Oil Distillation

Grade Level: 8-12
Length: 45-70 Minutes
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by Jim Lokken, with additional information from lessons produced by Oresome Resources Mineral & Energy Education and Carolina Biological Supply Company

NGSS Standards

HS-PS1-3 Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

Crosscutting Concepts

Energy and Matter Tracking energy and matter flows into, out of, and within systems helps one understand their system's behavior.

Patterns Observed patterns in nature guide organization and classification and prompt questions about relationships and causes underlying them.

Structure and Function The way an object is shaped or structured determines many of its properties and functions.

Related Resources

Supporting Materials
Identification of Petroleum Factions; Fractional Distillation of Crude Petroleum; Where Does That Oil Go

Overview

Crude oil is composed of many fractions that can be used for different purposes.

Objectives

- Students will understand that crude oil is made up of various components
- Students will perform an experiment to fractionally distill crude oil or a substitute for crude oil.
- Student will identify the characteristics of different components of crude oil.

Materials

- ☐ Safety Glasses and Aprons
- ☐ Bunsen Burner
- ☐ Heatproof Mat
- ☐ Thermometer (0-360C)
- ☐ Distillation Apparatus or Material to set up a Distillation Apparatus (per lab station):
  - Round bottom distilling flask with side arm
  - Retort stands and clamps as required to secure all apparatus
  - Rubber stoppers
  - Condensing tube
  - Two hoses for cool water delivery to condensing tube
  - Four conical receiving flasks
  - Bent delivery tube
  - Boiling chips
  - Large pipette for delivering crude oil to distilling flask

Notes

Materials (continued)

- Four "hard glass" (borosilicate) watch glasses
- Wooden splints

☐ Worksheets: Identification of Petroleum Factions; Fractional Distillation of Crude Petroleum
☐ Science Notebooks
☐ Crude Oil Sample or Crude Oil Substitute*
☐ SDS for Crude Oil/Substitute
☐ Scale
☐ Optional: Where Does That Oil Go Worksheet?
☐ For Carbonated Soda Alternative: Dark-colored, Fruit Flavored Soda

*there are recipes online to make a crude oil substitute, or you can purchase from entities like this: https://www.brecklandscientific.co.uk/S3101693-500ML-p/s3101693500ml.htm

Background

Crude petroleum is an exceedingly complex mixture consisting primarily of saturated hydrocarbons of the paraffin or methane series. The separation of components from such a mixture by the process of fractional distillation depends upon the fact that the compounds present in crude petroleum boil at different temperatures (have different boiling points, BP). Such a distillation is not efficient enough to permit the separation of individual pure compounds but yields "fractions" or mixtures of compounds having similar boiling temperatures. This experiment demonstrates what occurs in an oil refinery – the crude oil is heated to different temperatures and the vapors are piped into a tall refinery tower where they cool and condense at different levels.

Once they have been distilled into fractions, they are distilled further if necessary. Note that distilling oil into fractions is only possible because different fractions of oil have higher or lower boiling points. The substances have different boiling points because of differences in electrical forces between the particles. If students are not familiar with this concept, take some time to learn about it with simpler substances.

Preparation

This activity requires access to a distillation apparatus and needs to be performed in an area with great ventilation. A chemistry lab would be most appropriate.

You can create your own distillation apparatus using:

- Round bottom distilling flask with side arm
- Retort stands and clamps as required to secure all apparatus
- Rubber stoppers
- Condensing tube
- Two hoses for cool water delivery to condensing tube
- Four conical receiving flasks
- Bent delivery tube
- Boiling chips
- Large pipette for delivering crude oil to distilling flask
- Four "Hard glass" (borosilicate) watch glasses
- Wooden splints

