The Need To Conserve Energy:Take the Pop out of your Power Bill

Objectives

1) Compare the environmental costs of heating.
2) Measure reaction time and discuss the relationship to the reaction rate.

Green Chemistry Principles

1) Safety first-and last
2) Use less energy

IL State Standards (Science)

11.A.3b, 11.A.3c, 12.E.3c, 13.A.3a, 13.A.4a, 13.B.3d, 13.B.4c

Levels

High school: middle school with some adaptation of procedure, questions & discussion

Vocabulary

Bunsen burner, energy efficiency

Part 1 Materials-Heating with a Bunsen burner

- Bunsen burner
- 1 meter of hose
- Bucket
- Stopwatch
- 2-L soda bottle
- Variety of volumetric measuring containers
- Water

Part 2 Materials-Heating with an electric hotplate

- Hot plate
- Variety of volumetric measuring containers
- Water

Part 3 Materials-Heating with a microwave oven

- Microwave oven
- Variety of volumetric containers
- Water
- Microwave popcorn (optional)

Part 4 Materials-Comparing the environmental costs of heating

- Household electricity and natural gas bills
- Calculator
- Part 1-3 results

Time

One class period per part

Background/Overview

Conversion of energy from one form to another in most cases is inefficient. In the below activities, the students will be challenged to measure and determine which apparatus is more energy efficient than the others. Other activities include doing an energy assessment on their household and the school.

Part 1. Heating with a Bunsen burner

In this activity, we will measure how efficient it is to heat a sample of water using a Bunsen burner.

Using the balanced equation, calculate the amount of energy (?H_R) for the combustion of natural gas [methane, CH_4]. Look up standard heats of formation in a handbook or textbook. (Assume Standard Temperature and Pressure, STP).

$$\Delta H_r - (\Sigma \Delta H_f \text{ products}) - (\Sigma \Delta H_f \text{ reactants})$$

Procedure

1. Devise a method to determine how much natural gas is delivered from the connection on your desktop over time. You will be given the following apparatus: 1 meter of hose, a tub or bucket for holding water, a stopwatch or clock with a second hand, a 2-L soda bottle, and a variety of volumetric measuring containers such as large graduated cylinders.
2. Write a plan, paying particular attention to safety and how you will dispose of the natural gas you are measuring. When you have documented your plan, show it to your teacher and get approval before proceeding. Be sure to record your results during the procedure for use in the completion of this activity.
3. Set up a beaker containing a carefully measured amount of water (somewhere between 175 and 225 mL) on a ring stand or support suitable for heating it using the Bunsen burner. Measure the initial temperature of the water, and begin to heat it with the Bunsen burner. Start tracking the time.
4. Heat the water until the temperature rises by 30–50 °C. Measure the final temperature to the nearest 0.1 °C. Note the time when heating has finished.
5. Calculate the amount of heat absorbed by the water, the amount of heat released by combustion, and the percent efficiency of the heating process. Use the following equations in your calculations. (Assume STP.)

Questions and Answers for Discussion- Heating with a Bunsen burner

1. When you have calculated the percent efficiency of the heating, record your results along with the rest of the class on the board in the front of the classroom, or as your teacher directs. Calculate the average efficiency, and discuss the precision in the range of results in the data from your class. Discuss any result that differs significantly from the average, and if time allows, repeat the experiment until the class results show greater precision.

The answers will vary somewhat. Typical results are efficiencies of 10–20%. If students' results vary widely, consider having them redo the procedure after a discussion of ways to control variability.

2. Several simplifying assumptions were made during this activity. List some of these assumptions and describe the impact they might have on the results. We assumed the gases were at STP. The values for the amount of heat released will vary if the temperature and pressure are other than standard. Another assumption is that the results for water are typical for all substances. Also, we are assuming the natural gas is pure methane.

3.Some school laboratories use propane or ethanol as fuel for burners. How would this activity have to be modified if propane were used? The equation would need to incorporate the formulas for the propane or ethanol, and the heat of combustion calculation would be different.

4. What modifications could be made to the lab setup to improve the efficiency of the heating? Students could try containers of different shapes for the water or try containers made of other substances, such as metal.

Part 2. Heating with an electric hot plate

Procedure

1. The energy released by the hot plate depends on its energy rating. Look at the bottom or sides of the hot plate for its power rating in watts.
2. Since a watt = $\frac{1\ J}{s}$, we can calculate the total amount of energy released from the hot plate using the following equation:

$$\text{Energy released by hot plate} = \textit{total wattage of hot plate} \times \textit{time} \times \frac{1\ J/s}{1\ watt}$$

3. Using a procedure similar to the activity above, heat a sample of water and use the results to calculate the efficiency of the electric hot plate in heating the water.

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Questions & Answers for Discussion- Heating with an electric hot plate

1. When you have calculated the percent efficiency of the heating, record your results along with the rest of the class on the board in the front of the classroom, or as your teacher directs. Calculate the average efficiency, and discuss the precision in the range of results in the data from your class. Discuss any result that differs significantly from the average, and if time allows, repeat the experiment until the class results show greater precision. As in the section above,

answers will vary somewhat. The efficiency is likely to be significantly higher with this method. If students' results vary widely, consider having them redo the procedure after a discussion of ways to control variability.

2. Compare the convenience and safety of heating with a hot plate to heating with a Bunsen burner. What are some of the advantages and disadvantages of each method?

Electric hot plates are safer, more stable, and more efficient than Bunsen burners. Bunsen burners are faster and can heat irregularly shaped objects.

