Effect of Changes in Temperature and the Handling of Beer on Amount of Carbon Dioxide Released When Poured

Minh Tran, Charlie Wan, Mallika Manyapu, Alison Scott, Alejandra Mendez, Orion Keifer

Background

Many studies have examined the prevalence and frequency of binge drinking among college students and young adults (6) (7) (8) (9). A study done by Weschler et al. showed that 50% of men and 39% of women engaged in these behaviors (10). In a university setting, binge drinking and rapid beer consumption are common and it is often turned into a game of who can drink the fastest. The immediate side effect sometimes observed from this behavior is excessive burping due to the release of carbon dioxide gas from the beer.

The carbonation of beer is an important component to consider when consuming beer in social situations, brewing beer, or storing it. (2). Carbon dioxide is a byproduct yeasts produces during fermentation. Also, it is used as a natural source of bittering and adds fizziness to beer (2). Major factors that affect the amount of carbon dioxide dissolved in beer include the temperature at which the beer is stored, the pressure surrounding the beer, and the amount of time the beer has been exposed to the atmosphere (2). In this experiment, we examined the effects of the temperature at which the beer is stored as well as the duration that the beer bottle has been opened. Both of these factors were tested for by measuring the amount of carbon dioxide released from the beer.

To test the effects of temperature on beer, the study compared the amount of carbon dioxide released from beers stored at 5 °C to the amount of carbon dioxide released from beers left at room temperature (25°C). The hypothesis for the effect of temperature on the amount of carbon dioxide dissolved in beer is that more carbon dioxide will be released from the beer at warm temperatures compared to cold temperatures. The null hypothesis is that there is no difference in the amount of carbon dioxide released from the beer at warm and cold temperatures. The rationale is that as temperature increases, the solubility of the carbon dioxide in beer will decrease. This means more carbon dioxide will be released from the beer and into the head space of the bottle. Consequently, when beer is consumed, less carbon dioxide will enter the person's stomach. Conversely, carbon dioxide is more soluble at cold temperatures and less carbon dioxide is released from the beer into the head space.

To test the effects of time, this study examined the amount of carbon dioxide released from beers that have been opened at different times. One beer was opened for 25 minutes before being consumed, while another beer was consumed immediately after being opened. The hypothesis is that more carbon dioxide will be released from a beer when it is immediately consumed after being opened. Conversely, less carbon dioxide will be consumed after the beer has been opened for 25 minutes. The null hypothesis is that there is no difference in the amount of carbon dioxide released from the beer when it is consumed immediately and after it has been opened for 25 minutes. The hypothesis is based off the principle that the solubility of a gas in a liquid solution is directly proportional to the pressure of the gas above the solution, also known as
Henry’s Law. Since the atmospheric pressure is less than the pressure of gases in the head space of a beer, the solubility of carbon dioxide in an opened bottle of beer will be less than the solubility of carbon dioxide in a closed bottle of beer. Thus, less carbon dioxide is consumed by the drinker.

In this particular experiment, a balloon (1 liter optimum capacity) was used to simulate a person’s stomach. Similar to the stomach, a balloon will expand as liquids and gases enter. In this case, expansion of the balloon is caused by the release of carbon dioxide gas as well as the liquid beer itself. It is expected that the balloon will expand more when warm beer is poured into it due to the increased release of carbon dioxide from beer at warm temperatures. It is also expected that the balloon will expand more when beer is immediately opened and poured. This is because less carbon dioxide will have been lost to the atmosphere. However, because the balloon does not maintain body temperature (37 °C), we might see unexpected results as the balloon does not simulate a stomach exactly.

Procedure

Preparation of Materials
1. Obtain a water container (big enough to fit a box with dimensions 8x8x8 inches)
2. Fill the tank about 2/3 full of water. When the water has settled, use a permanent marker to mark on the container the height of the water.
3. Using a 500 mL graduated cylinder, measure the volume of water that was used to mark the initial line. (The water volume will be greater than 500 mL, so fill the cylinder, dump it out, and repeat this process until you have measured all the water. (Add the portions of water measured to get the total volume)
4. Fill the container to the initial line with water.
5. Because beer bottles are not completely full of beer, find the total volume of the beer bottle by filling an empty beer bottle with water to the very top.
6. Pour this volume of water into the graduated cylinder to find the volume. In this case, a glass bottle of Bud Light has a total volume of 380 mL. Also, a bottle of Bud Light contains 355 mL of beer.
**Experimental Procedure**

Here is a chart of the four different types of beers that will be tested.

