

IB CHEMISTRY HL IA

Clay Soil Swelling

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Contents

1	Introduction	1
2	Purpose	1
3	Background Information	1
4	Proof of Concept	1
5	Hypothesis	2
6	Variables	2
6.1	Manipulated Variable	2
6.2	Responding Variable	2
6.3	Controlled Variable 1: Clay swelling duration	2
6.3.1	How to control it	2
6.3.2	Why it must be controlled	2
6.4	Controlled Variable 2: Volume of initial clay	2
6.4.1	How to control it	2
6.4.2	Why it must be controlled	3
6.5	Controlled Variable 3: Volume of solution mixed with clay	3
6.5.1	How to control it	3
6.5.2	Why it must be controlled	3
7	Equipment and Materials	3
8	Safety, Environmental, and Ethical Considerations	3
9	Procedure	4
10	Evidence	5
10.1	Qualitative Observations	5
10.2	Quantitative Data	6
10.3	Uncertainty Propagation	6
11	Analysis	7
12	Conclusion	12
12.1	Summary	12
12.2	Evaluation	12
12.3	Suggested improvements	12
	References	12

1 Introduction

2 Purpose

The purpose of this investigation is to determine the relationship between the factor by which the volume of sodium bentonite swells and the concentration of H^+ of an acidic solution $/\text{mol dm}^{-3}$ when the 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 \AA) is lower than that of Na^+ (1.02 \AA), 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.

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.

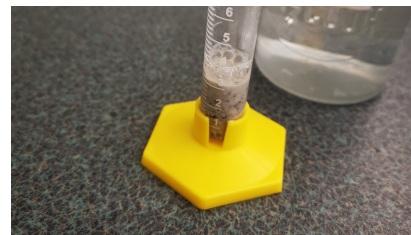


Figure 1: Proof of Concept Trial of 1.0 mL 1.0 mol dm^{-3} HCl with 1.0 mL bentonite clay

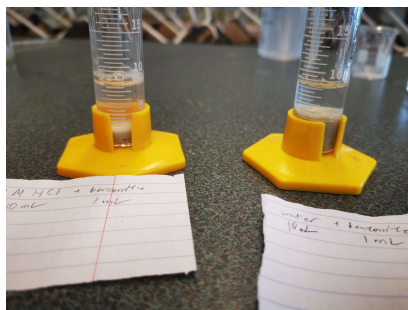


Figure 2: Proof of Concept Trial of 10 mL 1.0 mol dm^{-3} HCl (left) and 10 mL of water (right) with 1.0 mL bentonite clay

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.

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 $[\text{H}^+]$ to see the optimal holistic result in the relationship between the factor of swelling and $[\text{H}^+]$. 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.

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 $[\text{H}^+]$ means a linear increase of the amount 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 $[\text{H}^+]$.

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

Inconsistent durations of time between trials will entail that the clays that were allowed more time to swell will be able to swell more than it should relative to the other trials. Note that in the process, there will be a slight difference in duration allowed between the 5 trials that share the same $[\text{H}^+]$. This is not significant as due to the slow nature of clay swelling, a difference in duration by under a minute will not lead to major inconsistencies.

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.

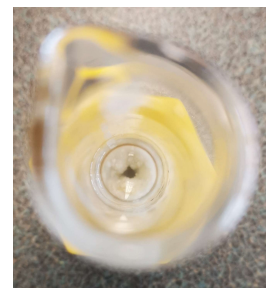


Figure 3: Hole in bentonite clay in test trial between 10 mL of water with 1.0 mL bentonite

6.4.2 Why it must be controlled

Differing the volume of initial clay between trials will lead to major differences in sodium ions present in the clay. This will lead to inconsistencies of the swelling factor as there will be more/less sodium ions ready to be exchanged with hydrogen ions.

6.5 Controlled Variable 3: Volume of solution mixed with clay

6.5.1 How to control it

Measure the same volume of solution for each trial.

