Visualization of the Carbon Dioxide Bubbles following a Chemical Reaction between an Acetic Acid and Sodium Bicarbonate Reaction

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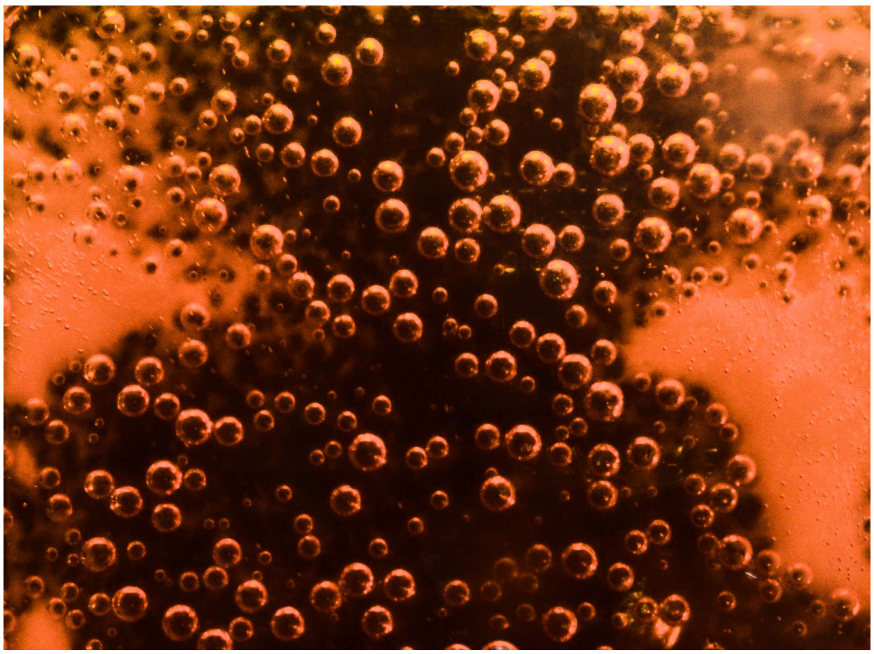

Figure 1. Residual Bubbles Suspended in a Solution following a Chemical Reaction between Acetic Acid and Sodium Bicarbonate

Background

The photograph in Figure 1 is of the residual bubbles suspended in a solution following a chemical reaction between acetic acid and sodium bicarbonate. This chemical reaction is mostly known by its popular application in teaching children basic chemistry using a vinegar and baking soda volcano. As a kid, the focus of the experiment is mostly on the reaction itself, however, the intent of this photograph was to capture the bubbles from the reaction as well as any other evidence of fluid mechanics in the experiment. Using this image, the fluid mechanics following the reaction can be analyzed and be used to explain what is occurring within the photograph.

Set Up

The first step for staging this experiment was to place a container on a black tabletop. Next was to ensure that there was sufficient lighting to capture the photograph. This was accomplished by placing a lamp overhead pointing overtop the container to brighten the surrounding area. To illuminate the experiment directly, a flashlight was placed on the tabletop and pointed towards the container. A black backdrop made of posterboard was placed on the tabletop opposite the flashlight to reduce light reflection that would detract from the photograph. After the lighting was staged, one tablespoon of baking soda was added to the container. In a separate bowl, food coloring, two parts yellow, one part red, was added to ½ cup of vinegar [1]. The solution was mixed until the food coloring had completely dissolved into the vinegar. The solution was then slowly poured into the container with the baking soda, starting the chemical reaction which was allowed to continue until complete. The entire experiment set up is shown in Figure 2.