<table>
<thead>
<tr>
<th>Beer #</th>
<th>Temperature</th>
<th>Exposure to atmosphere (opening it)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Room temp</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>Room temp</td>
<td>Yes for 25 min</td>
</tr>
<tr>
<td>3</td>
<td>5 °C</td>
<td>None</td>
</tr>
<tr>
<td>4</td>
<td>5 °C</td>
<td>Yes for 25 min</td>
</tr>
</tbody>
</table>

**Experiment Procedure for the 1st Beer**

1. The 1st beer you will be testing will be unopened and at room temperature.
2. To make sure it is at room temperature, leave it stored in a room away from sunlight for 24 hours.
3. To begin the experiment, open the beer.
4. Immediately cover the opening of the beer bottle with an empty balloon.
5. Invert the bottle and shake. You will notice the balloon expanding as the beer flows into the balloon and carbon dioxide is released.
6. Shake the balloon and bottle for 30 seconds. (This is done to mimic the drinking and swallowing process. It also mimics the movement of the fluids in the stomach.)
7. After 30 seconds, immediately detach the balloon and tie a knot to seal it.
8. Place this filled balloon in the water container. (It will float to the top since it filled with gases. Use your fingers to push it under the water while being careful to avoid getting any water on your fingers.)
9. When the balloon is submerged, have a group member mark the increase of the volume of water with a permanent marker.
10. Take out the balloon and fill with water to match the new line.
11. Measure the total volume of water with the graduated cylinder and subtract this total volume from the initial volume. You will now have the volume of all the liquid and gas in the balloon.
12. Because the bottle had air in it when the balloon was removed, you must add the volume of the bottle to get the total volume of air and liquid in the beer. Add 380mL to the balloon volume.
13. Subtract 355mL (the original volume of liquid beer in the bottle) from the total volume of gas and liquid. Now you have the volume of only gas.

**Experiment Procedure for 2nd beer**
1. The 2nd beer you will be testing will be opened for 25 minutes and at room temperature.
2. To make sure it is at room temperature, leave it stored in a room away from sunlight for 24 hours.
3. Open the beer and let it sit for 25 minutes.
4. After 25 minutes, follow steps 4-13 of the procedure for the 1st beer.

**Experiment Procedure for 3rd beer**
5. The 3rd beer you will be testing will be unopened and at 5 °C.
6. To make sure it is at 5 °C, set a refrigerator to 5 °C and place a thermometer in it to make sure it has reached this temperature.
7. Place a beer in it for at least 2 hours, it should reach 5 °C as long as the refrigerator is 5 °C.
8. Follow steps 3-13 of the procedure for the 1st beer.

**Experiment Procedure for 4th beer**
9. The 4th beer you will be testing will be opened for 25 minutes and at 5 °C.
10. To make sure it is at 5 °C, set a refrigerator to 5 °C and place a thermometer in it to make sure it has reached this temperature.
11 Place a beer in it for 2 hours, it should reach 5 °C as long as the refrigerator is 5 °C.
12 When it has reached 5 °C, open the beer and put it back in the refrigerator for 25 minutes.
13 After 25 minutes, take it out and follow steps 4-13 of the procedure for the 1st beer.

**Results**
*closed indicates a beer that was consumed immediately, while “open” indicates a beer that was left open for 25 minutes before consumption.*

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before CO2</td>
<td>Before CO2</td>
<td>Before CO2</td>
</tr>
<tr>
<td><strong>Closed at room temperature</strong></td>
<td>5.45 L 0.925 L</td>
<td>5.50 L 0.985 L</td>
<td>5.30 L 0.885 L</td>
</tr>
<tr>
<td><strong>Closed at cold (5 degrees Celsius) temperature</strong></td>
<td>5.45 L 0.405 L</td>
<td>5.50 L 0.430 L</td>
<td>5.30 L 0.385 L</td>
</tr>
<tr>
<td><strong>Open at cold (5 degrees Celsius) temperature</strong></td>
<td>5.45 L 0.235 L</td>
<td>5.50 L 0.245 L</td>
<td>5.30 L 0.220 L</td>
</tr>
<tr>
<td><strong>Open at room temperature</strong></td>
<td>5.45 L 0.275 L</td>
<td>5.50 L 0.290 L</td>
<td>5.30 L 0.265 L</td>
</tr>
</tbody>
</table>

Average balloon size before consumption | 5.43 L
Average CO2 with room temp/closed | 0.932 L
Average CO2 with cold temp/closed | 0.407 L
Average CO2 with room temp/open | 0.277 L
Average CO2 with cold temp/open | 0.233 L
*Graph 1-This graph illustrates the above data collected, the general trends seen throughout the experimental trials, and the statistical differences between these trends. As seen above, closed/room temp releases the most gas overall compared to other combinations of open/closed and cool/room temp. Furthermore, each condition showed statistical difference as illustrated in the graph and in the table below.
### Statistical Analysis:

