Investigate the effects of temperature on the dissolved oxygen concentration in water

Introduction:

Redox reactions have always incentivized me to understand them deeply, because these reactions are the principal sources of energy, both natural and artificial. Personally, I have served as the Carbon Footprint Reduction Captain (CFR) at my school, leading various projects aimed at decreasing pollution and preserving the environment. One of the most significant catastrophes destroying the aura of my school's vicinity was a nearby lake, which was heavily contaminated with waste discarded by residents and businesses. This had a detrimental impact on marine life, therefore we organised a clean-up drive at the lake to avert such an adverse situation. To study the quality and degree of pollution in the water, I collected a particular volume of the water to investigate upon it. I was highly captivated to pursue multiple techniques of researching the BOD for the water sample, and investigate whether temperature influences the oxygen concentration in water. Due to the increased frequency of use of machines in industries they are required to use the cooling process, which involves, cold water pipes coiled around the machinery to cool it down. As the heat is conducted and transferred from the machinery to the cold water pipe, the machinery cools and the heated water pipe is regenerated to bring in more cold water, but the hot water is regularly excreted and discarded into rivers near the industry. Due to the hot water being released into the rivers, the temperature of the river water increases. Rising global temperatures reduce the solubility of oxygen in water making it problematic for marine life, because of reduced dissolved oxygen levels in water. Furthermore, the industrial liquid waste discharged causes the dissolved oxygen concentration in the water to decrease exponentially, hence due to a lack oxygen in water to consume, the marine life in water bodies find it difficult to survive, causing extinction. Having read multiple research papers to understand my area of focus for the investigation, the results stated that oxygen concentration decreases as the temperature increases **(Kulkarni J Sunil, 2016, p.5)** hence these few things catapulted my interest to further investigate upon the relationship between the temperature of water and dissolved oxygen concentration of water sample and interpret the accuracy of the stated hypothesis from many research papers along with it’s correlation and therefore my research question became:

“How does the temperature (*$\mathbf{30}$°C, $\mathbf{40}$°C, $\mathbf{50}$°C, $\mathbf{60}$°C, $\mathbf{70}$°C) *affect the dissolved oxygen concentration in 200cm^3 of Lake Water”

Background Information:

Biological oxygen demand is a water quality indicator which measures the quality of oxygen required by microbes to oxidise organic matter in water. Water is considered clean and unpolluted if its BOD level is less than 5 ppm. Water bodies have a specific amount of dissolved oxygen on which aquatic life depends for its respiratory demands. When organic matter is present in a water body, aerobic microorganisms use the dissolved oxygen in the water to break down the organic matter, decreasing the oxygen accessible to aquatic life. The basic idea behind measuring BOD is to compare the initial and final amount of dissolved oxygen concentration in a sample. The process of eutrophication has a profound influence on lakes ability to support biodiversity because of the algae and aquatic weeds that grow leading to the reduction of dissolved oxygen concentration in water required by the marine life.

Hypothesis:

Concentration of dissolved oxygen decreases as the temperature of the water sample increases due to it’s inverse relationship. Thus an increase in temperature would reduce the dissolved oxygen content as the solubility of oxygen will decrease as temperature increases since the kinetic energy of the molecules increases at higher temperatures as they gain more energy and begin to move faster. Thus, the oxygen molecules in the water sample foster a greater tendency to escape the solvent and return into the gaseous state.

Aim of the Experiment:

This investigation particularly focuses on studying and analysing whether the temperature of water affects it’s quality in terms of concentration of dissolved oxygen and biological oxygen demand (BOD). The research will be carried out using water samples from a lake containing polluted water and heating it to different temperatures range: $\mathbf{30}$°C $-$ $\mathbf{70}$°C.

Dissolved oxygen refers to free oxygen molecules encountered between water molecules. A dipole-induced dipole attraction is a weak attraction that occurs when a polar molecule induces a dipole in an atom or a nonpolar molecule by causing the electron arrangement in the nonpolar species to change. To keep the particles together in these states, strong attractive forces must exist between the molecules or atoms. Because the molecule is diatomic and both atoms have equal electronegativity, the oxygen molecule is nonpolar and the only intermolecular forces present are London Dispersion forces and thus O_2 is a nonpolar molecule with a zero dipole moment. Water molecule is polar and due to it's polarity it has a net dipole moment. The oxygen and water molecules form a weak intermolecular force of attraction. Because the oxygen atom in the water molecule has a higher electronegativity than the hydrogen atoms because it has more positively charged protons in its nucleus, and the shared electrons are closer to the oxygen atom nucleus in water than the hydrogen nuclei. As a result, the water molecule has a negative dipole close to the oxygen atom and a positive dipole close to the hydrogen atom. The polarity of water induces dipoles in free oxygen molecules due to the random movement of electrons within the molecule.

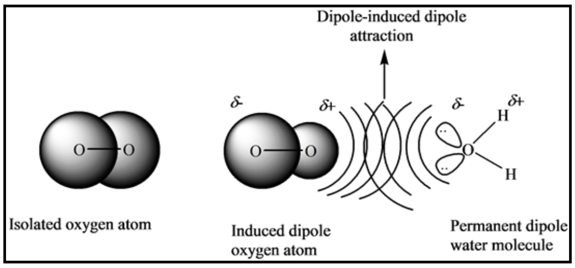


Figure 1: Oxygen in the Water Sample

<u>The Winkler Titration Method:</u> The Winkler method is a manual redox titration method which is utilised to determine the concentration of dissolved oxygen in water, by using redox reaction in titration. From this, calculations can be derived to calculate the DO[1]. As the level of pollution increases, the dissolved oxygen in water decreases as oxygen is used by bacteria in decomposition reactions. It is critical that the water sample not be exposed to the surrounding , until the oxygen is repaired with the addition of chemicals due to the presence of additional oxygen sources in the open air or surroundings. The basic chemistry behind the Winkler method is that manganese (II) sulfate is added to the water to fix the amount of dissolved oxygen in water. The manganese (II) ions are oxidised under alkaline conditions to manganese(IV) by the oxygen in the water:

<u>Fixing the Oxygen:</u> $$2Mn^{2+}(aq) + O_{2}(g) + 4OH^{-}(aq) \rightarrow 2MnO_2(s) + 2H_2O(l)$$

<u>Acidification / Oxidation of Mn from Mn^{2+} ions to Mn^{4+} :</u>

The sample is acidified with sulfuric acid to produce manganese (IV) sulfate:

$$Mn(OH)_2(s) + 4H^{+}(aq) \rightarrow Mn^{4+}(aq) + 3H_2O(l)$$

There is no change in oxidation number in this reaction. Iodide ions are oxidised to I_2 by the manganese(IV) ions:

$$MnO_2(s) + 2I^{-}(aq) + 4H^{+}(aq) \rightarrow Mn^{2+}(aq) + I_2(aq) + 2H_2O(l)$$

<u>Oxidation of I^- ions to I_2:</u> This iodine can then be titrated against a standard sodium thiosulfate solution:

$$2S_2O_3^{2-}(aq) + I_2(aq) \rightarrow S_4O_6^{2-}(aq) + 2I^{-}(aq)$$

By comparing the coefficients it's evident that in the overall sequence of equations, for every 1 mole of O_2 in the water, 4 moles of $S_2O_3^{2-}$ are used. Hence the number of moles of dissolved oxygen is $\frac{1}{4}th$ of the number of moles of sodium thiosulfate $(Na_2S_2O_3)$ used in the titration. This is therefore used to find the number of moles of Oxygen (O_2) that is dissolved in water and reacts with Manganese Sulphate $MnSO_4$.

<u>Digital Probe Method:</u> A dissolved oxygen (D.O) metre is an electronic device that converts signals from a probe placed in water into ppm units of DO. The probe contains a selectively permeable membrane, allowing DO to pass from the stream water into the solution. The DO that has diffused into the salt solution changes the electric potential of the salt solution, which is sent to the metre via an electric cable, which converts the signal to ppm.

[1] "5.2 Dissolved Oxygen and Biochemical Oxygen Demand | Monitoring and Assessment | US EPA." 5.2 Dissolved Oxygen and Biochemical Oxygen Demand | Monitoring & Assessment | US EPA, 6 Mar. 2012, archive.epa.gov/water/archive/web/html/vms52.html.

Variables:

Independent Variable: Temperature of Water **Range:** $(30°C, 40°C, 50°C, 60°C, 70°C)$ **Reason:** To analyze how temperature of water affects the oxygen concentration in water. The independent variable is the temperature of the water sample whose Dissolved Oxygen Concentration, is measured and analysed by calculating the initial and final concentration of oxygen and finding the change in oxygen concentration (content) over the fixed time period. **Method:** Heat the water sample to different temperatures and carrying out the experiment. **(Range:** $\mathbf{30}$℃ $-$ $\mathbf{70}$℃**)**	**Dependent Variable:** The concentration of oxygen or oxygen content ($\mathbf{mg/L}$). **Method:** This is the variable that is investigated, using Winkler's and D.O Probe Method. Hence, Dissolved Oxygen Concentration values at different temperatures, is the dependent variable for this investigation since the Concentration of Dissolved Oxygen is affected by temperature of the water sample. The DO would be determined by average titre used in redox reaction. **Method:** Heating water sample to different temperatures and finding the BOD value through calculations. As the temperature of the water increases it consumes more of the oxygen reducing the level of biological oxygen demand and O_2 concentration.

Controlled Variables

Controlled Variables	Reason To Control	Method to Control
Temperature of Surroundings ($\mathbf{26}$℃)	To keep the experiment fair and only have one independent variable as different room temperature would influence the readings and the final result causing inaccurate hypothesis to be reached	Timely measurements were made of the surrounding temperature to ensure that it is constant, else it is taken into account ensuring that all the readings are taken for the same room temperature.
Water Sample $\mathbf{200}\boldsymbol{cm^3}$	To keep the experiment fair and ensure result reliability is high otherwise different volumes could give a discrepancy in the dissolved oxygen concentration affecting the conclusion of our investigation and result reliability.	The same volume of water is tested out for different trials and temperatures. Also using the BOD flash formulated for the Winkler's process. The BOD bottle is calibrated for specific volumes
Apparatus Used	So that incase a systematic error occurs in the experiment it is consistent throughout the experiment avoiding inaccuracy. Different brands of equipment too can give different readings, so it was essential to use equipment of the same brand	The same apparatus will be used throughout the experiment for different trials to ensure a fair experiment is conducted.

Volume of Sulfuric Acid $\mathbf{2.00}\ \boldsymbol{cm^3}$	Although sulfuric acid does not take part in the reaction directly, it is essential to keep the volume uniform to ensure that the experiment is fair and reliable results are obtained, the same volume of H_2SO_4 is added to each solution and heated to different temperatures. Otherwise, erroneous data would be obtained.	Using the same volume of sulphuric acid (H_2SO_4) (2.0cm^3), delivered accurately into the solution using a graduated pipette.
Volume of Reagents used : Manganous (II) Sulphate, Alkali Azide Solution and Sulphuric Acid (H_2SO_4) $\mathbf{2.00}\ \boldsymbol{cm^3}$	To ensure that the experiment is fair and provides reliable results to pursue. Adding reagents in different ratio's for each experiment trial with different temperature of water sample would distort the readings as it would affect the amount of oxygen that reacts and give incomparable results.	A fixed volume of each reagent was used to make the sample solution (2.00 cm^3 each)
Concentration of Reagents used : Manganous (II) Sulphate, Alkali Azide Solution and Sulphuric Acid (H_2SO_4) $\mathbf{0.025\ moldm^{-3}}$	So that to make it certain that the experiment is fair and provides reliable results to pursue. Adding reagents in different ratio's for each experiment trial with different temperature of water sample would distort the readings and give incomparable results. Since a change in concentration would change the amount of moles that the reagent contains and thus cause inaccurate readings to be tabulated.	Using the same fixed concentration for each of the reagents by making standard solutions with appropriate moles. (Refer to the preparation of stock solutions in the procedure section)
Amount of Starch added ($\mathbf{2.00}\ \boldsymbol{cm^3}$)	Different amounts of starch would yield colours of different intensity making it relatively harder to be able to find the neutralisation point or the end point which might be exceeded leading the erroneous data and results.	Adding a fixed volume of starch indicator for each trial using the dropper ($\mathbf{2.00}\ \boldsymbol{cm^3}$)
Room temperature and Pressure	Because pressure is one of the factors influencing oxygen concentration in water, pressure is maintained to prevent erroneous changes in oxygen concentration and to only investigate the effect of temperature on it, preventing deviation of the research.	The experiment was conducted in a closed room, with the windows closed to prevent air entering the room and influencing the pressure.