Part 3. Heating with a microwave oven

Microwave ovens have long been used in the home, and now they are being more widely used in scientific laboratories. Use the experience and information from the previous two activities to determine the efficiency of heating a sample of water using a microwave.

Procedure

1. Look at the bottom or sides of the microwave for its power rating in watts.
2. Since a watt = $\frac{1\ J}{s}$ we can calculate the total amount of energy released from the microwave using the following equation:

$$\text{Energy released by microwave} = total\ \ wattage\ \ of\ \ microwave \times time \times \frac{1\ J/s}{1\ watt}$$

3. Using a procedure similar to that described in Activity 1, heat a sample of water and use the results to calculate the efficiency of the microwave in heating the water.

Questions & Answers for Discussion-Heating with a microwave oven

1. When you have calculated the percent efficiency of the heating, record your results along with the rest of the class on the board in the front of the classroom, or as your teacher directs. Calculate the average efficiency, and discuss the precision in the range of results in the data from your class. Discuss any result that differs significantly from the average, and if time allows, repeat the experiment until the class results show greater precision.

The answers will vary somewhat. Typical results are efficiencies of 80%. If students' results vary widely, consider having them redo the procedure after a discussion of ways to control variability.

2. Compare the results of the three methods of heating. Which was most efficient, and which was least efficient? Did the results follow what you expected?

The microwave is likely to be demonstrated as the most efficient, followed by the hot plate and the Bunsen burner. This is a reasonable result, because the microwaves heat by directly affecting the motions of the polar molecules. In the other methods, the heat must be transferred to the container and then to the object to be heated.

Part 4. Comparing the environmental costs of heating

The data you have gathered thus far helps determine the efficiency of various types of heating but does not determine the total cost of heating. For example, it does little good to choose electricity over natural gas if the power plants that generate the electricity contribute significantly more pollution than does the production of natural gas.

Procedure

1. Use your household electricity and natural gas bills to calculate the cost in dollars for each of the experimental trials you did above. Calculate the cost for heating a sample of water by 10 ºC for each method. If natural gas is not available in your community, use the national average price or substitute the cost of propane. Although the cost in dollars is not a perfect reflection of the total cost to the environment, it does reflect how difficult it is to bring the energy source to market. Which energy source was most expensive? Which was least expensive?

2. There are many ways to generate electricity and produce natural gas. Some require less energy to produce than others. Using the Web and other sources, investigate which power source tends to require less energy and contributes less total pollution to your local environment.
3. Using the information you have collected regarding efficiency, dollar cost, and environmental cost, make a recommendation for how best to minimize the energy used to heat substances in your school lab.

Questions & Answers for Discussion: Comparing the environmental costs of heating

1. Use your household electricity and natural gas bills to calculate the cost in dollars for each of the experimental trials you did above. Calculate the cost for heating a sample of water 10 ºC for each method. If natural gas is not available in your community, use the national average price or substitute the cost of propane.

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> The average cost of electricity has remained fairly stable over the past 10 years. The national average is approximately 6.75 cents per kilowatt hour. Natural gas prices fluctuate, but the U.S. Department of Energy's Energy Information Agency cites the most recent national average at about $8.50 per thousand cubic feet of commercial natural gas (www.eia.doe.gov)

2. There are many ways to generate electricity and produce natural gas. Some require less energy to produce than others. Using the Web and other sources, investigate which power source tends to require less energy and contributes less total pollution to your local environment.

> This is obviously a huge question. There is an interesting discussion of this issue at the Canadian website www.iclei.org/efacts/economic.htm. An excerpt follows.
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> All energy use has some negative impact on the environment. Burning fossil fuels such as coal and oil produces emissions of greenhouse and acid gases, which result in global warming and acid rain, respectively. Fossil fuels are also responsible for urban air pollution (smog) and its associated health hazards. Nuclear power plants expose the environment to low levels of radiation during many stages of the nuclear fuel cycle, and also impose the risk of a major accident such as Chernobyl. Even renewable technologies using energy from natural resources have some negative impacts on the environment. Hydroelectric dams, for example, can flood vast areas of land and damage aquatic ecosystems. In general, however, renewables such as solar and wind energy have a smaller impact on the environment than fossil fuels and nuclear power.
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> When the use of a commodity, gasoline for example, imposes a burden on society that is not covered by its stated price, this burden is called an externality. The costs of externalities are borne by parties who were not part of the transaction. In the case of gasoline, the damage caused by acid rain and global warming, and the health costs of urban air pollution, are not considered in the price when an automobile owner purchases gasoline. Total costs that involve these indirect effects are problematic to calculate. Imperfect markets tend to distort the choices of consumers, leading to overconsumption and misuse of items such as clean air and water that are very difficult to assign a dollar value to, and are perceived as public goods, free for anybody to exploit. You may want to limit the range of discussion to make it appropriate to your particular group of students.

3. Using the information you have collected regarding efficiency, dollar cost, and environmental cost, make a recommendation for how best to minimize the energy used to heat substances in your school lab.

> Students can make suggestions based on your lab results. Students will likely suggest the most efficient heating method that was the lowest cost. A more advanced discussion will include the "total cost" as discussed above.

References

- Jansen, Michael P. J. Chem. Educ. 1997, 74, 212–214.
- International Council for Local Environmental Initiatives site. Fact sheet from Energy Educators of Ontario, 1993; www.iclei.org/efacts/economic.htm.
- U.S. Department of Energy, www.energy.gov.