EFFECT OF TEMPERATURE ON RISE HEIGHT AND PRESSURE OF DIET COKE AND MENTOS EXPLOSION

Lillian Papalia
MIT Department of Mechanical Engineering
Cambridge, MA, USA

ABSTRACT

The Diet Coke and Mentos explosion is a common experiment in many middle schools, and was popularized by Mythbusters in 2006. The cause of the Diet Coke and Mentos explosion is not a chemical reaction, but instead a physical reaction between the rough surface of Mentos and dissolved gases. As temperature increases, the solubility of gases decreases leading to the reaction occurring faster and higher geysers. In order to determine the effects of temperature on maximum height of Diet Coke and Mentos geyser, bottles were heated and cooled to various temperatures, and height of geyser was measured using video analysis. The results showed a statistically significant linear relationship between temperature and maximum height of geyser. To increase the maximum height by one meter, the temperature must increase by about 15 °C, and therefore the pressure increases by about 3,400 Pa.

Keywords: Diet Coke | Mentos | Carbonation | Bernoulli's Equation

INTRODUCTION

Mixing Diet Coke and Mentos may be one of the first science experiments a child experiences, but what causes this eye-catching explosion displayed in Figure 1? Many people believe it is a chemical reaction, but it is actually a physical reaction. The rough surface of a Mentos helps break the bonds between carbon dioxide gas and water. As a result, many carbon dioxide bubbles are formed, leading to a large explosion [1]. What other physical factors contribute to the maximum geyser height? The factor of choice to investigate was temperature due to the interesting relationship between solubility of gases in liquid and temperature. To determine the effect of temperature, bottles at various temperatures were combined with Mentos, and the height of geyser was measured. This experiment is frequently used in middle schools, but often not to its fullest potential. Many young students are intrigued by the large explosion, but do not understand the science behind it. The Diet Coke and Mentos effect is a perfect way to spark scientific interest in young students. The experiment is an easy and interesting way to teach the scientific method.

Figure 1: Eye-catching Diet Coke and Mentos explosion.

Five bottles of Diet Coke were heated or cooled to various temperatures using a refrigerator and instant pot. The temperature of each bottle of soda was recorded using a temperature probe before the explosion. In order to determine the height of the geyser, a slow motion video was recorded of each reaction. By using image processing software and the height of the bottle as a scale, the maximum height of geyser was determined. The entire experimental process was repeated five times for each temperature setting to capture 25 data points. The data was plotted on a scatterplot to easily visualize the relationship between temperature and height of geyser. Also from the video analysis the initial velocity of the geyser was determined. Using Bernoulli's Equation, the pressure in the Diet Coke bottle was calculated and the relationship between temperature and pressure was visualized.

BACKGROUND

THE ROLE OF SURFACE STRUCTURE IN GAS RELEASE

The underlying process of the Diet Coke and Mentos explosion is not a chemical reaction, but instead a physical reaction. Because it is a physical reaction there is no change in chemical composition. Inside of carbonated beverages there are many dissolved carbon dioxide gas molecules. The gas molecules want to escape, but most are held inside the soda by surface tension. A Mentos looks smooth to the human eye, but under a microscope it is revealed Mentos have a very rough surface (Figure 2). The rough surface of the Mentos assists in the breaking of the bonds between the carbon dioxide gas and water molecules. This creates the explosive eruption of soda once Mentos are dropped into the bottle [1]. A previous study suggests the height of geyser increases as the number of Mentos dropped into the bottle increases [2]. This makes sense because the carbon dioxide has more surface area to help break the bonds as number of Mentos increases.

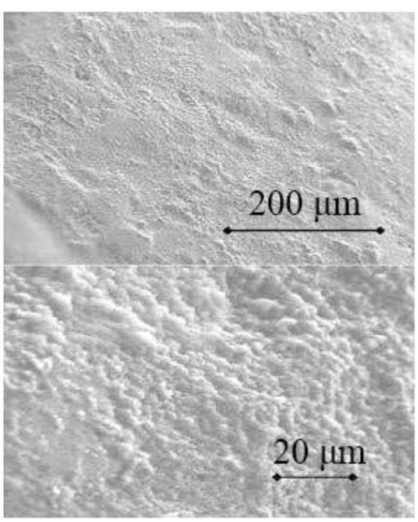

Figure 2: Rough surface of a Mentos revealed from scanning electron microscope images. [3].

