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Performing and Developing a More Efficacious Method of Electrolysis on Seawater Utilizing Chemical Compounds and Electrochemistry

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Abstract

Today, 95% of the ocean and 99% of the ocean floor remains unexplored as oxygen production, food supply, and other life or death factors require submarines to consistently resurface to resupply.The goal of this research project was to develop an efficient system of oxygen production that employed the most accessible resource found underwater - seawater - along with utilizing minerals to help process the water so that oxygen can be produced from it through electrolysis.

The first process in the system was to remove the harmful chlorine ions present in the water. To do this, the chlorine ions bonded with silver in either silver nitrate or lead nitrate to form a precipitate. Next, the solution was electrolyzed with an increasing current through which 2 gases were formed: carbon dioxide and water. To prove that the gas produced was oxygen, a wooden stick was lit on fire then partially extinguished to leave a small spark within the embers of the splint. Then, when the splint was placed into the anode, the flame got larger due to the presence of oxygen.

In total, the system can produce approximately 0.25 liters of oxygen per hour with 150 mL of seawater. Standard-sized submarines process and electrolyze. This commercial process also utilizes seawater, but to rid of the chlorine, the water is thoroughly distilled the reionized before finally being electrolyzed. Assuming that submarines process the same load of water but utilize the new method 25,000 liters of oxygen can be produced using silver nitrate and 88,00 liters of oxygen can be produced using lead nitrate. These values can be converted into the crew size that the submarine can support using the standard measure that humans need 550 liters of oxygen per day: a crew size of 40 if silver nitrate is used and a crew size of 160 with lead nitrate.

On submarines today, crew sizes vary from 30-130 members on deck or 16,500 or 71,500 liters of oxygen respectively. The additional oxygen that is produced from the lead nitrate can be used to expand crew size for operations under water. Furthermore, because sea water is processed, underwater facilities can run in the ocean for longer periods of time since seawater is found everywhere. With the development of this technology, underwater exploration will reach new heights as permanent underwater facilities can be created.

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Introduction/Current Situation

The most imposing challenges with underwater expeditions are handling underwater pressure and oxygen supply. Underwater pressure is usually accommodated with through strong structural systems and materials within the submarine. On the other hand, managing oxygen supply is more temporal and is limited based on the amount of supplies. To supply oxygen to underwater stations, oxygen tanks and chemically produced oxygen is used which both take up space in the facility or submarine [5]. These methods are both time-consuming and have limitations.

Oxygen tanks require constant refilling and chemical oxygen requires waste removal and resuppl seawater that has been distilled then realized. In fact, since the oxygen tanks are so large in size, they limit the amount of time the submarine can be underwater to a maximum of 90 days before it has to go up again, as that space is used up by the tanks instead of additional food and supplies. The objective of this research is to create a cost-efficient system of oxygen production that submarines and underwater facilities can utilize in a time efficient, low energy manner.

Materials and Methods

Materials:

- Salt Water (5.25g per 150mL)
- Raw Materials (wood, PVC pipes),
- Saw
- Cylinder water containers
- Graphite Cathode & Anode tubes
- Wires w/ alligator clips
- Oxygen flow sensor (liters per min)
- Ammonia (150ml)
- Silver Nitrate (15.27g per 150mL) (Based of the 3 percent chlorine concentration in water)
- Energy source (DC power voltage supply, max 30 volts)
- Parafilm
- Lead Nitrate (14.88 g per 150mL) (Based of the 3 percent chlorine concentration in water)

Methods:

In order to construct the system, a three part PVC structure was constructed consisting of a "mixing chamber", anode chamber, and cathode chamber.

