

The Relationship Between The Amount of Sodium Chloride in a Sodium Chloride Solution and Oxygen Saturation of the solution

Marko Vejnović

January 14, 2019

Rationale

Regarding chemistry overall, I am most interested in industrial chemistry. Due to my affinity for physics and engineering, I am naturally drawn to everything regarding engineering, including industrial chemistry. My original idea for my internal assessment was to conduct experiments which would show the relationship between the voltage applied and the thickness of the anodized layer in a process of aluminum anodization. However, as preliminary experiments showed, the thickness of this layer was immeasurable with the tools available.

I, therefore decided to apply another passion of mine, one which sadly I was not able to pursue in my last two years of high school education - environmental chemistry. Being always passionate for biology and ecology, I decided to look into phenomena that govern the sustainability and longevity of biotopes¹. Being a diver, it was clear to me that I wanted to do research to see how chemistry could be applied in aqueous environmental systems. Knowing that oxygen saturation is a major factor in the habitability of aqueous biotopes, I knew that I wanted to measure the relationship between the salinity of water and the oxygen saturation in it.

1 Introduction

1.1 Oxygen saturation

Oxygen saturation² is the measure of the amount of oxygen dissolved in water measured in $\left[\frac{\text{g}}{\text{l}}\right]$ (Utah State University Extension).

As all aerobic organisms require oxygen, aquatic lifeforms all require a sufficient amount of dissolved oxygen. However, an over-abundance in dissolved oxygen can, although it is unlikely, induce the *gas bubble disease*, which cause hyperinflation of all fish organs which contain air.

¹Regions of homogeneous environmental conditions and populations of organisms (Merriam Webster)

²Synonymous with dissolved oxygen

The process through which oxygen dissolves into water is usually due to a pressure difference between the partial pressure of oxygen in the atmosphere and the pressure of oxygen in water.

Oxygen becomes “stuck” in between water molecules which are bounded by hydrogen bonds (Senese). A figure representing this mechanism is given in figure 1.

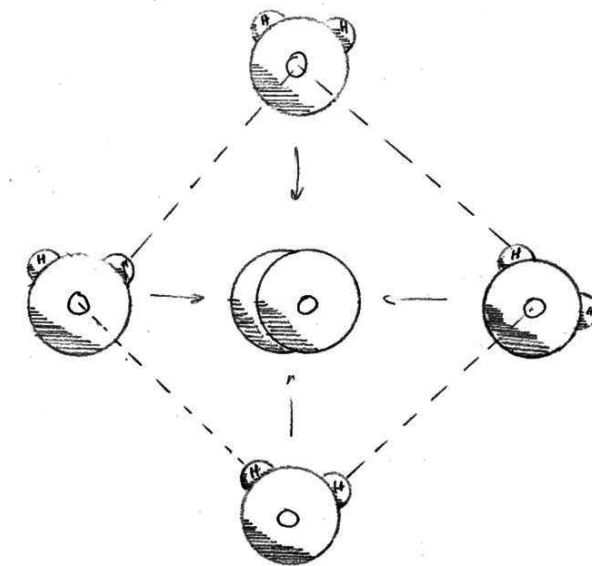


Figure 1: How oxygen dissolves in water

1.2 Salinity

Salinity is the measure of dissolved salts in water, measured in either $\left[\frac{g}{l}\right]$ or $\left[\frac{g}{kg}\right]$ (“Key Physical Variables In The Ocean: Temperature, Salinity, And Density”). Due to the fact that all of the salts in water are predominantly are $NaCl$ molecules, the term salinity onward in this paper refers to the amount of dissolved $NaCl$ molecules.

Salinity, too, affects the habitability of aqueous habitats, as certain organisms require salt, yet others can only sustain life in relatively salt-less bodies of water.

1.3 Relation between salinity and dissolved oxygen

The key reason why it is expected of an increase in salinity of water to be followed by a decrease in the amount of dissolved oxygen is governed by the fact that water is a polar molecule. As a salt dissolves in water, the polar salt attracts the water molecules, decreasing the strength of the hydrogen bonds between water - making it so that the hydrogen bonds between water molecules cannot keep the oxygen molecules in place as much.

1.4 Research goal

The goal of this research is to empirically determine the relationship between the salinity of water and the maximum dissolved oxygen capacity of water.

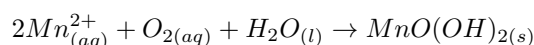
2 Method

To determine the relationship between the salinity of water and the amount of dissolved oxygen it was decided that the *Winkler method* would be employed, due to its relative ease of conduction as well as the availability of the materials required.