EFFECT OF CHANGE OF TEMPERATURE IN SODA

The carbonation process is executed at high pressures and low temperatures in order to maximize carbon dioxide absorption. Increasing the temperature of a liquid decreases the solubility of gases inside the liquid [4]. The lower the solubility of the gases, the more the gases want to escape the liquid. This leads to a higher geyser because the gases want to escape the liquid faster, leading to a faster reaction [5]. Another effect of increasing temperature is introducing more energy into the system. This means the liquid and gas molecules are traveling at higher velocities. In a previous study, strawberry Mentos and 355 mL bottles of Diet Coke were used to compare temperature to geyser height [2]. The results displayed the average height of geyser increases linearly with temperature for the 355 mL bottles of Diet Coke. This study shows for each degree Celsius increase, the average height of geyser increases by about 13 centimeters. Another suggested result of this experiment is that higher temperatures lead to faster reaction times [2]. The results of the previous study relate a faster reaction time with higher geyser height.

CHEMICAL CHARACTERISTICS OF DIET COKE

Non-diet sodas produce a smaller eruption than diet sodas. This is because aspartame, an ingredient in diet sodas, lowers the surface tension more than sugar or corn syrup, causing the geyser to be higher [5]. This is why Diet Coke was selected as the soda of choice.

BERNOULLI'S EQUATION AND PRESSURE

By assuming the explosions produce a uniform bubbly flow, Bernoulli's equation can be applied to determine the initial pressure in the Diet Coke bottles. The equation is the following:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \qquad (1)$$

where P_1 is the pressure at elevation 1, P_2 is the pressure at elevation 2, ρ is the density of the fluid, v_1 is the velocity at elevation 1, v_2 is the velocity at elevation 2, g is the acceleration due to gravity, h_1 is the height of elevation 1, h_2 is the height [m] of elevation 2.

EXPERIMENTAL DESIGN

DIET COKE TEMPERATURE PREPARATION

Five bottles of Diet Coke bottle were heated or cooled to various temperature ranges: maximum cold (0-10°C), medium cold (10-20°C), room temperature (23-26°C), medium hot (29-40°C), and maximum hot (40-

50°C). In order to cool the bottles, one was placed in the freezer and another was placed inside the refrigerator for two hours before data collection. To heat the soda, two bottles were placed in a heated water bath inside an Instant Pot. The Instant Pot was set on sauté mode for about 5 minutes to heat the water, and then the bottles were left inside to reach equilibrium (about one hour). One bottle was removed from the Instant Pot approximately 15 minutes earlier in order to reach a temperature between room temperature and maximum hot, about 30-40°C. The temperature of the water bath was checked frequently and if the water cooled too much the Instant Pot was turned back on for a few minutes. One bottle was left at room temperature.

TEMPERATURE DATA COLLECTION

The bottles were transported outside to the dedicated explosion area. The tripod was set up about 10 meters away for warmer temperatures and 5 meters away for cooler temperatures to capture the maximum geyser height. One bottle was moved into the frame of the camera. The set up for capturing the temperature is shown in Figure 3. The temperature probe (TMP) was connected to the laptop using the Lab Quest Mini, and logger pro was opened on the laptop. The cap of the bottle was removed and the temperature probe was inserted into the soda to measure temperature in degrees Celsius. The probe was kept in the soda until the temperature stabilized, and the temperature [°C] was recorded in the lab notebook. The laptop and sensors were then moved to the same area as the tripod, and the slow motion video was started.

Figure 3: Schematic of experimental set up.

EXPLOSION VIDEO COLLECTION

Seven Mentos were loaded into a paper cone in order to successfully drop all the Mentos into the soda before the eruption began. The Mentos were dropped into the Diet Coke. After the explosion ended, the slow motion video was stopped. The process was then repeated for all five trials of five temperature ranges (25 total explosions).

LOGGER PRO VIDEO ANALYSIS

For the video analysis the origin was placed at the top of the bottle, and the height of the bottle was used as a scale. A data point was placed at the maximum height of geyser in each frame, and from this data the maximum height of geyser was determined for each trial. Logger Pro also calculated the velocity at each point. The initial velocity and maximum height were extracted from Logger Pro for all 25 trials.

