The Study of the Effect of Sodium Chloride on the Boiling Point of Water

By Patrick Tuttle

Writing for Engineering

Instructor: Thomas Barber

The City College of New York

Fall 2018

Abstract

Water's unique chemical and physical properties is vital to supporting life. The boiling point of pure water, namely under Earth's standard atmospheric conditions, is 212 ^{0}F; however, substances, such as salt, can alter water's boiling point. To test this, tap water and salt water's boiling temperature was measured using a gas stove and a thermometer. It was found that tap water's boiling point was 211 ^{0}F; whereas, 150 grams of salt in an equal volume of water was 213 ^{0}F.

Introduction

Water is the most abundant resource on Earth and is crucial in sustaining life. In fact, 71% of Earth's landmass is covered in water [1]. Earth's water; however, is not created equally. The water throughout the globe varies in different minerals and elemental compounds. The ocean, for example, contains seawater, which has a salinity of 3.5% [2]. Salinity is the amount of dissolved sodium (Na^+) and chloride (Cl^-) ions. When sodium and chloride ionically bond, they form a solid known as sodium chloride (NaCl), or commonly known as table salt. Conversely, freshwater's salinity in nearly zero [2].

Water's unique properties, in terms of states of matter—solid, liquid, and gas—is a primary reason for Earth's ability to sustain life, particularly for water-dwelling organisms. Of the three primary states of matter, solids, due to their lower energy state, are the most abundant, naturally occurring on Earth [3]. Most elements and compounds have higher densities as solids than as liquids. Pure water's liquid form; however, is denser than its solid form (ice). As a result, ice floats on the liquid water. If the opposite were true, and ice did not float, the ice, as it froze, would sink to the bottom of the body of water. Eventually, the entire body of water would freeze and most fish, single-cell organisms, and other organism vital to sustaining human life would not survive.

Change in, and the resistance to change in, the states of matter is equally as vital to maintaining life on Earth, or any planet for that matter. Boiling is the change from a liquid to gas. Condensation is the change from a gas to liquid. Freezing occurs when a substance changes from a solid to a liquid and melting is the reverse. Phase changes need a mechanism for change, which is the addition or removal of energy, typically in the form of heat. For example, to melt ice, added heat is required. Freezing, on the other hand, requires the removal of heat. To determine which process—heating or freezing—requires more energy, an understanding of intermolecular forces is required. Hydrogen bonding, the primary intermolecular force between water molecules (H_20) is the strongest intermolecular force [4]. As water changes states from a gas to a liquid to a solid, the number of hydrogen molecules per unit area increases. Additionally, the distance between hydrogen bonds will decrease. As bond length decrease, the energy required to break the bonds increases. For water, it requires -80 cal/g to freeze water and 540 cal/kg to boil water, which is why most substances on Earth are solid (less energy for formation).

At a standard atmospheric pressure of 1 atmosphere, water boils at 100 ^{0}C (212 ^{0}F) [5]. Since water is the most vital resource for life, a planet must have a similar pressure to surface temperature ratio to Earth to support life. In addition to changing pressure, adding impurities, or elements other than water and oxygen, will change water's boiling point. Seawater, which contains salt, has a different boiling point than freshwater. If salt is added to freshwater, the boiling point of the water will increase.

The Environmental Protection Agency sets regulations for industrial plants who discharge waste products in to the atmosphere and into bodies of water. Brine, or salt-saturated water, is a primary byproduct of the chemical industry. Companies are required to dilute the brine under a certain concentration before dumping it into fresh water and seawater. Additionally, different regions require discharged fluids to be under a certain temperature. If these regulations are relaxed overtime, microecosystems will suffer, as a result. Salinity and toxicity levels would increase, making the freshwater potentially uninhabitable for freshwater organisms. Global temperature changes are also a concern for varying seawater salinity levels. As seawater temperature rises, more seawater will evaporate, and salinity levels increase. Phytoplankton, which produces over 50% of Earth's atmospheric oxygen, responds negatively to a change is seawater temperature and/or salinity [6]. In fact, since 1950, phytoplankton population has decreased by 40% [6]. As global deforestation and seawater temperature increases over time, it becomes more and more important to regulate industrial emissions, including salt water.

