Making Use of Earth's Biggest Resource:
A Quantitative Look at Ocean Water Purification

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Abstract: Three methods of simple sea water purification were examined and compared to one another to find the most effective and the most efficient way of lowering the salt levels of sea water. Water filtration using a Brita filter was least effective, but very efficient. Freezing the water was effective in cutting the water down to below a third of its initial salt concentration, while distilling the water was most effective, and required the most amount of energy.

Introduction: Drinkable water is going to be one of, if not the most, sought after natural resources of the 21st century. Is there a feasible way of making ocean water drinkable if it is harnessed effectively and efficiently? If so, is it possible to apply this on a large enough scale to nullify the problem of water shortage? According to a study by Alaa El-Sadek [1], Egypt has been trying to desalinate water on a mass scale, however the energy and equipment needed to power reverse osmosis (the purification technique they are trying) has been the limiting factor of their plan. Reverse osmosis uses a high pressure pump and a semi-permeable membrane, however the energy required to run this pump can be expensive for a large-scale purification system like is needed in Egypt. The country is now looking at the possibility of individuals desalinating the water they need themselves, but for an individual to get a reverse osmosis system in their homes is extremely expensive. The motivation for this paper was a need for individuals to desalinate water themselves in an inexpensive and efficient manner- the world's lack of water may soon require that everyone be able to do so

This experiment looked at three possible ways that the average household can lower salt in sea water to a drinkable level. The experiment was conducted to quantitatively determine what method of salt water purification is most effective, without purchasing special equipment or having an extensive knowledge in chemistry.

The first method of desalination was with a normal household Brita filter which uses a "carbon and ion exchange resin" [2] to improve the water. This works by passing water through the filter, where the carbon removes many of the dissolved halogen compounds, and the ion exchange softens the water by removing calcium carbonates [2].

The second method explored is distillation. The salt in the water will increase the temperature at which the solution will begin to boil, however once boiling begins, the water molecules will vapourize and leave behind the salt and any other compound that has a higher boiling point than water. The vapour that boils off is pure water, and if it is caught and condensed, the result should be relatively pure liquid water. There are two simple ways to change water from its vapour state back to its liquid form. The first is by running the vapour into a very cold environment, thus removing some of the energy from the water molecules and lowering their temperature to below boiling point (100˚C); this returns the molecules to their lower energy, liquid state. The second method forces the vapour into a container that has a large surface area. As the molecules move along the surface of the container, they exchange energy with the environment outside the container, causing condensation to occur. It is this second method that was used in this experiment.

Purifying salt water by freezing it is a well known concept, but an uncommon practice. Icebergs are examples of pure ice formed from salt water. Icebergs form over long periods of time during which salt water is exposed to temperatures below 0˚C. The salt in the ocean lowers the freezing temperature of the water by getting in between the water molecules and interrupting the hydrogen bond formation required for ice to be created. The idea behind freezing salt water is to exploit the fact that pure water will turn to ice first, before the salt freezes: the right temperature must be obtained as to not freeze salt and water together.

Methods: Throughout the experiment, knowing the concentration of salt in the water was imperative. A refractometer was used to take these measurements. The uncertainty in each measurement with the refractometer is +/- 1 PPT (parts per thousand). This is because the divisions of the scale are very small, and the clarity of the reading differs depending on the brightness of light present.

Obtaining the water: After testing multiple locations on the coast around Vancouver, it was determined that English Bay has the highest salt concentration, 27 PPT: the water for this experiment was taken from that location. This concentration was also the closest value to what NASA has determined is the salinity of the water off the coast of BC [3].

Filtration: A new Brita water filter was used, and 1 Litre of sea water was passed through the filter five times. The filter uses a carbon and ion exchange resin. The initial volume of water was recorded, as was the final volume left after the last filtration. The concentration of salt in the water was measured after each pass through the filter.

