiesel in the United States is 20 percent biodiesel, 80 percent petroleum diesel (B20).

Many newer vehicles are also capable of using pure biodiesel, B100. Biodiesel is also commonly used as a fuel additive (in lower level blends of 2 and 5 percent) to reduce emissions of particulates, carbon monoxide, hydrocarbons, and other air pollutants from diesel-powered vehicles. For example, low-sulfur diesel fuel currently used in the United States is lower in lubricity—the characteristic of diesel fuel necessary to keep diesel fuel injection systems properly lubricated—than higher sulfur diesel fuels. Since biodiesel has no sulfur content and high lubricity, it can be blended with low-sulfur diesel to improve engine lubricity without increasing sulfur emissions. One of the disadvantages of biodiesel is that it can freeze and cause engines to stall at colder temperatures. Proper blending with petroleum diesel and other fuel additives can counteract this problem.

Today, biodiesel is produced from vegetable oils, yellow grease, and tallow. Domestic production increased dramatically over the past decade; however, consumption has not increased at the same rate. Exports increased, mostly to Europe, due to favorable U.S. pricing and currency rates as well as European biodiesel use requirements. European and domestic policy changes may impact U.S. biodiesel exports in the near term. Current research is focused on developing algae as a potential biodiesel feedstock because it is expected to produce high yields from a smaller area of land than vegetable oils.

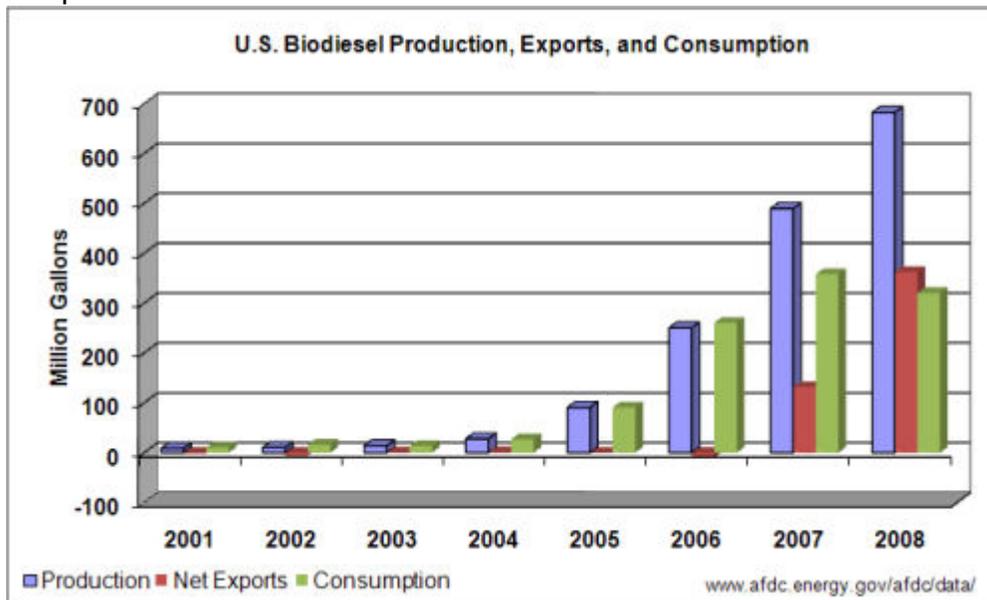
Since biodiesel is made from a renewable source, it has a favorable energy balance ration. An energy balance ration compares the energy required to grow or extract, process, and distribute a fuel to the energy stored in the fuel. According to the USDA, biodiesel's ratio is 3.2. This means that for every unit of fossil-fuel-derived energy required to grow (fertilizers, feedstock, and pesticides), process (think harvest and extract) and transport (from field to refinery to fuel station) biodiesel, there are at least 3.2 units of energy contained in the fuel. By contrast, corn ethanol has an energy balance ratio of 1.34, and petroleum diesel's ratio is negative (-0.84) as is gasoline! (Tickell, 2006).

Production Costs

The cost of producing biodiesel depends on a number of factors, including the following:

- Feedstock used in the process
- Capital and operating costs of the production plant
- Current value and sale of byproducts, which can offset the per-gallon cost of production
- Yield and quality of the fuel and byproducts

The overall cost of biodiesel production depends mainly on the feedstock used and its price; the prices of most feedstocks are subject to market fluctuations, which can also make biodiesel production costs vary over time. Although the price of conventional diesel is not a direct component of production costs, it provides the baseline against which to compare the cost.



Pre-Lab Tasks

1. What is biodiesel?
2. What are the “ingredients/sources” used to make biodiesel?
3. What process is used to make biodiesel? Describe.
4. Where can biodiesel be used?
5. Will biofuels solve our energy problem?
6. What are some advantages to using biodiesel? What are some disadvantages?
7. Where does biodiesel get its energy? **THE SUN**
8. In 2009, \$100 billion/yr. was spent by the U.S. on imported oil. The population of the U.S. was 305 million. What was the price per person that was sent outside the U.S. for oil in 2009? **\$327.00/person**. What about a 4-5 person household, how much would going outside the U.S.? **\$1311.472 and \$1539.344**.