2.1 Winkler method

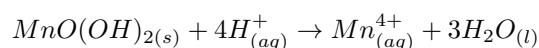
The Winkler method is a chemical process which is used to measure the amount of dissolved oxygen in water. Normally, it involves four distinct steps.

The first step is adding manganese(II) sulfate, with which oxygen molecules react under alkaline conditions:

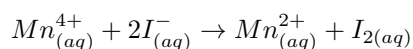


This step allows for binding the oxygen in the water, creating manganese(IV) ions.

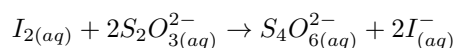
Next, sulfuric acid is added, forming manganese(IV) sulfate:



Sodium(I) iodide is added. Iodide ions become oxidized to I_2 , creating a very orange solution.



The final step involves titrating the iodine against sodium thiosulfate:



The importance of the method lies in the fact that there is a linear relationship between the number of moles of thiosulfate used and the number of moles of oxygen, and that relation is:

$$n(O_2) = \frac{1}{4}n(Na_2S_2O_3)$$

2.2 Safety and environmental precautions

The experiment itself was not necessarily dangerous, however, the chemicals employed were handled with care.

2.2.1 Manganese(II) sulfate

Manganese(II) sulfate is dangerous to the environment, so it was disposed of according to the mentor's requests.

2.2.2 Sodium Iodide

Sodium Iodide is both toxic and irritation inducing ("Sodium Iodide"), therefore, it was handled with the use of safety goggles and latex gloves. Due to it being extremely toxic to aquatic life, it was disposed of in accordance with the mentor's advice.

2.2.3 Sodium thiosulfate

Sodium thiosulfate induces skin irritations ("Sodium Thiosulfate"), so it was handled with care.

2.2.4 Sulfuric acid

Sulfuric acid is highly irritating and causes permanent eye damage ("Sulfuric Acid"). Because of this, eye goggles were worn at all times. Due to its very high acidic properties, a base ($NaOH$) was present nearby to neutralize any potential spills that might occur. Incidentally, a minor spill did occur, and the basic sodium hydroxide was used to neutralize the acid, after which it was cleaned up with water.

After the experiment, the remaining sulfuric acid was disposed of per school protocol - in a separate container for acidic solutions.

2.3 Method

2.3.1 Solutions

Before the actual experiment could be conducted, some solutions had to be prepared.

Sodium iodide A Sodium iodide solution was prepared by adding sodium iodide to a solution of sodium hydroxide. The exact concentration of this solution is not important, as long as it is assured that sodium iodide is in excess.

Starch solution A solution of starch to be used as an indicator was done by dissolving starch in distilled water under light temperature and with mild stirring. The concentration is again irrelevant.

Sodium thiosulfate A sodium thiosulfate solution was prepared by dissolving sodium thiosulfate in distilled water.



Figure 2: The prepared solutions

Saline solutions The $NaCl$ solutions were not prepared prior to the experiment as doing that would make the times between adding the salt and titrating the solution. However, a 100ml of distilled water was poured in plastic containers in which the titration would be done.

2.3.2 Experiment

With the solutions prepared it was possible to conduct the experiment. Throughout the whole experiment the temperature was kept a constant:

$$t = 20^{\circ}\text{C}$$

It was assumed that pressure was constant.

First, water was poured into 6 plastic containers of 100ml. Plastic containers were used because of the fact that they are closable, unlike beakers.

Next, $NaCl$ was dissolved in each of these containers. Given that the maximal solubility of $NaCl$ in water is $\frac{36\text{g}}{100\text{ml}}$ (Rumble, John R.), it was decided that the salt would be added in increments of 6g. The maximum salt mass for this value is 30g. The choice of making the maximum 30g rather than 36g was made due to two reasons - one being that it was easily possible that some salt would not dissolve due to errors when measuring the volume of water and the mass of the salt - and the other, more important one being that when a relationship is established, it should be able to predict a minimum of oxygen dissolved at around 36g.

Since this experiment requires a constant amount of oxygen to be dissolved in water, and since the maximum saturation of oxygen is being tested for, it was decided that a magnetic stirrer would be used at maximum power to increase the amount of oxygen dissolved in water to its maximal capacity. It

was made sure that the power of the magnetic was not too high to be able to form bubbles inside the container. To make sure that this amount was constant between all trials, the time of the “oxidization” of water was kept constant at 1 minute between all trials.

After each bottle was saturated with oxygen, manganese(II) sulfate was added to the bottle using a plastic pipette. This process was repeated until manganese(II) sulfate was added to all bottles.