#### Statistical Summary

<table>
<thead>
<tr>
<th>Test Conditions</th>
<th>Significant or Not? (w/ p value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>closed/cold vs. closed/room temp</td>
<td>p = 0.0009--significant</td>
</tr>
<tr>
<td>open/cold vs. open/room temp</td>
<td>p = 0.0205--significant</td>
</tr>
<tr>
<td>cold/closed vs. room temp/open</td>
<td>p = 0.0023--significant</td>
</tr>
<tr>
<td>room temp/closed vs. room temp/open</td>
<td>p = 0.0004--significant</td>
</tr>
</tbody>
</table>

#### In Depth Statistical Analysis:

1) **Unpaired t test: closed/cold vs. closed/room temp**
   
   P value and statistical significance:
   
   The P value equals 0.0009. This difference is considered to be statistically significant. Confidence Interval: The mean of closed/cold minus closed/room temp = 0.51417, with the 95% confidence interval of this difference from 0.39115 to 0.63718
   
   - $t = 13.3014$
   - $df = 3$
   
   Summary of Data
   
<table>
<thead>
<tr>
<th>closed/room temp</th>
<th>closed/cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.93167</td>
</tr>
<tr>
<td>SD</td>
<td>0.05033</td>
</tr>
</tbody>
</table>

2) **Unpaired t test: open/cold vs. open/room temp**
   
   P value and statistical significance:
   
   The P value equals 0.0205. This difference is considered to be statistically significant. Confidence Interval: The mean of open/cold minus open/room temp equals -0.04917, with the 95% confidence interval of this difference from -0.08391 to -0.01442
   
   - $t = 4.5031$
   - $df = 3$
   
   Summary of Data
   
<table>
<thead>
<tr>
<th>open/cold</th>
<th>open/room temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.23333</td>
</tr>
<tr>
<td>SD</td>
<td>0.01258</td>
</tr>
</tbody>
</table>

3) **Unpaired t test: cold/closed vs. cold/open**
   
   P value and statistical significance:
The P value equals 0.0023. This difference is considered to be statistically significant. Confidence Interval: The mean of cold/closed minus cold/open equals 0.16667, with the 95% confidence interval of this difference from 0.11189 to 0.22145

\[ t = 9.6825 \]
\[ df = 3 \]

Summary of Data

<table>
<thead>
<tr>
<th></th>
<th>Cold/closed</th>
<th>Cold/open</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.40667</td>
<td>0.24000</td>
</tr>
<tr>
<td>SD</td>
<td>0.02255</td>
<td>0.00707</td>
</tr>
</tbody>
</table>

4) Unpaired t test: room temp/closed vs. room temp/open

P value and statistical significance:
The P value equals 0.0004. This difference is considered to be statistically significant. Confidence Interval: The mean of room temp/closed minus room temp/open equals 0.64917, with the 95% confidence interval from 0.52846 to 0.76988

\[ t = 17.1150 \]
\[ df = 3 \]

Summary of Data

<table>
<thead>
<tr>
<th></th>
<th>Room Temp/closed</th>
<th>Room Temp/open</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.93167</td>
<td>0.28250</td>
</tr>
<tr>
<td>SD</td>
<td>0.05033</td>
<td>0.01061</td>
</tr>
</tbody>
</table>

First Principle: Henry's Law

According to Henry’s Law, the amount of carbon dioxide dissolved in a given volume of beer is directly proportional to the partial pressure of carbon dioxide in equilibrium with the beer. Henry’s Law is written as \( P = k \cdot C \) in which \( P \) stands for the partial pressure of the gas above the solution, \( C \) stands for the concentration of the dissolved gas in solution, and \( k \) stands for Henry’s Law constant for the solution (13). In other words, gas is more liquid soluble in a container when the pressure is increased. Before the bottle was opened, the carbon dioxide above the beer is at a pressure slightly higher than atmospheric pressure. When the bottle is opened, gas escapes and the partial pressure of carbon dioxide above the beer decreases (4). Therefore, the solubility of carbon dioxide in beer is decreased and is released into the atmosphere.

Therefore, if a person drinks a whole beer immediately after opening it, he will also be drinking most of the gas that was originally in beer. Since the beer is consumed faster than the gas is released, more carbon dioxide ends up in the person’s stomach. If the bottle is left open for 25 minutes, the concentration of carbon dioxide in solution comes into equilibrium with the atmosphere and thus the beer goes flat. Both Henry’s Law and the data from the experiment provide support for the hypothesis that more carbon dioxide is released when beer is poured into the balloon immediately after opening it.