Objective

The objective of this experiment is to quantitatively determine the boiling point of tap water and salt water.

Materials

- 5.0 Liters of Tap Water
- Digital Scale
- Thermometer (50-400 ^{0}F)
- 12.5 Tablespoons of Table Salt
- Gas Stove
- 3 Gallon Saucepan
- Stopwatch
- Sink

- 1 Tablespoon
- 2 Liter Measuring Cup
- 1 Styrofoam Plate
- Pen or Pencil
- Data Table
- 1 Plastic Serving Spoon

Procedure

1. Ensure the sauce pan is clean and dry. Additionally, verify the measuring cup and spoon are clean, the stopwatch is set to zero seconds, and the data table and pencil are on-hand.

Figure 1: Materials Needed for Experiment

2. Determine the boiling point of tap water.
   a. Add 2.5 liters of tap water to the empty, dry sauce pan.
      I. Record the amount of water added in Table 1.
   b. Connect a thermometer to the side of the sauce pan.
      I. Submerge the tip of thermometer into the water.

Figure 2: Saucepan and Thermometer Set-up.

c. Record the temperature of the water in Table 1.

d. Ignite the gas stove and set the flame to 9, or the highest intensity, and start the stopwatch.

e. Record the water temperature in Table 1 for 1-minute intervals.

   I. When a single bubble forms in the water, mark an asterisk in Table 1.

   II. When the water is noticeably boiling, mark two asterisks in Table 1.

f. Record temperature, in 1-minute intervals, for 3 additional minutes.

g. After the 3 minutes have elapsed, stop the stopwatch.

h. Empty the boiling water in the sink.

   I. Avoid the hot water and steam when discarding the pot's contents.

i. Run cold tap water over the pan.

j. Wash and dry the sauce pan.

3. Determine the boiling point of salt water.

   a. Place a paper plate on a digital scale and press tare to zero the scale.

   b. With a measuring spoon, place 12.5 tablespoons of table salt on plate

   c. Record the mass (in grams) of the salt in Table 1.

   d. Add 2.5 liters of tap water to the empty, dry sauce pan.

      I. Record the amount of water added in Table 1.

   e. Connect a thermometer to the side of the sauce pan.

      I. Submerge the tip of thermometer into the water.

   f. Add the 12.5 tablespoons of salt into the water and stir using the plastic serving spoon.

I. The salt does not need to be fully dissolved; however, stirring for at least one minute is best.

g. Repeat steps 2.c through 2.k.

4. Using excel or MATLAB, plot, on one graph, change in temperature as a function of time for both tap water and salt water.