Distillation: Keeping with the goal of this experiment, simple materials were used. 1 litre of sea water was put into a kettle, and an approximately 3-metre long hose was attached to the spout (sealed with duct tape). The hose was positioned such that it was on a gradual but continuous downward slope. The water was put on the natural gas stove for 130 minutes, at the end of which some water still remained in the kettle. The amount of time that was spent on the element's two power levels (Med & Low) was recorded. The energy required for each distillation was approximated by calculating the known energy output of the element at each power level.

Freezing: Based on the chemistry behind freezing salt water and a quick preliminary test, it was determined that the freezer set at -6˚C would be most effective for this experiment, and so was used throughout. Containers were filled with 3 different volumes (250mL, 500mL, and 1L) of water, sealed, and put into the freezer. Initially, each sample was left in the freezer until approximately 75% of its volume was ice. After the samples were removed from the freezer, they were immediately strained in a very fine (1-2mm) strainer, and the ice was separated from the water. The volume and salinity measurements of the liquid that had never frozen were recorded; the ice was left in the container to melt at room temperature for 35 minutes, at which point the ice was once again strained, and the volume and salinity of the water were recorded. Finally, once the ice that was left had completely melted, its volume and salinity were measured. The water that had a salinity of 15 PPT or below was kept in a separate container; the procedure was repeated by refreezing this water. The energy was calculated based on time left in the freezer.

Results and Discussion

The sea water was obtained in English Bay, and had the highest salt concentration of any of the surrounding areas along the local coast. This is likely as a result of the tides and currents at this time of year (February), and the results would likely be different at other times of the year.

Filtration: As is shown in Figure 1, filtration lowered the salt concentration in the sea water by a small amount. The concentration of salt started at 27PPT and dropped to as low as 23PPT. The water was filtered five times, however the minimum salt level remained between 23 and 24 PPT immediately after the first filtration. This is likely because the filter is only capable of lowering salt concentrations to a certain amount, and below that point, the filter is ineffective. The carbon filter is likely only capable of removing salt to a base level, and this Brita filter's base level appears to be around 23/24PPT. This method did not require any energy after the manufacturing of the filter, and all water put in for the first filtration was present after the fifth filtration.

Distillation: This method had the best results, as the salt concentration in the water was consistently taken to below detectable levels and, as shown in Figure 2, the amount of pure water produced was quite substantial. The method of condensation used relied on a large surface area for the steam to pass through. The vapour condensed as temperature from the surrounding room provided the gradient needed to change the phase of the water from vapour to liquid. With a good seal between the spout of the kettle and the hose, little steam escaped from the system. Occasionally, steam would begin escaping from the end of the hose, however when the stove

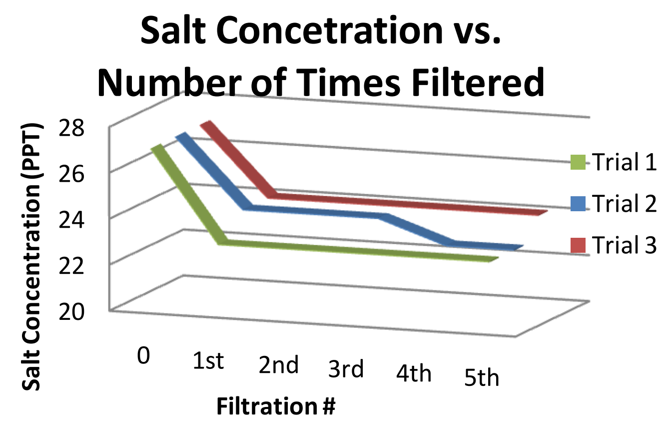

Figure 1: Salt Concentration vs. Number of Times Filtered for each trial: This graph shows the relationship between the concentration of salt in the 1 Litre of sea water and the number of times the water has been put through the Brita water filter. It is clear that after the first filtration, the salt concentration remains relatively unchanged for the subsequent filtrations. The uncertainties for these measurements are in salt concentration and each is +/- 1 PPT.

was turned down, and a slower boil was reached, the steam stopped escaping.