9. Comparing Biodiesel Sources

A “good” sized biodiesel plant will create approximately 30 million gallons (MMG) of biodiesel/year. Your task is to determine the land area necessary to supply various feedstocks for such a plant. Here is the data on the feedstock sources you will consider.

Feedstock Source	Yield (MT/ha @ as-is moisture)	Harvest moisture (%)	Oil Content (%)	Extraction efficiency (%)	Area needed to supply the plant (acres)
Soybeans (solvent extraction)	3.9	10%	19.1 @ 13% moisture	96	
Soybean (expeller)	3.9	10%	19.1 @ 13.% moisture	74	
Palm Oil	10	n/a	23 @ as-is moisture	85	
Canola or 00 Rapeseed	2.5	10%	43 @ 8.4% moisture	96	

Units of measure:

MT = Mega Ton (10⁶)

ha = hectare

ac = acre

Assumptions:

1M= 2200 lbs

1ha = 3.9 MT

7.34 lb/ gal or 0.88 g/cm³ is the density of biodiesel

1ha= 2.471 ac
 100 kg oil yields approximately 100 kg biodiesel

Complete the table above. Show calculations for at least one feedstock source. Which feedstock requires the least amount of land area?

First convert oil content to the harvest moisture. For example:

$$X_2 = X_1 (100-M_2)/(100-M_1) \quad \text{where} \quad \begin{array}{l} M_1 = \text{moisture content at state 1} \\ M_2 = \text{moisture content at state 2} \\ X_1 = \text{percentage at moisture content } M_1 \\ X_2 = \text{percentage at moisture content } M_2 \end{array}$$

Oil percentage @ harvest (10% moisture): $19.1(100-10) / (100-13) = 19.76\%$

Instructor Version

Feedstock Source	Yield (MT/ha @ as-is moisture)	Harvest moisture (%)	Oil Content (%)	Extraction efficiency (%)	Area needed to supply the plant (acres)
Soybeans (solvent extraction)	3.9	10%	19.1 @ 13% moisture	96	330,000
Soybean (expeller)	3.9	10%	19.1 @ 13% moisture	74	433,725
Palm Oil	10	n/a	23 @ as-is moisture	85	126,509
Canola or 00 Rapeseed	2.5	10%	43 @ 8.4% moisture	96	243,650

Instructor: $[30 \times 10^6] \times (7.34 \text{ lb biod/gal biod}) \times (100 \text{ lb oil}/100 \text{ lb biod} \times \text{lb crop oil}/0.96 \text{ extracted oil}) \times (\text{lb crop}/0.1976 \text{ lb crop oil}) \times (\text{MT}/2200 \text{ lb} \times \text{ha}/ 3.9 \text{ MT}) \times (2.471 \text{ ac/ha}) = \underline{\underline{330,000 \text{ acres}}}$

Which feedstock requires the least amount of land? **PALM OIL**

Biodiesel Production & Testing

Safety Checklist

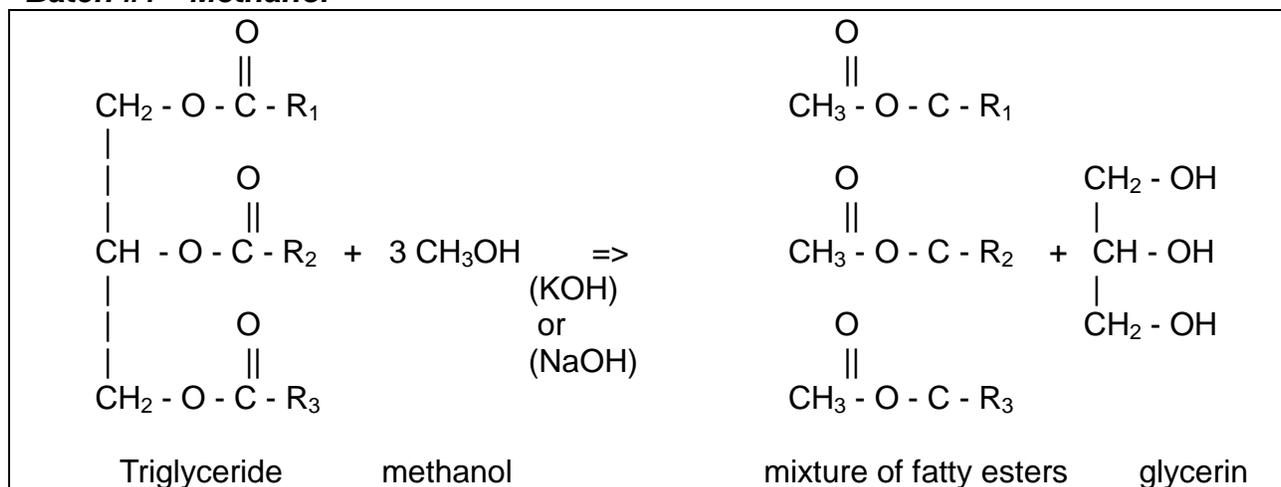
- Proper attire is worn (long pants and closed-toe shoes).
- Food and drinks are stored and consumed outside the laboratory.
- Lab coat and safety glass are worn.
- Latex or nitrile gloves are used when handling samples and chemicals.
- Insulated gloves are used when handling hot materials.
- Chemical aprons are worn when handling methanol or sodium hydroxide.

