

Chemistry 51

Experiment 9

The Energy Content of Fuels

BACKGROUND

Fuels are substances that burn to give off a relatively large amount of heat. In an overall sense, such burning is simply a combustion reaction between the fuel and oxygen. How much heat is generated depends on what kind of fuel is used and how much of it is burned.

Many fuels are hydrocarbons such as methane (CH_4) and propane (C_3H_8), *i.e.* compounds containing only hydrogen and carbon. Other fuels such as ethanol ($\text{C}_2\text{H}_5\text{OH}$) contain oxygen in addition to carbon and hydrogen. These “oxygenated” fuels are currently mandated in many urban areas because they are believed to lead to less pollution. In this experiment, the amount of heat given off by known amounts of several fuels will be measured – butane (C_4H_{10}), methanol (CH_3OH), ethanol ($\text{C}_2\text{H}_5\text{OH}$), kerosene, lamp oil, and candle wax. Kerosene, lamp oil, and candle wax are each mixtures of hydrocarbons, but we will approximate their compositions as $\text{C}_{10}\text{H}_{22}$, $\text{C}_{12}\text{H}_{26}$, and $\text{C}_{40}\text{H}_{82}$ respectively.

The experimental procedure is to use the fuels to heat water and then measure the amount of energy absorbed by the water. It takes 1 “calories” (cal) of energy to raise the temperature of 1 gram of liquid water 1 °C.

OVERVIEW OF THE METHOD

1. Take a known amount of water and find its mass.
2. Using an assigned fuel in a burner, heat the water.
3. Measure the temperature change for the water.
4. Measure the mass of fuel burned, *i.e.*, the change in the mass of the burner.
5. Calculate the heat absorbed by the water.
6. Finally, calculate the amount of heat per gram of fuel burned.

Each pair of students will investigate one fuel, doing several trials and possibly adjusting the procedure, until they are satisfied that they have a reliable estimate of the energy content of that particular fuel. Results for the whole lab section will then be combined to draw conclusions about relative energy content of the fuels.

IMPORTANT NOTES ABOUT THE WEIGHING PROCEDURES: The success of this experiment depends heavily on the accuracy of several mass measurements. The most difficult of these is the accurate determination of the change in the mass of fuel, because this change is rather small – typically about $\frac{1}{2}$ g. It must be measured to 0.001 g precision. Be sure that the balances you use read 0.000 g before using them! The masses of the coke cans with water must be measured to a precision of 0.1 g.

GETTING ORGANIZED

1. Obtain the following items:
 - 1 empty soft drink can
 - 1 thermometer
 - 1 flag stand with a metal ring attached
 - 1 glass stirring rod
 - 1 lamp containing an assigned fuel (or a candle)
2. Use the table at the end of this document to record your data.

MAKING THE MEASUREMENTS

We suggest that you start by using the following procedure. After you have tried it once or twice, you may wish to make modifications.

IMPORTANT NOTE ABOUT WEIGHING: since many students are using the balances, it is important to re-check the zero and leveling bubble before each weighing.

1. Obtain a dry soda can with two holes punched in opposite sides near the top.
2. Weigh the empty soda can to the nearest 0.1 gram.
3. Add approximately 100 mL of water to the can.
4. Weigh the can + water to the nearest 0.1 gram, and calculate the mass of the water in the can.
5. Thread a glass rod through the holes in the can and suspend it from the ring attached to a ring stand.
6. Put a thermometer in the can and measure the temperature of the water, estimating it to the nearest 0.1 degree.
7. Place a fuel burner under the can. Adjust the ring so that the bottom of the can is about 2 cm from the top of the wick of the burner.
8. Weigh the fuel burner and determine its mass to the nearest 0.001 gram.
9. Place the fuel burner under the soda can and light the burner. (Do this fairly quickly after weighing.)
10. If necessary, cautiously adjust the height of the can so that the top of the flame is just below the bottom of the can.
11. Heat the water until the temperature has increased about 20 oC, then extinguish the flame.
12. Stir the water gently until the temperature stops rising and then carefully read the temperature, estimating it to the nearest 0.1 degree.
13. As quickly as possible, determine the mass of the fuel used by reweighing the fuel burner (to the nearest 0.001 g), then subtract that mass from the original mass of the burner.

