Self-Inflating Balloon Challenge

University of Minnesota - Twin Cities AIChE Student Chapter

Sarah Tanck, Brian Carrick, Conner Czarnecki, Hunter Nieson, Liz Schulz

<table>
<tr><td>I. Objective</td><td>The objective of this module is to help students understand how chemical engineers scale up reactions in industry through mass balances. This module also shows how engineers can work in teams to troubleshoot and balance effectiveness with profitability.</td></tr>
<tr><td>II. Materials</td><td>a) 1 pair splash goggles per person
b) 1 calculator per person
c) scales (could do one scale per group, or per multiple groups)
d) citric acid (8 g per person plus 16 g per group)
e) baking soda (10 g per person plus 20 g per group)
f) 80 g of tap water
g) 3 paper cups per person
h) 2 spoons per person
i) 1 sandwich bag per person (cheap options work well here because the seals break easier meaning that the students will need to calculate a more precise amount)
j) 1 gallon sized bag per group
k) secondary containment devices (could be a sink or tupperware that the sandwich bag will fit inside of) - depending on size of secondary containment devices, students could share
l) internet access (if you want them to research values (like density of CO_2), an alternative to this could be writing out various values on the board for them to choose from)</td></tr>
<tr><td>III. Procedure</td><td>1) Introduce the activity to the group by reading the intro on the student paper.
2) If you have already spoken about balancing reactions, stoichiometry, and gas volumes, give the students an opportunity to solve the problem on their own, being available for any questions asked. If the students are not familiar with these concepts, more help can be offered by explaining …..
a. balancing equations
b. stoichiometric ratios
c. densities
i. Students can try and solve these problems in any way they want. Creativity is encouraged and there is no ‘right’ way as long as they are learning to experiment and communicate their logic. The way we calculated the starting materials we wanted to use was to first determine the volume of the bag and calculate (using CO_2 density) the amount of moles we would need to fill that bag. We then used stoichiometry to determine the amount of starting materials needed to make that many moles of CO_2.</td></tr>
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3) Once the students have calculated the amount of citric acid and baking soda needed for the reaction, hand out the materials to each individual student. Ensure that students wear goggles and are working in secondary containment devices when running their reaction before explaining that they should pour their citric acid and baking soda in one corner of the bag, twisting that corner, and adding 20-40 g of water to the other corner of the bag. They then should squeeze out the excess air before sealing the bag, untwisting the corner of the bag, and allowing the reaction to occur.
4) After each student has completed their reaction, place the students into groups and have them repeat the project with a gallon sized bag learning from each individual student's previous experiment. (write their group name on the bag before the experiment starts) Repeat step 3 for running the experiment with the gallon sized bag.
5) Once these reactions have finished, line the bags up at the front of the classroom and qualitatively compare them (which bags are the fullest, and least full). Have the students complete the conclusion questions.

If time permits, allow the students to work on the Further Experimentation section. This section is designed to be student-led and come from an interest in the project. Some of these could spark into bigger projects if the students choose to allow for more trial and error. These experiments don't have any one 'right' way to do them, instead allow for the students to be creative.

IV. Theory

Mass/Energy Balance

Stoichiometry is the balancing of a chemical reaction; **3** moles of CO_2 gas are produced when **1** mole of citric acid reacts with **3** moles of baking soda due to the law of conservation of mass. It isn't only mass that needs to be conserved; however, you also need to conserve energy consumed by the reaction. Since the reaction of citric acid and baking soda becomes colder, it is called endothermic. These types of reactions absorb thermal energy from their surroundings and store it in the newly formed chemical bonds and this is why the temperature of the water decreases, it is giving away energy to the reaction.

Expansion of Gases and Ideal Gas Law

As this reaction proceeds, CO_2 is produced from the two solid compounds (citric acid and baking soda). Gases are known to fill any container in which they fill as they have very weak interactions between molecules, unlike the strong interactions present in liquids and solids that bring the molecules close together into condensed states of matter. For example, as liquid CO_2 evaporates into a gas, it expands to 535 times its initial volume. The increase in volume is described according to the ideal gas law and varies depending on the pressure (P), temperature (T), the number of moles of gas within the bag (n), and the ideal gas constant (R):

$$PV = nRT$$

Thus, as the reaction proceeds there is a balance between the number of moles of gas produced and the temperature in the bag due to the endothermic reaction which drives the volume of the bag to increase.