6.5.2 Why it must be controlled

Differing the volume of solution mixed with the clay between different trials will lead to major difference of the amount H^+ ions available to be exchanged with Na^+ ions in the clay. Because this ion exchange is essential to the behaviour of swelling in bentonite clay, the volume of the solution mixed with the clay must be controlled.

7 Equipment and Materials

- Lab Apron
- Lab Goggles
- Waste Beakers
- Distilled Water
- Sodium Bentonite Clay
- 1.00 mol dm^{-3} hydrochloric acid (HCl) ($\pm 0.03 \text{ mol dm}^{-3}$)
- $0.100 \text{ mol dm}^{-3}$ hydrochloric acid (HCl) ($\pm 0.006 \text{ mol dm}^{-3}$)
- (1) 10.00 mL Graduated Cylinder ($\pm 0.02 \text{ mL}$)
- (5) 25.0 mL Graduated Cylinders ($\pm 0.3 \text{ mL}$)
- (3) 100.0 mL Volumetric Flasks ($\pm 0.2 \text{ mL}$)
- 10.00 mL pipette ($\pm 0.04 \text{ mL}$)
- (5) Weigh Boats
- Pipette pump
- Scoopula
- (2) Stir rod
- Paper towel
- Digital Balance ($\pm 0.003 \text{ g}$)
- Timer

8 Safety, Environmental, and Ethical Considerations

- Always remember to wear your lab apron and eye protection before proceeding with the experiment
- No consumption of food or water during the experiment
- Read the Safety Data Sheet of hydrochloric acid before beginning the experiment
- Thoroughly wash any skin that has been in contact with hydrochloric acid
- 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, labelling the beaker with contents and approximate $[\text{H}^+]$
- Take caution when attaching/detaching a pipette pump onto/from a pipette, ensuring that the distance between your two hands do not apply overwhelming torque onto the pipette

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 mol dm^{-3} HCl to obtain a 100 mL solution of 0.5 mol dm^{-3} HCl
4. Repeat Steps 2 and 3 using 0.1 mol^{-3} HCl to obtain a 100 mL solution of 0.05 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 mol dm^{-3} HCl to obtain a 100 mL solution of 0.01 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 record the mass of the bentonite clay
10. Place another weight boat on the digital balance, tare the balance, then transfer enough bentonite clay using the scoopula such that the mass read by the balance matches the mass found in Step 9.
11. Repeat Step 10 for all 5 weigh boats.
12. Using the 10 mL pipette, transfer 10 mL of a solution to each 25 mL graduated cylinder
13. Flick the bottom of each weight boat such that all the clay reaches to one corner, then proceed to transfer the clay of each weigh boat to each 25 mL graduated cylinder as quickly as possible
14. Set a timer for 10 minutes
15. As the timer approaches its end, start flicking each graduated cylinder to force all the bentonite clay to be submerged at the bottom of the graduated cylinder
16. Once the timer ends, record the final volumes of bentonite clay in each 25 mL graduated cylinder
17. If the solution is acidic, first transfer remaining solution into the waste beaker, using an acid designated stir rod to remove the majority of the clay. Fill up the graduated cylinder with water, then transfer the water and any large chunks of clay into the waste beaker again
18. Repeatedly fill the graduated cylinder with water and scrub the interior with a stir rod wrapped by paper towel until no clay remains
19. Repeat Steps 10 to 18 for all solutions
20. Wash your hands thoroughly after the experiment and clean the laboratory workspace