The first bottle was placed on a magnetic stirrer which was set to lightly stir, but remained turned off. A burette containing sodium thiosulfate was placed over the stirrer. Sulfuric acid was added to the bottle and the stirrer was powered on. Titration was done until the solution reached an extremely pale yellow color at which point starch was added, as shown in figure 3. This caused the solution to become blue. It was then titrated to the point of the solution becoming translucent.

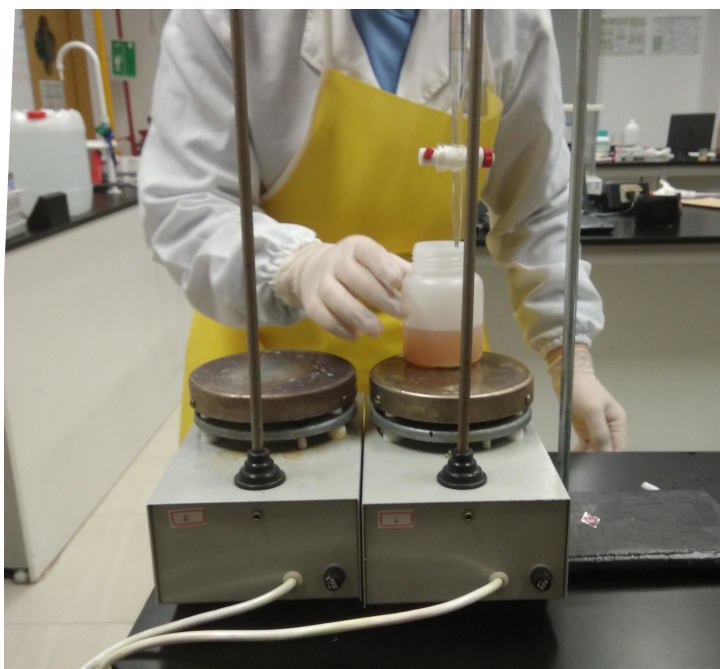


Figure 3: Titration

3 Data

3.1 Raw Data

The raw data is presented in the following.

3.1.1 Manganese(II) sulfate solution

The concentration of the solution was:

$$c(MnSO_4) = 3M$$

3.1.2 Sodium Iodide solution

The volume of the water in the solution was:

$$V(H_2O) = (50.0 \pm 0.5)ml$$

The mass of the solutes was:

$$m(NaI) = (30.00 \pm 0.01)g$$

$$m(NaOH) = (16 \pm 0.01)g$$

3.1.3 Sulfuric acid

The concentrated sulfuric acid was 50% by volume.

3.1.4 Starch solution

The volume of water was:

$$V(H_2O) = (50 \pm 0.5)ml$$

The mass of the solute starch was:

$$m((C_6H_{10}O_5)_n) = (2.00 \pm 0.01)g$$

3.1.5 Sodium thiosulfate solution

The volume of water was:

$$V(H_2O) = (50.0 \pm 0.5)ml$$

The mass of sodium thiosulfate was:

$$m(Na_2SO_3) = (2.00 \pm 0.01)g$$

3.1.6 Titration

The measurements obtained during the titrations are given in the tables 1, 2 and 3.

#	$V(H_2O)$	$m(NaCl)$	Starting $V(Na_2SO_3)$	Ending $V(Na_2SO_3)$
1	$(100.0 \pm 0.5)\text{ml}$	0g	$(16.90 \pm 0.05)\text{ml}$	$(17.9 \pm 0.05)\text{ml}$
2	$(100.0 \pm 0.5)\text{ml}$	$(6.03 \pm 0.01)\text{g}$	$(17.90 \pm 0.05)\text{ml}$	$(18.70 \pm 0.05)\text{ml}$
3	$(100.0 \pm 0.5)\text{ml}$	$(12.03 \pm 0.01)\text{g}$	$(18.70 \pm 0.05)\text{ml}$	$(19.40 \pm 0.05)\text{ml}$
4	$(100.0 \pm 0.5)\text{ml}$	$(18.01 \pm 0.01)\text{g}$	$(19.40 \pm 0.05)\text{ml}$	$(20.00 \pm 0.05)\text{ml}$
5	$(100.0 \pm 0.5)\text{ml}$	$(23.95 \pm 0.01)\text{g}$	$(20.00 \pm 0.05)\text{ml}$	$(20.40 \pm 0.05)\text{ml}$
6	$(100.0 \pm 0.5)\text{ml}$	$(30.03 \pm 0.01)\text{g}$	$(20.40 \pm 0.05)\text{ml}$	$(20.90 \pm 0.05)\text{ml}$