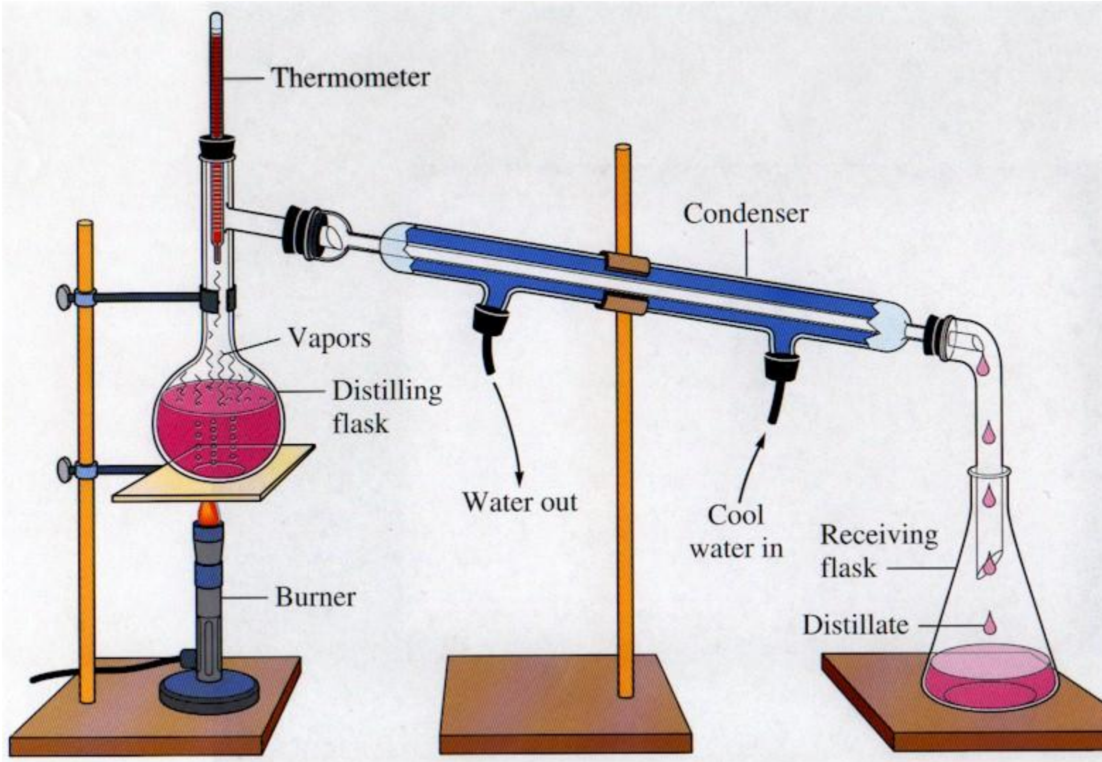


Image from: http://jupiter.plymouth.edu/~wwf/distillation_files/image001.jpg

Someone with knowledge of how to operate a distillation apparatus should lead this activity or advise you before you attempt this experiment. Crude oil includes many toxic and flammable chemicals. Use proper safety precautions at all times. See below for an alternative laboratory using a dark-colored soda. The soda alternative can also be performed first as a way to develop proficiency with the technique before advancing to the crude oil distillation.

Identify all potential hazards in this experiment, including:

- Heat – Bunsen burner and all glass components and connections.
- Glassware – Ensure all apparatus is securely supported and stable. Warm and cool all glass components gradually to avoid thermal shock.
- Stoppers – Ensure they are able to withstand the heat applied
- Hoses – Ensure all hoses are connected tightly to avoid leakage
- Use a round-bottomed rather than flat-bottomed distillation flask for smoothness of boiling
- Never more than half fill the distillation flask with the liquid to be distilled
- Use boiling chips in the distillation flask (before the heating has begun) to ensure smoothness of boiling
- Do not use a stopper to connect the condenser to the receiving flask as this will prevent vapors from escaping.

Introducing the Lesson

Present students with a container of crude oil or a crude oil substitute. Read through the Safety Data Sheet for your crude oil/substitute. Instruct students to wear eye protection at all times.

Explain that their task is to distill and identify fractions produced from the crude oil. Remind students of safety protocols and pass out the worksheets.

Activity

Set up the distillation apparatus from which fractions can be taken according to observed temperature changes. Begin by having students calculate the density of the crude oil by dividing weight by volume. The result should be recorded on their Fractional Distillation of Crude Petroleum worksheet.

Now it is time to begin the distillation. Have students follow these lab directions:

1. Secure loose hair and clothing. Put on gloves and protective eyewear.
2. Heat the bottom of the distilling flask gently with the lowest burner

flame.