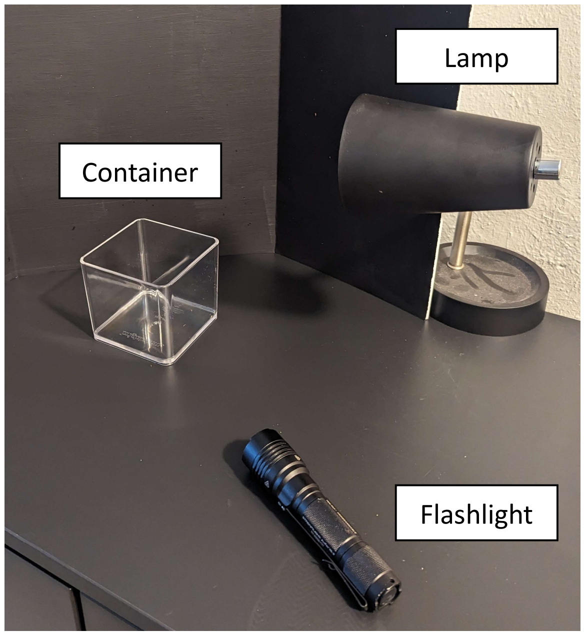

Figure 2. Experiment Set Up

Chemistry and Physics of the Fluid

This photograph is the result of a chemical reaction between sodium bicarbonate and acetic acid, more commonly known as baking soda and vinegar respectively, as well as surface tension. The chemical reaction (Eq. 1) between the acetic acid and sodium bicarbonate demonstrates three key concepts that are pivotal to the photograph: 1) stoichiometry, 2) limiting reagents, and 3) the conservation of mass [2].

$$NaHCO_3(s) + CH_3COOH(l) \leftrightarrow CO_2(g) + H_2O(l) + NaC_2H_3O_2(aq) \quad \text{Eq. 1}$$

Stoichiometry is the process used to quantify what products will yield from a reaction with given reactants. Namely, a product cannot be created if its components are not a part of the reactants [3]. The reaction between acetic acid and sodium bicarbonate yields gaseous carbon dioxide, liquid water, as well as aqueous sodium acetate because of stoichiometry [2]. A solution of water and sodium acetate remained in the container following the reaction, capturing the carbon dioxide bubbles within it. The bubbles are formed because of surface tension. Surface tension is caused by intermolecular forces ‘pulling’ the surface molecules of the solution inward to create the smallest liquid surface possible [4]. The surface tension that creates bubbles is the pressure balanced between the outward force caused by the carbon dioxide and the inward force being exerted by the solution [5]. For a spherical surface, Eq. 2 show how surface tension, γ is related to the internal pressure, Pi and external pressure, Po.

$$Pi - Po = 4\gamma/r \qquad \text{Eq. 2}$$

The conservation of mass, which means that the mass of the initial system will equal the mass of the final system, also dictates how much product the reactants will yield [2]. The mass, moles, and molecular weight of the sodium bicarbonate and acetic acid are shown in Table 1 and the equations used to calculate the values are shown in Eq. 3 through Eq. 5 The vinegar used in this experiment contained a 5% concentration of acetic acid, meaning of the estimated 119 grams of vinegar, only 5.95 grams were acetic acid [6].

Table 1. Mass, Moles, and Molecular Weight of Sodium Bicarbonate and Vinegar [6]

Compound	Sodium Bicarbonate	Acetic Acid
Mass (g)	32.53	5.95
Moles (mol)	0.387	0.099
Molecular Mass (g/mol)	84.077	60.052

$$moles = \frac{mass}{Molar\ Mass} \qquad \text{Eq. 3}$$

$$Mass_{acetic\ acid} = \%_{acid} * mass_{vinegar} \qquad \text{Eq. 4}$$

$$Surplus_{NaHCO_3}(grams) = mol_{NaHCO_3} - mol_{CH_3COO} \qquad \text{Eq. 5}$$

In this experiment, there was a surplus of sodium bicarbonate meanwhile acetic acid was the limiting reactant. The sodium bicarbonate surplus left approximately 32.44 grams of sodium bicarbonate in the solution at the conclusion of the reaction. The leftover sodium bicarbonate is seen by the large areas of light orange area along the left and right sides of the photograph.

Visualization Techniques

To capture this image, five different trials of the reactions were completed. The first trial of the experiment was conducted to help stage the lighting and to adjust camera settings so future trials could be documented throughout. Three of the subsequent trials were recorded via a slow-motion video from the side and one was photographed. During these recordings and photographs, the camera was resting on the table and slightly angled up, so the full container was within the frame. Additional photographs of the reaction were taken five to ten minutes after the reaction concluded. This allowed some of the bubbles to diffuse into the air, leaving bubbles trapped on the bottom of the container and ensured that the surface of the vinegar was relatively undisturbed while pictures were taken. The camera was held by hand and photographs were taken from a side and overhead view.

Photographic Techniques

Throughout this experiment several different visualization and photographic techniques and angles were utilized. This included taking a slow-motion video of the reaction, photographs from the side during and after the reaction, and finally photographs from above after the reaction had completed. Ultimately, the photographs taken from overhead yielded the best results and one was selected for submission. The camera used to photograph this experiment was the Canon EOS M50 Mark II with a 15 to 45 mm lens. The photograph selected had the camera characteristics listed in Table 2 at the time of the photograph.