Table 1: The measurements obtained during the first titration

#	$V(H_2O)$	$m(NaCl)$	Starting $V(Na_2SO_3)$	Ending $V(Na_2SO_3)$
1	$(100.0 \pm 0.5)\text{ml}$	0g	$(20.90 \pm 0.05)\text{ml}$	$(21.80 \pm 0.05)\text{ml}$
2	$(100.0 \pm 0.5)\text{ml}$	$(6.07 \pm 0.01)\text{g}$	$(21.80 \pm 0.05)\text{ml}$	$(22.50 \pm 0.05)\text{ml}$
3	$(100.0 \pm 0.5)\text{ml}$	$(12.01 \pm 0.01)\text{g}$	$(22.50 \pm 0.05)\text{ml}$	$(23.10 \pm 0.05)\text{ml}$
4	$(100.0 \pm 0.5)\text{ml}$	$(17.99 \pm 0.01)\text{g}$	$(23.10 \pm 0.05)\text{ml}$	$(23.60 \pm 0.05)\text{ml}$
5	$(100.0 \pm 0.5)\text{ml}$	$(24.01 \pm 0.01)\text{g}$	$(23.60 \pm 0.05)\text{ml}$	$(24.10 \pm 0.05)\text{ml}$
6	$(100.0 \pm 0.5)\text{ml}$	$(30.00 \pm 0.01)\text{g}$	$(24.10 \pm 0.05)\text{ml}$	$(24.50 \pm 0.05)\text{ml}$

Table 2: The measurements obtained during the second titration

3.2 Data Processing

3.2.1 Sodium Iodide solution

The concentration of the sodium iodide solution was equal to:

$$\begin{aligned}
c(NaI) &= \frac{n(NaI)}{V(H_2O)} \\
&= \frac{(30.00 \pm 0.01)\text{g}}{\frac{149.89 \frac{\text{g}}{\text{mol}}}{(50.0 \pm 0.5) \cdot 10^{-3}\text{l}}} \\
c(NaI) &= (4.00 \pm 0.04)\text{M}
\end{aligned}$$

3.2.2 Starch solution

Due to the fact that starch is a polymer of glucose monomers, it was impossible to accurately calculate the concentration of the starch indicator solution, however, this piece of information was irrelevant, since starch was only acting as an indicator.

#	$V(H_2O)$	$m(NaCl)$	Starting $V(Na_2SO_3)$	Ending $V(Na_2SO_3)$
1	$(100.0 \pm 0.5)\text{ml}$	0g	$(24.50 \pm 0.05)\text{ml}$	$(25.40 \pm 0.05)\text{ml}$
2	$(100.0 \pm 0.5)\text{ml}$	$(6.04 \pm 0.01)\text{g}$	$(25.40 \pm 0.05)\text{ml}$	$(26.10 \pm 0.05)\text{ml}$
3	$(100.0 \pm 0.5)\text{ml}$	$(11.58 \pm 0.01)\text{g}$	$(26.10 \pm 0.05)\text{ml}$	$(26.70 \pm 0.05)\text{ml}$
4	$(100.0 \pm 0.5)\text{ml}$	$(18.03 \pm 0.01)\text{g}$	$(26.70 \pm 0.05)\text{ml}$	$(27.30 \pm 0.05)\text{ml}$
5	$(100.0 \pm 0.5)\text{ml}$	$(24.02 \pm 0.01)\text{g}$	$(27.30 \pm 0.05)\text{ml}$	$(27.80 \pm 0.05)\text{ml}$
6	$(100.0 \pm 0.5)\text{ml}$	$(29.99 \pm 0.01)\text{g}$	$(27.80 \pm 0.05)\text{ml}$	$(28.20 \pm 0.05)\text{ml}$

Table 3: The measurements obtained during the third titration

3.2.3 Sodium thiosulfate solution

The concentration of the sodium thiosulfate solution was:

$$\begin{aligned}
c(Na_2SO_3) &= \frac{n(Na_2SO_3)}{V(H_2O)} \\
&= \frac{(2.00 \pm 0.01)\text{g}}{\frac{126.05 \frac{\text{g}}{\text{mol}}}{(50.0 \pm 0.5) \cdot 10^{-3}\text{l}}} \\
c(Na_2SO_3) &= (0.317 \pm 0.005)\text{M}
\end{aligned}$$

3.2.4 Titration

The amount of sodium thiosulfate used was calculated by subtracting the ending volumes and starting volumes of sodium thiosulfate in the burette. The results are given in tables 4, 5 and 6.