An interesting observation was noted during all four of the trials. The water that condensed out of the system was very clear, much like the water being put into the kettle initially; however, the water remaining in the kettle became very cloudy with salt, and clumps of salt crystals formed. Additionally, salt formed along the sides of the kettle as the water level receded.

When taking the salinity readings with the refractometer for this method, the condensed liquid consistently had a reading at the very bottom of the meter: 0PPT. The reading of the liquid left in the kettle, however, had readings at or above 100PPT.

This meant that the concentration of salt in the water was such that for every 1000 grams of water (or 1 Litre), there would be 100 grams of salt. The exception for this was with the fourth and final trial. The smallest amount of water was condensed out and this distillation used the least amount of energy: the salinity of the liquid left in the kettle was 86PPT.

When this is applied to the theory of what is occurring during the boiling process, the results make sense. The pure water will be boiled off first as the water molecules get sufficient energy to change phase. This evaporation of water will increase the concentration of the salt because the amount of salt in the kettle remains the same as the volume of water decreases: thus, the greater the

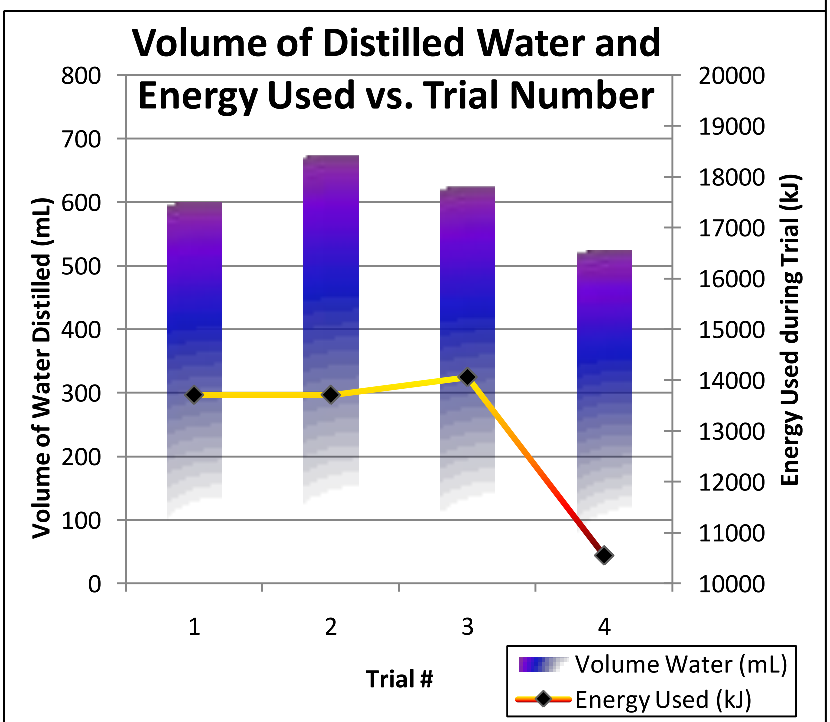

Figure 2: Volume of Distilled Water and Energy vs. Trial Number. This graph shows the amount of water that was condensed out of the system after 130Mins. All of the water obtained through this method had a salinity of 0PPT. The uncertainty in the volume of water obtained was +/- 15mL as a result of the accuracy in the measuring equipment as well as water remaining in the hose after being disconnected. The secondary axis shows energy usage for each trial. The uncertainty in the power measurements are +/- 1500kJ. This is as a result of a lot of heat energy escaping from the system because it was an open flame, and not a closed system. Information for energy consumption was obtained without permission from Wolf Appliances [4].

decrease in volume of liquid in the kettle, the greater the change in salinity concentrations in the water. The energy usage, as shown in Figure 2, varies depending on the amount of heat applied.

