Change in Pressure during Chemical Reaction

In a reaction of acetic acid with sodium carbonate carbon dioxide is produced. If the reaction proceeds in a closed container, the produced carbon dioxide causes a pressure increase. This is the basis of a "bomb" made from vinegar, baking soda and a plastic container from a Kinder Egg. Is it possible to estimate the pressure increase by calculation?

What you need

- vinegar
- baking soda
- glass flask with a volume of about 1 l and reasonably wide ground glass neck – this is necessary for its good sealing properties
- Vernier GPS-BTA pressure sensor (the sensor comes with accessories, including tubing, syringe and stopper)

Tasks

Preparation

1. Measure the volume of the flask.
2. Pour a few tablespoons of baking soda into the flask (not all of it will react, but it is better to have more than less).
3. Draw approximately 10 ml of vinegar into the syringe. If there are bubbles of air inside, remove them.
4. Seal the flask using a stopper with two outputs (it is in the box with the pressure sensor).

5. Screw a tube to one of the outputs; connect its other end to the pressure sensor.
6. Screw the syringe to the second output. It should look like the picture.
7. Connect the pressure sensor to the computer and run the Vernier Logger Lite program.
8. Set the Sampling Rate to 10 Hz and check *Continuous Data Collection*.

Calculation

Below this text there are some questions which should make the calculation easier. If you like challenges, you can proceed in the calculation of the pressure increase after adding 1 ml of vinegar without following the questions; on your own.

All calculations can be made with a certain approximation. You can round off the resulting values and use sensible estimations.

1. What is the volume occupied by 1 mole of gas under normal conditions?
2. What is the volume of air in the flask?
3. What is the number of moles of air in the flask? (consider that the pressure and temperature in the flask does not significantly differ from so called normal conditions)
4. Find a chemical equation describing the reaction between vinegar and baking soda.
5. How many molecules of carbon dioxide are produced during a reaction of one molecule of acetic acid?
6. What is the concentration of acetic acid in vinegar?
7. How many grams of acetic acid are there in 1 ml of vinegar? (consider the density of acetic acid to be the same as the density of water)

8. What is the molar mass of acetic acid?
9. What is the number of moles of acetic acid in 1 ml of vinegar?
10. What is the number of moles of carbon dioxide produced in the reaction?
11. What is the total number of moles of gas in the flask?
12. What is the equation of state of an ideal gas? What is the relationship between the pressure and the number of moles?
13. What is the pressure change after injecting 1 ml of vinegar into the flask?

Measurement

1. Start the measurement.
2. Inject 1 ml of vinegar from the syringe into the flask.
3. After a few seconds, once the pressure stabilizes, repeatedly inject vinegar into the flask. This forms “steps” in the graph.
4. Stop the measurement. Read from the graph the pressure changes in individual cases (the "height of the step"). Calculate the average pressure increase after adding 1 ml of vinegar.
5. Compare the measurement results with theoretical estimation.

Notes for teachers

1. What is the volume occupied by 1 mole of gas under normal conditions?

   22.4 dm^3 = 22.4 l

2. What is the volume of air in the flask?

   this needs to be measured; in our case it was ca. 1 l

3. What is the number of moles of air in the flask? (consider that the pressure and temperature in the flask does not significantly differ from so called normal conditions)

   1/22.4 mol = 0.0446 mol (for different volume of the flask this can be a different value)

4. Find a chemical equation describing the reaction between vinegar and baking soda.

$$CH_3COOH + NaHCO_3 \longrightarrow CO_2 + CH_3COONa + H_2O$$

5. How many molecules of carbon dioxide are produced during a reaction of one molecule of acetic acid?

   one

6. What is the concentration of acetic acid in vinegar?

   8 %

7. How many grams of acetic acid are there in 1 ml of vinegar? (consider the density of acetic acid to be the same as the density of water)

   the mass of 1 ml of water is 1 g; 8 % from 1 g is 0.08 g

8. What is the molar mass of acetic acid?

   approximately 60 g/mol

9. What is the number of moles of acetic acid in 1 ml of vinegar?

   0.00133 mol

10. What is the number of moles of carbon dioxide produced in the reaction?

    it is the same, i.e. 0.00133 mol

11. What is the total number of moles of gas in the flask?

    0.0446 mol + 0.00133 mol = 0.459 mol

12. What is the equation of state of an ideal gas? What is the relationship between the pressure and the number of moles?