USE OF BERNOULLI'S EQUATION

Bernoulli's equation was utilized to calculate the pressure inside the Diet Coke bottle for each trial. Assuming the explosion produced a uniform density bubbly flow, Bernoulli's equation can be applied to solve for the initial pressure. The density was calculated by extracting a frame from the geyser mid explosion. An assumption was made that the geyser was shaped like a long cylinder, and the height and radius of bottle nozzle were used to calculate the volume of fluid in the geyser. The mass of fluid in the geyser was calculated using the height of soda still in the bottle. Each 2L bottle holds 2 kg of soda, and the soda not in the bottle was transferred to the geyser. Using a proportion of how much fluid is left in the bottle, the mass of Diet Coke in the geyser was estimated. The estimated density of the uniform bubbly flow was $450\ [\frac{kg}{m^3}]$.

RESULTS AND DISCUSSION

A plot of height [cm] vs time [s] from the Logger Pro video analysis for a temperature of 42.2 °C is shown in Figure 4. From this data the maximum height of geyser was extracted, and the maximum height of geyser for this trial was 281 cm. The explosion at 42.2 °C produced the tallest explosion of all trials at 281 cm, while the 2.2°C explosion produced the smallest at 5.2 cm. The plots for all 25 trials had parabolic behavior similar to Figure 4.

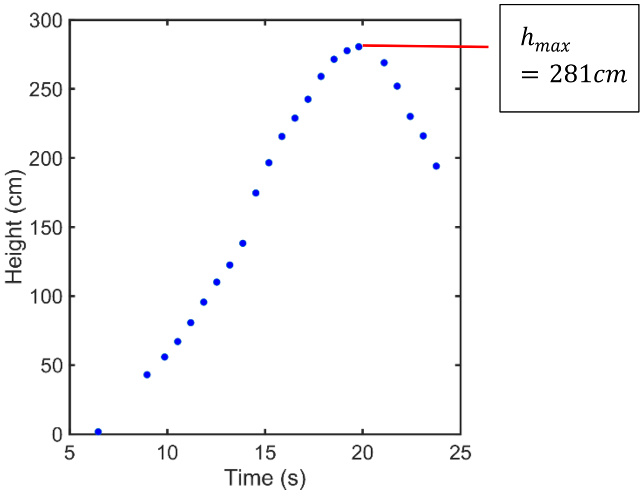

Figure 4: Plot of height [cm] vs time [s] for 42.2 °C.

Figure 5 displays maximum height [cm] vs temperature [°C] for all 25 trials. There is a statistically significant linear relationship between temperature and height. The slope of the line of best fit is 6.7± 1.0 [cm/°C], meaning for each degree of temperature increase, the maximum height of geyser increases by 6.7 cm. A quadratic fit was also applied to the data, but the quadratic term did not have a statistically significant coefficient, implying the linear fit was the better model. The increase in height of geyser with an increase in temperature agrees with the background information. The data supports the theory that the lower the solubility of the gases, the more the gases want to escape the liquid, leading to a higher reaction.

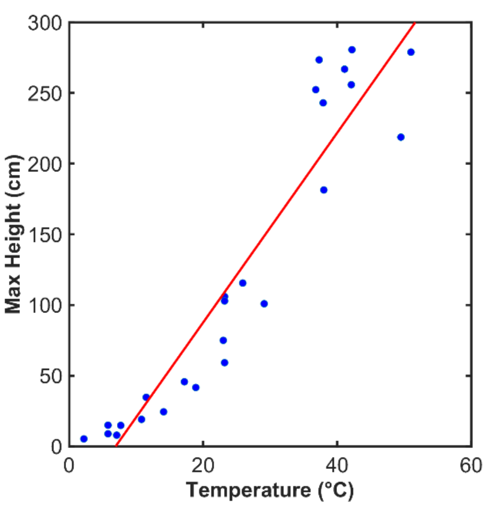

Figure 5: Plot of Height [cm] vs Temperature [°C] for all 25 trials. The red line is a statistically significant line of best fit with equation f(T) = (6.7± 1.0 [cm/°C])*T – (46.55± 29 [m]).

Figure 6 shows a plot of Pressure [Pa] inside Diet Coke bottle vs Temperature [°C] for all 25 trials. The pressure and maximum height of geyser relationships to temperature are very similar as shown by figures 4 and 5. The figures suggest a correlation between higher geyser heights, higher temperatures, and higher initial pressures. Combining the results from figures 4 and 5, it can be inferred each Pascal of pressure adds about 0.03 cm to the maximum height of geyser. In order to increase the maximum height by one meter, the temperature must increase by about 15 °C, and the pressure must increase by about 3,400 Pa.