Experimental Procedure

Name	Capacity	Purpose	Uncertainty
Analogue Thermometer	-	To measure the temperature of the water sample being heated	± 0.05℃
Measuring Cylinder	$100cm^3$	To measure the volume of water sample.	$\pm 0.01 cm^3$
Burette	$50cm^3$	To contain and pour the solution of Na_2S_2O3 in order to slowly drop the solution, efficiently determining the end point or neutralisation point.	$\pm 0.02 cm^3$
Graduated Pipette	$10\ cm^3$	To deliver a fixed volume of reagent accurately.	$\pm 0.05 cm^3$
Retort Stand and Clamp	-	To hold the burette for the titration process	-
BOD Bottle	$200\ cm^3$	To contain the solution made from the water sample and reagents and to carry out the experiment in the BOD bottle to ensure that the vapours do not escape.	-
Digital Stopwatch	-	To measure the time the sample of water is heated for.	$\pm 0.01 s$
Weigh Balance	-	To measure the weight of starch	$\pm 1.0 g$
DO Probe	-	To measure the dissolved oxygen concentration of water	$\pm 0.1\ mgdm^{-3}$

Chemicals Required	Purpose Of Requirement	Hazard, Dangers and Risks	Safety Measure/Precautions
Distilled Water **H_2O** **$200cm^3$**	To calculate the Biological Oxygen Demand.	No hazards as such, but avoid consumption of water as it might contain waste materials that are harmful.	Accurate Instruments used, to use the correct volume of water
100% Concentrated Solution of Sulphuric Acid **H_2SO_4** **$2.0cm^3$**	Used to oxidise the iodide ions (I^{2-})	If comes into contact, can burn the skin. Irritate and burn the eyes. Long exposure may lead to blindness (in severe cases).	Ensured wearing a lab coat, safety eyewear(goggles), hand gloves to avoid direct contact with any reagent. These all methods helped to minimise the contact with any chemicals.
Manganous (II) Sulphate **$MnSO_4$** **$2.0cm^3$**	Provides Alkaline conditions to oxidise Manganese (Mn^{2+})	Skin Irritation, gastrointestinal irritation with nausea, respiratory tract irritation.	Lab coat, safety eyewear(goggles), hand gloves to avoid direct contact with any reagent.
Aqueous Sodium Thiosulphate **$Na_2S_2O_3$** **$2.0\ cm^3$**	For Redox Reaction and Neutralisation reaction to occur.	Skin and Tract Irritation	Wear gloves and lab coat to prevent contact.
Starch Indicator Solution **5 drops**	A starch solution is used as an indicator in an iodometric titration because it can absorb the I_2 that is released. Titrated with standardised thiosulfate solution, this absorption causes the solution's colour to change from deep blue to light yellow representing end point.	Skin Irritation	Wear gloves and lab coat to prevent contact. Use a dropper in order to slow add the indicator solution to obtain colour change during titration.

Table 3: Chemicals and Reagents Required

Preparation of Chemicals and Stock Solutions:

- **Sodium Thiosulfate (0.025 dm^3):** Dissolve 28.42g of $Na_2S_2O_3 \cdot 5H_2O$ in boiled distilled water and make up a solution equating to the volume of $1000\ cm^3$. Dilute the solution 4 times in order to obtain a solution of concentration $0.025\ moldm^3$.
- **100.00 cm3 of 3.00 M Manganese (II) Sulphate (Mn(II)SO4):** Dissolve 50.85 g of manganese (II) sulphate in distilled water in 100.00 cm3 of volumetric flask.
- **Alkali Azide Solution**: Dissolve 100g of KOH and $50g$ of KI in $200cm^3$ of distilled water.
- **Starch Indicator Solution:** $1g$ of starch should be dissolved in water of volume $100cm^3$, add a few drops of formaldehyde solution.