Figure 4: Lab setup prior to mixing between bentonite clay and the solution

10 Evidence

10.1 Qualitative Observations

- The sodium bentonite clay is a grey powder that appears in various sizes (fine to the size of a grain of sand). Fine parts of the clay easily stick to glassware and the weigh boats
- The hydrochloric acid is a clear colourless solution for all $[H^+]$ concentrations used in this experiment
- None of the trials lead to a hole in the submerged clay that was observed in the proof of concept mixture between water and bentonite clay
- When the clay is mixed with water
 - The submerged clay releases black solids resembling sesame seeds
 - The solution immediately changes into a murky white
 - The submerged clay turns into a dark grey in the form of fluffy particles significantly larger than the dry grains of clay
- When the clay is mixed with $0.01 \text{ mol dm}^{-3} \text{ HCl}$
 - The clay turns into a dark grey, but not as dark as in the trials with water
 - Initially, solution mixed with the clay remains clear and colourless. However, the solution turns white and murky upon agitation
- When the clay is mixed with $0.05 \text{ mol dm}^{-3} \text{ HCl}$ or $0.1 \text{ mol dm}^{-3} \text{ HCl}$
 - The solution overtime turns from clear and colourless to white and murky
 - Submerged clay is white than that of the 0.01 mol dm^{-3} trials
- When the clay is mixed with $0.5 \text{ mol dm}^{-3} \text{ HCl}$ or $1.0 \text{ mol dm}^{-3} \text{ HCl}$
 - The solution immediately turns white and murky
 - There is bubbling at the meniscus of the solution
 - All the submerged clay is fine and does not stick to the glassware

10.2 Quantitative Data

- The initial volume of the bentonite clay was $1.00 \text{ mL} \pm 0.02 \text{ mL}$. This initial volume was standardized to be $0.810 \text{ g} \pm 0.003 \text{ g}$.

Table 1: Raw data of final volume of bentonite clay for 5 trials of each hydrochloric acid concentration

Concentration of HCl in the solution / mol dm^{-3}	Final Volume of submerged bentonite clay / $\text{mL} \pm 0.3 \text{ mL}$				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0 (Distilled Water)	8.5	8.5	7.5	9.0	8.0
0.0100 ± 0.0007	8.0	8.5	9.0	9.5	7.5
0.050 ± 0.003	5.5	5.5	5.5	6.0	5.0
0.100 ± 0.006	5.0	5.0	5.0	5.0	5.0
0.50 ± 0.02	4.0	4.5	4.0	4.5	4.0
1.00 ± 0.03	3.0	3.0	2.8	2.8	2.0

10.3 Uncertainty Propagation

The 1.00 mol dm^{-3} HCl and $0.100 \text{ mol dm}^{-3}$ HCl solutions were prepared by a lab technician using the following materials.

- 12.0 mol dm^{-3} HCl ($\pm 3\%$ according to (*Hydrochloric Acid, Concentrate 12M, ACS, 2.5L, DG APPLICABLE*, n.d.))
- 1000.0 mL Volumetric Flask ($\pm 0.6 \text{ mL}$) for acid dilution
- 100.0 mL Graduated Cylinder ($\pm 0.3 \text{ mL}$) for measuring volume of distilled water

The uncertainty for 1.00 mol dm^{-3} HCl and $0.100 \text{ mol dm}^{-3}$ can then be calculated. A sample calculation for 1.00 mol dm^{-3} HCl is shown below.

$$C_2 = 1.00 \text{ mol dm}^{-3}, \quad C_1 = 12.0 \text{ M} \pm 3\%, \quad V_2 = 1000.0 \text{ mL} \pm 0.6 \text{ mL}$$

$$V_1 = \frac{C_2 V_2}{C_1}$$

$$V_1 = \frac{1.00 \text{ mol dm}^{-3} \cdot 1000.0 \text{ mL}}{12.0 \text{ mol dm}^{-3}}$$

$$= 83.3 \text{ mL}$$

From the uncertainty for the 100.0 mL graduated cylinder

$$V_1 = 83.3 \text{ mL} \pm 0.3 \text{ mL}$$

$$\Delta C_2 = C_2 \left(\frac{\Delta C_1}{C_1} + \frac{\Delta V_2}{V_2} + \frac{\Delta V_1}{V_1} \right)$$

$$= 1.00 \text{ mol dm}^{-3} \left(3\% + \frac{0.6 \text{ mL}}{1000.0 \text{ mL}} + \frac{0.3 \text{ mL}}{83.3 \text{ mL}} \right)$$

$$= 0.03 \text{ mol dm}^{-3}$$

$$C_2 = 1.00 \text{ mol dm}^{-3} \pm 0.03 \text{ mol dm}^{-3}$$

The uncertainties for the rest of the diluted solutions are then determined in a similar fashion given the following considerations:

- The 0.50 mol dm^{-3} HCl solution was diluted from the $1.00 \text{ mol dm}^{-3} \pm 0.03 \text{ mol dm}^{-3}$ HCl solution

- The $0.050 \text{ mol dm}^{-3}$ HCl solution and $0.0100 \text{ mol dm}^{-3}$ HCl solution were diluted from the $0.100 \text{ mol dm}^{-3} \pm 0.006 \text{ mol dm}^{-3}$ HCl solution
- 3 $100.0 \text{ mL} \pm 0.2 \text{ mL}$ volumetric flasks were used for acid dilution
- A $10.00 \text{ mL} \pm 0.04 \text{ mL}$ pipette was used to measure volume of distilled water

11 Analysis

To find the factor of swelling, we must take the final volume of submerged bentonite clay and divide that by the initial volume of bentonite clay. Because the initial volume of bentonite clay was 1.00 mL , then the factor of swelling for each of the 5 trials would be the same. However, due to the presence of uncertainty in both the 25 mL graduated cylinder used for the final volume of submerged bentonite clay and the 10 mL graduated cylinder used to measure the initial $1.00 \text{ mL} \pm 0.02 \text{ mL}$ of bentonite clay. A sample calculation of this is shown below using the first trial of the mixture between distilled water and bentonite clay.

Let F = Factor of swelling of the bentonite clay

V_f = The final volume of bentonite clay /mL

V_i = The initial volume of bentonite clay /mL

$$F = 8.5, \quad V_f = 8.5 \text{ mL} \pm 0.3 \text{ mL}, \quad V_i = 1.00 \text{ mL} \pm 0.02 \text{ mL}$$

$$\begin{aligned} F &= \frac{V_f}{V_i} \\ \therefore \Delta F &= F \left(\frac{\Delta V_f}{V_f} + \frac{\Delta V_i}{V_i} \right) \\ &= (8.5) \left(\frac{0.3 \text{ mL}}{8.5 \text{ mL}} + \frac{0.02 \text{ mL}}{1.00 \text{ mL}} \right) \\ &= 0.5 \\ F &= 8.5 \pm 0.5 \end{aligned}$$

The next step is to determine the upper and lower bounds of each trial's factor of swelling using this calculated uncertainty as exemplified below using the first trial of the mixture between distilled water and bentonite clay.

$$\begin{aligned} F_{upper} &= F + \Delta F = 8.5 + 0.5 = 9.0 \\ F_{lower} &= F - \Delta F = 8.5 - 0.5 = 8.0 \end{aligned}$$

Now, the overall value of the factor of swelling can be determined using the average between the maximum and minimum values selected from the upper and lower bounds of each trial's factor of swelling along with half the difference between the same values. This calculation is shown below using the trials for the mixture between bentonite clay and distilled water.

$$\begin{aligned}
F_{max} &= 9.5, \quad F_{min} = 7.1 \\
\bar{F} &= \frac{F_{max} + F_{min}}{2} \\
&= \frac{9.5 + 7.1}{2} \\
&= 8 \\
\Delta F &= \frac{F_{max} - F_{min}}{2} \\
&= \frac{9.5 - 7.1}{2} \\
&= 1 \\
F &= \bar{F} \pm \Delta F \\
F &= 8 \pm 1
\end{aligned}$$

Tables 2 to 5 present all the processed data for all trials.