Problem Statement

Your team had been provided with Lab and Safety equipment, as well, as the ingredients from your biodiesel operative. In your top secret laboratory in the BRL, you will utilize the following procedure to make 3 “special” batches of biodiesel. Additionally, you will utilize your lab created biodiesel to generate electricity by powering a generator! Additional properties testing of your biodiesel will also be required to determine performance under “extreme” conditions as a fuel!

Biodiesel Production

Batch #1—Methanol



Known: The average molecular weight of soybean oil (as triolein) is 885.46g /mol.

Determine the molecular weight for methanol CH₃OH: 32 g.

Determine the molecular weight of glycerin: 92 g.

On a weight basis how much biodiesel will you produce?

885.46g Triglyceride + 96 g Methanol \Rightarrow 889 g fatty esters + 92g glycerin

Determine: In our lab we will use 200g of soybean oil, how much Methanol will be need?
22 g.

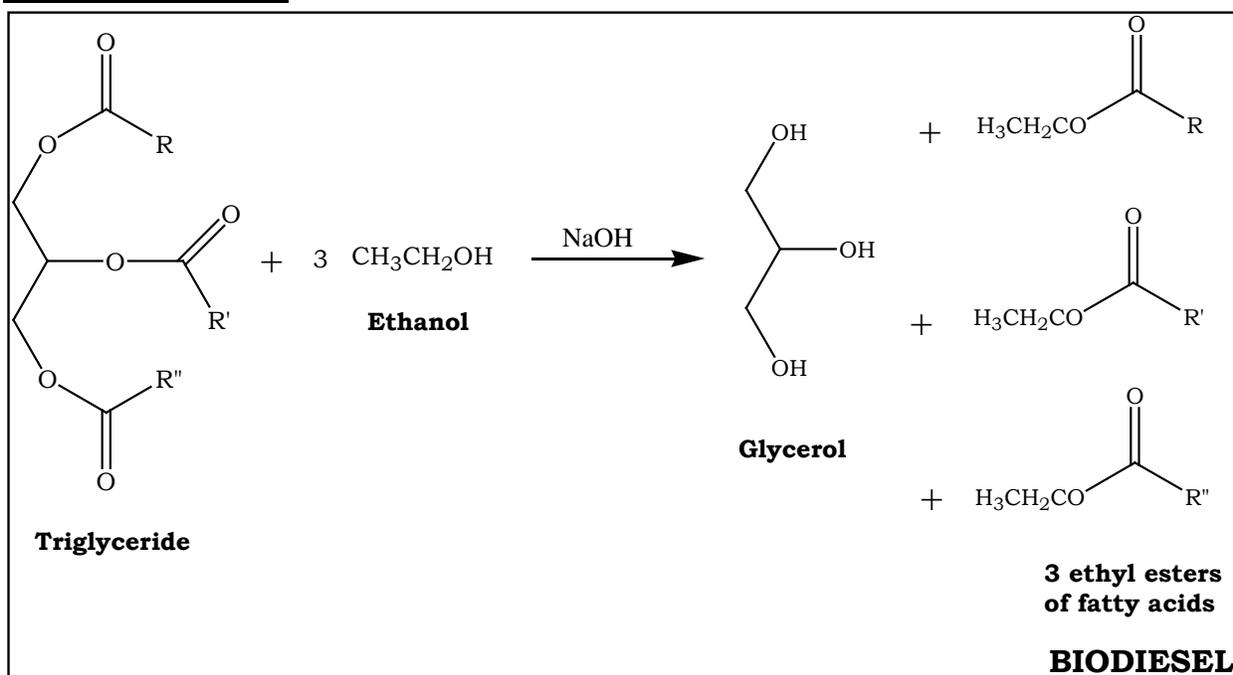
In production we don't actually conduct the reaction this way. We may, in production, add 60%-200% XS methanol (catalyst) to ensure that the reaction goes to completion and methanol can be recovered in accordance with the following:

On a 100 lb. of oil basis, the reaction mass balance with 100% XS methanol becomes:

100 lb. oil + 21.7 lb methanol = 0.45 lb. biodiesel +10.4 lb. glycerol +10.7 lb XS NaOH

Determine: In order increase the reaction, we will multiply the Methanol by 200%.....how much will we need? 44 g.

Batch #2 – Ethanol



Known: The average molecular weight of soybean oil (as triolein) is 885.46 /mol.

Determine the molar weight for ethanol CH₃CH₂OH: 46.07 g

According to the above “formula” for biodiesel, we need to multiply the ethanol molar weight x 3 = 138 g.