Reaction Engineering

	Reaction engineering is an important aspect of many chemical processes around the world where chemical engineers maximize the production of compounds while requiring the smallest amount of reactants or energy. Through modifying the way a reaction proceeds (changing the amount of reactants or the reaction temperature), the desired response can be fine-tuned to fit numerous specifications. For example, according to the ideal gas law, if the reaction does not produce the right amount of gas or reaches too cold of a temperature, the balloon will not fully inflate. But if too much gas is produced, the balloon may burst! This is why chemical engineers optimize the reaction to blow up the perfect balloon through balancing the reaction progress and energy within the system. The same calculations you performed through this demonstration are used to design reactions that produce millions of tonnes of gas each year; you are all on your way to becoming chemical engineers! **Process Economy** Most of the world's products either directly or indirectly involve chemical reactions; fertilizer is produced through the Haber-Bosch process, many plastics are derived from petroleum, and even Lucky Charms are produced using chemistry. An important concern when developing new products is their economic viability, do they make more money than it costs to produce? As such, companies are focused on producing their products with as little waste as possible and buying the starting materials at low prices. Efficiency can also be achieved through minimizing the amount of chemicals utilized or by speeding up the process through using chemical excess. **Chemical Excess** Chemical excess is one way to modify the reaction kinetics (speed of reaction) or amount of products. Additional amounts of one starting material may cause the reaction to speed up or enable full conversion of the other material if the reaction is otherwise not finished. Chemical engineers use excess to their advantage while meeting deadlines or operating thresholds to maximize the amount of product that a certain reaction produces or decrease the reaction time. Beware and take caution when dealing with chemical excess, especially in scaled-up reactions. The materials may react in unpredicted manners when in excess, leading to the possibility of explosions or other hazards. **Pressure** Pressure is the amount of force exerted over a specific area. It arises from the interactions of molecules bumping against each other and the containers they are in; if the molecules in a container are moving faster, then they will likely have a higher pressure if they are trapped in a container. One way to measure pressure is applying a counter-force on the exterior of a container. By stacking light weights on the sealed bag until the begins to cave in, you can calculate the pressure within the bag due to Newton's second law: "for every action there is an equal and opposite reaction"

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Hello, I'm excited to have you here on the job! Here at Balloon Inc., we create self-inflating balloons using a reaction that produces carbon dioxide. Currently, we only make one size balloon, but we are hoping to scale up our reaction to create larger balloons soon. Your first job here at Balloon Inc. is to calculate the amount of starting materials we need to add to make these larger balloons. Your goal is to have the balloon be as inflated as possible without causing the seal on it breaking. I've written the reaction we use below (keep in mind that it is an **unbalanced equation**) to help you get started. Feel free to look up other values you might need to use and record the sources you use. If you need any help getting started, feel free to ask me or my project engineer (your teacher).

Unbalanced Chemical Equation

$$\_\_\_\ C_6H_8O_{7\,(aq)} + \_\_\_\ NaHCO_{3\,(aq)} \rightarrow \_\_\_\ H_2O_{(l)} + \_\_\_\ CO_{2\,(g)} + \_\_\_\ Na_3C_6H_5O_{7\,(aq)}$$

(Citric Acid) (Baking Soda) (sodium citrate)

*Keep in mind that baking soda will need to be aqueous (dissolved in water) for this reaction to happen

How big is the bag that you are trying to fill? ______________________________

What information and assumptions are you using to calculate how much starting material you need?

How much Citric Acid are you using for your 1st reaction? ______________________________

How much Baking Soda are you using for your 1st reaction? ______________________________

Start Your Reaction

Measure out your citric acid and baking soda and add them to the zip lock bag. Record your exact measurements below

Citric Acid: ________ Baking Soda: ________

Add 20 g of water to the other corner of the bag (it is helpful to twist the corner with baking soda and citric acid to keep it separate from the water)

Seal the bag making sure to squeeze out as much of the air as possible.

Place your bag in secondary containment or a sink and allow the water to mix with the citric acid and baking soda.

What observations can you make from the reaction?

Touch the bag after the reaction is finished and add any more observations made.
(Do not break the seal yet)

This looks like some great work!!! I have a few other engineers working on the same project. I want you to collaborate with them and just see if you can do an even better job filling up a bigger balloon. My project engineer is going to assign you to groups now. Take a minute to look at the work they did, and use all of your past experiments to improve your assumptions for this next experiment.