Table 2: The uncertainty of the factor of swelling per trial for each concentration used in the experiment

Concentration of HCl in the solution /mol dm ⁻³	Uncertainty of the factor of swelling per trial				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0 (Distilled Water)	0.5	0.5	0.5	0.5	0.5
0.0100 ± 0.0007	0.5	0.5	0.5	0.5	0.5
0.050 ± 0.003	0.4	0.4	0.4	0.4	0.4
0.100 ± 0.006	0.4	0.4	0.4	0.4	0.4
0.50 ± 0.02	0.4	0.4	0.4	0.4	0.4
1.00 ± 0.03	0.4	0.4	0.4	0.4	0.3

Table 3: The upper bound of the factor of swelling per trial for each concentration used in the experiment

Concentration of HCl in the solution /mol dm ⁻³	Upper bound of the factor of swelling per trial				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0 (Distilled Water)	9.0	9.0	8.0	9.5	8.5
0.0100 ± 0.0007	8.5	9.0	9.5	10.0	8.0
0.050 ± 0.003	5.9	5.9	5.9	6.4	5.4
0.100 ± 0.006	5.4	5.4	5.4	5.4	5.4
0.50 ± 0.02	4.4	4.9	4.4	4.9	4.4
1.00 ± 0.03	3.4	3.4	3.2	3.2	2.3

Table 4: The lower bound of the factor of swelling per trial for each concentration used in the experiment

Concentration of HCl in the solution /mol dm ⁻³	Lower bound of the factor of swelling per trial				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0 (Distilled Water)	8.0	8.0	7.1	8.5	7.5
0.0100 ± 0.0007	7.5	8.0	8.5	9.0	7.1
0.050 ± 0.003	5.1	5.1	5.1	5.6	4.6
0.100 ± 0.006	4.6	4.6	4.6	4.6	4.6
0.50 ± 0.02	3.6	4.1	3.6	4.1	3.6
1.00 ± 0.03	2.6	2.6	2.4	2.4	1.7

Table 5: The overall factor of swelling for each concentration of HCl

Concentration of HCl in the solution /mol dm ⁻³	Factor of swelling
0 (Distilled Water)	8 ± 1
0.0100 ± 0.0007	9 ± 1
0.050 ± 0.003	5.5 ± 0.9
0.100 ± 0.006	5.0 ± 0.4
0.50 ± 0.02	4.3 ± 0.6
1.00 ± 0.03	2.5 ± 0.9

Plotting this processed data as Factor of swelling of bentonite clay as a function of [HCl] results in the graph in Figure 5.

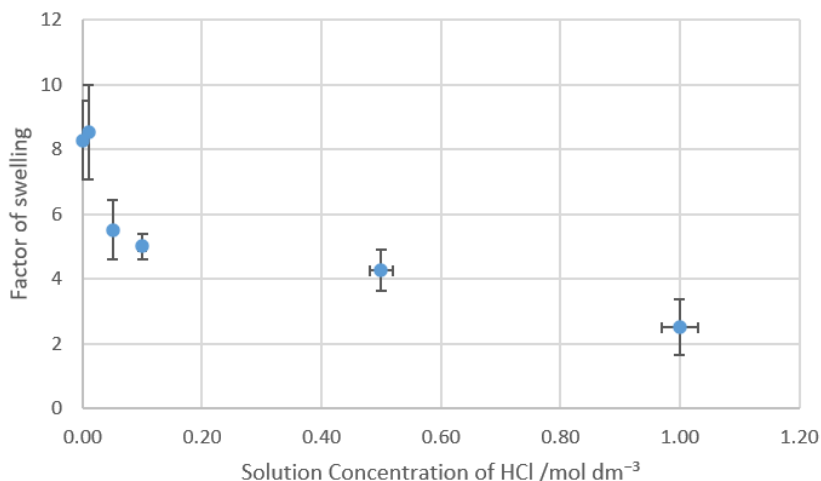


Figure 5: Factor of swelling of bentonite clay as a function of [HCl]

Recall that the original hypothesis stated that the relationship between the responding and manipulated variable is inversely proportional, which is evident in the graphed data. However, the parts of the hypothesis that aren't so evident in the experimental data is that the relationship would initially be linear and then approach a horizontal asymptote.

