Experiment 1

Zymurgy: Beer Brewing

A review of Stoichiometry and Gas Laws

Pre-lab Assignment

Before coming to lab:

- Read the lab thoroughly.
- Answer the pre-lab questions that appear at the end of this lab exercise. The questions should be answered on a separate (new) page of your lab notebook. Be sure to show all work, round answers, and include units on all answers.
- On a new page , (not the same page as you answered the pre-lab questions) follow the guidelines in the "Lab Notebook Policy and Format for Lab Reports" section of the lab manual to complete in your lab notebook the following sections of the report for this lab exercise: Title, Lab Purpose, Procedure and Data Tables.

Background

Beer is a beverage obtained by the YEAST-caused fermentation of a malted cereal, usually barley MALT, to which HOPS and water have been added. Among the earliest records of its use is a Mesopotamian tablet (c.7000 BC), inscribed with a cuneiform recipe for the “wine of the grain.” The origin of beer brewing, however, has not been determined; nor is it known whether our prehistoric ancestors invented bread or beer first.

The Mesopotamians and the Egyptians are thought to have been the first to render barley more suitable for brewing by malting, a process in which the barley grains are germinated, developing the enzymes that transform starch into fermentable sugars. The Greeks brewed beer from unmalted grains until they learned malting from the Egyptians. No conclusive evidence exists of beer brewing in Britain prior to the Roman occupation. The Teutonic and Celtic tribes, however, made MEAD, brewed from corn and honey. The term beer did not come into common use until the Celtic word *beor* was applied to the malt brew produced in the monasteries of North Gaul. It is thought that Gaulish monks first used hops, which have a preservative and aromatic effect on beer.

Brewing

The centuries-old technique of brewing involves four steps: (1) mashing: the infusion of malt, water, and crushed cereal grains at temperatures that encourage the complete conversion of the cereal starch into sugars; (2) boiling: the concentration of the resulting “wort,” including the addition of hops; (3) fermentation: the addition of yeast to the wort, resulting in the production of alcohol and carbon dioxide gas, by-products of the action of yeast on sugar. The chemical reactions for fermentation can be represented by the equations below:

For maltose (malt):

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 4CH_3CH_2OH + 4CO_2$$

(maltose) (ethanol)

For dextrose:

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2$$

(dextose) (ethanol)

The last step (4) is aging: the stage in which proteins settle out of beer or are “digested” by enzymatic action. The aging process may last from 2 to 24 weeks. The carbonation that occurs during fermentation is now drawn off and forced back into the brew during bottling. The uniform clarity of modern beers results from filtration systems that use such agents as cellulose and diatomaceous earth. Additives are frequently used to stabilize foam and to maintain freshness, although European brewers less commonly use them. With few exceptions, bottled and canned beer is PASTEURIZED in the container in order to ensure that the yeast that may have passed through the filters is incapable of continued fermentation. Genuine draft beer is not pasteurized and therefore must be stored at low temperature.

Types of Brewed Beverages

Most beer produced in the United States is lager--a pale, medium-hop-flavored beer that is kept for several months at a temperature of about 0.5 ° C (33 ° F) in order to mellow. It averages 3.3 to 3.4 percent alcohol by weight and is high in carbonation. European lagers--Pilsner is an example--are stored for a longer time and have higher alcohol content.

Few dark beers are brewed in the United States with the exception of the seasonal bock, a dark-brown beer that owes its color to a roasting of the malt, and is heavier and richer in taste than lager. Stout, a very dark beer, is brewed with a combination of roasted and regular malt and has a strong hop taste. Another dark beer, porter, was originally a mixture of ale and beer and is today a sweet, malty brew, with a 6 to 7 percent alcohol content. Malt liquor is a beer made from a high percentage of fermentable sugars which are largely derived from malt. The resulting beverage has a higher alcohol content (5 to 9 percent by weight) than regular beer. The flavor is mildly fruity and spicy, without a hint of hops.

Low-calorie beers are made either by reducing the amount of grain used to make the brew or by adding an enzyme to reduce the starch content of the beer. They are lower in alcohol content (2.5 to 2.7 percent) than regular beer.

Many other fermented beer-like beverages are also produced. In Japan, steamed rice is hydrolyzed and fermented into Sake. Kvass, a type of Russian beer, is brewed from barley-rye malt and fruits. In many tropical areas, palm toddy is made from the sugary sap of coconut or palm trees. It is not intoxicating when fresh, but becomes so in a few hours.

