The Effect of Seawater Salinity on Specific Heat Capacity

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1. Introduction

As a diver, something that always troubles me is the water temperature, especially in winter. Water, well-known for its high specific heat capacity, gains and loses heat slowly. However, every time I go diving, there is different sensible temperature. I become interested in the factors influencing the specific heat capacity of water, and salinity is what want to investigate in in this lab.

The research question is how does seawater salinity affect its specific heat capacity, assuming that all other factors, like pH value, initial temperature, mass, etc., are held constant.

This report bases its finding on the first law of thermodynamics, which is expressed mathematically as the formula:

$$\Delta Q = mc\Delta T,$$

where ΔQ is the change of heat in the system, m is the mass of liquid, c is the specific heat of a substance, and ΔT is the change in temperature.

Also, according to the conservation of energy, when the water is heated, the heat it absorbs equals the amount of energy the heat source releases, assuming there is no energy loss. This is expressed mathematically as:

$$\Delta Q_{absorb} = \Delta Q_{release}$$

Therefore,

$$\Delta Q = cm\Delta T = Pt, \text{ so}$$

$$c \propto t,$$

where P is the power of the heating source, t is the time of the heating.

Based on this formula deduced, the specific heat capacity of seawater proportional to the heating time. We hypothesize that there is a negative relationship between the salinity and the specific heat capacity. In other words, when salinity increases, the specific heat capacity decreases. In order to show this relationship, we only need to show that salinity of seawater is proportional to the heating time required for it to rise certain temperature.

Aiming to prove the hypothesis, this report will change the salinity of seawater and keep everything else constant. Then by measuring the time it takes for a certain mass of that seawater to raise a certain amount, we can obtain the heat absorbed, and thus determine the relationship between specific heat of that seawater sample and its salinity.

2. Method

2.1   Apparatus

- Five beakers of 100mL
- A stirring rod
- A thermometer (± 0.5˚C)
- Table salt
- A balance (± 0.1g)
- A hot plate
- Distilled water
- A dropper
- A weigh boat
- A timer

2.2   Procedure

First, a beaker was put on the balance. The balance was zeroed. Distilled water was added into the beaker. Little amount of water was added using a dropper in the end until the balance shows 100.0g. The beaker was labelled with Trial 1.

Now, with the same method, the other four beakers were filled with 95.2g, 90.9g, 87.0g, 83.3g of distilled water, respectively. The beakers were labelled with Trial 2, Trial 3, …

A weigh boat was placed on the balance. The balance was zeroed. No Sodium Chloride was added to Trial 1. For Trial 2, 4.8g of Sodium Chloride was weighed on the balance and added into the beaker of Trial 2. Similarly, for Trial 3, 9.1g of Sodium Chloride was added; for Trial 4, 13.0g; for Trial 5, 16.7g. After the Sodium Chloride was added into each trial, the solution in each beaker was mixed using a stirring rod until the Sodium Chloride fully dissolved.

After all the solutions were prepared, the hot plate was connected to power and turned on to Level High. The temperature of Trial 1 solution was measured using a thermometer and recorded as t_0. When the hot plate was heated enough, Trial 1 was put on the hot plate. Simultaneously, the timer was started to record the time.

The timer was stopped as soon as the temperature measure from the thermometer increased 30°C from t_0 to t1. The time the heating took was recorded as ΔT. The same procedure was done for all the rest of the trials. The measures were recorded in a table.

3. Results

3.1   Raw data

Table 1. Masses, temperature, and heating time for all solutions

Trial	mass of water m_1 ($\pm$ 0.1g)	mass of table salt m_2 ($\pm$ 0.1g)	initial temperature T_0 ($\pm$ 0.5°C)	final temperature T_1 ($\pm$ 0.5°C)	time of heating t ($\pm$ 1s)
1	100.0	0.0	22	52	215
2	95.2	4.8	22	52	202
3	90.9	9.1	22	52	190
4	87.0	13.0	22	52	174
5	83.3	16.7	22	52	159

3.2   Processed data

With the raw data shown in Table 1, we can calculate the salinity and differences as shown in Table 2:

Table 2. Specific Heating Capacity of Solutions of Different Salinities

| Trial	salinity (ppt)	Total mass m ($\pm$ 0.1g)	temperature difference ΔT ($\pm$ 1°C)	Heating time t ($\pm$ 1s)
1	0	100.0	30	215
2	50	100.0	30	202
3	100	100.0	30	190
4	150	100.0	30	174
5	200	100.0	30	159

Sample calculation for Trial 2:

a. $salinity = \frac{m_2}{m_1} \times 1000 = \frac{4.8g}{95.2g} \times 1000 = 50 \, ppt$

b. $m = m_1 + m_2 = 4.8 + 95.2 = 100.0 \, g$

c. $\Delta T = T_1 - T_0 = 52 - 22 = 30 \,^{\circ}C$

By plotting the salinity against the heating time, we get the following figure showing their relationship:

Chart1. Relationship between salinity and heating time
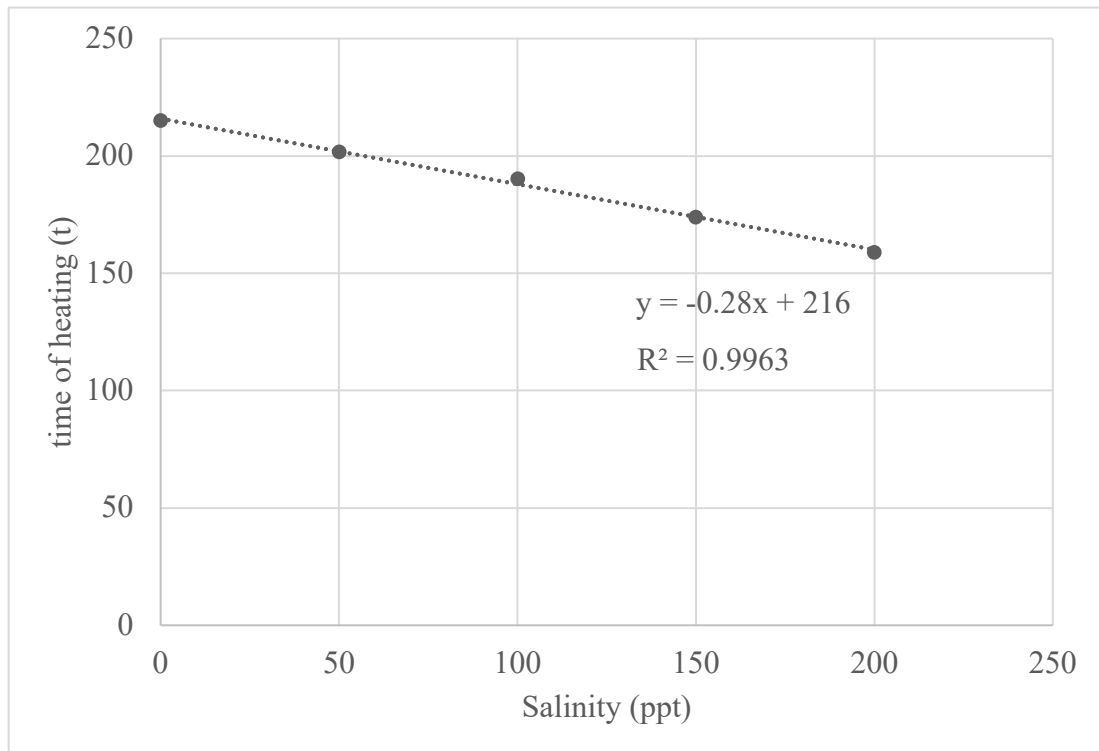
By plotting the line of best fit, there is a good fit showing there is a linear relationship between salinity and heating time. Since time of heating is proportional to the specific heat capacity, we can thus deduce that there is also a linear relationship between the salinity of seawater and its specific heat capacity.

4. Discussion

The result validates the hypothesis that there is a negative relationship between seawater salinity and the heating time required for the seawater to rise 30˚C. This negative relationship was expected and could be explained by molecular chemistry. Water has very high specific heat

capacity because of the strong intermolecular forces from Hydrogen bond. Heat is a result of the random motion of water molecules. When table salt, or NaCl, is dissolved in water, it becomes Na^+ and Cl^- ions that breaks the hydrogen bond, which means it takes less energy to increase the motions of the ions in the water than before. Since it takes less energy to activate the ions, the specific heat capacity decreases.

The data obtained in this experiment is accurate and precise. As shown in Chart 1, the linear fit has a R-value of 0.9963. It is very close to 1, which means that the linear fit is almost perfect. The uncertainty is also negligible compared to the large scale used.

The slight disparity of Trial 3 may result from several possible factors. First, it is possible that there was a delay in stopping the timer in the end when the temperature reached 52˚C, resulting the recorded time to be longer than the true value. It is also possible that the heat plate was not heated enough to start with. When the beaker was put on the heat plate, the heating rate was not constant yet and some extra heat was absorbed by the plate itself, resulting in less heat for the seawater.

To improve the experiment based on these two possible error sources, a digital temperature sensor could be used instead of an analogue thermometer. In that way, the reading of both heating time and temperature of seawater will be without any delay, and the change of temperature versus time could be shown clearly. The result would thus be more accurate. In addition, a sealed container will work better than a beaker. When a beaker is heated, a lot of extra heat is needed because the open beaker dissipates heat into the colder air while it is absorbing heat from the heat plate. When a more sealed container is used, this extra heat loss can be prevented, and the result will be thus more convincing.

Besides, considering sustainability, this experiment could have done better. The amount of water and table salt in each sample could be used less. Moreover, in order to save time, the highest heating level is used for the heating plate. This could not only lead to energy waste, but also potentially give less accurate result, because the lower the power, the longer the heating takes, and thus the time difference will be more prominent between different trials.

5. Conclusion

In this experiment, it is hypothesized that there is a negative relationship between seawater salinity and the specific heat capacity. The experiment was conducted based on the first law of thermodynamics. It was designed to first find the negative relationship between salinity and heating time, and then deduce the relationship between salinity and specific heat capacity. The data shown in Chart 1 validates this hypothesis. The result is very precise given a R-value of 0.9963. However, there still existed some possible sources of error that would be minimized using alternative approaches suggested.