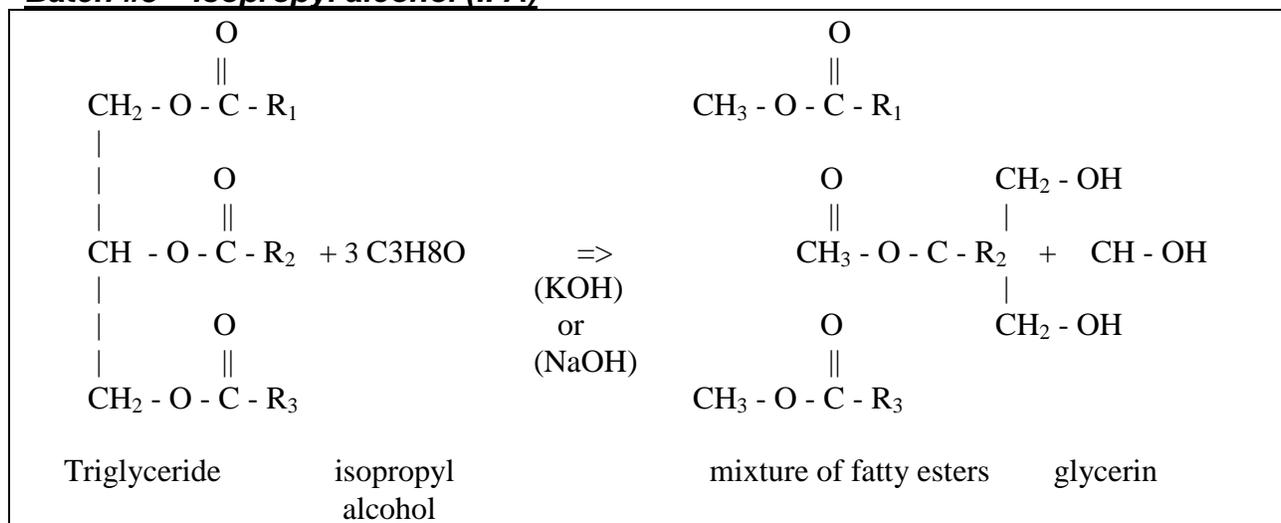
On a weight basis how much biodiesel will you produce?

885.46g Triglyceride + 138g ethanol \Rightarrow ___**931**g fatty esters + 92g glycerin

Determine: In our lab we will use 200g of soybean oil, how much ethanol will be need?
 ___**31.1**__g.

Determine: In order increase the reaction, we will multiply the ethanol by 200%.....how much will we need? ___**62.2**__g.

Batch #3 – Isopropyl alcohol (IPA)



Known: The average molecular weight of soybean oil (as triolein) is 885.46 /mol.

Determine the molar weight for IPA C₃H₈O: ___**61.0**__g

According to the above “formula” for biodiesel, we need to multiply the ethanol molar weight x 3 = ___**180**__g.

On a weight basis to make biodiesel, we would need how much ethanol?

885.46g Triglyceride + 180 g IPA \Rightarrow ___**973**__g fatty esters + 92g glycerin

Determine: In our lab we will use 200g of soybean oil, how much IPA will be need?
 ___**41**__g.

Determine: In order increase the reaction, we will multiply the IPA by 200%.....how much will we need? ___**82**__g.

Pre-experiment Checklist

- Each team of 2-4 has:
 - 400-500 ml Erlenmeyer flasks /beakers
 - 250-500 ml Erlenmeyer flasks/beakers
 - 500-ml separatory funnel
 - small beakers
 - thermometers (200°F max.)
 - combination hot plate / magnetic stirrers
 - 2 magnetic stir bars and magnetic wands
- The following are available:
 - tongs / laboratory gloves for handling hot flasks
 - aluminum foil or weigh boats
 - balance (0.1 g precision minimum)
 - graduated cylinders
 - soybean oil
 - alcohols: methanol, ethanol, IPA
 - sodium hydroxide (NaOH; also known as “lye” or “caustic soda”)

Procedure

Batch #1 methanol

1. Weigh out 2.0 g of sodium hydroxide on a small piece of aluminum foil or weigh boat using balance.
2. Place 250 ml flask on balance and tare.
3. Add pre-determined amount of team’s alcohol for each batch to flask.
 - a. Batch #1: Weigh out _____g methanol in a 250-ml flask/beaker
4. Add a magnetic stir bar to the methanol flask. Add the sodium hydroxide to the methanol. Place on the stirring hotplate (no heat) and stir to dissolve the sodium hydroxide completely, approximately 5 minutes.
5. Use a magnetic wand to remove the stir bar. Set methanol/NaOH flask aside.
6. Add 200 g of soybean oil to 500 ml flask.
7. Add magnetic stir bar to oil flask and heat flask up to a temperature of 60°C (140°F) on hot plate while stirring vigorously. Note: hotplate takes time to heat up and then retains heat for a long time. Do not crank the thermostat – be patient!
8. Once the oil reaches temperature, slowly add the methanol/NaOH mixture.
9. Stir throughout the reaction (about 1 hr) with the stir bar.
10. The mixture will thicken and darken, then become thinner than the original oil.

