IB CHEMISTRY HL IA
Clay Soil Swelling

Research Question:

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Contents

1 Introduction

2 Purpose

The purpose of this investigation is to determine the relationship between the factor by which the volume of sodium bentonite increases and the concentration of H^+ of an acidic solution when an acidic solution and sodium bentonite mixes.

3 Background Information

Clay soils, such as sodium bentonite, are composed of negatively charged ”platelike layers” that are balanced by cations nested in between those layers (Chen, Grabowski, & Goel, 2022). Clay swelling when mixed with a solution mainly occurs as a result of the attraction of water molecules into the interlayer space of the clay, causing the interlayer space to grow (Chen et al., 2022).

The effect that the acidity of the solution plays on the degree to which the clay swells will vary depending on the composition of the clay. Sodium bentonite is expected to swell less when mixed with higher acidity solutions due to the interlayer cation replacement of Na^+ with H^+, in which because the ionic radius of H^+ (0.012 Å) is lower than that of Na^+ (1.02 Å), then the amount of clay swelling is reduced (Rama Vara Prasad, Hari Prasad Reddy, Ramana Murthy, & Sivapullaiah, 2018).

4 Proof of Concept

Before the experiment was performed, a proof of concept was done to determine whether there is a difference in swelling between different concentrations and what the range of concentrations should be in order to obtain a holistic result.

Initially, two test trials were done where 1.0 mL of 1.0 mol dm^{-3} HCl and 1.0 mL of water were each mixed into 1.0 mL of bentonite clay in 10 mL graduated cylinders. In both mixtures, the bentonite clay was not completely mixed with the solutions, with virtually all the acidic solution being absorbed by the clay as seen in Figure 1.

Figure 1: Proof of Concept Trial of 1.0 mL 1.0 mol dm^{-3} HCl with 1.0 mL bentonite clay

This heavy absorption of the clay was heavily problematic for the actual experiment, as not only does it not ensure complete absorption of the solution but also leads to difficulty in cleaning out the mixture especially in a 10 mL graduated cylinder. On the packaging of the bentonite clay, it recommends that the clay and solution should be mixed at a 1:10 ratio.

Two additional test trials were done with 10 mL of 1.0 mol dm^{-3} HCl and 10 mL of water, each mixed into 1.0 mL of bentonite clay in 25 mL graduated cylinders. Mixing between bentonite clay and the solutions were way better with a significant difference in swelling between the two mixtures (the acid swelled the clay by a factor of about 3, while the water swelled the clay by a factor of about 5.6). These two test trials are shown in Figure 2.

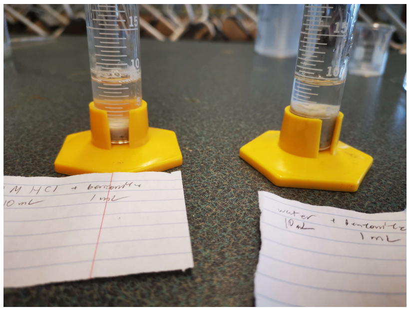

Figure 2: Proof of Concept Trial of 10 mL 1.0 mol dm^{-3} HCl (left) and 10 mL of water (right) with 1.0 mL bentonite clay

It was at this point when there was the realization that it is likely better to mix the clay into the solution rather than the other way around to ensure optimal absorption of the solution by the clay. However, what is to come next is determining the best maximum [H^+] to see the optimal holistic result in the relationship between the factor of swelling and [H^+]. In this proof of concept, the method of mixing the solution into the clay was continued to ensure that there is consistency between the test trials.

One interesting qualitative observation at this point was that in the mixture of bentonite clay with water, there was a hole in the immersed bentonite clay, as seen in Figure 3.

It is unknown why this occurs, but it may be suggested that this could be as a result of mixing solution into the clay, therefore mixing clay into the solution may mitigate this issue.

Finally, 10 mL of 2.0 mol dm^{-3} was mixed with 1.0 mL of bentonite clay. The factor to which the bentonite had swollen by in this mixture (2.8 times) doesn't differ much compared to the mixture with 10 mL of 1.0 mol dm^{-3} HCl, therefore it was decided that 1.0 mol dm^{-3} will be the maximum concentration for this investigation.

