A major challenge in teaching organic chemistry is that the students are primarily nonchemistry majors who see no connection between chemistry and any other facet of their lives. Student interest, and success, can be increased by showing how organic concepts relate to everyday life. The laboratory experiment presented in this article is intended to connect a standard organic reaction, catalytic hydrogenation, to issues of nutrition and health.

Using vegetable oil as a starting material provides an opportunity for the discussion of many related topics. Presenting the structure of fatty acids could be a start to a discussion about unsaturation and the relation between melting range and the way molecules pack together. The relative health benefits of saturated and unsaturated fats and the toxicity of trans-fatty acids are topics that allow a connection between the structure of a compound and its biochemical role. These topics all relate to the use of "partially hydrogenated vegetable oils" that are found in most baked goods sold today. This experiment provides a valuable opportunity to look at a common consumer product through the lens of organic chemistry.

Most modern hydrogenation experiments are carried out on commercially available compounds to yield a single isolable product (1–4). Instead of using hydrogenation as a synthetic reaction this experiment endeavors to measure the efficiency of hydrogenation using vegetable oil. While examples exist for preparing partially hydrogenated vegetable oils (5), the opportunity to employ stoichiometry and the ideal gas law in making the hydrogenation quantitative has not been explored. This is an occasion to show how basic concepts from general chemistry can be used in studying organic reactions. In addition, the apparatus used in this experiment is simpler than those employed elsewhere for quantitative hydrogenation (3, 4).

**Procedure**

All reagents were obtained from commercial sources and used as received. Vegetable oils (canola, corn, olive, peanut, safflower, and sunflower oils) and balloons were purchased from a supermarket. All of the glassware used was standard laboratory equipment. All of the oils listed underwent hydrogenation using the following procedure and gave comparable results.

A 250-mL beaker filled with water was heated on a stirrer hot plate to maintain a steady temperature between 40 and 60 °C. The apparatus was assembled as shown in Figure 1 except for attaching the 5-mL conical vial.

To the vial was added 0.10 g of vegetable oil, 3.0 mL of isopropanol (solvent), and a spin vane. A small amount of 10% palladium-on-carbon (approximately 15 mg) was added to the conical vial and the vial was secured to the take-off adapter. The vial was then clamped above (not in) the water bath.

A 20-mL syringe fitted with a small gauge needle was used to remove air from the system. The septum on the take-off adapter was pierced and enough air was removed from the system to draw water up into the graduated pipet to the 0.0-mL mark (pipet mostly filled with water). The syringe was then removed. The constancy of the water level demonstrated that the system was leakproof. The system was then charged with hydrogen using a balloon filled with hydrogen secured to a hose barb-to-luer lock adapter with a stopcock and small gauge needle attached (Figure 2).

The needle of the balloon assembly was pushed through the septum on the take-off adapter and the stopcock was opened. The flow of gas was used to push all the water out of the pipet and was continued for an additional 20 seconds to ensure excess hydrogen for the reaction was in the system. The balloon assembly was then removed. Using the syringe some hydrogen was then removed from the system to bring the water level up to the 22.0-mL mark (pipet nearly empty of water). The conical vial was lowered into the water bath and the stirrer was turned on to a moderate speed.
The water level in the pipet was measured every five minutes while the reaction was stirred and heated. When the uptake of hydrogen had slowed to less than 0.2 mL per five-minute period (usually within two hours) a final reading was made and the conical vial was removed from the water bath. The reaction mixture was disposed of in an appropriately labeled container.

Hazards

Hydrogen is a flammable gas and forms explosive mixtures with air. Palladium-on-carbon is an extremely flammable solid. Sparks and open flames should not be allowed in the laboratory during this experiment. The risk of fire is kept low as the amount of hydrogen required for a 16-student laboratory section is only what is needed to fill two medium-sized balloons. Also, the catalyst is not weighed out in order to minimize its spread and contact with air. No incidents of fire have occurred in carrying out this experiment at the author’s institution.

Data Analysis

The goal of this experiment is to calculate the efficiency of the reaction by comparing the actual amount of hydrogen consumed with a theoretical value calculated from the fatty acid composition recorded on the nutrition labeling. The label identifies the number of grams of saturated, monounsaturated, and polyunsaturated fats in a serving size of the oil. Calculations can then be made of the mass of each of the fatty acids as triglycerides. The number of moles of each fatty acid can then be calculated and converted to the number of moles of carbon–carbon double bonds in the original sample. From this amount a theoretical volume of hydrogen consumed can be calculated using the ideal gas law by comparing the actual to the theoretical a percent efficiency can be calculated.

Discussion

This experiment has been successfully run for the last four years by three instructors. Student results range, depending on the vegetable oil used, from 5 to 15 mL of hydrogen consumed. Calculated efficiencies are typically 100–120%. Hydrogen appears to be adsorbed by the catalyst or lost through the Tygon tubing or the septum. The loss is typically in the range of 2 to 3 mL. This could be taken into account by having students work in pairs with each pair running both a “real” hydrogenation and a control with everything except the oil. While this and fluctuating ambient lab temperatures adversely affect accuracy, they also provide an opportunity to talk about experimental design.

In conclusion, a new hydrogenation experiment for the introductory organic chemistry laboratory is described. It provides an opportunity to discuss fats and fatty acids, their physical behavior, and their nutritional value. The ideal gas law is used to determine the efficiency of the hydrogenation. While results are routinely above theoretical expectations, a way of correcting for this is proposed. With this experiment links are made between the organic chemistry laboratory and the local fast food restaurant or the dormitory vending machine.

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Supplemental Material

Instructions for the students, including a prelab assignment and lab write-up, and notes for the instructor, including sample calculations, are available in this issue of JCE Online.

Note

1. Canola oil is approximately 58% oleic acid, 26% linoleic acid, and 10% linolenic acid. Since most nutrition labels do not differentiate polyunsaturated fatty acids it is necessary to use these percentages when calculating hydrogen consumption by canola oil.

Literature Cited