Beer Consumption

In 2007, United States brewers produced 6.7 billion gallons of beer. The Czech Republic has the highest annual per capita consumption of beer (more than 163 L/year, almost 45 gal for each person), with Germany and Denmark a close second and third. The United States is 10th on the per capita consumption list, but produces the largest amount of beer in the world.

Procedure:

For a successful fermentation, aseptic techniques must be used. In other words, no foreign yeast or bacteria can enter the wort. Yeast and bacteria are everywhere, in the air, on your hands, in your breath etc. Extreme care when cleaning is the only way to ensure a reasonable product.

1. Begin boiling 500 mL of water in a 600 mL beaker.

2. While waiting for the various boiling steps, assemble the fermentor and sterilize it with a solution of 10 mL bleach and 5 g of trisodium phosphate in 100 mL of water. Be sure to rinse completely with distilled water and protect from bacterial contamination.

3. **REMOVE the Bunsen Burner from under the boiling water**, wait 1 minute, and add 15 g of dried malt extract to the boiling water.

4. Replace the Bunsen Burner under the hot water and boil over a low fire for 10 to 15 minutes. This assures that the malt extract is completely dissolved, sterilizes the wort, and causes the proteins to flock or precipitate. Use caution or else the mixture may boil over creating a large mess!

5. **REMOVE the Bunsen Burner from under the boiling water**, wait 1 minute, and add 15 g of dextrose to the wort and then bring back to a boil. The additional dextrose increases the alcohol content of the beer.

6. Remove about 10-15 mL of the wort. Place it in a small beaker and cool to room temp. Use a 5.00 mL volumetric pipette and an analytical scale to precisely determine the density of the wort.

7. Add 0.1 g of hops, cover with a watch glass and gently boil for 45 minutes. Maintain a volume between 375 mL and 400 mL by adding water as needed. Hops is added to beer for three reasons: to increase the bitteress, to flavor the beer and to add a spicy to flowery bouquet. The hops leaf is rich in alpha acids (humulone) and beta acids (lupulone) which are the bittering agents of the hops. It requires approximately 45 minutes of boiling to burst the lupulin glands of the hops leaf so the alpha and beta acids can be released.

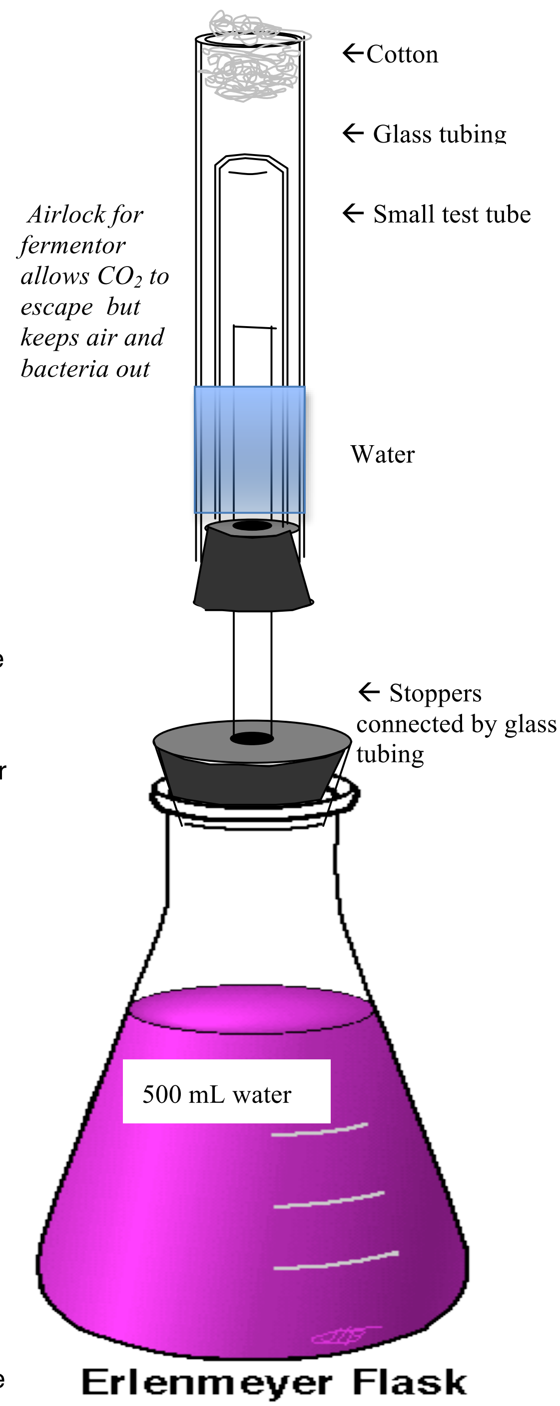
8. For an additional hop flavor add another 0.1 g of hops and boil for 5 minutes uncovered. This will impart the flavor and bouquet to the beer, but no additional bitterness.