3. When the temperature reaches 100C, remove the receiving flask. This is your first fraction.
4. Replace the receiving flask with a clean flask.
5. Carefully collect three further samples at higher temperatures, to give fractions as follows:
   a. Room temperature to 100C
   b. 100-150C
   c. 150-200C
   d. 200-250C
6. Measure the weight and volume of each fraction, to calculate their density. Construct a data table in your science notebook to record this information. You will be recording other characteristics in later steps.
7. Set aside some of each fraction.
8. Construct a table to record the results of each of the following tests on each of your four fractions:
   a. The temperature range at which it boiled
   b. The density (calculated in step 5)
   c. Record the color
   d. Test for viscosity (how easily do they pour?)
   e. Test the smell (gently waft the smell toward you with your hand and describe the smell. Liken them to familiar aromas)
   f. Test for flammability. Pour a small sample onto a hard watch glass and light the fraction with a burning splint. Record how easily it ignites, how quickly it burns and how much smoke is produced.
9. With the samples that you set aside, combine them to see that they form a mixture very like the original sample (be sure to include some of the black residue left in the distilling flask).
10. Have students assign their own names to the respective fractions, according to their probable uses and in terms of their physical properties.
11. Students should complete their worksheets, using the Identification of Petroleum Fractions sheet as a reference.

Wrap-up

Review the fractions that were distilled from crude oil.

>>Optional: Have students read the "Where Does That Oil Go?" summary article and complete the worksheet.

Discuss the different uses of these fractions, and the characteristics of each petroleum fraction that make it useful. Which fraction was most abundant? Which fraction do we utilize most? Consider possible ways to conserve petroleum products.

Assessment

The successful distillation of oil fractions will serve as a formative assessment of students' ability to follow lab protocols. Observe student cooperation, participation, and adherence to lab safety guidelines during lab work. Assess student worksheets for completeness, neatness, and accurate work. See suggested answers for worksheet, but each distillation will be slightly different, so use common sense, your own observations, general guidelines on "Fractional Distillation of Crude Petroleum Worksheet," and comparisons to other student answers to evaluate answers on the data sheet. Students who have met the performance expectation will demonstrate an understanding of how the structure of substances at the bulk scale (specifically viscosity and boiling range) provides evidence for the strength of electrical forces between particles.

Appendix

Alternative Distillation Activity Using Carbonated Soda:
Adapted from Carolina Biological Supply Company

Background

This activity simulates crude oil distillation using a dark fruit-flavored carbonated soda, such as cherry cola or grape soda, as a substitute for crude oil. The 3 main ingredients to be separated are carbon dioxide gas, flavoring, and water. All other ingredients are left behind in the flask, including high fructose syrup; coloring; leftover water; the preservative, phosphoric acid; and any other ingredients. These are the materials you will need:

- Bunsen Burner
- Liquid soap/glycerin
- 5 mm glass tubing
- 2-hole rubber stopper
- Laboratory thermometer/temperature probe
- 3 test tubes
- Tap water
- Bromthymol blue
- Test tube rack
- Glass marker

- 400 mL beaker
- Ice
- Dark colored, fruit-flavored carbonated soda
- Boiling chips
- Erlynmeyer flask
- Aquarium/Rubber Tubing

Preparation

Prepare your indicator. Add 5 drops of bromthymol blue to tap water to fill tube #1. The water should be slightly blue to green. If it is yellow (pH<7) add a tiny amount of baking soda until the water turns green (neutral) or slightly blue (slightly alkaline). In the experiment, students will use this indicator to observe CO2 bubbles from the heated soft drink mixing with the water and forming slightly acidic carbonated water.

Procedure

Have students follow this lab procedure.

1. Secure loose hair and clothing. Put on gloves and protective eyewear.
2. Use a small amount of liquid soap/glycerin to lubricate one end of a 5 mm glass tubing.
3. Insert the tubing into one hole of a 2-hole rubber stopper.
4. Use a small amount of liquid soap/glycerin to lubricate the bulb end of a laboratory thermometer or temperature probe and insert this through the other hole of the 2-hole rubber stopper.
5. Label 3 test tubes as 1, 2, and 3.
6. Add 20 mL of tap water to tubes #2 and #3. Mark this volume on the test tube with a glass marker, then dump the water out into the sink. Place the test tubes in the test tube rack.
7. Add 10 mL of water-bromthymol blue solution made by your teacher to test tube #1. Place this in the test tube rack.
8. Fill a 400-mL beaker half full of ice. Add water until beaker is ¾ full.
9. Assemble the apparatus as shown in Figure 1.

Figure 1. From Carolina Biological Supply Company

10. Add 75 mL of carbonated soda and 2 boiling chips to a 250 mL Erlenmeyer flask.
11. Connect rubber tubing or aquarium tubing to the glass tubing in the rubber stopper.
12. Put stopper assembly into mouth of the flask. Adjust so the thermometer is above the liquid in the flask.
13. Place other end of tubing into test tube #1.
14. Use the Bunsen burner to slowly heat the liquid in the flask. Observe gas bubble into the test tube.
15. Record in your science notebook your observations of gas bubbling and any change in color in the indicator. Remember, if the indicator turns yellow, then the water is becoming more acidic. What does this demonstrate about the gas that is being added to the test tube?
16. While still heating the soft drink, remove the tubing from test tube #1 and put it into test tube #2.
17. Place test tube #2 into the ice bath. See Figure 2.