#	$V(H_2O) [\pm 0.5\text{ml}]$	$m(NaCl) [\pm 0.01\text{g}]$	$\Delta V(Na_2SO_3) [\pm 0.10\text{ml}]$
1	100.0ml	0.00g	1.00ml
2	100.0ml	6.03g	0.80ml
3	100.0ml	12.03g	0.70ml
4	100.0ml	18.01g	0.60ml
5	100.0ml	23.95g	0.40ml
6	100.0ml	30.03g	0.50ml

Table 4: The mass of salt vs. the volume of sodium thiosulfate used in the first titration

#	$V(H_2O) [\pm 0.5\text{ml}]$	$m(NaCl) [\pm 0.01\text{g}]$	$\Delta V(Na_2SO_3) [\pm 0.10\text{ml}]$
1	100.0ml	0.00g	0.90ml
2	100.0ml	6.07g	0.70ml
3	100.0ml	12.01g	0.60ml
4	100.0ml	17.99g	0.50ml
5	100.0ml	24.01g	0.50ml
6	100.0ml	30.00g	0.40ml

Table 5: The mass of salt vs. the volume of sodium thiosulfate used in the second titration

The average of the data of all three titrations was calculated, as well as the errors according to the formula $\Delta x = \frac{x_{max} - x_{min}}{2}$. Both the averages and the uncertainties are given in table 7.

#	$V(H_2O)$ [± 0.5 ml]	$m(NaCl)$ [± 0.01 g]	$\Delta V(Na_2SO_3)$ [± 0.10 ml]
1	100.0ml	0.00g	0.90ml
2	100.0ml	6.04g	0.70ml
3	100.0ml	11.58g	0.60ml
4	100.0ml	18.03g	0.60ml
5	100.0ml	24.02g	0.50ml
6	100.0ml	29.99g	0.40ml

Table 6: The mass of salt vs. the volume of sodium thiosulfate used in the third titration

#	$\bar{m}(NaCl)$	$\bar{V}(Na_2SO_3)$
1	0.00g	(0.93 ± 0.15) ml
2	(6.05 ± 0.03) g	(0.73 ± 0.15) ml
3	(11.87 ± 0.24) g	(0.63 ± 0.15) ml
4	(18.01 ± 0.03) g	(0.57 ± 0.15) ml
5	(23.99 ± 0.05) g	(0.47 ± 0.15) ml
6	(30.01 ± 0.03) g	(0.43 ± 0.15) ml

Table 7: The mass of salt vs. the volume of sodium thiosulfate used

Next, the number of moles of sodium thiosulfate used was calculated. The values are given in table 8.

This was done according the following general formula:

$$n(Na_2SO_3) = c(Na_2SO_3) \cdot V(Na_2SO_3)$$

#	$\bar{m}(NaCl)$	$\bar{n}(Na_2SO_3)$
1	0.00g	$(2.95 \pm 0.52) \cdot 10^{-4}$ mol
2	(6.05 ± 0.03) g	$(2.31 \pm 0.51) \cdot 10^{-4}$ mol
3	(11.87 ± 0.24) g	$(2.00 \pm 0.51) \cdot 10^{-4}$ mol
4	(18.01 ± 0.03) g	$(1.81 \pm 0.50) \cdot 10^{-4}$ mol
5	(23.99 ± 0.05) g	$(1.49 \pm 0.50) \cdot 10^{-4}$ mol
6	(30.01 ± 0.03) g	$(1.36 \pm 0.50) \cdot 10^{-4}$ mol

Table 8: The mass of salt vs. the number of moles of sodium thiosulfate used

Finally, the amount of dissolved oxygen was calculated according to the fact that:

$$DO = \frac{1}{4} n(Na_2SO_3) \cdot 2 \cdot 16.00 \frac{\text{g}}{\text{mol}} \cdot \frac{1}{V(H_2O)}$$

4 Analysis

4.1 Further calculations

From table 9, a graph was plotted using the *pgfplots* program (Feuersanger) and is given in figure 4.