11. Watch the temperature to ensure that it does not exceed 60°C (140°F). Do not use the thermometer as a stirring rod.
12. After one hour, turn off the hot plate and stirring. Remove stir bar using magnetic wand.
13. Pour the mixture into the 500-ml separatory funnel. Allow the mixture to settle for at least 10-15 minutes. The bottom layer contains glycerin and some soap; the top layer is the biodiesel (fatty acid methyl esters or fatty acid ethyl esters).
14. Drain the bottom liquid (glycerin and soap) into a small beaker.
15. After separation has been completed, “wash” the biodiesel with distilled water to remove any remaining alcohol and soap.
 - a. Spray a small amount of distilled water into the separatory funnel (about 10 initial squirts/sprays of water into the separatory funnel, about 10-20%/vol.).
 - b. Wait about 5 minutes and observe the separation of the “white/milky”, soapy bottom layer from the top biodiesel layer.
 - c. Separate this “milky” soap bottom layer from the biodiesel top layer into a clean beaker (this can be disposed of down the drain). Get as much of the bottom layer as possible.
16. Now “dry” the biodiesel to remove the excess water from washing.
 - a. Pour the biodiesel remaining in the separatory funnel into a 400ml beaker and place on top of the stirring hotplate.
 - b. Add a magnetic stir bar and a thermometer.
 - c. Slowly heat to 80°C, and keep at this temperature~ 30 minutes or until the biodiesel becomes clear (the cloudiness will gradually disappear as water evaporates).
 - d. Turn off the hotplate and allow biodiesel to cool. Remove the stir bar with the magnetic wand.
 - e. We will use the results of your data analysis below to select a biodiesel sample to put into the generator and you can enjoy the benefits of your fuel by powering an appliance!

Batch #2 Ethanol (EtOH)

1. Weigh out 2.0 g of sodium hydroxide on a small piece of aluminum foil or weigh boat using balance.
2. Place 250 ml flask on balance and tare.
3. Add pre-determined amount of team’s alcohol for each batch to flask.
 - a. Batch #1: Weigh out _____g ethanol in a 250-ml flask/beaker
4. Add a magnetic stir bar to the ethanol flask. Add the sodium hydroxide to the ethanol. Place on the stirring hotplate (no heat) and stir to dissolve the sodium hydroxide completely, approximately 5 minutes.
5. Use a magnetic wand to remove the stir bar. Set ethanol/NaOH flask aside.
6. Add 200 g of soybean oil to 500 ml flask.
7. Add magnetic stir bar to oil flask and heat flask up to a temperature of 50-60°C (130-140°F) on hot plate while stirring vigorously. Note: hotplate takes time to

- heat up and then retains heat for a long time. Do not crank the thermostat – be patient!
8. Once the oil reaches temperature, slowly add the ethanol/NaOH mixture.
 9. Stir throughout the reaction (about 1 hr) with the stir bar.
 10. The mixture will thicken and darken, then become thinner than the original oil.
 11. Watch the temperature to ensure that it does not exceed 60°C (140°F). Do not use the thermometer as a stirring rod.
 12. After one hour, turn off the hot plate and stirring. Remove stir bar using magnetic wand.
 13. Pour the mixture into the 500-ml separatory funnel. Allow the mixture to settle for at least 10-15 minutes. The bottom layer contains glycerin and some soap; the top layer is the biodiesel (fatty acid methyl esters or fatty acid ethyl esters).
 14. Drain the bottom liquid (glycerin and soap) into a small beaker.
 15. After separation has been completed, “wash” the biodiesel with distilled water to remove any remaining alcohol and soap.
 - a. Spray a small amount of distilled water into the separatory funnel (about 10 initial squirts/sprays of water into the separatory funnel, about 10-20%/vol.).
 - b. Wait about 5 minutes and observe the separation of the “white/milky”, soapy bottom layer from the top biodiesel layer.
 - c. Separate this “milky” soap bottom layer from the biodiesel top layer into a clean beaker (this can be disposed of down the drain). Get as much of the bottom layer as possible.
 16. Now “dry” the biodiesel to remove the excess water from washing.
 - a. Pour the biodiesel remaining in the separatory funnel into a 400ml beaker and place on top of the stirring hotplate.
 - b. Add a magnetic stir bar and a thermometer.
 - c. Slowly heat to 105°C, and keep at this temperature~ 30 minutes or until the biodiesel becomes clear (the cloudiness will gradually disappear as water evaporates).
 - d. Turn off the hotplate and allow biodiesel to cool. Remove the stir bar with the magnetic wand.
 - e. We will use the use the results of your data analysis below to select a biodiesel sample to put into the generator and you can enjoy the benefits of your fuel by powering an appliance!

Batch #2 Isopropyl (IPA)

1. Weigh out **11.35 g** of sodium hydroxide on a small piece of aluminum foil or weigh boat using balance.
2. Place 250 ml flask on balance and tare.
3. Add pre-determined amount of team’s alcohol for each batch to flask.
 - a. Batch #1: Weigh out _____g IPA in a 250-ml flask/beaker
4. Add a magnetic stir bar to the IPA flask. Add the sodium hydroxide to the IPA. Place on the stirring hotplate (no heat) and stir to dissolve the sodium hydroxide completely, approximately 5 minutes.