The mixing chamber contained 2 parts including an upper and lower level. Both of these levels were separated by a valve. On the upper level, the simulated seawater was poured in addition to either silver nitrate or lead nitrate, depending on the trial. Once the chemical was added, the simulated seawater was thoroughly stirred to ensure that all parts of the nitrate came in contain with the chlorine for the formation of a precipitate. Once the solution was prepared, the valve was turned to allow the new solution to drain into the lower level of the mixing chamber where the singular valve split into 2 additional sections: one for the node and one for the cathode. The anode site contained positive charge on a graphite anode and was the site of oxygen production. The cathode side contained a negative charge on a graphite cathode and was the side of hydrogen production. Both sides of these chambers were left open so that the respective electrodes could be place in solution. However, in order to make sure that the gas was being stored inside the respective chambers, a layer of parafil, wrapping around the entry point of the wire, was added. This in turn create a tight seal to store the gases which important to conduct the flame test.

To ensure that the gas created was in fact oxygen, a flame test was conducted. Due to costs of professional oxygen purity detectors and oxygen meters that could detect such a minimal flow of oxygen, a flame test was conducted instead to accommodate for the lack of resources and to verify the accuracy of the results qualitatively. The flame test conducted of lighting a splint, then exhausting the flame, but leaving a spark within the embers of the splint.

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Theoretically, if oxygen was in fact produced, then the oxygen would fuel the combustion reaction and reignite the flame.

The system was run for 10 min and the amps produced were recorded every minute. These results were tracked in a table. The results were then converted to liters of oxygen produce (explanation for this transformation can be found in the appendix) Finally, in order to predict how many people could be supported the standard of 22.9 liters of oxygen per hour or about 550 liters of oxygen per day needed per person was used..

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(The step by step procedure and the construction of the model can be found in the appendix.)

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Results

The system created allowed for an average current of 0.41 amps for the 10 trials using silver nitrate (Figure 1). In the case of Lead Chloride, the system created allowed for an average current was 1.33 amps for the 10 trials (Figure 4). During both trials, the voltage was set at a standard 30 volts. These initial data values proved that the electrolysis is possible with sea water that contains a chlorine precipitate.

The increase in amps per minute of both electrolyzed solutions followed a linear pattern and so linear regression was conducted. The calculated the equation of linear regression was 0.41x + 0.336 for silver nitrate (Figure 2) and 0.33x + 1.18 for lead nitrate (Figure 4).

During the next part of the analysis, the amount of oxygen produced was calculated. First, the coulombs in the solution was calculated by multiplying the amps by the time. Then the number of Faradays was calculated by dividing the number of coulombs by 96,485. The number of faraday is also equal to the number of moles of electrons. The moles of electrons was divided by 8 to equal the moles of oxygen gas. Finally, the moles of oxygen gas multiplied by 22.4 to give the liters of oxygen produced (formulas can be found in the appendix).

After these plugging in the average voltages into the conversions mentioned above, it was calculated that for both lead nitrate and silver nitrate, the oxygen production in liters per hour was less than one. However, to extrapolate the system onto a real world scale, the experiment was scaled up from 150 mL to 96,000 L (the amount of water that current submarines electrolyze) which would equate to 27,626 L of oxygen for silver nitrate (Figure 3) and 88,829 L of O2 for lead nitrate (Figure 6).

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(All figures are located in the “Graphs and Data” section of this document, located below)

GRAPHS AND DATA

Silver Nitrate:

FIGURE 1

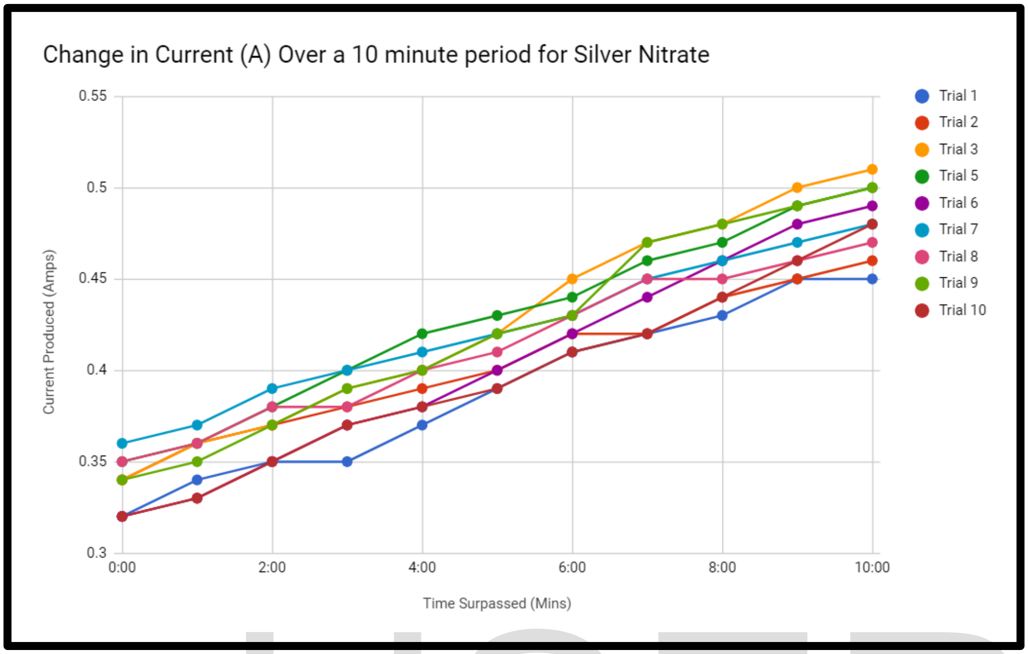


FIGURE 2