Do the calculations (below) after each trial to see how they are coming out. After a couple of trials, you may think of possible improvements in the design of the experiment. In any case, do enough trials (they go rapidly) until you have some confidence in your technique and in the reproducibility of the results.

CALCULATIONS

To determine the amount of heat absorbed by the water from the burning fuel (q), you must obtain the following information each experiment: the mass of the water that was heated, the change in temperature of the water, and the mass of the fuel burned. Since it takes 1 calorie of energy to raise the temperature of 1 gram of water 1 °C, the total heat absorbed (q in cal) is equal to the temperature change (ΔT) x the mass of water x specific heat capacity for water ($C_P = 1.00 \text{ cal}/(\text{g}^\circ\text{C})$) as in Equation 1.

$$q = \left(\frac{\Delta T (\text{°C})}{1} \right) \left(\frac{\text{mass of water (g)}}{1} \right) \left(\frac{1 \text{ cal}}{\text{gram}^\circ\text{C}} \right) \quad \mathbf{1}$$

Use this formula to calculate the heat absorbed, and then divide this value by the grams of fuel burned to obtain the “fuel value” of calories/(gram of fuel).

Do these calculations for each trial as you go along. You should be looking for improved consistency of your results for the “fuel value”, and this may take five or six trials. When you have three or four consistent runs in a row, you are done with the data acquisition!

The energy units in our book are Joules (J) rather than calories (cal), and 1.00 calorie = 4.18 J. Thus, you can convert your “fuel value” to Joules (*i.e.* q in J) by multiplying by $\frac{4.18 \text{ J}}{\text{cal}}$.

$$q = \left(\frac{\Delta T (\text{°C})}{1} \right) \left(\frac{\text{mass of water (g)}}{1} \right) \left(\frac{1 \text{ cal}}{\text{gram}^\circ\text{C}} \right) \left(\frac{4.18 \text{ J}}{\text{cal}} \right) \quad \mathbf{2}$$

or

$$q = \left(\frac{\Delta T (\text{°C})}{1} \right) \left(\frac{\text{mass of water (g)}}{1} \right) \left(\frac{4.18 \text{ J}}{\text{gram}^\circ\text{C}} \right) \quad \mathbf{3}$$

Enter the average of your best experiments on the board and on the computer. We will need to get good values from everyone to start to make some conclusions about the experiment.

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QUESTIONS TO ANSWER

1. Is there any difference between the hydrocarbon fuel values and the oxygenated fuel values? Do you see any other relationships in the results for the different fuels?
2. There has been considerable lobbying on the part of grain farmers in the Midwest in promoting ethyl alcohol (ethanol) as a fuel alternative to gasoline. Based on this experiment what sort of problems and/or benefits may result from this substitution?
3. Suppose you put 50 mL of water in the can instead of 100 mL. In what ways, if any, would this affect the results of the experiment? What would happen if you used 200 mL of water? Can you think of any advantages or disadvantages of using either 50 mL or 200 mL of water in this experiment?
4. There are many possible sources of error in this experiment. List three that you can think of. Would each error have a large effect, a medium effect, or a small effect on the calculated fuel value? Also indicate whether the effect would be to give an answer that would be too high, too low, or could go either way.

5. Carbohydrates (which include sugars and starches) are also a form of fuel. A carton of Dannon yogurt provides “100 calories” and 17 g of carbohydrates. Assuming that the latter are the only source of energy in the yogurt, what is the “fuel value” of the carbohydrates? Give a statement of comparison with the fuel values you are finding in this laboratory!

Trial #	1	2	3	4	5
Fuel (give name and formula)					
Mass of can + water (grams)					
Mass of empty can (grams)					
Mass of water (grams)					
Final water T (°C)					
Final water T (°C)					
T change (ΔT)					
Total heat absorbed					
Initial mass of burner (g)					
Initial mass of burner (g)					
Mass of fuel burned (g)					
Heat per gram of burned fuel (calories/g)					
Heat per gram of burned fuel (Joules/g)					