<u>Procedure for Winkler's and DO Probe Process:</u> Using a measuring cylinder, measure $200cm^3$ of volume of water sample and add it to a beaker. While pouring the water ensure that there should be no air bubbles that could momentarily impact the results. Next connect an electric heater and place the beaker filled with the water sample into the electric heater. Place a thermometer into the water sample and tabulate and note down the temperature reading of the water sample to ensure that the heating is being started off from the same initial temperature for each reaction (benchmark the temperature) to ensure a fair experiment is carried out. Next switch on the electric heater and heat the water sample until the desire temperature is achieved. Repeat this process of heating for each trial and also for different trials of heating it to different temperatures to make comparisons to other results. Next, once the sample is heated to the required temperature swiftly transfer the water from the beaker to the insulated BOD Bottle ($200cm^3$) to avoid heat loss. Following that, the Winkler Method (titration) is used to calculate the dissolved oxygen concentration in the water samples. Add a fixed volume of $2.0cm^3$ of 1% concentrated Manganous (II) Sulphate solution to the water sample in the BOD bottle using a graduated pipette of $(10cm^3 \pm 0.05cm^3)$ to accurately deliver a fixed volume of reagent. Shaking the BOD bottle ensures that the reagents have mixed well together and improves the efficiency of mixing the solutions. Using a dropping pipette, carefully add $2.0cm^3$ of 80% concentrated sulphuric acid ($2.0cm^3$) to accurately deliver a fixed volume of acid. Add $2.0cm^3$ of Alkali Azide and allow the solution to settle until the precipitate has dissipated, resulting in a brown solution. Immediately put the stopper over the bottle upon addition of the reagents to ensure no air bubble interaction takes place. If dissolved oxygen is present, an orangish- brown precipitate will appear and shake the BOD bottle if the precipitate settles at the bottom of the bottle. Next, place the burette on the clamp stand. $50cm^3$ burette was filled with 0.025 mol dm^{-3} $Na_2S_2O_3$ for the titration process. Finally, using the titration method, place the sample solution in the BOD bottle beneath the burette containing Aqueous Sodium Thiosulfate and gradually open the valve/stopcock allowing the alkali to run into the solution sample. Furthermore, ensure to swirl the conical flash while the solution of $Na_2S_2O_3$ drips into the solution to ensure the two solutions mix properly and make sure neutralization of the acid occurs. Finally, add $2.0cm^3$ starch indicator solution to the conical flask that turns the solution blue. Continue to add alkali from the burette until a colour change is visible. Close the valve of the burette and record the reading since the end point or neutralisation point is reached as soon as a colour change from blue to colourless is observed. Record the final value of sodium thiosulphate used. To improve the reliability of the results, repeat the titration for at least 5 trials in order to calculate a mean value. Repeat each step for each temperature that will be investigated ($\mathbf{30°C, 40°C, 50°C, 60°C, 70°C}$).

Figure 1: Reagents and Apparatus Set up for the Experiment

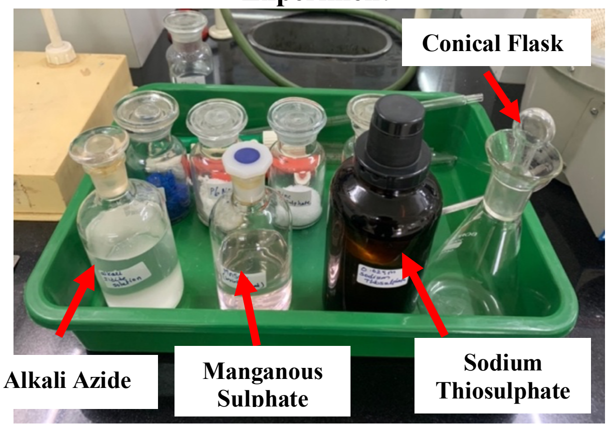


Figure 2: Apparatus Set up with Lab Coat and Gloves for Safety Purposes

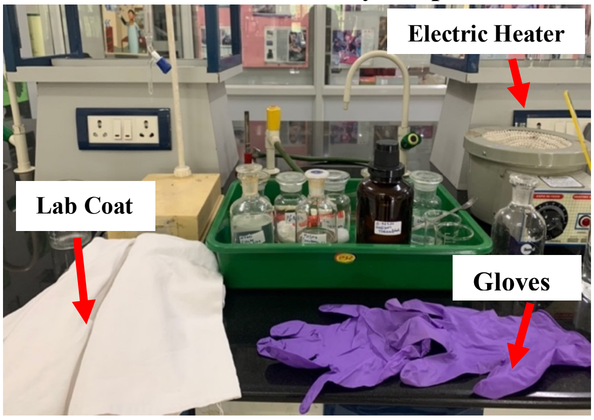


Figure 2: Apparatus and Reagents along with the process used for the

Safety Issues: Ensure to wear safety gloves, lab coat and eyewear throughout the experiment to avoid injuries and contamination of any chemical reagents or samples and to protect from the chemicals used. Since concentrated sulfuric acid is highly corrosive thus as a result it is essential to neutralize it before discarding it. Manganese (II) Sulphate can cause irritation of the skin and eyes and hence as a result must be utilised with care. It is important to avoid contact with chemicals for long durations or for a prolonged period of time as they can be fatal, especially because they cause harm to the organs. The electric heater that was used to raise the temperature of the water sample must be insulated well and used with care to avoid any potential dangers or injuries that may occur. Make it a priority to keep hands dry at all times to avoid touching any electrical component or switches with wet hands that can cause electric shocks. Dispose the chemicals properly to avoid harm.

Ethicality in Experiment and Environmental Concerns: Since the chemicals are extremely vital for the experiment, make efficient calculations and use the appropriate amounts only to avoid wastage. Turn off the electric heater whenever not in use, this helps to conserve electricity preventing the wastage of it. If there are any unused chemical reagents or solutions then do not dispose them directly into the sink as they can cause severe damage to aquatic life. Neutralize the solutions and acids before discarding and disposing them. Since the experiment composed of no living matter thus as a result, no unethical practises were involved in the experiment. Although a substantial amount of water was utilised throughout the experiment and a considerable amount was wasted considering the fact that the experiment required a lot of water usage.

Assumptions made in the experiment:

- No energy loss to surroundings in the form of heat.
- Dissolved Oxygen Concentration values determined by the D.O probe are theoretical
- All chemicals and reagents used in the experiment have no impurities
- The standard solutions have negligible uncertainties.

Data Processing and Analysis

Qualitative Observations

Over addition of 2.00 cm^3 of Manganese (II) Sulphate solution and Alkali Azide solution to the water samples (200 cm^3), an orangish-brown precipitate formed and was observed. Next up, adding 2.0 cm^3 concentrated sulphuric acid caused the cloudy insoluble precipitate to vanish, producing a orange-brown mixture with a slight layer of white on top of the precipitate. Next, shaking the bottle causes this precipitate to dissolve and vanish producing a dark yellowish solution which is clear. Beginning the titration process, as a small amount of Sodium Thiosulfate ($Na_2S_2O_3$) is allowed to drip into the solution, the solutions dark yellow colour turns slightly light, causing the darkness of the sample to diminish. Adding a starch indicator causes the solution to turn dark blue, and then the addition of sodium thiosulphate ultimately turns the solution colourless denoting the neutralisation and end point of the titration. The flask was constantly swirled while the sodium thiosulfate ($Na_2S_2O_3$) was being added to ensure efficient mixing of the reagents to determine the end point accurately.