5. Use a magnetic wand to remove the stir bar. Set IPA/NaOH flask aside.
6. Add 200 g of soybean oil to 500 ml flask.
7. Add magnetic stir bar to oil flask and heat flask up to a temperature of 60°C (140°F) on hot plate while stirring vigorously. Note: hotplate takes time to heat up and then retains heat for a long time. Do not crank the thermostat – be patient!
8. Once the oil reaches temperature, slowly add the IPA/NaOH mixture.
9. Stir throughout the reaction (about 1 hr) with the stir bar.
10. The mixture will thicken and darken, then become thinner than the original oil.
11. Watch the temperature to ensure that it does not exceed 60°C (140°F). Do not use the thermometer as a stirring rod.
12. After one hour, turn off the hot plate and stirring. Remove stir bar using magnetic wand.
13. Pour the mixture into the 500-ml separatory funnel. Allow the mixture to settle for at least 10-15 minutes. The bottom layer contains glycerin and some soap; the top layer is the biodiesel (fatty acid methyl esters or fatty acid ethyl esters).
14. Drain the bottom liquid (glycerin and soap) into a small beaker.
15. After separation has been completed, “wash” the biodiesel with distilled water to remove any remaining alcohol and soap.
 - a. Spray a small amount of distilled water into the separatory funnel (about 10 initial squirts/sprays of water into the separatory funnel, about 10-20%/vol.).
 - b. Wait about 5 minutes and observe the separation of the “white/milky”, soapy bottom layer from the top biodiesel layer.
 - c. Separate this “milky” soap bottom layer from the biodiesel top layer into a clean beaker (this can be disposed of down the drain). Get as much of the bottom layer as possible.
16. Now “dry” the biodiesel to remove the excess water from washing.
 - a. Pour the biodiesel remaining in the separatory funnel into a 400ml beaker and place on top of the stirring hotplate.
 - b. Add a magnetic stir bar and a thermometer.
 - c. Slowly heat to 105°C, and keep at this temperature~ 30 minutes or until the biodiesel becomes clear (the cloudiness will gradually disappear as water evaporates).
 - d. Turn off the hotplate and allow biodiesel to cool. Remove the stir bar with the magnetic wand.
 - e. We will use the use the results of your data analysis below to select a biodiesel sample to put into the generator and you can enjoy the benefits of your fuel by powering an appliance!

Data Analysis

Watch what happens during the transesterification and record your observations. Walk around and look at other biodiesel stations. As a group, identify the best looking biodiesel sample. Is it methanol or ethanol? This best sample will be used for producing power in the biodiesel generator. The others will be used for further biodiesel properties testing.

Biodiesel Determination of Free and Total Glycerin, etc. (Bonanza Mini-Analyzer)

Biodiesel Density and Freezing Point

Background

Your top biodiesel team will determine two very important biodiesel fuel properties, density and freezing point, of 5 biodiesel samples using a graduated cylinder, balance, beakers, test tubes/glass containers, rock salt, water, ice and thermometers. Additionally, you will compare this to pure soybean oil.

Pre-experiment Checklist: Optional based on sample availability

- Samples are available for analysis
 - biodiesel #2 from production procedure(methanol and/or ethanol)
 - Biobus waste grease biodiesel
 - REG soybean biodiesel
 - REG animal fat biodiesel
 - REG combination biodiesel
 - Soybean oil

Procedure-follow for all samples

1. Weigh an empty graduated cylinder (provided by instructor) on a balance. Record the mass in grams.
2. Transfer approximately 20 mL of biodiesel into the graduated cylinder. Record the volume of the biodiesel in mL.
3. Weigh the graduated cylinder with the biodiesel on the balance. Record the mass in grams (g).
4. Determine the mass of the biodiesel (biodiesel + graduated cylinder – graduated cylinder).
5. Calculated the density of the biodiesel, mass/volume.
6. If glycerol's density is 1.26 g/mL (larger than that of biodiesel), why does it sink to the bottom of the separator funnel/beaker? Higher density sinks to the bottom!
7. Transfer the biodiesel samples evenly into a test tube, and set in the blue test tube rack.
8. REPEAT STEPS 1-7 FOR ALL SAMPLES BEING TESTED.
9. Set up an ice bath by dissolving some rock salt in water and ice in 100 ml or larger beaker.
10. Place a thermometer into each test tube/glass container, and place into the icy bath!
11. At every 1 minute interval, record the temperature of the biodiesel and the appearance/physical state (cloudy, gel, solid, liquid, etc.).
12. When the biodiesel gets "cloudy", record time & temperature)
13. When the biodiesel "gels", record time & temperature.
14. When the biodiesel solidifies (freezes), record the time & temperature.
15. If the biodiesel doesn't freeze and the temperature inside the test tubes/glass containers is below -20°C, stop monitoring.

16. Remove the biodiesel samples, place in the test tube rack, and let them sit at room temperature.
17. Monitor the temperature at which the biodiesel melts and record when time & temperature (gel, cloudy, liquid) biodiesel gets to the liquid state, and seems to clarify in appearance.

Data Analysis

Which biodiesel sample(s) changed form first in the ice bath? What was the temperature? Did any of the samples not change below -20°C ? Which melted/liquefied first? What was the temperature? Which would you want to “sell” as a winter fuel in Iowa?

Energy Content Determination (HHV): Optional

Background

Your team will measure the higher heating value (HHV) of the five biodiesel samples using the Parr 6400 bomb calorimeter and pure soybean oil.