This method is also effective in separating the water from anything else that is dissolved with a higher boiling point, which is extremely beneficial if the cleanliness of the water is in question.

While there appears to be no correlation between energy usage and volume distilled, trial 4 was boiled on the low setting of the burner so used substantially less energy: this did not result in substantially less water obtained. This suggests that boiling at a low velocity for longer is more efficient for getting the same amount of water out as rapid boil does for a shorter time.

Freezing: This method is the least conventional way of removing salt from sea water used over the course of this experiment, and was the method that was examined in the greatest detail. As shown in Figure 3, it was found to be possible to lower salt concentrations to less than a third of their initial amounts. Based on the results from different amounts of time spent in the freezer, the 250mL and 500mL samples were found to separate best when left for 300 minutes, while the 1L samples had the best results when left in the freezer for 400 minutes or longer (up to 500 minutes).The chemical model behind this is that the ice lattice starts to form slightly below 0˚C, which forces the salt to concentrate in the unfrozen water. This is further supported by the fact that freezing at lower temperatures (-8˚C and -19˚C) resulted in the salinity of the ice being much greater than the ice that formed at higher temperatures. The reason for this may have to do with the speed at which the ice lattice forms, and the affect of salt at different temperatures: salt will be frozen along with the water if the surrounding water molecules are frozen quickly; also, a salt molecule can only have a certain amount of impact on the freezing temperature before ice forms. In his experiment, Mayer found that it is the water molecules around the salt ions that do not form ice immediately, but in order to keep any salt from the ice, emulsification is needed [5]. It was found for this experiment that the ideal temperature for freezing the water was -6˚C, or approximately the low setting on a freezer.

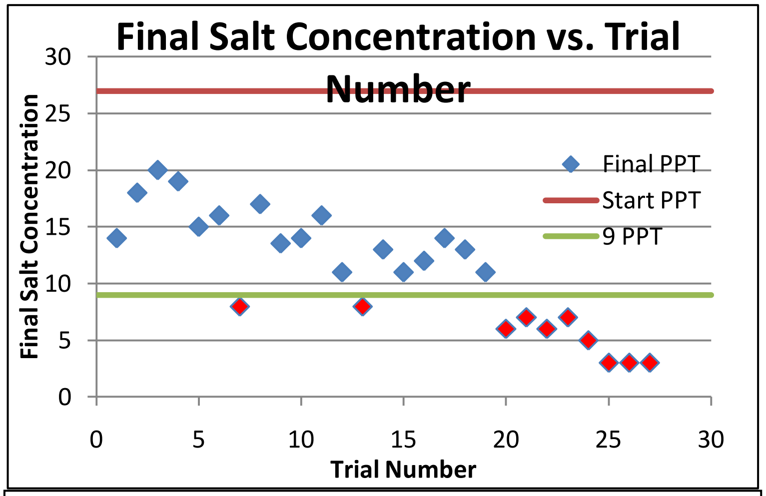

Figure 3: Final Salt concentration of ice after freezing vs. Trial number: This graph shows that 10 of the 27 samples were brought below 9 PPT, with an uncertainty of +/-1PPT

It was observed that the most effective trials had the highest salt concentrations in the unfrozen liquid. This is shown in Figure 4. As with distillation, this fits the chemical theory of what is occurring in each container. As the water molecules gradually form crystals and leave liquid form, the same amount of salt is in a smaller volume of water, thereby increasing its salinity. The average energy for the freezing process was determined by using the approximate daily energy output of a 20 year old freezer [6], and then extrapolating for the average time that the water was in the freezer for, which was 270mins. The amount of energy calculated for this method of desalination was 1350kJ. This is substantially more energy efficient that the distillation method. Based on the chemical theory discussed above, it is likely that the water freezes at a faster rate to start with, and then as the salt concentration of the leftover liquid increases, the rate of freezing decreases, thus having an exponential relationship between the amount of ice being formed, and the amount of salt left in the solution.