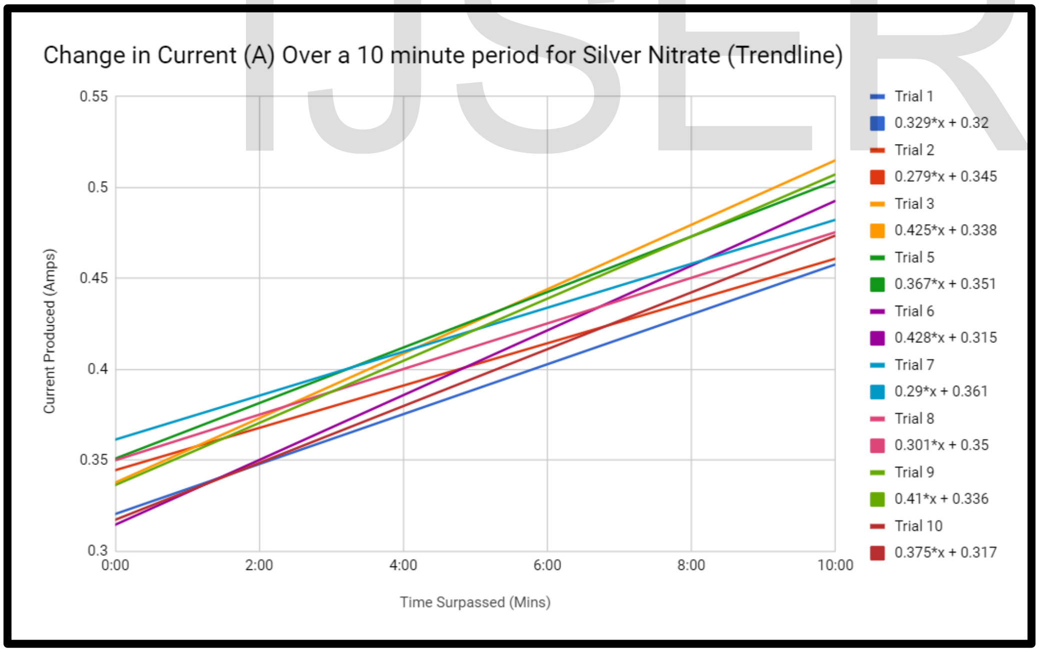
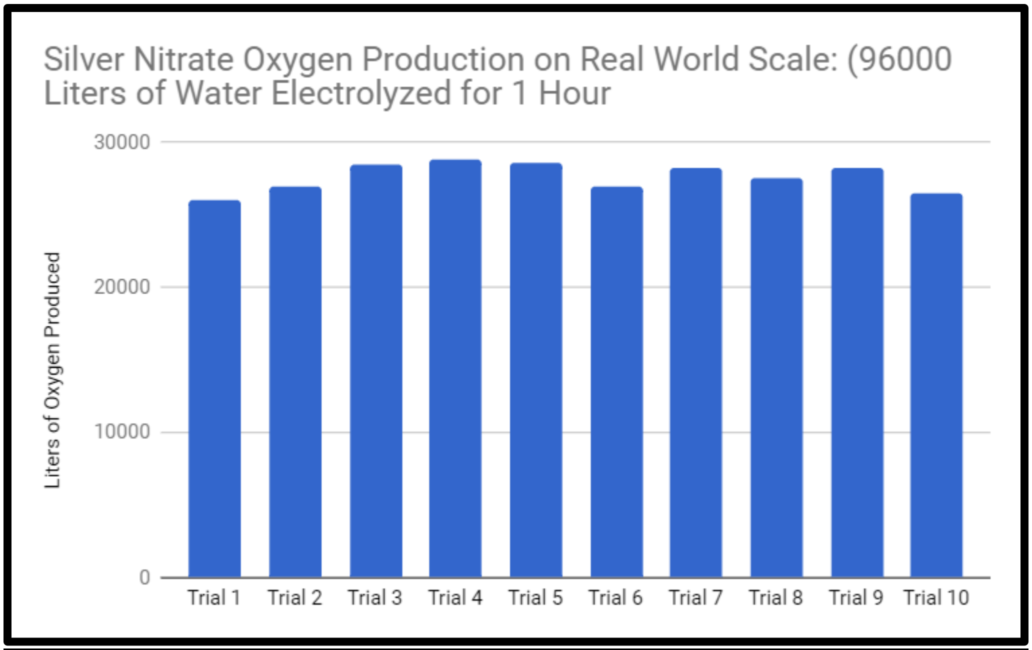