Given that the slope change is very immediate at around when [HCl] = 0.050 mol dm⁻³ as well as the maintenance of a lower slope for a significantly wider domain between [HCl] = 0.100 mol dm⁻³ to [HCl] = 1.00 mol dm⁻³,

the original section of the hypothesis regarding an initial linear relationship transitioning to an asymptote has been proved to be false.

However, the possibility of the presence of a horizontal asymptote is not removed. In hindsight of seeing the experimental relationship from the concentrations of HCl used in this experiment in that the final 3 data points maintain a relatively steady curve that sit above a factor of swelling of 2, it could be argued that since the minimum logical factor of swelling is 1, then the effects of an asymptote could have been observed had the domain of concentrations of HCl been significantly extended.

At a glance, the overall trend of the graph may either appear to be logarithmic, exponential, or of a reciprocal function. However, a logarithmic relationship does not have a horizontal asymptote, meaning that such a relationship would not apply to this experiment as the swelling factor must approach a plateau as Na^+ ions are depleted.

Figures 6 and 7 present the exponential and reciprocal best-fit trendline respectively. Visually speaking, the reciprocal trendline has a significantly better fit than the exponential trendline.

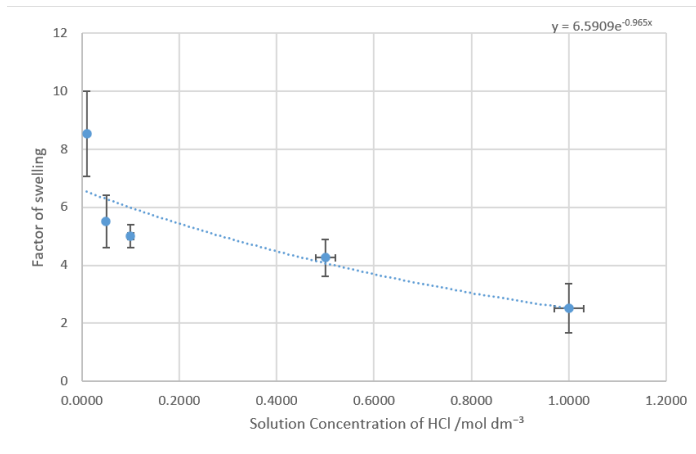


Figure 6: Factor of swelling of bentonite clay as a function of [HCl] with a logarithmic trendline

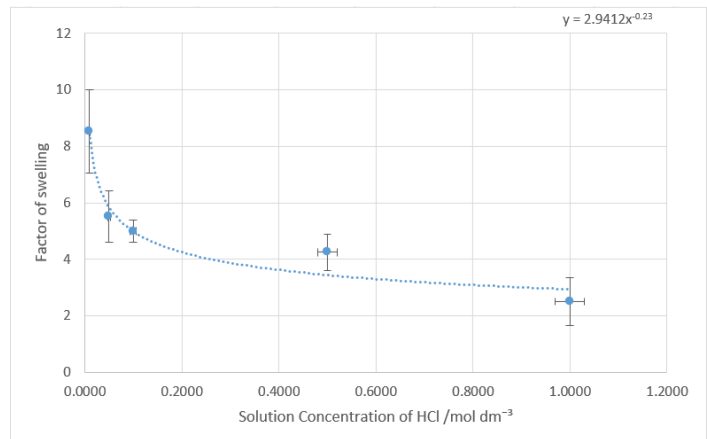


Figure 7: Factor of swelling of bentonite clay as a function of [HCl] with a reciprocal trendline

Numerical confirmation that the reciprocal trendline has a better fit can be performed by performing two separate linearizations where one assumes an exponential trend and the other assumes a reciprocal function trend. Then, the coefficient of determination can be determined and compared for both linearized graphs.