While the yield of fresh water was not nearly as substantial as that from the distillation process, there was a clear relationship between the percent yield and the final salinity of the water, as shown in Figure 4.

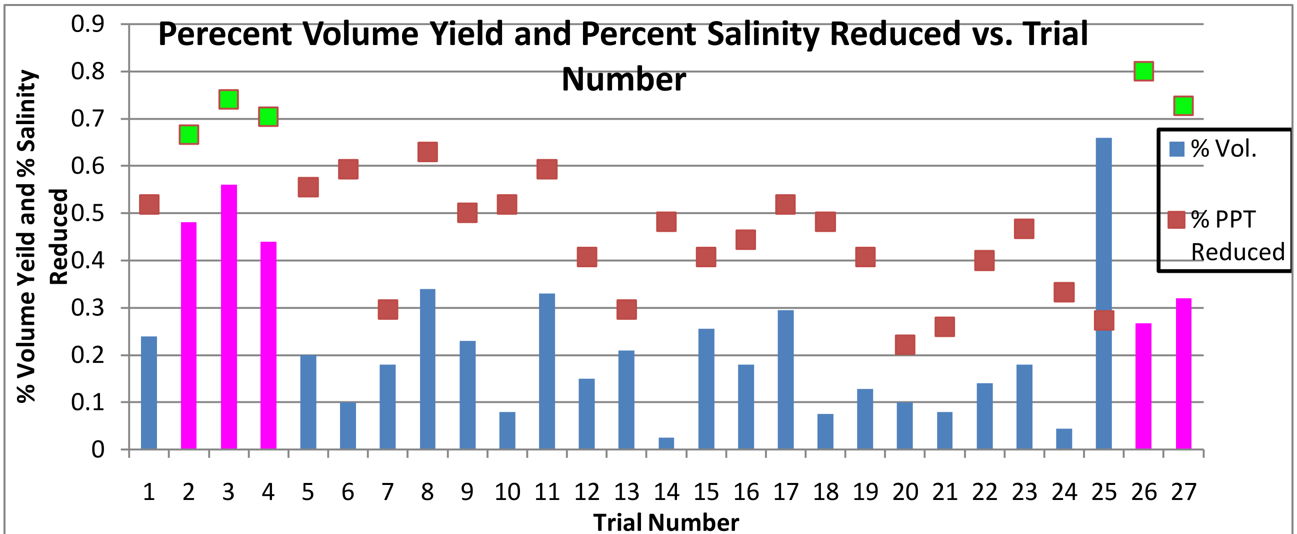

Figure 4: The percent volume yield is shown as the upper plot and percent salinity reduced is shown as the bar plot**.** This graph shows the relationship between the inital and final salinity levels for each trial: for trials 22 to 27, the salinity started at 15PPT, not 27 PPT. Figure 3 (previous page) shows the final salinity after one or two freezings. The trials that had an above average yield **and** a reduction of more than 67% are highlighted in pink and green.

Conclusion: This experiment has demonstrated two ways of significantly lowering the salt concentrations of sea water using simple household equipment. It has also shown a third method that is not nearly as effective in separating the pure water from the ocean water. There are a couple of further experiments that would be good extensions of this one. The first would be to test the effectiveness of freezing when the sample is left in the freezer until the liquid reaches a salinity of between 36 and 38 PPT to see if the results are consistently better. The second experiment is to boil the water using the sun's heat, and capture the water in the shade. This would be very applicable in places with hot climates.

As was discussed in the introduction, in order for a problem like water shortage to be dealt with on a massive scale, the general public must be able to purify its own water. With the current technology, there seems to be no feasible way for an institution such as the government to purify enough water for a population to use. The two methods of purifying salt water discussed in this paper are both effective and simple. While a freezer and a stove were used to give energy to the water system, both can be replaced with other, more natural sources of energy.

References

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