Note: The total volume at this point should be between 375 and 400 ml.

8. Warm the fermentor by running warm tap water over the outside of the flask so that the heat shock will not crack it.

9. Decant the hot wort into the fermentor leaving as much of the residue solids behind as possible and seal with the air lock. The

The Fermentor



air lock consists of a large glass tube containing an inverted test tube, water at the bottom, and a cotton plug at the top.

10. Cool as rapidly as possible to reduce the possibility of bacterial growth getting a head start on the yeast. This can be accomplished by setting up a large sink with ice water to cool your samples.

11. When the temperature is below 30 °C, add a pinch the yeast. At temperatures greater than 37 °C the yeast can be killed, and if the temperature is too low, the yeast will not reproduce rapidly.

12. Set the wort in a cool, dark place until fermentation is complete. Fermentation is complete when the foam on the surface dissipates due to the lose of activity of the yeast. This could take from one to three weeks.

To be done in one to three weeks:

13. Place 1 teaspoon of dextrose in a sterile, capable bottle and siphon the wort into the bottle. Cap the bottle as soon as possible. The yeast will feed on the dextrose and produce more alcohol and CO_2 thus carbonating the beer.

Data

Mass of 5.00 mL of wort + small beaker __________ g

Mass of empty small beaker __________ g

Volume of wort __________ mL

Calculated density of wort __________ g/mL

Pre-lab Questions

1. The alcohol that will be produced in your beer will come from two reactions. What are the reactions?

2. What is the purpose of adding hops to beer?

3. In the procedure, you are warned to let the wort cool before measuring its density. If the wort was still hot and you measured its density, would the resulting density be higher than it should be, or lower than it should be? Clearly explain why.

4. Using the table of ΔH_f in your textbook (pg 1059), calculate ΔH for the fermentation reaction of dextrose.

5. What is the purpose of cleaning the glassware thoroughly before starting the experiment? What specifically are you trying to get rid of?

Post-Lab Questions

Answer in your notebook. Be sure to show all work with units, rounded correctly.

1. Given the above weights of reactants and the stoichiometry of the reaction, calculate the total mass of alcohol in grams produced by the reaction. Recall that the alcohol will be produced by the fermentation of maltose and the fermentation of dextrose.

2. Given that the density of alcohol is 0.789 g/mL, calculate the volume percent of alcohol in your bottle of beer. Assume that 375 ml of beer will be produced.

3. Calculate the volume of CO_2 at STP produced in the fermentation process. Again, recall that CO_2 will be produced by the fermentation of maltose and the fermentation of dextrose.

4. When the beer is bottled in one to three weeks, one teaspoon of dextrose is used for priming (adding carbonation in the bottle). What volume of CO_2 at STP is produced after bottling?

1 teaspoon = 0.1667 fluid ounces, 1 fluid ounce = 29.57 mL and Density of dextrose= 1.54 g/mL

5. The average human has 7 pounds of blood for each 100 pounds of body weight. Using the percent alcohol for your beer, if one bottle of the beer is consumed, what will the percent blood alcohol be for your weight? Note that a bottle of beer has a volume of 355 mL.

6. Considering only the fermentation of dextrose, how much heat (in Joules) will be produced by the reaction? If the beer you produced has a volume of 355 mL, how many degrees will the temperature of the beer increase during the fermentation? Why do think in reality the temperature change will be much less?

7. Sodium hydroxide is sometimes added by brewers to neutralize acids that might be present in the water used in brewing beer before other analysis are performed. Assuming the acid in the beer is carbonic acid,

a. Write the equation for the reaction between carbonic acid and sodium hydroxide.

b. If the concentration of carbonic acid is 0.158 M in a bottle of beer (volume of 355 mL), how many grams of sodium hydroxide would be needed to be added neutralize the acid?

8. In order for a product to be successful, it has to have a good name. Would Spam or Fritos be as successful without their names? Or how about Google, which was originally called Backrub? Name you beer. Your name should be creative, and chemistry-related would be even better.