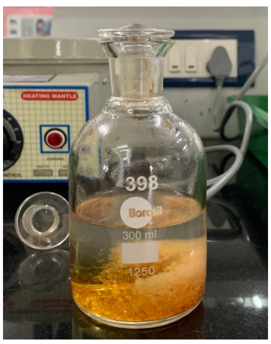


Figure 3: Precipitate After Addition of Concentrated Sulfuric Acid (H_2SO_4)

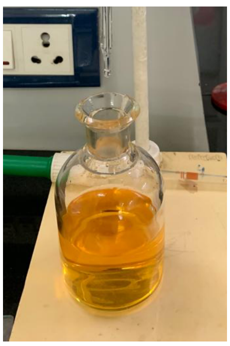


Figure 4: Clear Dark Yellow Solution After Shaking the Bottle

Figure 5: Dark Blue solution produced after the addition of starch indicator

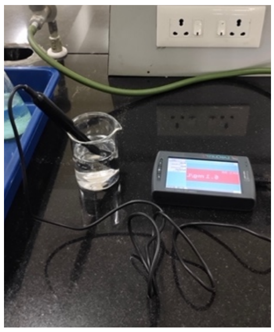


Figure 6: Calibration of D.O Probe

Quantitative Analysis

RAW DATA												
Temperature ± 0.05°C	Initial volume of sodium thiosulfate ($Na_2S_2O_3$) $\pm 0.05 cm^3$	Final volume of sodium thiosulfate $Na_2S_2O_3$ $(\pm 0.05) cm^3$					Change in volume of sodium thiosulfate ($Na_2S_2O_3$) $(\pm 0.05) cm^3$					Average volume of sodium thiosulfate $Na_2S_2O_3$ used $\pm 0.05\ cm^3$
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	
30.0	0.00	12.10	11.50	11.60	12.00	11.70	12.10	11.50	11.60	12.00	11.70	11.78
40.0	0.00	10.30	9.80	10.30	10.50	9.90	10.30	9.80	10.30	10.50	9.90	10.16
50.0	0.00	10.00	9.80	9.50	9.60	9.60	10.00	9.80	9.50	9.60	9.60	9.70
60.0	0.00	8.30	7.80	8.00	8.50	8.50	8.30	7.80	8.00	8.50	8.50	8.22
70.0	0.00	7.00	7.30	7.10	7.00	7.10	7.00	7.30	7.10	7.00	7.10	7.10

Table 4: Readings for Temperature and Average Volume of Sodium Thiosulfate used

For each Winkler Method Titration Starch Indicator added causes the solution to produce a dark blue colour. As the stop cock is gradually opened enabling the sodium thiosulfate solution to flow into the conical flask a reaction occurs and a colour change is observed from: **"Blue To Colourless"**

***Sample Calculation**: For 30 °C*

$$\boldsymbol{Change\ in\ Volume\ of Na_2S_2O_3 = \ Final\ \ Volume\ of\ Na_2S_2O_3\ - Initial\ Volume\ of\ Na_2S_2O_3}$$
$$\mathbf{= 12.10 - 0.00 = 12.10 \pm 0.10\ cm^3}$$

$$\boldsymbol{Change\ in\ Volume\ of Na_2S_2O_3 = Volume\ of\ Na_2S_2O_3\ used}$$

$$\text{Average Volume of Na2S2O3 used} = \frac{\text{Change in volume (Trial1 + Trial2 + Trial3 + Trial4 + Trial5)}}{5}$$

$$= \frac{12.10 + 11.50 + 11.60 + 12.00 + 11.70}{5} = 11.78cm^3$$

$$\text{Uncertainty in Average} = \frac{\Delta\text{Trial1} + \Delta\text{Trial2} + \Delta\text{Trial3} + \Delta\text{Trial4} + \Delta\text{Trial5}}{5}$$

$$\text{Uncertainty in Average} = \frac{0.10 + 0.10 + 0.10 + 0.10 + 0.10}{5} = \pm 0.10$$

***Sample Calculation of Uncertainty** (30°C):*

$$\text{Average Change in volume of sodium thiosulfate} = \mathbf{11.78} \boldsymbol{cm^3}$$
$$\text{Uncertainty in volume of sodium thiosulfate used: } 0.05 + 0.05 = \pm\mathbf{0.10}$$
$$\textbf{Number of Moles (mol)} = \ \textbf{Concentration (moldm}^{-3}\textbf{)} \times \textbf{volume (dm}^3\textbf{)}$$
$$\boldsymbol{n = cv}$$
$$\text{Moles of sodium thiosulfate used} = 1.2\text{x}10^{-2}\ \text{x}\ 0.025 = \mathbf{3.00\ x\ 10^{-4}}\boldsymbol{moles}$$
$$\text{Uncertainty in Moles of sodium thiosulfate used} = \frac{0.10\text{x}10^{-3}}{1.2\text{x}10^{-2}}\ \text{x}\ 3.00\ \text{x}\ 10^{-4} = \mathbf{2.50\ x\ 10^{-6}mol}$$

***Moles of O2 in Water Sample**:*

4 moles of $S_2O_3^{2-}$ is used when Manganese sulfate reacts with one mole of O_2

Sample Calculation (for 30°C);

$$\boldsymbol{n} = \frac{\mathbf{3.00\ \times\ 10^{-4}}\ \boldsymbol{mol}}{\mathbf{4}} = \mathbf{7.50\ x\ 10^{-5}}\ \boldsymbol{mol}$$

Mass of Oxygen (O_2) in $200cm^3$ Water Sample:

$$\text{Mass} = \text{moles x Mr}$$

Mr of $O_2 = (16.00 \text{ x } 2) = 32.00\text{gmol}^{-1}$ (referred to the Periodic Table to get the ARR of Oxygen)