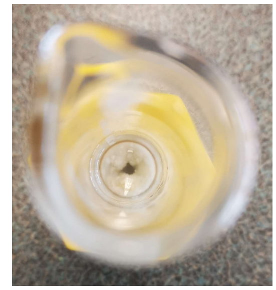

Figure 3: Hole in bentonite clay in test trial between 10 mL of water with 1.0 mL bentonite

5 Hypothesis

The hypothesis for this experiment is that the relationship between the factor by which the volume of sodium bentonite swells and the concentration of H^+ ions of the mixed solution will be indirectly proportional in linear fashion given that a linear increase in [H^+] means a linear increase of H^+ ions that become available to replace Na^+ ions.

However, it is predicted that there will be a point where a decrease in swelling will begin to slow down when a deficiency of Na^+ ions in between the bentonite clay layers grows. It is hypothesized that this effect will be manifested as a horizontal asymptote on the plotted graph of the Factor of swelling as a function of [H^+].

6 Variables

6.1 Manipulated Variable

The manipulated variable is the pH of the solution mixed with the bentonite clay. In this lab, the manipulated variable will be changed by acid dilution.

6.2 Responding Variable

The responding variable is the factor by which the clay has swollen by. The responding variable will be measured using a 25 mL graduated cylinder.

6.3 Controlled Variable 1: Clay swelling duration

6.3.1 How to control it

For each trial, set a timer for a set amount of time and record the final volume when the timer ends.

6.3.2 Why it must be controlled

6.4 Controlled Variable 2: Volume of initial clay

6.4.1 How to control it

Consistently use a set volume of bentonite clay for each trial. Note that because bentonite is rather sticky and therefore is tough to clean out of a thin graduated cylinder, then it is best to standardize the volume of clay committed for the experiment by taking the volume of the dry bentonite with a graduated cylinder and transferring it to a weigh boat to determine what mass of clay is associative with the set volume of clay.

6.4.2 Why it must be controlled

7 Equipment and Materials

- Lab Apron
- Lab Goggles

- Waste Beakers
- Distilled Water
- Sodium Bentonite Clay
- $1.0\,\mathrm{mol\,L^{-1}}$ hydrochloric acid (HCl)
- $0.1\,\mathrm{mol\,L^{-1}}$ hydrochloric acid (HCl)
- (1) 10 mL Graduated Cylinder
- (5) 25 mL Graduated Cylinders
- (3) 100 mL Volumetric Flasks
- 10 mL pipette
- (5) Weigh Boats
- Pipette pump
- Scoopula
- Stir rod
- Digital Balance
- Timer

8 Safety, Environmental, and Ethical Considerations

- When performing acid dilution, always add the acid into the water and not the other way around.
- Dispose of any waste containing acid to a waste beaker

9 Procedure

1. Put on lab apron and eye protection
2. Using the 10 mL pipette, transfer 50 mL of distilled water to the 100 mL volumetric flask
3. Top up the 100 mL volumetric flask with $1.0\,\mathrm{mol\,dm^{-3}}$ HCl to obtain a 100 mL solution of $0.5\,\mathrm{mol\,dm^{-3}}$ HCl
4. Repeat Steps 2 and 3 using $0.1\,\mathrm{mol^{-3}}$ HCl to obtain a 100 mL solution of $0.05\,\mathrm{mol\,dm^{-3}}$ HCl
5. Using the 10 mL pipette, transfer 10 mL of distilled water to the 100 mL volumetric flask
6. Top up the 100 mL volumetric flask with $1.0\,\mathrm{mol\,dm^{-3}}$ HCl to obtain a 100 mL solution of $0.01\,\mathrm{mol\,dm^{-3}}$ HCl
7. Using a scoopula, transfer bentonite clay into the 10 mL graduated cylinder until there is 1 mL of bentonite clay.
8. Place a weigh boat onto the digital balance and tare the balance.
9. Transfer all the bentonite clay in the 10 mL graduated cylinder into the weight boat and

10 Evidence

11 Processed Data

12 Analysis

13 Evaluation

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