Similarly to Integrated Rate Laws, graphing the natural logarithm of the factor of swelling as a function of $[\text{H}^+]$ will linearize an exponential relationship, while graphing the reciprocal of the factor of swelling as a function of $[\text{H}^+]$ will linearize a reciprocal relationship. A sample calculation is shown below using the factor of swelling from distilled water, with the results of these calculations performed for all trials presented in Table 6 and the resulting graphs presented in Figures 8 and 9.

$$F = 8 \pm 1$$

$$F_{\text{exponential}} = \ln F$$

$$= \ln 8$$

$$= 2.1$$

$$\Delta F_{\text{exponential}} = \frac{\Delta F}{F}$$

$$= \frac{1}{8}$$

$$= 0.1$$

$$F_{\text{exponential}} = 2.1 \pm 0.1$$

$$F = 8 \pm 1$$

$$F_{\text{reciprocal}} = F^{-1}$$

$$= 8^{-1}$$

$$= 0.12$$

$$\Delta F_{\text{reciprocal}} = F_{\text{reciprocal}} \times \frac{\Delta F}{F}$$

$$= 0.12 \times \frac{1}{8}$$

$$= 0.02$$

$$F_{\text{reciprocal}} = 0.12 \pm 0.02$$

Table 6: Natural logarithm and reciprocal of factor of swelling for each concentration of HCl

Concentration of HCl in solution /mol dm ⁻³	Natural logarithm of factor of swelling	Reciprocal of factor of swelling
0 (Distilled Water)	2.1 ± 0.1	0.12 ± 0.02
0.0100 ± 0.0007	2.1 ± 0.2	0.12 ± 0.02
0.050 ± 0.003	1.7 ± 0.2	0.18 ± 0.03
0.100 ± 0.006	1.6 ± 0.1	0.20 ± 0.02
0.50 ± 0.02	1.4 ± 0.1	0.24 ± 0.04
1.00 ± 0.03	0.9 ± 0.3	0.4 ± 0.1

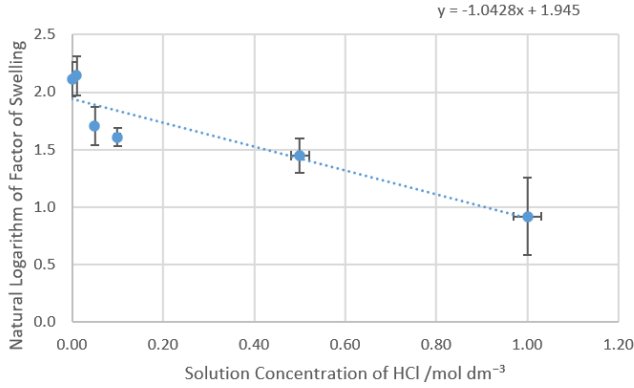


Figure 8: Natural logarithm of factor of swelling of bentonite clay as a function of [HCl] as a linearization under an exponential trend of the original relationship

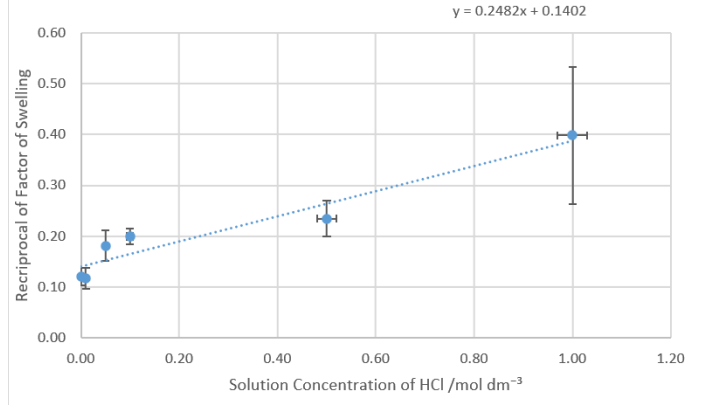


Figure 9: Reciprocal of factor of swelling of bentonite clay as a function of [HCl] as a linearization under a reciprocal trend of the original relationship

Calculations for the coefficients of determination for the Natural logarithm of factor of swelling of bentonite clay as a function of [HCl] and the Reciprocal of factor of swelling of bentonite clay as a function of [HCl] is shown below.