#	$\overline{m}(NaCl)$	\overline{DO}
1	0.00g	$(2.36 \pm 0.43) \cdot 10^{-2} \frac{g}{l}$
2	$(6.05 \pm 0.03)g$	$(1.85 \pm 0.42) \cdot 10^{-2} \frac{g}{l}$
3	$(11.87 \pm 0.24)g$	$(1.60 \pm 0.42) \cdot 10^{-2} \frac{g}{l}$
4	$(18.01 \pm 0.03)g$	$(1.45 \pm 0.41) \cdot 10^{-2} \frac{g}{l}$
5	$(23.99 \pm 0.05)g$	$(1.19 \pm 0.41) \cdot 10^{-2} \frac{g}{l}$
6	$(30.01 \pm 0.03)g$	$(1.09 \pm 0.41) \cdot 10^{-2} \frac{g}{l}$

Table 9: The mass of salt vs. the dissolved oxygen

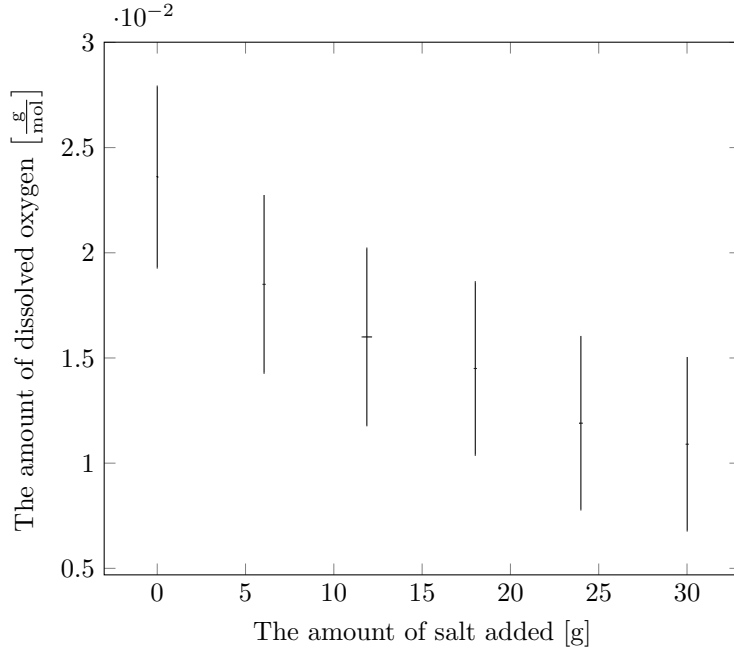


Figure 4: The graph of the relationship between the mass of salt added and the amount of sodium thiosulfate employed.

The first fit produced was done using a *python* (Python Software Foundation) script. This script is given in the appendix. The results are shown in figure 5. Note that the domain of the graph is extended.

The fitted function is a quadratic polynomial $ax^2 + bx + c$ with the coefficients:

$$\begin{aligned}
 a &= 1.00839942 \cdot 10^{-5} \\
 b &= -7.06457161 \cdot 10^{-4} \\
 c &= 2.31642928 \cdot 10^{-2}
 \end{aligned} \tag{1}$$

The extended domain shows an issue with this graph - it is impossible for the amount of dissolved oxygen to increase after it has reached a minimum. The minimum can be expected to be found at the maximum solubility of $NaCl$ at $t = 20^\circ C$ in water. This value is $\frac{36g}{100ml}$ (Rumble, John R). At this point, the graph must remain constant, since the amount of salt added will not further dissolve. Therefore, the

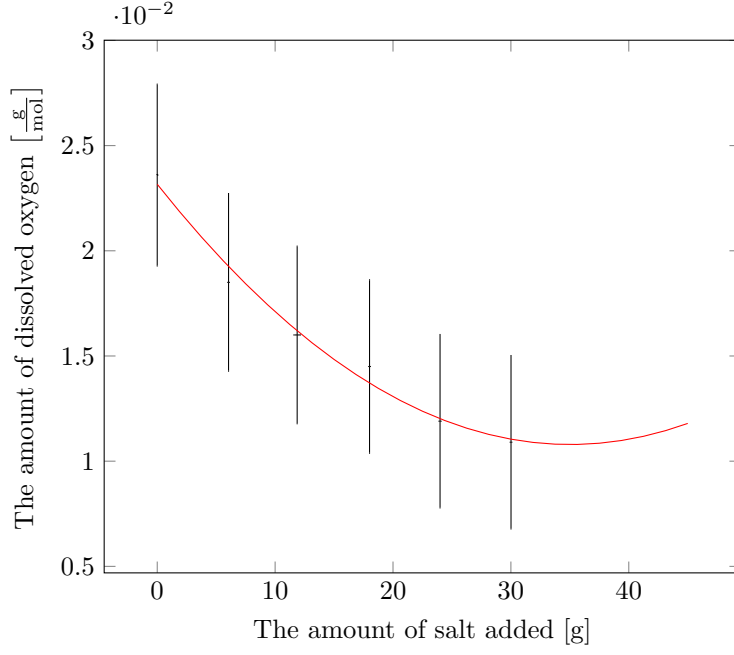


Figure 5: The graph of the relationship between the mass of salt added and the amount of sodium thiosulfate thiosulfate

x coordinate of the minimum of the dissolved oxygen function $\left(-\frac{b}{2a}, \frac{\sqrt{b^2-4ac}}{4a}\right)$ is equal to 36g as well as all of the values bigger than 36g.