Pre-Experiment Checklist

- Samples are available for analysis
 - biodiesel #2 from production procedure
 - Biobus waste grease biodiesel
 - REG soybean biodiesel
 - REG animal fat biodiesel
 - REG combination biodiesel
 - Pure soybean oil

Procedure-follow for all 6 samples

1. Follow procedure for bomb calorimeter outlined in Biomass Properties Lab Handout.
2. Determine units to use on the calorimeter (review pre-lab material).
3. Analyze 2 replicate of 0.6 g samples of each type of biodiesel.
 - a. Have 2 team members prepare one sample at a time, and place in the bomb for energy content determination, and then while awaiting the final result they can also prepare the duplicate sample.
 - b. Record the energy content of each sample, and then clean out the cup, etc. and prepare for the second sample of this biodiesel type.

Data Analysis

Determine the average energy content for each type of biodiesel and the soybean oil. Note differences, and compare.

Review the data provided in the pre-lab and in the biomass properties lab and/or Dr. Brown's Text, 'Biorenewable Resources'.

Where does your data fall in relation to the “published” results?

Optional - Total and Free Glycerin Determination...In Development

Optional – pH determination of biodiesel

Background

MANY people have reported problems with trying to "read" the pH of biodiesel by putting the pH meter straight into the biodiesel. The pH scale commonly used (pH = 0-14) is a measurement for aqueous solutions. Although biodiesel can hold a tiny amount of water, for all practical purposes, biodiesel is a non-aqueous solution, so pH cannot be determined the traditional way.

Water must be added to measure the relative amount of acidic and basic ions (included as part of the soap impurity) present in the biodiesel. Soap is the salt of a weak acid and a strong base. Therefore, when biodiesel is mixed with water, some of the soap is washed out of the biodiesel into the water. The pH of the wash water should always be above 7 to start. As the biodiesel is further "washed", the pH of the wash water should continue to fall until it reaches the pH of the water being used to wash. It may be beneficial to leave a little bit of soap in the biodiesel so that any water will be basic (caustic) rather than acidic. Acid will attack steel but base does not, and the expensive parts of a diesel's fuel system are made from steel.

Procedure

1. Put similar amounts of biodiesel and water in a container and shake hard for a few seconds.
2. After biodiesel and water layers separate, measure the pH of the water.

Optional - Oil/Biodiesel Viscosity Test with 'Falling Ball' Method

Background

Your team will determine one of the important biodiesel properties, i.e. viscosity of available biodiesel samples. Viscosity can be generally described as “stickiness” of a fluid, being expressed with unit of centipoise (cP) or centistokes (cSt). Viscosity of a fuel is very important because it affects atomization of the fuel being injected into the engine combustion chamber. A small fuel drop is desired, so that complete fuel combustion occurs. A high viscosity fuel, such as raw vegetable oil, will produce larger drop of fuel in an engine combustion chamber, which may not burn as clean as fuel that produces a smaller droplet. Unburned oxidized fuel will build up in the engine around valves, injector tips and on piston sidewalls and rings, eventually resulting in broken rings in few cases. Hence, it's essential to ensure the biodiesel produced could match the ASTM standard of viscosity for biodiesel in market, so that it's engine- and environmental friendly.

Pre-experiment Checklist

- Oil or biodiesel samples
- 100ml graduated cylinder
- Marble
- Ruler
- Stopwatch
- Calculator

Procedure

Measuring Ball Density

1. Measure the diameter of a marble with Vernier Caliper in centimeter (cm). Calculate the radius of marble in cm, and volume of the marble in cm^3 . (Radius, $r = d/2$,
Volume = $4/3 \cdot \pi \cdot r^3$)
2. Weigh the marble in grams (g). Calculate the density of the marble in g/cm^3 . (Density = mass/volume)

Measuring Biodiesel Density

3. Weigh an empty 100ml graduated cylinder on a balance. Record the mass in grams (g).
4. Transfer approximately 100ml of oil/biodiesel into the graduated cylinder and record the exact volume.
5. Weigh the graduated cylinder with the oil/biodiesel on the balance and record mass.

- Determine the mass of the oil/biodiesel by difference.
- Calculate the density of the oil/biodiesel in g/ml. (Density = mass/volume)

Measuring Velocity of Dropping Ball

- Use a marker pen to draw a horizontal line across '90ml' level. This will serve as starting point of dropping ball to start the stopwatch.
- The bottom of cylinder will serve as ending point of dropping ball to stop the stopwatch.
- Measure the height between calibrated starting point and ending point of dropping ball in cm.
- Drop the marble into the oil/biodiesel. Once the marble reaches starting point, start the stopwatch.
- Stop the stopwatch as soon as the marble reaches the ending point. Record the time in seconds.
- Calculate the velocity of dropping marble in cm³/s. (Velocity = height/average time)

Measuring Oil/Biodiesel Viscosity

- Calculate the viscosity of the oil/biodiesel in centipoise (cP) using the following equation:

$$\text{Viscosity (cP)} = \frac{2 \times (\text{density of marble} - \text{density of oil}) \times g \times r^2}{9 \times \text{ball velocity}}$$

, where g = gravitational acceleration = 980 cm/s²
 r = radius of marble, cm

Optional

- If the sample is biodiesel, calculate kinematic viscosity of biodiesel (another way to express viscosity) in centistokes (cSt).

$$\text{Kinematic Viscosity (cSt)} = \frac{\text{Viscosity (cP)}}{\text{biodiesel density (g/cm}^3\text{)}}$$

- Compare the value with ASTM standard of kinematic viscosity for biodiesel in market.