FIGURE 3


Silver Nitrate Oxygen Production on Real World Scale: (96000 Liters of Water Electrolyzed for 1 Hour
Liters of Oxygen Produced
30000
20000
10000
0
Trial 1
Trial 2
Trial 3
Trial 4
Trial 5
Trial 6
Trial 7
Trial 8
Trial 9
Trial 10

Lead Nitrate

FIGURE 4

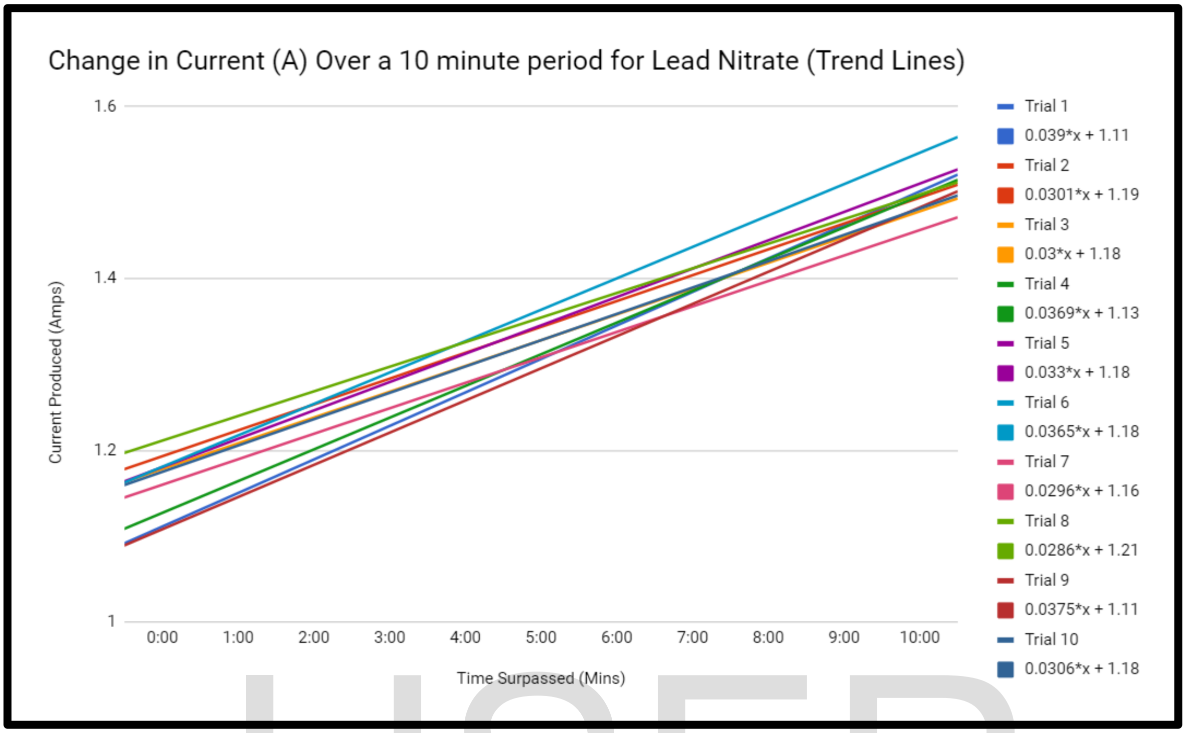


FIGURE 5

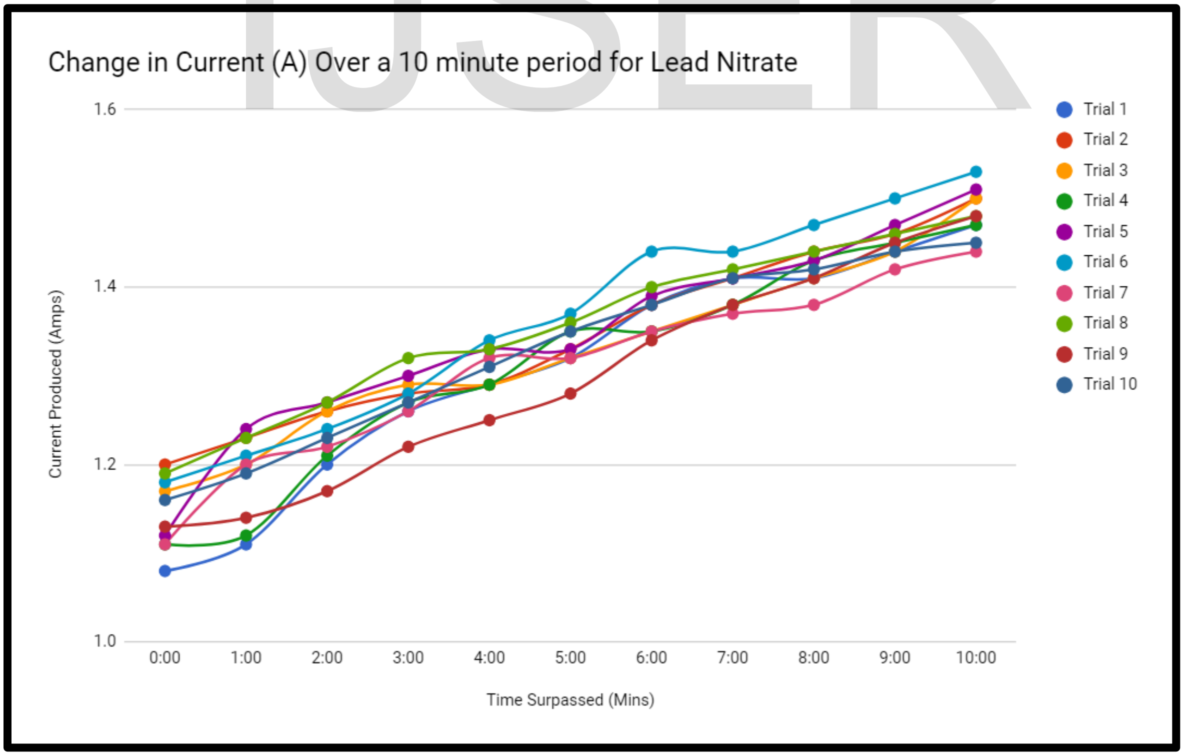


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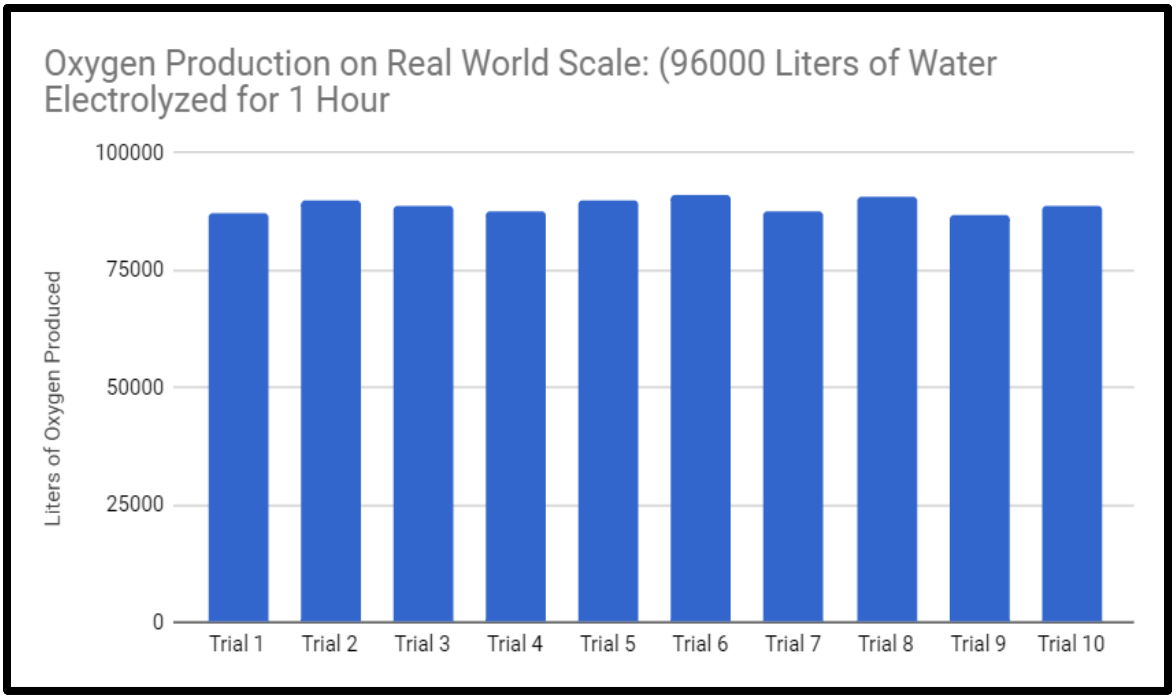
FIGURE 6



Data Analysis

Statistical Error Analysis:

Silver Nitrate:

- The mean of Trial 1 minus Trial 2 equates to -0.0136
- 95% confidence interval of this difference: From -0.0514 to 0.0242
- The intermediate values used in calculations are:
  - t = 0.7526
  - df = 20
- Standard error of difference = 0.018
  - This low standard of error means there is relatively a less spread in the sampling distribution, meaning that all of the trials were conducted similarly and that the data should be accurate based on the trials.

Lead Nitrate:

- The mean of Trial 1 minus Trial 2 equals -0.0373
- 95% confidence interval of this difference: From -0.1417 to 0.0672
- Intermediate values used in calculations:
  - t = 0.7442
  - df = 20
- Standard error of difference = 0.050
- This low standard of error means there is relatively a less spread in the sampling distribution, meaning that all of the trials were conducted similarly and that the data should be accurate based on the trials.

