The Airbag Lab: An Application of Stoichiometry (Honors Chemistry Lab 25)

Timing is everything in an airbag's ability to deploy quickly enough to save a life in a head-on collision. An airbag must be able to deploy in a matter of milliseconds from the initial collision impact, and be prevented from deploying when there is no head-on collision. Thus, the main component of the airbag system is a sensor that can detect head-on collisions and immediately trigger the airbag's deployment. The crash sensor is a steel ball that slides inside a smooth bore. The ball is held in place by a permanent magnet or by a stiff spring, which inhibit the ball's motion when the car drives over bumps or potholes. However, when the car decelerates very quickly, as in a head-on crash, the ball suddenly moves forward and turns on an electrical circuit, initiating the process of inflating the airbag. Once the electrical circuit has been turned on by the sensor, a pellet of sodium azide (NaN_3) is ignited. A rapid reaction occurs, generating nitrogen gas (N_2). This gas fills a nylon or polyamide bag at a velocity of 150 to 250 miles per hour. This process, from the initial impact of the crash to full inflation of the airbag, takes only about 40 milliseconds. Ideally, the body of the driver should hit the airbag while the airbag begins to deflate. Otherwise, the high internal pressure of the airbag would create a surface as hard as stone. Inside the airbag is a gas generator containing a mixture of NaN_3, KNO_3, and SiO_2. When the car undergoes a head-on collision, a series of three chemical reactions inside the gas generator produce gas (N_2) to fill the airbag and convert NaN_3, which is highly toxic, to harmless glass. Sodium azide (NaN_3) can decompose at 300ºC to produce sodium metal (Na) and nitrogen gas (N_2). The signal from the deceleration sensor ignites the gas-generator mixture by an electrical impulse, creating the high-temperature condition necessary for NaN_3 to decompose. The nitrogen gas that is generated then fills the airbag. The purpose of the KNO_3 and SiO_2 is to remove the sodium metal (which is highly reactive and potentially explosive, by converting it to a harmless material. First, the sodium reacts with potassium nitrate (KNO_3) to produce potassium oxide (K_2O), sodium oxide (Na_2O), and additional N_2 gas. The N_2 generated in this second reaction also fills the airbag, and the metal oxides react with silicon dioxide (SiO_2) in a final reaction to produce silicate glass, which is harmless and stable.

Reaction 1: $2NaN_3 \rightarrow 2Na + 3N_2$

Reaction 2: $10Na + 2KNO_3 \rightarrow K_2O + 5Na_2O + N_2$

Reaction 3: $K_2O + Na_2O + SiO_2 \rightarrow Na_2K_2SiO_4$ (alkaline silicate glass)

In this lab, you will conduct an experiment where you will design and construct an airbag by reacting an acid and a base together, generating a gas that will fill a sealable bag. You will then test your design by constructing a vehicle with an airbag and passenger (an egg) and subjecting the vehicle to an impulse (i.e., crash).

Pre-lab Question: The reactants in this acid-base reaction will be acetic acid and sodium bicarbonate. Write and balance the reaction that will occur inside your airbag. Is this an oxidation reduction reaction or a metathesis reaction? Please justify your answer.

1. You will test out the reaction by adding 1 gram of sodium bicarbonate to 25 ml of acetic acid in a sealable sandwich bag. You may choose to wrap the sodium bicarbonate in a tissue before dropping it into the acetic acid. This will allow you to control the reaction.

2. Determine the best way to drop the wrapped sodium bicarbonate into the acetic acid in the bag without losing any gas. You will also need to flatten the bag to remove air and seal the bag as quickly as possible.

3. Drop the sodium bicarbonate into the acetic acid and record your observations. After the reaction becomes slow or stops, mix the ingredients to make sure the reaction is complete. Again, record your observations. You may choose to include the amount of time for inflation, etc. in your observations. Pay special attention to the inflation of the bag and think about how you could change this to make a better airbag. Also note that your final airbag design must not exceed 12.0 grams.

4. Based on the first investigation, calculate the amounts of acetic acid and sodium bicarbonate you would need to react to fully inflate the bag and leave the least amount of left-over reactants. In other words, what is the most gaseous product you can generate to fill the bag, but not have it pop open and not leave excess reactants?

5. You will need to get the volume of the bag. Create your own plan to do this. Describe your plan in your lab book, also record your measurements and volume.

6. Calculate the moles of sodium bicarbonate and the moles of acetic acid you used in step 1. You are using a 0.8 M solution of acetic acid. That means there is 0.8 mole of acetic acid in 1 liter of solution. Depending on what order we complete labs this semester, you may not be familiar for the concept of molarity. I will explain molarity, if that is the case.

7. Design and conduct a procedure to experimentally determine the density of the acetic acid. What is the density your determined? Explain how you could use this information in your design?

8. Using your calculated values, test your hypotheses by experimentation to determine the best amounts of acetic acid and sodium bicarbonate to use in your airbag. Record all ideas, procedures, calculations and investigations results in your lab notebook. Please note that you will only be given 300 mL of acetic acid and 10 grams of sodium bicarbonate and your final airbag design must not exceed 12.0 grams. Additional reagents will incur a 2-point deduction per 3 grams of material. This is all part of the airbag challenge.

9. You will be graded on the efficiency of your airbag design, which means using the least mass of chemicals to create the maximum amount of carbon dioxide gas. Each group must work efficiently and effectively to produce the most volume of gaseous product without going over 12.0 grams. Design and build a vehicle for your passenger (a raw egg) so that when it falls, the airbag will protect it. The vehicle will be dropped from a height of 2 meters. Alternatively, we may as a class choose to roll a vehicle down an incline and into a wall. We will discuss this prior to designing your vehicles. Record all information for your design in the lab book, including a schematic. The only materials you can use for the vehicle are: small cardboard box, two sealable plastic bags, tissue paper, 0.8 M solution of acetic acid, sodium bicarbonate, and tape. During the development of your vehicle, you may also use: graduated cylinders and other glassware in the classroom, electronic balance, and a meter stick. You will not be given an egg for testing your design; eggs will only be used in the final competition.

Post Lab Questions:

Q1. Did your design protect the passenger? Please describe what you could have adjusted to improve the efficiency of your design.

Q2. Which starting material used in a real airbag inflator is the least important for proper inflation? Do you feel it would be necessary to have it present in an exact stoichiometric ratio? Please justify your response.

Q3. What is the correct stoichiometric ratio between NaN_3 and KNO_3 to ensure all the Na is reacted? What would be some possible consequences if an excess of KNO_3 was left over?

Q4. Was the reaction endothermic or exothermic? Please sketch a graph of the energy versus the reaction progress.

Q5. A typical airbag contains 50.0 g of sodium azide, NaN_3. Upon impact, the airbag deploys and inflates within 40 milliseconds to a volume of about 60 L, at a velocity nearing 250 mph. The airbag inflates due to the decomposition reaction of NaN_3 and fills with nitrogen gas as indicated in the background information.

a. If 50.0 g of NaN_3 decompose, how many moles of N_2 will be produced? How many grams of N_2 will be produced?

b. How many moles of Na will be formed from this reaction? How many grams of Na will be formed?

c. A second reaction must occur to remove the Na, which is highly reactive and potentially explosive, as you seen in my demonstrations. How many additional grams of the N_2 will form in this second reaction?

Please self-assess your lab report using the rubric/checklist