Preparation & Combustion of Biodiesel | A Lab Investigation

Summary

In this investigation, students use canola oil, typically used in the kitchen, to produce biodiesel by reacting it with methanol using a potassium hydroxide catalyst. They then burn a sample of the biodiesel produced. The sample is placed underneath a soda can that contains a measured amount of cold water. The initial and final temperatures of the water are recorded. The collected data is used to calculate the heat of combustion of the biodiesel, which is compared to the theoretical heat of combustion of diesel fuel from crude oil. The concepts of renewable and non-renewable fuels are also discussed.

Objective

Students learn about a reaction used to produce biodiesel, heat of combustion, and the concepts of renewable and non-renewable fuels.

Materials for Each Group

- 25-mL graduated cylinder
- 10-mL graduated cylinder
- Canola oil (25 mL)
- Methanol (4 mL)
- Plastic container with a screw-top lid (needs a capacity of at least 50 mL)
- Dropper
- 9 M potassium hydroxide (KOH) (12.5 g KOH in 25-mL solution)
- Sodium chloride (0.5 g)
- Large test tube (needs a capacity of at least 30–35 mL)
- Cork or stopper to seal large test tube
- Test tube rack
- 12-oz empty, clean aluminum soft drink can with pull tab
- Ring stand
- Ring
- Thermometer
- Stirring rod
- Matches
- Balance
- Tea light candle with metal cup and wick
- Watch glass

Safety

- Be sure you and the students wear properly fitting goggles.
- Burners must not be used, since many reagents are flammable.
- Methanol particularly poses a serious fire hazard, and its flame is almost invisible. Avoid flames or sparks. Methanol is also toxic by ingestion. Skin contact causes dermatitis. Work in a well-ventilated area.
- When working with alcohols such as methanol, the National Science Teachers Association recommends that "the primary reagent alcohol container be kept in the chemical storeroom. The minimum quantity of alcohol needed for the experiment should be available to students":

  http://bit.ly/highschoolnrg7

- *Extreme caution* should be used with 9 M KOH. It is caustic and corrosive. The instructor must dispense drops of the concentrated base directly into each group's container. 9 M potassium hydroxide is caustic and corrosive. Avoid skin contact. In the event of skin or eye contact, rinse well with water. Have contact area evaluated by qualified medical personnel.
- Instructors should follow their own state's rules for proper disposal of waste. The waste layer in the investigation contains mostly glycerol, excess methanol, and potentially unreacted potassium hydroxide. A useful document is "Biodiesel Safety and Best Management Practices for Small-Scale Noncommercial Use and Production" from Penn State's College of Agricultural Sciences:

  http://bit.ly/highschoolnrg8

Time Required

Two class periods, approximately 45–50 minutes each. The biodiesel reaction mixture must sit for at least 30 minutes or overnight.

Pre-Lab Discussion

This investigation introduces the concept of heat of combustion of a fuel. It also highlights the difference between renewable and non-renewable fuel sources, in particular, biodiesel and diesel obtained from crude oil. A discussion of the basic organic structures presented in the investigation would be helpful.

Lab Tips

Instead of shaking the bottle with the reaction mixture for 10 minutes, a magnetic stir bar apparatus could be used.

One option for the plastic containers with screw-top lids are "baby soda bottles," also known as soda bottle preforms. These are sold by science supply companies and look like large plastic test tubes with 2-liter soda bottle screw-top lids.

The reaction mixture is transferred to a test tube after mixing so it is easier to see the two layers separated and to decant the top biodiesel layer. Separatory funnels could be used instead if available. The time needed for the investigation can be shortened if a centrifuge is available; portions of the reaction mixture can be centrifuged to obtain the two separated layers rather than leaving them to separate overnight.

Chilled water should be used in the combustion portion of the investigation. Ice can be added to cool the water if needed. However, unmelted ice should be removed from the water before using it in the soft drink can.

Instructors may wish to use only a few 25-mL graduated cylinders that would be reserved for this activity, as they will become coated with oil and may be difficult to clean thoroughly. Student groups can share the cylinders.

Integrating into the Curriculum

This investigation would fit into units on chemical reactions, thermodynamics, combustion, and green chemistry.

TEACHER'S KEY

Analyzing Evidence

1. Using the temperature and weight data from the heating of the water in the can, calculate how much thermal energy was used to heat the water. The specific heat capacity of water is 4.18 J/(g · °C), meaning it takes 4.18 J to raise the temperature of 1 g of water by 1 °C.