Sample Calculation (for 30℃);

$$\text{Mass of } O_2 = \text{moles x Mr}$$

$$\text{Mass of } O_2 = 7.5 \text{ x } 10^{-5} \text{ x } 32.00\text{gmol}^{-1} = 2.4 \text{ x } 10^{-3} g$$

Concentration of Dissolved O2 in ppm Calculation;

$$1g \rightarrow 1000mg$$

$$2.4 \text{ x } 10^{-3} g \rightarrow 1000 \text{ x } 2.4 \text{ x } 10^{-3}\text{g}$$

$$\mathbf{2.4mg}$$

A weight-to-weight ratio for describing concentrations. The number of parts per million (ppm) of a contaminant per million units of total mass. One mg or dm^3 is equivalent to 1 ppm.

$$\text{concentration} = \frac{\text{mass (mg)}}{\text{volume (dm}^3)} \rightarrow \text{concentration} = \frac{2.4 \text{ mg}}{0.200 \text{ dm}^3} = 12.00\text{mgdm}^{-3} = \mathbf{12.00ppm}$$

Table 5: Final Processed Data For Winkler's Method with Percentage Error

Temperature(± 0.05℃)	Concentration of Dissolved Oxygen in Water (ppm) (± 2.5ppm)
30.0	**12.00**
40.0	**10.00**
50.0	**9.73**
60.0	**8.21**
70.0	**7.20**

Table 6: Raw Data for D.O Probe

Temperature (± 0.05℃)	Dissolved Oxygen Probe Readings ($\pm 0.01\text{mgdm}^{-3}$)					Average Dissolved Oxygen ($\pm 0.01\text{mgdm}^{-3}$)	Absolute Uncertainty	Percentage Error compared to Winkler's Method Readings (%)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5			
30.0	13.15	13.00	12.40	12.80	13.30	12.93	± 0.45	7.20
40.0	11.00	11.20	11.15	11.40	12.40	11.43	± 0.70	12.51
50.0	9.90	10.00	9.95	8.85	10.20	9.78	± 0.68	0.51
60.0	8.50	9.00	9.15	9.40	9.30	9.07	± 0.45	9.48
70.0	7.60	8.50	8.00	8.30	7.80	8.04	± 0.45	10.45

Average Dissolved Oxygen (DO Probe) Calculation for 30℃:

$$\text{Average Dissolved Oxygen} = \frac{\text{Trial1} + \text{Trial2} + \text{Trial3} + \text{Trial4} + \text{Trial5}}{5}$$

Uncertainty Calculation for 30℃:

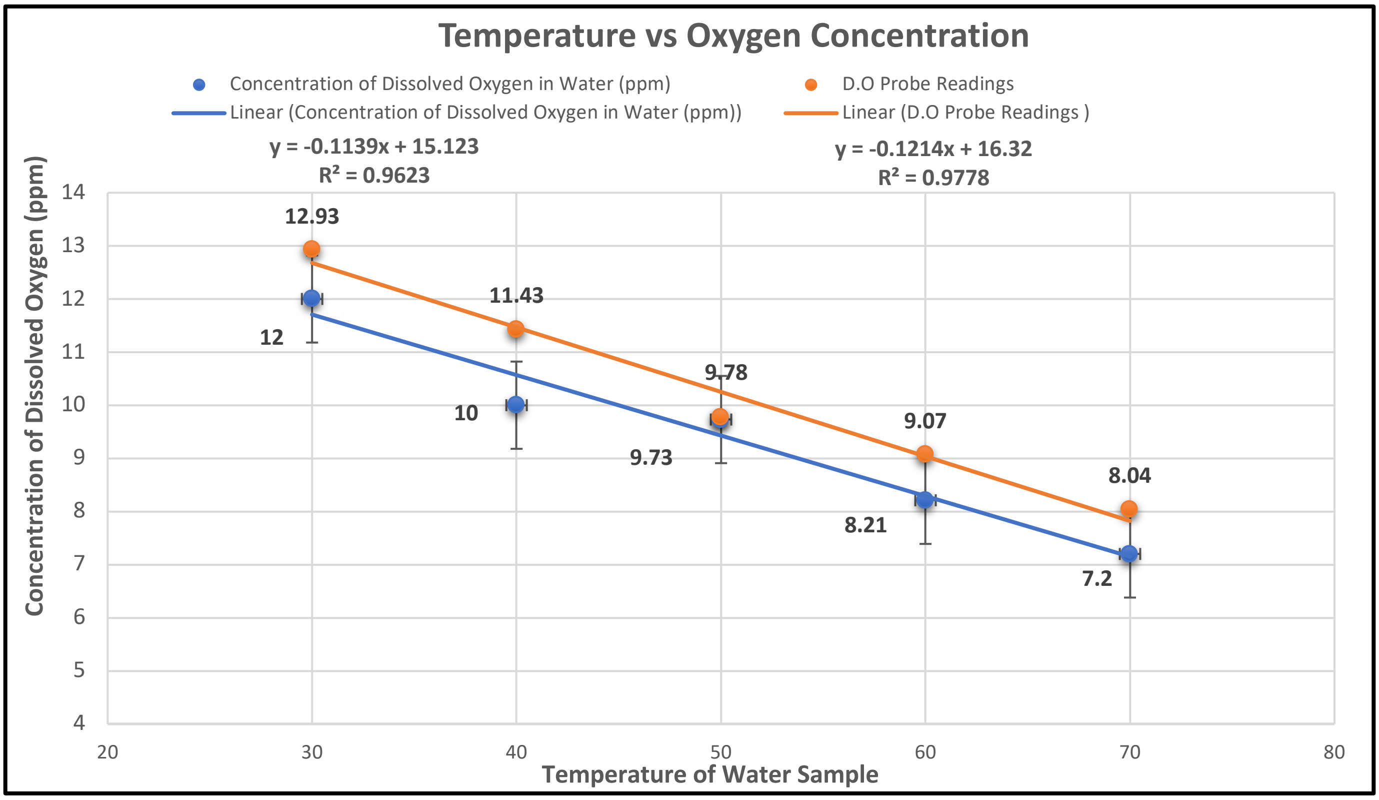
$$\frac{\mathbf{13.30 - 12.40}}{\mathbf{2}} \approx \mathbf{0.45}$$