First Principle: Solubility of gases in liquids

When the temperature of the beer is increased, the solubility of carbon dioxide in beer also decreases (5). The carbon dioxide that is initially dissolved in the beer has relatively weak intermolecular interactions with liquid solvents. When the beer is left at warmer temperatures, the molecules gain kinetic energy. This causes the molecules to
move around a lot more and collisions occur more frequently. The collisions break the intermolecular bonds between the carbon dioxide molecules and the liquid molecules. Due to broken intermolecular bonds, the carbon dioxide gas becomes less soluble and begins to escape from the liquid beer and into the head space of the bottle. Thus, upon release, more carbon dioxide is released from the head space in a warm beer. If the beer is stored at colder temperatures the bonds between the carbon dioxide and the liquid become more crystalline due to less kinetic energy moving the molecules around (11). The data can also be explained by Le Chatelier’s principle that warmer beer shifts the equilibrium to the left and favors the endothermic reaction. The system of equilibrium counteracts the increased temperature by absorbing extra heat, meaning that less carbon dioxide dissolves at a higher temperature (5). Therefore, theoretically there is less carbon dioxide that enters the human body after consuming a warm beer. When the cold beer enters the human’s stomach and is exposed to warmer temperatures a reverse of the equilibrium may occur. The cold beer that has more soluble carbon dioxide in it will immediately begin to release carbon dioxide due to the change in temperature.

**Discussion**

The results from the four conditions in the experiment support both of the predicted hypotheses. Our first hypothesis predicted that if beer is consumed immediately after it is opened then the drinker ingests a larger volume of carbon dioxide compared to a beer that is consumed after it has been exposed to atmospheric pressure for a longer time. By keeping the temperature of the beer constant, this allows us to examine the amount of carbon dioxide released from an opened bottle of beer. As shown in the statistical analysis, the p value is significant (p = 0.0004) when comparing the data for “closed/cold and closed/room temperature.” The mean of carbon dioxide released when consuming room temperature beer immediately after it was opened was 0.932, and the mean of carbon dioxide released when consuming a room temperature beer 25 minutes after it was opened was 0.277. The pressure in the beer was altered, which significantly effected the amount of carbon dioxide that is released from the beer.

Our second hypothesis predicted that when beer is stored at warmer temperatures, more carbon dioxide will come out of solution than beer stored at colder temperatures. This was also supported by statistical data, and the balloon expanded less when cold beer was poured into it than when warm beer was poured into it. The data shows there is a significant value of p = 0.0009 when comparing the temperatures of beer opened immediately and poured into the balloon. The mean of carbon dioxide released when cold beer was immediately poured into the balloon was 0.407, and the mean of carbon dioxide released for room temperature beer poured in the same conditions was 0.932.

These results are useful when deciding what kind of beer to consume when playing drinking games in a college setting. Since more carbon dioxide is released when consuming beer right after it is opened, the drinker swallows more gas, which enters the stomach. When this occurs, excess carbon dioxide is forced out of the stomach, up through the esophagus, and out of the mouth as a burp. This slows down the amount of beer the person can drink during competitive drinking games such as “flip cup,” Therefore, it is better to drink beer that has been left open for 25 minutes as opposed to
drinking it immediately after opening the bottle. The data also shows that drinking warm beer will cause more carbon dioxide to come out of solution. While playing a drinking game, the person typically drinks a cold beer, which increases in temperature when it enters the human body. More carbon dioxide is released with this change in temperature, and the excess gas is forced out the stomach as a burp. Consuming a cold beer during a drinking game will cause the person to drink more slowly and thereby have a lower likelihood of winning the game.

If this experiment were to be repeated, there would need to be many improvements in the procedure in order to get more accurate results. More appropriate materials should have been used such as the red recycling container used to store water. The container did not have a scale on it so the amount of water in the container was determined by the amount of water that was put in. This made it difficult to measure the change in the water level. There are more efficient ways of measuring the amount of water that would ensure more accurate results. In addition, there may have been a more efficient way of placing the balloon on the beer bottle without risking any carbon dioxide from being released into the air. A factor that we did not consider was that realistically, when anything is consumed, it changes temperatures as it enters the stomach. The stomach is at a higher temperature than room temperatures. It would have been interesting to see if we could have kept the balloon at this temperature and see how the amount of carbon dioxide released changed. Finally, more trials should be done in order enhance the quality of the data. If the experiment had just focused on changing one variable, more data could have been collected. For example, we could have just focused on the effect temperature has on the solubility of carbon dioxide in beer. In this experiment we also could have used beers that were stored at a larger range of temperatures.
References