Because $-\frac{b}{2a} = 36$ the following relation can be established:

$$b = -72a$$

The polynomial function only requires two coefficients now:

$$ax^2 - 72ax + c$$

The final fit function would therefore be:

$$DO(m_{NaCl})_{t=20^\circ\text{C}} = \begin{cases} ax^2 - 72ax + c & m_{NaCl} < 36.0\text{g} \\ a \cdot 36.0^2 - 72a \cdot 36.0 + c & m_{NaCl} \geq 36.0\text{g} \end{cases}$$

Using another *python* script (Python Software Foundation), again given in the appendix, the coefficients a and c have been calculated to be:

$$a = 9.63668258 \cdot 10^{-6}$$

$$c = 2.31226620 \cdot 10^2$$

The plot of the final fit is given in figure 6.

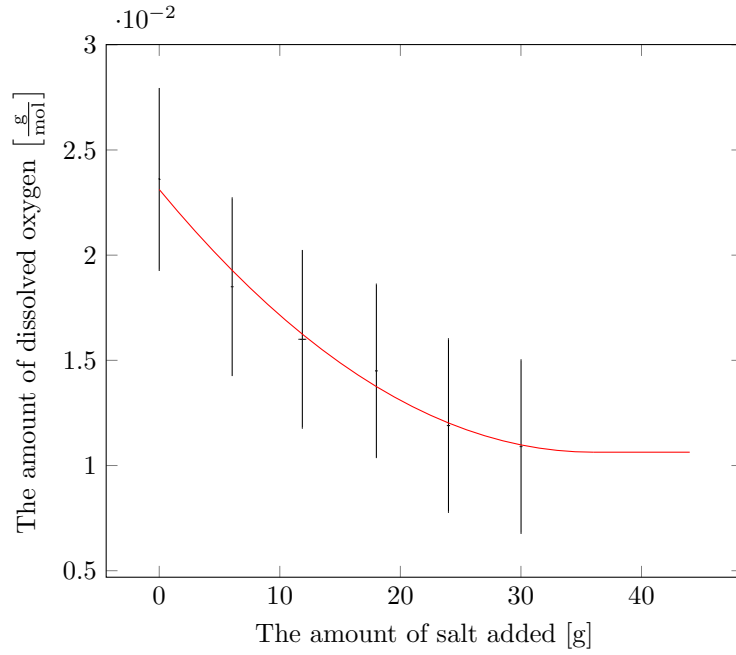


Figure 6: The graph of the relationship between the mass of salt added and the amount of sodium thiosulfate thiosulfate

4.2 Notes

4.2.1 Regarding salt saturation

Note that the coefficients in equation 1 indicate that the minimum of the dissolved oxygen, according to the formula for the x coordinate of the minimum of a quadratic function $(-\frac{b}{2a})$ is reached at a value of:

$$\begin{aligned} -\frac{b}{2a} &= -\frac{-7.06457161 \cdot 10^{-4}}{2 \cdot 1.00839942 \cdot 10^{-5}} \\ &= 35.03 \end{aligned}$$

4.2.2 Errors

This value indicates that this model predicts that the value of minimal oxygen saturation, and therefore the maximum amount of $NaCl$ that water can absorb is a value of 35.03g, which indicates an error of only 0.97g or 2.70%. When this is corrected for as explained in the second half of section 4.1, a more accurate model is achieved.

The uncertainty of the processed data is relatively high. This can be attributed to the relatively high uncertainty of the titration. Random errors are obviously at play, as it is unlikely that further measurements will improve the precision of the experiment.

The information presented in section 4.2.1 implies that the systematic errors were low and that the accuracy of the experiment was relatively high. Given that the information in section 4.2.1 is completely true, the systematic error was a measly 2.70%. Since the error is minimal, it is possible that this error stems from random error rather than systematic error.

5 Conclusion

The experiment was successful. A minimal systematic error indicates that the experiment was accurately conducted. For more precise data, however, it would be preferable that the experiment be conducted with higher volumes of water - even by a factor of $1 \cdot 10^1$ - $1 \cdot 10^2$. This would minimize the random error and would improve the overall precision of the results.