Percentage Error Calculation for 30℃:

$$Error = \left|\frac{Values\ by\ D.O\ Probe - Values\ of\ Winkler\ Method}{Values\ by\ D.O\ Probe}\right| \text{x } 100$$

$$Error = \left|\frac{12.93 - 12.00}{12.93}\right| \text{x } 100 = \mathbf{7.20}\%$$

Analysis of the Graph



Graph 1: Temperature vs Oxygen Concentration in Water for D.O Probe and Winkler's Method

The concentration of dissolved oxygen is the greatest for the lowest temperature denoting that cold water has a higher amount of dissolved oxygen. Gradually as temperature is increased the concentration of dissolved oxygen decreases, causing lack of availability of O_2 in water. Tabulating the graph of temperature against oxygen concentration, a relationship is obtained. The graph shows that as the temperature of 200cm^3 of water increases the concentration of dissolved oxygen or BOD value of oxygen decreases. At 30°C the concentration was $\mathbf{12.00}\boldsymbol{ppm}$, however doubling the temperature to 60°C caused the BOD content to substantially decrease by $\mathbf{32\%}\ \mathit{to}\ \mathbf{8.21}\boldsymbol{ppm}$. The lowest concentration of dissolved oxygen was interpreted for the water sample with the highest temperature of 70°C which had a oxygen concentration value of $\mathbf{7.00}\boldsymbol{ppm}$ for Winkler's Method and $\mathbf{8.04}\boldsymbol{ppm}$ **from the D.O Probe**. Winkler Method shows that as temperature is increased from 30°C *to* 70°C concentration of dissolved oxygen decreases from **$\mathbf{12.00}$ ppm to $\mathbf{7.20}$ ppm**, a $\mathbf{40\%}$ reduction. For the D.O Probe Method an increase in temperature from 30°C *to* 70°C causes the oxygen concentration to decrease by **$\mathbf{12.93}$ ppm** to **$\mathbf{8.04}$ppm, $\mathbf{37.82\%}$ reduction**. The change in dissolved oxygen is smaller in Winkler's Method than D.O Probe showing that the manual process of finding dissolved oxygen content is more accurate. The negative trends in both the curves confirms the hypothesis stated at the beginning of this investigation: **As the temperature increases the concentration of dissolved oxygen decreases.** In this graph, the horizontal bars represent errors in the temperature, which are small and constant for all the readings. The vertical error bars represent the uncertainty and error in the Dissolved Oxygen (DO) levels. The line of best fit has been illustrated that passes through maximum points to provide an accurate value of R^2 and make predictions for further (not investigated) temperature. A strong negative correlation is established between temperature and the concentration of dissolved oxygen since the values of $\boldsymbol{R^2} = \mathbf{0.9623}\ \boldsymbol{and}\ \mathbf{0.9778}$, almost equivalent to 1 denoting the strong relationship. The gap between the two curves seems to decrease, which shows that the percentage uncertainty decreases. Because the values for R2 are nearly equal to one (real values = 0.962 and 0.9778), there is a relatively small difference, indicating a strong relationship between the temperature of the water sample and the concentration of dissolved oxygen. The graph corroborates and helps to portray the accuracy with which the experiment was conducted because of the relatively small percentage uncertainty and absolute uncertainty, as evidenced by the small error bars on the graphs. The small percentage uncertainties are due to external factors that were challenging and difficult to control, causing the readings to be distorted.

There's a linear relationship between the temperature and dissolved oxygen in the water sample for both the Winkler Method and D.O Probe method. Thus the value for x for the linear equation resonates at what temperature the D.O Levels will become zero.

Winkler Method: $y = -0.1139x + 15.123$

$$0 = -0.1139x + 15.123$$

$$-0.1139x = -15.123 \longrightarrow \frac{-15.123}{-0.1139}$$

$$= \mathbf{132.77}°\mathrm{C}$$

D.O Probe Method: $y = -0.1214x + 16.320$

$$0 = -0.1214x + 16.320$$

$$-0.1214x = -16.320 \longrightarrow \frac{-16.320}{-0.1214}$$

$$= \mathbf{134.43}°\mathrm{C}$$

In terms of the safety, reliability and the accuracy of the data and findings of the experiment, several measures were carried out to ensure the reliability of the result was high. For instance a glass stopper was used to prevent heat loss from occurring and evade inaccuracy in results. Furthermore, the experiment was conducted in a closed room to prevent the wind blowing or draught affecting the temperature of the water sample and affecting the results. Lab coat, gloves and lab eyewear were worn to prevent contact and injuries occurring from usage of corrosive acids or any chemical agent.

Conclusion: Overall the study was able to experimentally derive a relationship between temperature $(30°C, 40°C, 50°C, 60°C, 70°C)$ and dissolved oxygen levels (DO).Observations made in the research led to the conclusion that as the temperature of the water sample was increased, the concentration of dissolved oxygen decreased depicting a inverse relationship. Hence, the results and findings of this experiment strongly supports and garners a base for my hypothesis and explanation, given throughout the report. The results obtained, interpreted and represented show that as the temperature increases, the concentration of dissolved oxygen in water sample decreases linearly. Thus relating to the introduction of this research, as claimed, that the aquatic and marine life have been going extinct recently due to several anthropogenic impacts, due to increasing temperature as a result of global warming. Moreover, it is important to conserve the resources and the environment. Thus as result, this investigation report certainly supports the hypothesis and nurtures to make a claim that all must abide by which is to attempt to constrain and reduce anthropogenic impacts and limit, prevent temperature of water from increasing so that it does not influence the amount of dissolved oxygen in the water and the aquatic species, animals have sufficient amount of oxygen to utilise for their survival, and this limit could be a step towards saving marine life. Although the experiment conducted was highly accurate as shown by the high R^2 value, there may have been some random errors in the experiment such as:

Student Reaction Time: Closing the burette valve with time delay leads to addition of more than calculated sodium thiosulfate solution which although is a minor issue, it causes deviations from accurate readings.