Table 2. Camera Specifications for the Photograph

Specification	Description
Aperture	f/14.0
Exposure	1/20
ISO	2000
Focal Length	15 mm
Focal Distance	0.23 m

Once the photograph was selected, it was edited to better demonstrate the desired flow visualization techniques. The original photograph, seen in Figure 3, dimensions were 6024 pixels wide and 4020 pixels tall. This was then cropped down to 2115 pixels wide and 1572 pixels tall to focus on the bubbles created by the reaction. After the photograph was cropped, the RGB curve was adjusted down linear, reducing the overall brightness. Then an s-curve was added to the RGB curve to enhance the contrast between colors [8]. Finally, minor touch ups were completed to eliminate defects in the photograph that were suspected to be lights reflecting off the surface of the solution. All the edits were focused on enhancing the carbon dioxide bubbles captured in the solution.

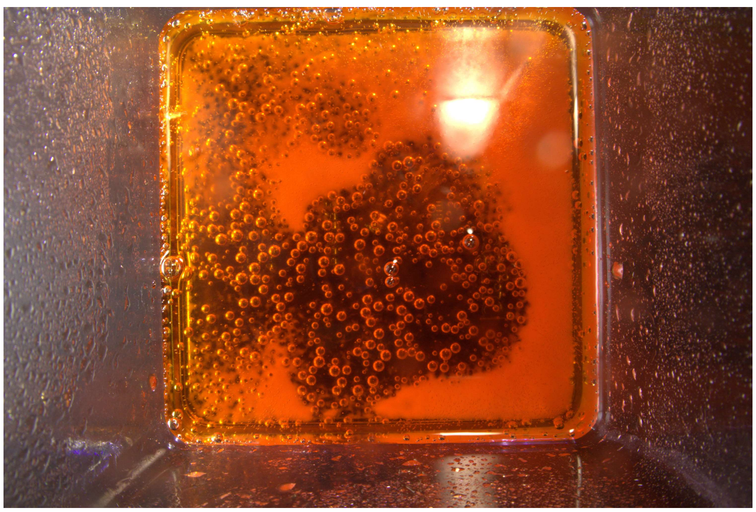

Figure 3. Original Overhead RAW Image Taken

Conclusions

There are still many techniques I need to learn about photography before I feel comfortable taking photographs, but this was a good initial step. The iterative process made me take multiple approaches to accurately capture the phenomena from the chemical reaction. It also helped me experiment with my camera and its features. Though I am happy with my initial attempt, during future iterations of this experiment, making the delineation between the bubbles and the solution would help improve this photograph. I would also like to experiment with different camera hardware options since most of my adjustments were software based.

References

[1] Osterloff, E. (2019). *How to make an erupting volcano*. Nhm.ac.uk. https://www.nhm.ac.uk/discover/how-to-make-a-volcano.html

[2] Veltri, L. M., & Holland, L. A. (2020). Microfluidics for Personalized Reactions to Demonstrate Stoichiometry. *Journal of Chemical Education*, *97*(4), 1035–1040. https://doi.org/10.1021/acs.jchemed.9b00544

[3] *Quantifying Chemical Reactions*. (2014). Alexander Street. https://video-alexanderstreet-com.colorado.idm.oclc.org/watch/quantifying-chemical-reactions-stoichiometry-and-moles

[4] *Surface Tension*. (2018). Funk & Wagnalls New World Encyclopedia; World Almanac Education Group, Inc. https://research.ebsco.com/c/3czfwv/viewer/html/37oq6ixtkj

[5] *Surface tension*. (n.d.). Labs.phys.utk.edu; University of Tennessee - Knoxville. Retrieved September 19, 2023, from https://labs.phys.utk.edu/mbreinig/phys221core/modules/m7/surface_tension.html

[6] *Online Food Calculator. Food Volume to Weight Conversions*. (2020). Aqua-Calc.com. https://www.aqua-calc.com/calculate/food-volume-to-weight

[7] Boone, J. (2017, September 20). *A Beginner's Guide to Color Curves for Powerful Correction*. Frame.io Insider. https://blog.frame.io/2017/09/20/beginners-guide-to-color-curves/