Data Analysis	Source	Oil/Biodiesel I	Oil/Biodiesel II	Oil/Biodiesel III	Oil/Biodiesel IV	Oil/Biodiesel V	Oil/Biodiesel VI
		Diameter of marble	cm				
Radius of marble (= diameter/2)	cm						
Volume of marble (= $1/3 \cdot \pi \cdot r^3$)	cm ³						
Mass of marble	g						
Density of marble (= mass/volume)	g/cm ³						
Mass of empty graduated cylinder	g						
Mass of graduated cylinder with biodiesel	g						
Mass of biodiesel	g						
Volume of biodiesel	ml						
Density of biodiesel (= mass/volume)	g/ml						
Height between starting and ending point	cm						
Travelling time of dropping marble	s						
Velocity of dropping marble (= height/time)	cm/s						
Viscosity (in formula)	cP						
Kinematic Viscosity (= viscosity / density)	cSt						

Optional – Oil/Biodiesel Viscosity Test with “DIY Viscosimeter”

Background

Your team will make a “DIY Viscosimeter” to estimate the viscosity of biodiesel. Viscosity can be generally described as “stickiness” of a fluid, being expressed with unit of centipoise (cP) or centistokes (cSt). It’s essential to ensure the biodiesel produced could satisfy the ASTM viscosity standard for biodiesel in market, so that it’s engine- and environmental friendly. However, a precise lab-use viscosimeter is very expensive and not easily accessible, especially for public learning community interested in making biofuel and understanding more about its properties. Thus, “DIY Viscosimeter” made with few household items could help us to estimate roughly biodiesel viscosity with minimal costs.

Pre-experiment Checklist

- Empty plastic bottle (roughly 1.25L to 1.5L in size)
- 2mm copper pipe
- Drill & 2mm drill bit
- Biodiesel (about 1.5L to 2L)
- Retort stand and clamps
- A bucket
- Thermometer & two 1-Liter beakers
- Heat plate
- Stop-watch & calculator

Procedure

Making DIY Viscosimeter

1. Cut the bottom off the plastic bottle using scissors.
2. Remove the cap of the bottle and drill a hole on it.
3. Make sure the ends of copper tube are smooth and round with no burrs. Insert the copper tube into the hole for about 1cm.
4. Screw back the bottle cap. Test the DIY Viscosimeter by filling it up with water, and ensure there’s no leakage around the cap. Replace the cap, if necessary.
5. Measure out and mark a vertical 10cm section on the side of the bottle. The line nearest the cut-off end of the bottle represents the start line, whereas the one nearest the cap represents the finish line.

Set-up DIY Viscosimeter

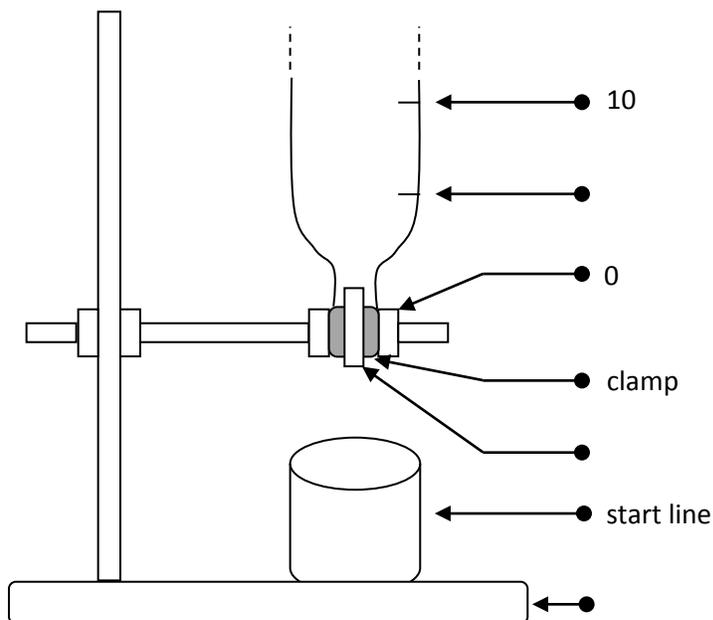


Figure 1. Set up of DIY Viscosimeter.

6. Set up the DIY Viscosimeter as shown in the Figure 1.
7. Place a bucket underneath the bottle, in order to contain flowing-out biodiesel.

Test Biodiesel Viscosity with DIY

8. Heat the biodiesel up to 40°C. Once biodiesel reaches desired temperature, put one finger over the end of copper pipe and fill the plastic bottle with biodiesel to above start line. (NOTE: One person needs to support the stand or bottle to ensure the bottle is held perpendicular to the bucket, while the bottle is filled up with biodiesel.)
9. Remove the finger and allow the biodiesel to flow out. Once the biodiesel reaches the start line, start the stop watch.
10. Measure how long the biodiesel takes to get to the finish line. Repeat the measurement for at least two times to obtain accurate result. If this test is done properly, the results should be within a few tenths of a second of each other.
11. Divide the results in seconds by ten to find out how far the biodiesel travelled in one second. This will give you the value in centistokes, which is the standard measure of viscosity in fuel oil.

12. Compare the value with ASTM standard of kinematic viscosity for biodiesel in market.