The relationship between the amount of $NaCl$ in water and the amount of dissolved oxygen has been established to be a quadratic one, until the water becomes saturated with $NaCl$. After this point the added salt plays no effect on the amount of dissolved oxygen:

$$DO(m_{NaCl})_{t=20^{\circ}C} = \begin{cases} ax^2 + bx + c & m_{NaCl} < 36.0g \\ a \cdot 36.0^2 - 72a \cdot 36.0 + c & m_{NaCl} \geq 36.0g \end{cases}$$

Regarding the impact of salt and oxygen on marine life - fish which survive in saltwater require less oxygen - as per the prediction of this study ("HOW DISSOLVED OXYGEN AFFECTS FISH BEHAVIOUR").

Overall, as hypothesized, salt content greatly influences the amount of oxygen that can be dissolved in a water body at a given time.

Works Cited

- “HOW DISSOLVED OXYGEN AFFECTS FISH BEHAVIOUR”. *Active Angling New Zealand*, 2019, <https://activeanglingnz.com/2017/02/23/the-importance-of-dissolved-oxygen/>. Accessed 13 Jan 2019.
- Feuersanger, Christian. *The PGFPLOTS Package*. Version 1.3, Institut Fur Numerische Simulation Universitat Bonn, 2019.
- “Key Physical Variables In The Ocean: Temperature, Salinity, And Density”. *Nature.Com*, 2014, <https://www.nature.com/scitable/knowledge/library/key-physical-variables-in-the-ocean-temperature-102805293>. Accessed 30 Dec 2018.
- Merriam Webster. “Definition Of BIOTOPE”. *Merriam-Webster.Com*, 2018, <https://www.merriam-webster.com/dictionary/biotope>. Accessed 30 Dec 2018.
- Python Software Foundation. *Python Language Reference*. Version 3.6.
- Rumble, John R. *CRC Handbook Of Chemistry And Physics*. 99th ed., CRC Press, 2018.
- Senese, Fred. “General Chemistry Online: FAQ: Solutions: How Can I Predict Oxygen Solubility In Water?”. *Antoine.Frostburg.Edu*, 2015, <http://antoine.frostburg.edu/chem/senese/101/solutions/faq/predicting-D0.shtml>. Accessed 7 Jan 2019.
- “Sodium Iodide”. *Pubchem.Ncbi.Nlm.Nih.Gov*, 2018, https://pubchem.ncbi.nlm.nih.gov/compound/sodium_iodide#section=U-S-Exports. Accessed 30 Dec 2018.
- “Sodium Thiosulfate”. *Pubchem.Ncbi.Nlm.Nih.Gov*, 2018, https://pubchem.ncbi.nlm.nih.gov/compound/Sodium_thiosulphate#section=GHS-Classification. Accessed 30 Dec 2018.
- “Sulfuric Acid”. *Pubchem.Ncbi.Nlm.Nih.Gov*, 2018, https://pubchem.ncbi.nlm.nih.gov/compound/sulfuric_acid#section=Safety-and-Hazards. Accessed 30 Dec 2018.
- Utah State University Extension. “Dissolved Oxygen”, *Extension.Usu.Edu*, 2017, <https://extension.usu.edu/waterquality/learnaboutsurfacewater/propertiesofwater/dissolvedoxygen>. Accessed 30 Dec 2018.

Appendix

First fit script

```
#!/usr/bin/env python

import numpy as np
from scipy.optimize import curve_fit

X = np.array([
    0.00,
    6.05,
    11.87,
    18.01,
    23.99,
    30.01
])

Y = np.array([
    2.36,
    1.85,
    1.60,
    1.45,
    1.19,
    1.09
]) * 0.01

def fit_func(x, a, b, c):
    return a * x ** 2 + b * x + c

fx = np.linspace(0, 40, 100)
fparams, fcovariances = curve_fit(fit_func, X, Y)
print(fparams)
```

Second fit script

```
#!/usr/bin/env python

import numpy as np
from scipy.optimize import curve_fit

X = np.array([
    0.00,
    6.05,
    11.87,
    18.01,
    23.99,
    30.01
])

Y = np.array([
    2.36,
    1.85,
    1.60,
    1.45,
    1.19,
    1.09
]) * 0.01
```



```
def fit_func(x, a, c):  
    return a * x ** 2 - 72 * a * x + c  
  
fx = np.linspace(0, 40, 100)  
fparams, fcovariances = curve_fit(fit_func, X, Y)  
print(fparams)
```