Figure 2. From Carolina Biological Supply Company

18. Heat the flask to boiling (around 100C). Collect the condensed distillate in test tube #2 up to the 20 mL mark.
19. Place test tube #2 in the test tube rack.
20. Move the tubing to test tube #3 and place it into the ice bath.
21. Collect another 20 mL of distillate in test tube #3.
22. Turn off the Bunsen burner. Place test tube #3 in the test tube rack.
23. Allow all equipment to cool.

Ask students to respond to the following questions in their science notebooks:

- Did the water in tube #1 turn yellow? If so, what does this prove?
- Smell tube #2 by wafting toward your nose. Describe the smell.
- Smell tube #3 by wafting toward your nose. Describe the smell as compared to tube #2.
- Describe what is left in the flask.
- Describe the order in which the fractions of flavoring, water, and CO_2 were removed from the soft drink solution.
- What is the major component in tubes #2 and #3?
- How is the boiling range of a substance – the structure at a bulk scale – related to the strength of electrical forces between particles?
- Based on boiling range and viscosity, which fraction do you think has the strongest electrical forces between particles? Which fraction

do you think has the weakest electrical forces between particles? Explain your reasoning.

To link their soda-based distillation experience to crude oil distillation, have students read the "Where Does That Oil Go?" piece and complete the worksheet.

Assessment

The successful distillation of soda fractions will serve as a formative assessment of students' ability to follow lab protocols. Observe student cooperation, participation, and adherence to lab safety guidelines during lab work. Assess student worksheets for completeness, neatness, and accurate work. Students who have met the performance expectation will demonstrate an understanding of how the structure of substances at the bulk scale (specifically boiling range) provides evidence for the strength of electrical forces between particles.

Fractional Distillation of Crude Petroleum Worksheet

CALCULATIONS:

1. Calculate density for the crude oil and each of its fractions.

2. Calculate by weight the percent represented by each fraction relative to the crude oil sample distilled.

QUESTIONS:

1. What requirement must be met if two compounds are to be separated by the process of fractional distillation?

2. Judging from the results of the laboratory demonstration, what general relationship exists between molecular weight and volatility?

3. From everyday experience, cite evidence tending to show that the viscosity of a liquid changes with change in temperature.

4. Among the products of the distillation of crude petroleum, is there any apparent relationship between boiling range and viscosity? Explain.

5. How is the boiling range or viscosity of a substance – the structure at a bulk scale – related to the strength of electrical forces between particles?

6. Based on boiling range and viscosity, which fraction do you think has the strongest electrical forces between particles? Which fraction do you think has the weakest electrical forces between particles? Explain your reasoning.

Fractional Distillation of Crude Petroleum Worksheet - *Suggested Answers*

CALCULATIONS:

1. Calculate density for the crude oil and each of its fractions.

2. Calculate by weight the percent represented by each fraction relative to the crude oil sample distilled.

QUESTIONS:

1. What requirement must be met if two compounds are to be separated by the process of fractional distillation?
   The two compounds must have different boiling points.

2. Judging from the results of the laboratory demonstration, what general relationship exists between molecular weight and volatility?
   Lower molecular weights are associated with higher volatility.

3. From everyday experience, cite evidence tending to show that the viscosity of a liquid changes with change in temperature.
   Many possible examples: honey, molasses, oil.

4. Among the products of the distillation of crude petroleum, is there any apparent relationship between boiling range and viscosity? Explain.
   Yes. Items that have a higher boiling point tend to be more viscous.

5. How is the boiling range or viscosity of a substance – the structure at a bulk scale – related to the strength of electrical forces between particles?
   Substances with higher boiling points and higher viscosity tend to have stronger electrical forces holding the particles together. Therefore, more thermal energy is required to overcome these electrical forces and change the state of the substance from a liquid to a gas.

6. Based on boiling range and viscosity, which fraction do you think has the strongest electrical forces between particles? Which fraction do you think has the weakest electrical forces between particles? Explain your reasoning.
   The fraction that was distilled at the lowest temperature has the weakest electrical forces between particles. The fraction that was distilled at the highest temperature has the strongest electrical forces between particles. I think this because I know more thermal energy was required to convert it to a gas.