Transfer of Heated Water into BOD Bottle: The longer the time taken to transfer the heated water sample (heated using an electric heater) from beaker to the BOD bottle, the higher the amount of energy loss that occurs to the surroundings which add to the uncertainty in the experiment. Due to the gap in curves for D.O Probe readings and Winkler Method, errors could be present perhaps due to flaws in the experiment process or procedure and slight uncertainties in apparatus. To tackle the issue of errors pertaining to the apparatus the experiment could be repeated several times taking greater number of trials to improve experimental accuracy and obtain reliable data.

In terms of the safety, reliability and the accuracy of the data and findings of the experiment, several measures were carried out to ensure the reliability of the result was high. For instance a glass stopper was used to prevent heat loss from occurring and evade inaccuracy in results. Furthermore, the experiment was conducted in a closed room to prevent the wind blowing or draught affecting the temperature of the water sample and affecting the results. Lab coat, gloves and lab eyewear were worn to prevent contact with chemicals and injuries occurring from usage of corrosive acids or any chemical agent. This helped to maintain keep the experiment ethical while achieving the aim of the investigation.

Strengths / Weaknesses and Improvements

Strength	Significance/ Effect on Results
Recording of Data along with Calculations	The most prominent strength in this experiment was the way in which the accurate calculations were carried out along with the recording of the data. Firstly, the calculations were carried out in a book manually and once the readings and calculations were done, they were transferred to excel to make graphs with trendlines.
200cm^3 BOD Bottle	One of the biggest strengths of this experiment and investigation was using the BOD bottle for the experiment. The usage of BOD bottle prevented the entrance of oxygen into the water sample. Thus, the contamination of the amount of moles of O_2 and the concentration of the oxygen was prohibited.
Use of Logger Pro and Excel	After carrying out the calculations, the data obtained, was fed into the excel software. Next once data was input into the excel, graphs were made in order to resonate the trendline. However, to furthermore enhance the tracing of results, a line of best fit was plotted and formulated onto the graph as well so as to consider the anomalous and outlier points. The equation line and R2 value has been included to depict the statistical relationship and proportionality.
Low Percentage Uncertainty and Low Standard Deviation	Due to the relatively low percentage uncertainty and standard deviation of the experiment, this is a major strength for the experiment and investigation, since the range or error is small, denoting that results are highly accurate. Furthermore, due to the high R2 value, it furthermore shows the high accuracy and precision of the results.
Pipette	Using a graduated pipette, enabled a fixed volume of reagent to be added to the solution accurately. This helps to raise result reliability. This also helps to get rid of high uncertainties and random errors.

Methodological Errors	Significance	Improvement
High Uncertainty for Winkler's Method	High Significance: Winkler's method is not highly accurate when comparing to finding the Dissolved Oxygen using a equipment – DO Probe due to the high uncertainty. Thus the errors could be due to these reasons.	In order to curtail down these errors, take greater amount of readings to eliminate the uncertainties. However considering Winkler's Titration is a manual process it could more accurate thus, it is necessary to improve the procedure of the Winkler's Method to avoid flaws within the experiment.
Subjective Titration Endpoint/Neutralisation Point	High Significance: Due to various reasons, after addition of the starch indicator and addition of sodium thiosulphate to achieve end point, it was relatively difficult to judge whether the solution changed colour from blue to colourless or is it still pale blue causing slightly higher readings.	To ensure the colour is clear, place a white card to ensure the colour is clear. Next up use a colour chart and mark the end point or use a reference standard solution.

Random Errors	Significance	Improvement
Parallax Error	Low Significance: This occurs due to viewing the burette incorrectly causing the reading obtained to be slight inaccurate	Take several trials and calculate mean value to reduce the error.
Precision of the DO Probe	Low Significance: DO Probe has high accuracy but low precision	Calibrate the instrument after every trial.
Vaporization of Chemicals	Low Significance: Affects aspects within the experiment and reaction occurring.	Ensure the chemicals are covered with aluminium foil to avoid it's vaporization.

Systematic Errors	Significance	Improvement
Heat Loss to the Surroundings	High Significance: During the titration when the solution of $Na_2S_2O_3$ was allowed to drip into the BOD bottle, because the glass stopper was removed, this causes heat loss to occur for the period of time when the reagent from the burette was being added.	Use foil, cover the BOD bottle with it, leave a small opening for sodium thiosulfate to drip into the solution. This would help to minimize heat loss.
Impurities in Chemicals	Low Significance: Impurities present in chemicals can affect the readings causing inaccurate values to be obtained.	Ensure that the chemicals utilised are of highest grade. Moreover take account of uncertainties in calculations to have a accurate conclusion.
Placement of DO Probe in the sample	High Significance: Depending on the depth at which the DO Probe is immersed into the sample can, the DO can vary.	Take DO readings from the same position depth to obtain accurate values and for a fair experiment.
Amount of Starch Added	High Significance: Addition of too much or too little starch can certainly impact and affect the colour intensity thus further negatively impacting the final titration.	Add a volume of starch which is consistent for each and every trial.

Further Scope of Investigation:

- Study the effect of pH of water on the concentration of dissolved oxygen?

Unresolved Questions:

- Is there any temperature above which concentration of dissolved oxygen increases?
- How does the level of pollution in water impact the BOD and concentration of dissolved oxygen?

Alternate Methods: Finally since two methods have already been explored to investigate the relationship between the temperature and concentration of dissolved oxygen in water. Thus another method to come to the same conclusion could the using the colorimetry method which uses colour sensitive reagents such a rhodazine D and indigo carmine ($C_{16}H_8N_2Na_2O_8S_2$). The DO concentration is measured by using the Indigo Carmine, which produces a blue colour with intensity directly proportional to the concentration of dissolved oxygen (DO). On the contrary, Rhodazine D is relatively more efficient and effective with lower concentrations and produces a purple-pink colour rather than the production of a blue colour.

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