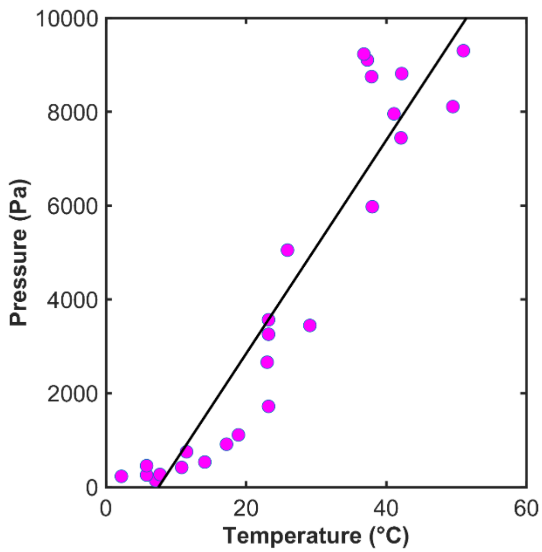

Figure 6: Plot of Pressure [Pa] inside Diet Coke bottle vs Temperature [°C] for all 25 trials. The black line is a statistically significant line of best fit with equation f(T) = (226 ± 34 [Pa/°C])*T – (1690 ± 980 [Pa]).

One source of error can be attributed to wind. During some trials the wind would affect the direction of the geyser, not allowing the geyser to reach peak vertical height. For further experimentation the explosions should be moved to a location with less wind. The results are similar to the previous study involving the 355 mL bottles. While the slope for the 355 mL bottles was more than two times the slope of the 2L bottles, there was a significant upward trend in the data for both scenarios. The difference in slope can be attributed to the size difference and different dimensions of the Diet Coke bottles. For the pressure calculations error could be caused by the numerous assumptions made in order to calculate density, and assuming the flow has a uniform density. For future experimentation, a more accurate method of calculating density can be applied to help reduce error.

CONCLUSIONS

By examining the effect of temperature on maximum height of Diet Coke geyser, it is evident temperature has a major impact on the explosion. The data shows a statistically significant linear relationship between temperature and height of explosion. The slope of the line of best fit is 6.7± 1.0 [cm/°C]. This means for every degree Celsius increase in temperature, the height of explosion increases by about 6.7 cm. This makes sense because when the temperature of the soda is increased, the solubility of gas is decreased. This causes the eruption to occur faster due to the gas particles wanting to escape the liquid. A statistically significant linear relationship was also found between temperature and pressure inside soda bottle. The slope of the line of best fit is 226 ± 34 [Pa/°C]. This suggest each degree Celsius adds 226 Pa of pressure to the soda bottle. Combining these two results, it can be determined to increase the maximum height by one meter, the temperature must increase by about 15 °C, therefore increasing the pressure by about 3,400 Pa. One important finding is the slope of line of best fit for height vs temperature differs from the past research with 355 mL bottles. Further research can be done to investigate the impact of size and shape of soda bottle on maximum height of geyser.

ACKNOWLEDGMENTS

Special thanks to Professor Peacock, Dr. Cedrone, Juergen Schoenstein, and Dr. Hughey providing guidance and making this experiment possible!

REFERENCES

[1] Science Buddies. “Spurting Science: Erupting Diet Coke with Mentos.” Scientific American, Scientific American, 14 June 2012, https://www.scientificamerican.com/article/bring-sciencehome-coke-mentos/. (Accessed 9/23/2020)

[2] Dukes et al. “Investigation of the Mechanism of the Diet Soda Geyser Reaction” Chemical Educator, 2014. Found in Google Scholar (Accessed 9/23/2014)

[3] Muir, Hazel. “Science of Mentos-Diet Coke explosions explained.” NewScientist, 12 June 2008, https://www.newscientist.com/article/dn14114-science-of-mentos-diet-coke-explosionsexplained/. (Accessed 9/23/2020)

[4] Debbi, Harold. “Is Carbonation Affected by the Temperature?” sciencing.com, 9 January 2018 https://sciencing.com/info-8793154-carbonation-affected-temperature.html (Accessed 9/23/2020)

[5] Hinskey, Daven. “Why Do Diet Coke and Mentos React?”. Mental Floss, 6 February 2013, https://www.mentalfloss.com/article/48759/why-do-diet-coke-and-mentos-react (Accessed 9/23/2020)