Identification of Petroleum Fractions Separated from Crude Oil

Name	Average C Composition	Boiling Range ^{0}C	Approx. % of Total Crude
Light gases *			
Petroleum ("ether")	$\sim C_2$	$\sim 0^0$	Small
Naptha ("white gas")	$\sim C_5$	$\sim 25^0$	Small
Gasoline	$\sim C_8$	$50\text{-}100^0$	~20%
Kerosene and Jet Fuel	$\sim C_{12}$	$150\text{-}200^0$	~20%
Heating oil and Diesel Fuel	$\sim C_{15}$	$200\text{-}250^0$	~25%
Lubricating oil and Mineral Oil	$\sim C_{30}$	$250\text{-}350^0$	~10%
Resibuum	$\sim C_{50 \text{ and up}}$	350^0	~25%

Although the boiling point of pure ether is -90^0, quantities of C1-C4 gases may be held in solution in petroleum at higher temperatures.

Where Does That Oil Go?

Directions: Read the following story and answer the questions on the next page.

Once the oil comes in, the well is capped and equipment is installed to control the flow, and to separate the crude oil from the natural gas. Prudhoe Bay, on the Arctic coast of Alaska, is ice-bound most of the year. So, the oil must run a long route to market. From the wells, the crude oil moves through small pipelines to the big trans-Alaska pipeline. There it begins the 800-mile journey to Valdez, where it is loaded on tankers for shipment Outside.

Once the oil reaches the lower 48, modern plants and refineries process the oil and natural gas into gasoline, jet fuel, heating oil, diesel, liquified gas and fertilizer. And those are just a few of the products that can be made from petroleum. Petrochemicals (chemicals made from oil and gas) are used as a base for a wide assortment of things, from plastics to vitamins to records, detergents, movie films, fabrics, and antifreeze.

This strange stuff we call petroleum is made up almost entirely of only two elements—hydrogen, a gas-like element that will burn; and carbon, a chemical element that is found in all living matter. If you really want to sound like a pro, you can use the scientific word for petroleum, which is “hydrocarbons.” These hydrocarbons are present in thousands of different combinations that can be separated and purified in the process called “refining.”

The first step in refining is to sort out the major “fractions” or parts of the hydrocarbons that make up crude oil. These fractions boil and vaporize (like steam) at different temperatures. So the simplest form of refining works like this:

a. The crude oil is heated in a furnace and the vapor is piped into a tall refinery tower.
b. Hot steam is pumped in below to speed up the process.
c. The vapors from the different fractions rise, cool off and condense (turn back into liquid) at different levels.
d. There they are drawn off and collected for further processing if necessary.

REVIEW:

1. Where does the oil from Prudhoe Bay go?

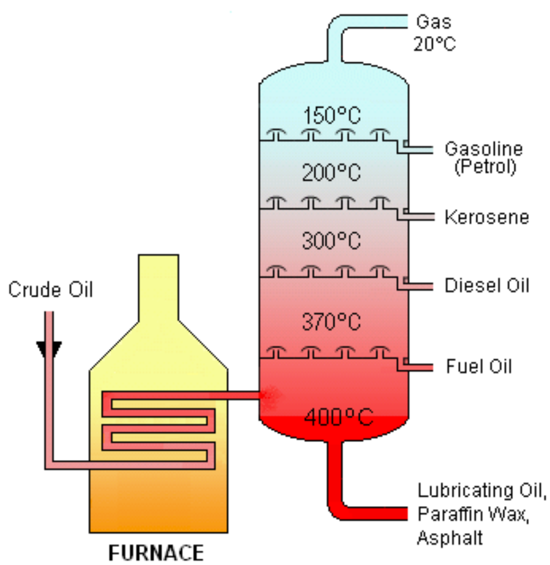
2. Define petrochemicals.

3. What are the major elements that make up petroleum

4. Here is a drawing of a refinery tower that shows at which points the different products are drawn off and collected.
a) Which fractions of oil are collected at the lowest temperatures?

b) Which fractions of oil require the highest temperatures to fractionate?

c) At what approximate temperature can you separate out gasoline?



Source Theresa Knott (Wikipedia Commons)

Suggested Answers:

1. down the pipeline to Valdez and onto tankers for shipment outside

2. chemicals made from oil and gas

3. hydrogen and carbon

4. a) Gases

b) lubricating oil, paraffin wax, asphalt

c) 150C