   Answers will vary. A sample calculation is:

   Data:

   Mass of biodiesel burned: 3.4 g (difference between biodiesel sample, metal cup, and wick before and after burning)

   Mass of water: 1.00 x 102 g water

   Initial water temperature: 5 °C

   Final water temperature: 67 °tC

   $E = mC\Delta T = (1.00 \times 102\ g)(4.18\ J/(g \cdot {}^\circ C))(67\ {}^\circ C - 5\ {}^\circ C) = 26 \times 10^3\ J$

2. Calculate the heat of combustion in kJ/g for the sample of biodiesel you burned. The heat of combustion is the quantity of thermal energy given off when a certain amount of a substance burns. Assume that all of the energy released by the burning biodiesel is absorbed by the water.

   Answers will vary. The method of gathering data for the heat of combustion is somewhat inefficient. A sample calculation, using the data from Analyzing Evidence question 1, 26×10^3 J, or 26 kJ, is given off by the burning biodiesel. The heat of combustion = 26 kJ / 3.4 g = 7.6 kJ/g

3. Petroleum diesel (from crude oil) produces 43 kJ/g of thermal energy when burned. Compare this to the thermal energy your biodiesel sample produced when it was burned.

   Gram for gram, biodiesel produces less energy.

4. Compare your calculated heat of combustion with those calculated by the rest of the class. What is the class mean?

   Answers will vary, depending on class data.

Interpreting Evidence

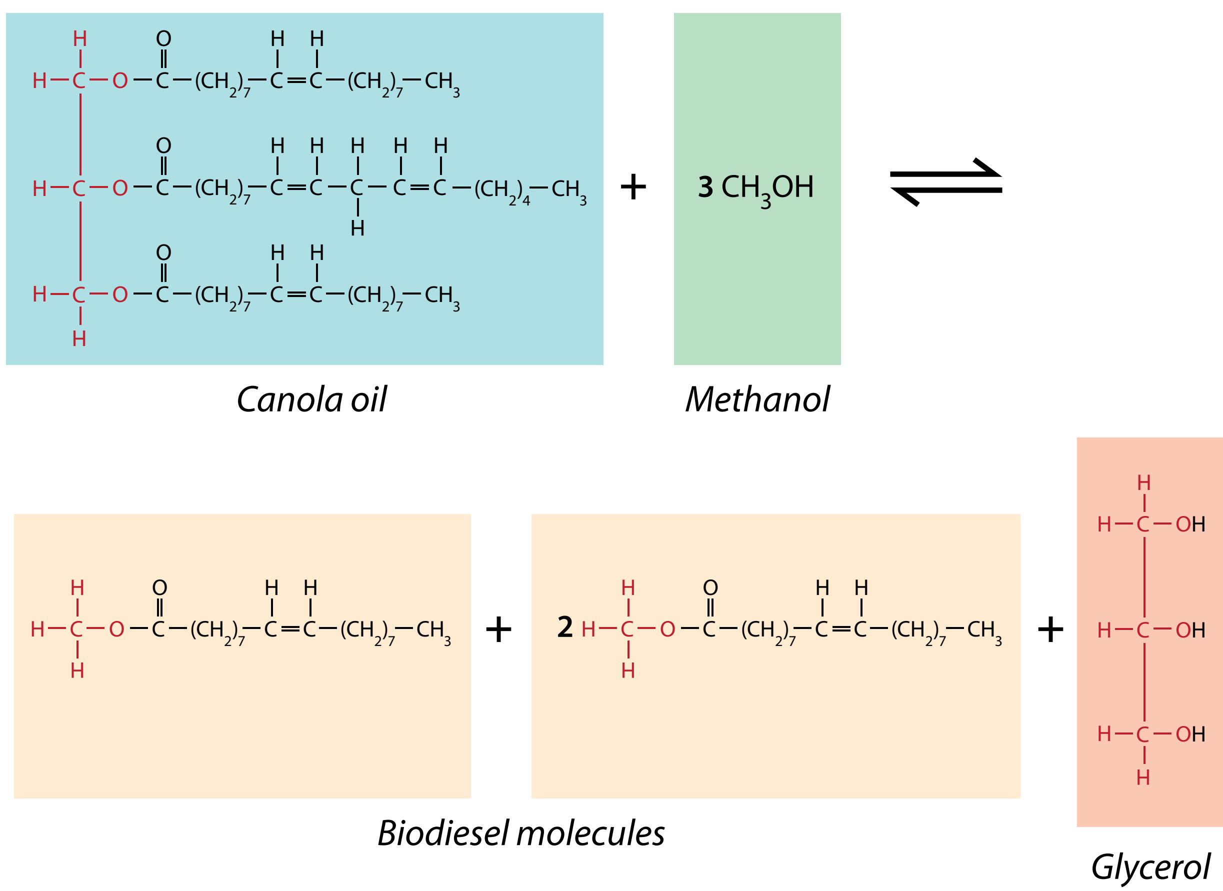
1. What evidence was there that a reaction occurred during the biodiesel preparation?