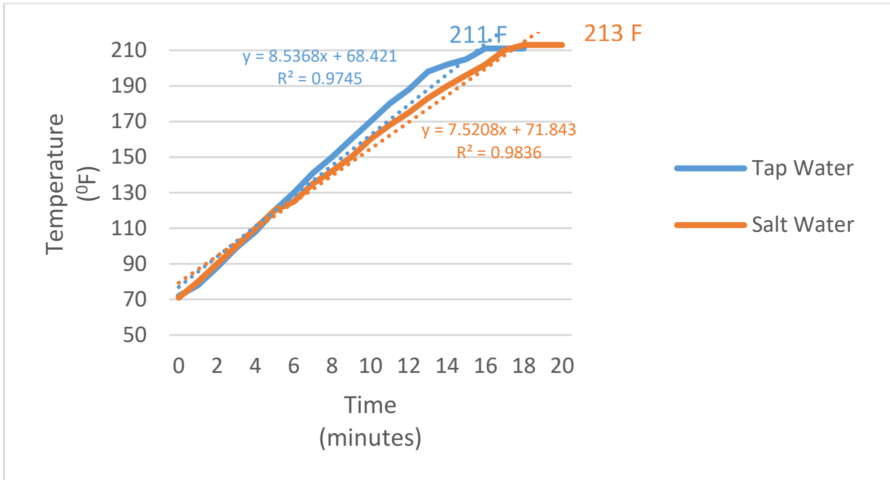
Results

Pure water and salt water temperature, as a function of time, both increases is a linear manner, as shown in Table 1 and Figure 3. The slopes of each plot on Figure 3 shows pure water had a slightly higher rate of temperature change (8.54 ^{0}F/min) than an equal volume of salt water (7.51 ^{0}F/min). Salt water's boiling temperature was higher than pure water, at 213 F and 211 F, respectively. Using the trendlines on Figure 3, temperature at any given point in time. For pure water: y(temperature) = 8.54 * x(time) + 68.421 F and salt water: y(temperature)= 7.52 * x(time) + 71.843 F.

Table 1— Determining the Boiling Point of Tap Water and Salt Water

Pure Water				Salt Water			
Water Volume (L)	2.5	Salt Mass (g)	0	Water Volume (L)	2.5	Salt Mass (g)	150
Time (minutes)	Temperature (^{0}F)	Time (minutes)	Temperature (^{0}F)	Time (minutes)	Temperature (^{0}F)	Time (minutes)	Temperature (^{0}F)
0	72	11	180	0	71	11	168
1	78	12	188	1	80	12	175
2	88	13	198	2	90	13	183
3	99	14	202	3	100	14	190
4	108	15	205	4	110	15	196
5	120	16**	211	5	120	16	202
6	130	17	211	6	125	17	210
7*	141	18	211	7*	135	18**	213
8	150			8	142	19	213
9	160			9	150	20	213
10	170			10	160		

Figure 3: Temperature as a Function of Time for EquiVolume Tap Water and Salt Water



Analysis

Adding salt to pure water does, in fact, raise the boiling point of water, at a given volume and pressure. At 1 atmosphere of pressure, the boiling point of water is 212 F; however, the calculated boiling temperature was 211 F, or 0.47% error. Although the error is small, sources of error are impurities and minerals in the tap water, human error when reading the thermometer, and instrument accuracy error. A digital thermometer would be more accurate than the analog thermometer used. Adding 150 g of table salt raised the boiling temperature of water 2 ^{0}F, or 0.013 ^{0}F per gram of salt per 2.5 L of water. This shows that boiling temperature of water is not strongly dependent on salinity, or salt concentration in the water. Further studies should be conducted to see the effect of common industrial waste products, such as metals, chemicals, and gases, on water's boiling point and toxicity, specifically for phytoplankton.

Reference List

[1] "The USGS Water Science School—How Much Water is there on, in, and Above the Earth", (2016). *United States Geological Survey* [Online]. Available: https://water.usgs.gov/edu/earthhowmuch.html

[2] "Why is the Ocean Salty", (2018). *National Ocean Service* [Online]. Available:

https://oceanservice.noaa.gov/facts/whysalty.html

[3] "States of Matter", (2016). *ER Services—Earth Science* [Online]. Available: https://courses.lumenlearning.com/suny-earthscience/chapter/states-of-matter/

[4] "Hydrogen Bonding", (2018). *Chemistry—LibreTexts* [Online]. Available: https://chem.libretexts.org/Textbook_Maps/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Physical_Properties_of_Matter/Atomic_and_Molecular_Properties/Intermolecular_Forces/Specific_Interactions/Hydrogen_Bonding

[5] "Boiling Point", (2018). *Encyclopaedia Britannica* [Online]. Available: https://www.britannica.com/science/boiling-point

[6] L. Morello, "Phytoplankton Population Drops 40 Percent Since 1950", (2010). *Scientific America* [Online]. Available: https://www.scientificamerican.com/article/phytoplankton-population/