Cost Analysis:

- Cost of current systems (annually): $84 million
- Cost of raw silver nitrate needed to process the sea water (to support the 96,000 liter electrolysis systems that current submarines utilize) **$174,151,296** (approx. $174 million)
- Cost of raw lead nitrate needed to process the seat water (to support the 96,000 liter electrolysis systems that current submarines utilize) **$46,838,833** (approx $47 million)

Savings:

- Silver Nitrate - inapplicable
- Lead Nitrate:
  $84,000,000 - $46,838,833 = **$37,161,167** (approx $37 million annually)
- The Savings generated by the lead nitrate can be used invested in managing the waste precipitate produced (lead chloride), purchasing additional supplies such as food or water

for the submarine to increase the time between resupply, and/or for additional costs associated with machinery in the submarine.

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Discussion

Underwater exploration continues to be an under-developed part of scientific exploration due to its many challenges that is poses such as limited oxygen supply underwater, high-water pressure in deeper areas of the ocean, and the limitation that space provides food and water storage. The focus of this research project was to creating a more time and energy efficient oxygen supply that can serve as a backup in times of emergency in underwater vessels and facilities. Current solutions for this issue include the electrolysis of distilled water, the use of chemical reactions, and the storage of oxygen tanks. All of these systems are ineffective and require a profusion of supplies and energy. In response to this, the goal of this project was to improve upon the electrolysis of seawater by working around the time-consuming and energy expensive step of distilling the water but still maintaining sufficient oxygen production by producing at least 82,500 liters of oxygen per hour since humans need 550 liters of oxygen per day and most submarine crews have around 150 people.

The proposed hypothesis was to add silver nitrate or lead nitrate and ammonia to the sea water solution to bind with the chlorine to allow for the conduction of electrolysis on seawater to produce oxygen instead of harmful chlorine. This would would require less time and energy since the water wouldn’t have to be distill the water then re-ionized the water but rather electrolyzed immediately with .

The concept was tested three times with 150 milliliters of the simulated saltwater solution that had a similar composition to seawater. All 3 trials, 10.13 grams of Silver Nitrate or 14.88 g of Lead Nitrate was added to combine with all the chlorine in the 3.5% simulated salt solution. After the silver nitrate was thoroughly mixed, 150 ml of ammonia was added to help with the settling of the precipitate. Next, the solution was poured into the PVC testing chamber and electrolysis was conducted with lead electrodes. Throughout the experiment, the current for all 3 trial solutions increased at a constant rate, so linear regression was conducted to predict the rate of increase. After further calculations, an approximate calculation for the volume of oxygen produced was also calculated from the average amperage and voltage for each trial. It was found that if the average remained consistent for all 3 trials, electrolysis of the compounds would result in less than 1 liter of oxygen per hour, but the experiment was run at 150 mL, so this was an expected result.

The new system was a success as it constantly produced oxygen at a linear rate and was able to separate the chlorine ions from seawater, allowing for normal electrolysis of water to be done with the remaining ions in the seawater. The system was able to produce oxygen, as the precipitate formed. Finally, the system can work even with the smallest of ions present in the seawater, the remaining solution after the separation between the solution of the precipitate and solution would still leave some extra ions that would cause faster electrolysis than normal electrolysis on water. there is a significant difference between the flow of a pipe with a leak and without a leak. Some of the trials may have had some extra ions mixed in with the silver nitrate or lead nitrate, resulting in higher or lower averages than most of the trials within the 10 min time period.

In total, this system was targeted for submarines that will be underwater for long periods of time to conduct experiments and further research into the largely unexplored ocean. If implemented, this system can make the oxygen production system easier and faster as it uses the actual seawater and is able to support up to 150 people while the system is running for only an hour. The silver nitrate is perfect for small-scale submarines that have 30-40 person crews, as the 27,626 LPH (real world scale) supports 45-50 people. In fact, the lead nitrate would provide an adequate amount of oxygen for larger scale expeditions or for nuclear submarines, as the 88,826 LPH can support approximately 145-155 person crews.