   Two layers formed in the reaction mixture.

2. Look again at the structures of two possible biodiesel and diesel molecules in the Preparing to Investigate section. What similarities do the molecules have that would help to explain how biodiesel can be used with little to no modification in diesel engines?

   They are both largely chains of carbon atoms of similar lengths. The biodiesel molecule has mostly hydrogen atoms bonded to the carbon atoms like the diesel molecule, but with some differences.

3. Draw the balanced equation for the reaction to form biodiesel from canola oil.



Reflecting on the Investigation

1. Is biodiesel a "better" fuel than diesel fuel from crude oil? Explain and support your answer.

   Answers will vary. A "yes" answer could be supported with the idea that it is a renewable source of fuel. A "no" answer could be supported with the idea that it has a smaller heat of combustion.

2. The combustion of biodiesel produces carbon dioxide (CO_2), a greenhouse gas. However, biodiesel is labeled as "carbon-neutral," meaning it does not increase the net amount of carbon (carbon dioxide) in the atmosphere. Why?

   The combustion does release carbon dioxide. However, the carbon from the biodiesel was previously absorbed from the atmosphere by the plants used to produce the biodiesel. The release is offset by the absorption.

3. What is a potential concern with diverting food crops to the production of biodiesel?

   Diverting food crops to the production of biodiesel can raise food prices for the consumer as well as possibly creating shortages of food.

4. Suppose that you wanted to make biodiesel for your own car using the method in this investigation. What challenges might you encounter in scaling up the process?

   Some challenges could be difficulties in shaking a large mixture; storage of the starting and finished materials and by-products, including a corrosive, highly basic solution; and obtaining necessary amounts of the starting materials.

Post-Lab Discussion

The viability and practicality of using biodiesel as a replacement fuel could be at the center of a rich discussion, particularly if students did further research on the topic. Additional biodiesel starting materials could be discussed, such as soybeans.

Students may be interested in learning more about how vegetable oils such as canola oil can be used directly in diesel engines. Some modifications are made to the engines. For example, the oil must be heated before it enters the engine, due to its higher viscosity than diesel fuel. This could be combined with a discussion of gelling that can occur in diesel and biodiesel fuels at low temperatures.

Students could explore the reaction stoichiometry semi-quantitatively, including an estimation of how many moles of oil and methanol are used, and which is in excess.

Extensions

1. The American Chemical Society (ACS) textbook *Chemistry in the Community* has an excellent series of questions where students decide whether it is viable for biodiesel made from soybeans to completely replace diesel made from crude oil. (*Chemistry in the Community*, 6th ed., New York: W. H. Freeman and Company/BFW, 2012, pp 374–375)
2. Both biodiesel and diesel fuels can "gel" at low temperatures, making modifications necessary for areas that experience cold weather. Students could determine the temperature at which their biodiesel sample gels and decide if it would be a reasonable fuel for their local area. Place a small sample (~1 mL) in a test tube. Leave the test tube in a freezer until the biodiesel gels, approximately 15 minutes. Remove the test tube. Gently stir the sample with a thermometer and observe the temperature at which the sample becomes liquid again.
3. Use a "fire syringe" to demonstrate the principle of the diesel engine, that thermal energy is produced when a gas is rapidly compressed and can ignite fuel. The product is available from science supply companies, such as *www.teachersource.com/product/fire-syringe-demo*. The link includes a video showing the fire syringe in action; see another example at *www.youtube.com/watch?v=MnpvQvCTj90*.
4. The ACS has a sustainable energy section online with links and podcasts about different biofuel sources, such as chicken feathers, and more at *http://bit.ly/highschoolnrg9*.
5. Students could read articles related to the topic from *ChemMatters*, an ACS magazine for high school chemistry students:
   - Hill, M. "From Fish Tank to Fuel Tank," *ChemMatters*, 2012, 30 (2), pp 12–14.
   - Nolte, B. "Tanking Up with Cooking Oil," *ChemMatters*, 2011, 29 (2), pp 5–7.
   - Kirchhoff, M. "Do You Want Biodiesel with That?" *ChemMatters*, 2005, 23 (2), pp 7–9.

Additional Resources

- "D.8 Synthesizing and Evaluating Biodiesel Fuel," *Chemistry in the Community*, 6th ed., New York: W. H. Freeman and Company/BFW, 2012, pp 371–373.
- "C.4 Combustion," *Chemistry in the Community*, 6th ed., New York: W. H. Freeman and Company/BFW, 2012, pp 337–341.
- "Biodiesel: Using Renewable Resources," *Introduction to Green Chemistry*, Washington, DC: American Chemical Society, 2002, pp 13–22.