With reference to Figure 8

$$\begin{aligned}
 RSS &= \sum_n (m[\text{HCl}]_n + F_0 - F_n)^2 \\
 RSS &= (-1.0428 \text{ dm}^3 \text{ mol}^{-1} \times 0 + 1.945 - 2.1)^2 + \\
 &(-1.0428 \text{ dm}^3 \text{ mol}^{-1} \times 0.0100 \text{ mol dm}^{-3} + 1.945 - 2.1)^2 \\
 &+ \dots + \\
 &(-1.0428 \text{ dm}^3 \text{ mol}^{-1} \times 1.00 \text{ mol dm}^{-3} + 1.945 - 0.9)^2 \\
 &= 0.16 \\
 \bar{F} &= \frac{\sum F}{n} \\
 &= \frac{2.1 + 2.1 + \dots + 0.9}{6} \\
 &= 1.6 \\
 TSS &= \sum_n (F_n - \bar{F})^2 \\
 &= (2.1 - 1.6)^2 + (2.1 - 1.6)^2 + \dots + (0.9 - 1.6)^2 \\
 &= 1.0 \\
 R^2 &= 1 - \frac{RSS}{TSS}
 \end{aligned}$$

With reference to Figure 9

$$\begin{aligned}
 RSS &= \sum_n (m[\text{HCl}]_n + F_0 - F_n)^2 \\
 RSS &= (0.2482 \text{ dm}^3 \text{ mol}^{-1} \times 0 + 0.1402 - 0.12)^2 + \\
 &(0.2482 \text{ dm}^3 \text{ mol}^{-1} \times 0.0100 \text{ mol dm}^{-3} + 0.1402 - 0.12)^2 \\
 &+ \dots + \\
 &(0.2482 \text{ dm}^3 \text{ mol}^{-1} \times 1.00 \text{ mol dm}^{-3} + 0.1402 - 0.4)^2 \\
 &= 0.0040 \\
 \bar{F} &= \frac{\sum F}{n} \\
 &= \frac{0.12 + 0.12 + \dots + 0.4}{6} \\
 &= 0.21 \\
 TSS &= \sum_n (F_n - \bar{F})^2 \\
 &= (0.12 - 0.21)^2 + (0.12 - 0.21)^2 + \dots + (0.4 - 0.21)^2 \\
 &= 0.054 \\
 R^2 &= 1 - \frac{RSS}{TSS}
 \end{aligned}$$

$$= 1 - \frac{0.16}{1.0}$$

$$= 0.84$$

$$= 1 - \frac{0.0040}{0.054}$$

$$= 0.92$$

12 Conclusion

12.1 Summary

From this investigation, it was determined that the relationship between the factor by which the sodium bentonite clay swells and the concentration of H^+ ions of an acidic solution mol dm^{-3} when the acidic solution and bentonite mix is inversely proportional, specifically of a reciprocal relationship ($F \propto \frac{1}{[HCl]}$).

The coefficient of determination for the reciprocal linearization (0.92) is a strong numerical support for the argument that there is a reciprocal relationship between the Factor of swelling and $[HCl]$. However, one may look at Figure 9 with skepticism regarding whether the trend is truly linear. While error bars give support to the argument that the trendline is linear, the way in which the data points from $[HCl] = 0.050 \text{ mol dm}^{-3}$, $0.100 \text{ mol dm}^{-3}$ sit above the trendline and the data point from $[HCl] = 0.50 \text{ mol dm}^{-3}$ sits below the trendline suggests the possibility of the relationship between $\frac{1}{F}$ and $[HCl]$ to be cubic or inversely sigmoidal. This remaining uncertainty ultimately must be solved through more data distributed in between $[HCl] = 0$ to $[HCl] = 1$.

12.2 Evaluation

12.3 Suggested improvements

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