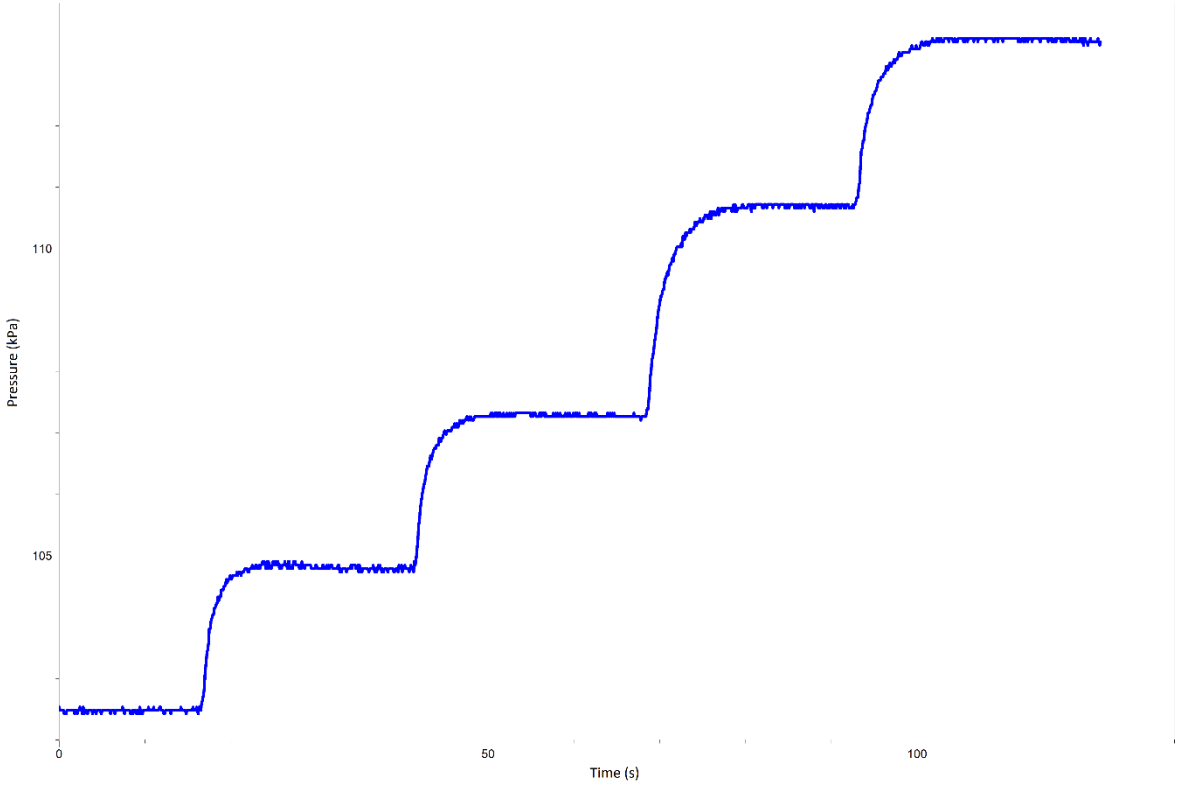
    pV = nRT, in addition to R*, the volume* V *and temperature* T *can also be considered constant; the pressure* p *is therefore directly proportional to the number of moles*

13. What is the pressure change after injecting 1 ml of vinegar into the flask?

    the number of moles increases by about 3 %, therefore the pressure too increases by about 3 % from 100 kPa to 103 kPa

    The pressure increase is about 3 kPa

A typical measurement is as follows:



The pressure difference (the height of individual "steps") was as follows:

- 2.33 kPa
- 2.50 kPa
- 3.44 kPa
- 2.73 kPa

The average value of pressure increase after the injection of 1 ml of vinegar was 2.75 kPa. This corresponds nicely to the theoretical estimation.