Safety Assessment Form

Basic Information:

AIChE Community Affiliation: *Student Chapter Name, Local Section Name, Other AIChE Community Name (Technical Entities, Divisions, Forums, Committees, Operating Councils, etc)., Undergraduate Student Member(s), Graduate Student Member(s), Professional Member(s)*	University of Minnesota - Twin Cities AIChE Student Chapter Sarah Tanck, Brian Carrick, Conner Czarnecki, Hunter Nieson, Liz Schulz
Primary Contact Name:	Sarah Tanck
Primary Contact Email Address:	tanck010@umn.edu
Name of Module:	Self-Inflating Balloon Challenge
Brief Description of Module:	Students explore the science behind scaling up a reaction using mass balances, teamwork, and experimentation.
Does your module have a demonstration or experiment component? *Indicate Yes or No*	Yes
Briefly describe any interactive portions of your module:	The students perform multiple reactions which produce CO_2 from citric acid and baking soda.

Materials Used/Waste Generated:

If you need additional space, please insert additional rows and continue numbering sequence.

	Item *Include concentration where applicable*	**Chemical State** *Where applicable, specify solid, liquid, or gas. Otherwise write "N/A"*	**Estimated quantity used** *include units where applicable*	**Estimated amount of waste generated** *Include units where applicable*	**Waste Classification** *Where applicable, specify Acid, Base, Organic, Metal, Oxidizer, Other (include explanation if other), or Regular trash*
1	Citric Acid	Solid/Aqueous Solution	8 grams per student 16 grams per team	depends on whether students use this as an excess reagent in the reaction	Citric acid is a weak acid and will be neutralized with baking soda after the reaction. Once neutralized, it can be flushed down a sink drain.
2	Baking Soda	Solid/Aqueous Solution	10 grams per student 20 grams per team	depends on whether students use this as an excess reagent in the reaction	Baking soda is a weak base and will be neutralized with citric acid after the reaction. Once neutralized, it can be flushed down a sink drain.
3	Sodium Citrate	Solid/Aqueous Solution	0 grams	10 g per student 21 g per team	Solution should be diluted and can then be flushed down a sink drain.
4	Water	Liquid	60 grams	60 grams	Can be disposed of down a sink drain.
5	Paper cups	Solid	3 per person	3 per person (although cups could be reused if this experiment was repeated)	Regular trash
6	Sandwich Bags	Solid	1 per person	1 per person	Regular trash
7	Gallon Bags	Solid	1 per team	1 per team	Regular trash

8	Paper cups	Solid	3 per person	3 per person (although spoons could be reused if this experiment was repeated)	Regular trash

Access to 120V power outlet:

Access required? *Respond Yes/No in the space provided*	No
If yes, specify reasoning/any equipment it will be used for: *Please note that outlets requested to plug in laptops/monitors will not be granted*	

Hazard Identification & Mitigation:

Please ask yourself the following questions prior to completing the below table. ***1) What can go wrong?*** *(Identification of Hazards);* ***2) How bad can it be?*** *(Severity of Hazards);* ***3) How easily or often can it happen?*** *(Frequency or Likelihood);* ***4) How is the risk managed?*** *(Both preventive & mitigation safety measures)*

Hazards: *Describe any hazards associated with the above list of materials used and waste generated and any other hazards associated with the execution of the module*	**There is the possibility that the pressure builds up and may cause the bag to break. The seal on the standard sandwich bags broke prior to the build-up of substantial pressure.** **Citric acid, sodium bicarbonate, and sodium citrate may serve as mild skin and eye irritants. Avoid ingestion and inhalation.**
Safety Measures: *Describe any safety measures that will be taken to mitigate hazards identified above*	**To minimize the chance of spills, limit the amount of citric acid and baking soda such that the reaction scale remains small. Perform the reaction within secondary containment devices to ensure the spill is controlled.** **If any compounds or solutions have contact with your skin, wash the affected areas with soap and water. Obtain medical attention if discomfort continues.** **In case of eye contact, remove contacts and flush eyes with water for 15 minutes while lifting the eyelids. Obtain medical attention if discomfort continues.** **Remind students to not drink or inhale the chemicals.** **Long hair tied back.**
Required PPE: *Specify required PPE, who is required to use it, and within what proximity*	**Students are required to wear goggles in case of splashes.** **Close toed shoes and long pants**

Certification:

I certify that this module is safe for presentation to K-12 community members (including students, parents, and educators) and to AIChE volunteers and community members. I additionally certify that this module is safe for presentation by K-12 community members (such as parents & educators) and by AIChE volunteers and community members.

Sarah Tanck	Sarah Tanck	8/24/21
Primary Contact Name	**Primary Contact Signature**	**Date**