This system was only run for 10 minutes yet it managed to deliver promising results for future underwater scientific research on submarines. With sustainable production (on the large-scale) in a little amount of time, the system would be able to produce much larger amounts of oxygen if ran for longer periods of time and higher voltages in real-life scenarios.. Since the system was built on a small scale and as a proof of concept, larger companies will be able to take the system and apply more voltage to help accelerate the process of electrolysis by providing more energy and a higher initial electrical charge.

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Applications

This research will open opportunities for scientists to potentially built underwater laboratories that they can potentially visit every few months to conduct research on the diverse and undiscovered ocean ecosystem which produces more than half of the oxygen in the atmosphere, and absorb the most carbon from it.

As the application is to people all around the world, this is an effective way to increase scientific study in oceans and expand the resources available to humans on Earth in a positive way. Having a reliable and cost effective oxygen supply has multiple impacts such as the ability to prevent groundwater depletion. This is most often caused by human activities, mainly from the overuse of groundwater, when the soil collapses, compacts, and drops. Finally, by preventing this issue, costs can be cut since the water table lowers, the water must be pumped farther to reach the surface, using more energy and money.

In future experiments, variables of salt concentration and electric current can be tested to further examine the efficiency of the system to simulate the variety of scenarios that real submarines would encounter.

Acknowledgments

We would like to thank our professors at The Shoulders of Giants Laboratory for allowing us to work in their lab and use some of their resources/tools. Additionally, we would like to thank them for their help in guiding our research towards a specific application. Without their efforts, the success of this project would not be possible.

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Appendix

<u>To Calculate the Moles of Oxygen:</u>

$$\frac{amps \times seconds}{96485} \times \frac{1}{8} = molesO_2$$

- Amperes x Time = Coulombs
- 96,485 Coulombs = 1 Faraday
- 1 Faraday = 1 Mole of Electrons
- Oxygen has eight electrons, so a mole of oxygen atoms requires eight moles of electrons which is why the moles of electrons are divided by 8

<u>To Convert from Moles to Liters:</u>

$$molesO_2 \times \frac{22.4LitersO_2}{1moleO_2} = LitersO_2$$

The mole value is multiplied by the molar volume constant, 22.4L assuming standard temperature and pressure

Faraday: unit of electric charge quantity, equal to approximately 6.02 x 10^{23} electric charge carriers. This is equivalent to one mole, or Avogadro's constant.

Columb: the SI unit of electric charge, equal to the amount of electricity produced in one second by a current of one ampere.

Standard for Oxygen Production: Produce oxygen at 23.9 LPH since humans need 550 liters of oxygen per day.

Drawing of Constructed System:

Complete Procedure

Part 1 - Pump and the feed

1. Connect pvc piping from the salt water source to the water pump. Attach another pipe out from the water pump.

Part 2 - Separating chlorine ions from the water

1. Add Silver Nitrate to the seawater and mix thoroughly
2. Add Lead Nitrate if using that
3. Immediately after silver nitrate or lead nitrate has been added, add Ammonia and mix thoroughly. The end result should lead to a purple precipitate at the bottom and clear/slightly cloudy liquid on top which will be transferred to the next step.

Part 3- Electrolysis

1.Connect the tubing from the filter to two small cylindrical water containers. The two tanks should be connected by tubing at the bottom. The purified water should be attached to the connection point
2. Attach wires to the positive and negative ends of an energy source. Remember to keep the power off until ready to test
3. Connect the other end of the wires to two graphite tubes. The Cathode is the negatively charged plate, and the Anode is the positively charged plate.
4. Make two holes the size of the Cathode and Anode plates in both containers
5. Insert the Anode in one section of the water tanks and the Cathode into the other. These graphite tubes should be inserted through the top of the container
Close the top of the both container but remember to leave a hole/ passageway

Part 4 -Testing

1. Turn on the feed from the saltwater source and turn on the power source for the electrolysis Record the flow of oxygen using the mass-flow meter and record/measure current change over 10-minute time period.
2. Shut of the water source and power source after a set period of time
3. Calculate the rate at which oxygen is being produced using the time surpassed and the change in pressure and the energy required to produce this oxygen.
4. Record results in a data table.