Cryodesalination Proposal

AIChE Projects
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Table of Contents

I. Abstract

Our system revolves around the idea of freezing seawater, forming nearly pure ice, separation of that ice from the resulting brine, and then the melting of the pure ice to freshwater. The team will come up with our own unique design, build a small scale version, and run tests on it to troubleshoot possible problems while at the same time making changes and improvements to optimize efficiency and cost. The final goal is to come up with a viable and profitable system that can be scaled-up and implemented worldwide to help regions that are in need of freshwater.

I. Project Summary

Cryodesalination is an innovative desalination method with strong potential to provide communities around the world access to cleaner drinking water. Although freeze desalination failed in the past due to difficulty of completely removing the brine from the water, Buchsbaum[1] was able to resolve this using the interaction between oil, ice, and brine in a separation column. The Cryodesalination (CDS) Project team hopes to expand this field by investigating its feasibility in desalinating ocean water more efficiently when compared to more conventional methods, such as reverse osmosis and vapor compression desalination. [1]The goal is also to research more efficient processes by investigating potential hybrid practices that utilize a combination of cryodesalination with other proven techniques, such as membrane filtration.

The CDS team hopes to produce a prototype by utilizing modern additive manufacturing techniques such as 3D printing. Many desalination techniques have already been proven to work, but are considered to be expensive due to high maintenance costs and initial investments. Additive manufacturing can drastically reduce these costs by yielding more durable components, such as chemically resistant plastic materials that will form the tank, the overall product in which the freezing, separating, and melting processes will occur; this process will use fewer pieces, making the desalination processes more economically feasible as well as more energy efficient.

II. Problem Statement

Nearly 71% of the world's surface is covered in water, yet only 2.5% of that is readily available to drink. With the world's current population approaching 8 billion, water scarcity is becoming a major problem everywhere on the planet. One possible way to deal with this problem is to convert the other 68.5% of the water into usable fresh water. This process is known as desalination, and essentially extracts fresh water by sending salt water through various treatments.

Cryodesalination is a relatively new idea that involves the freezing of salt water, which separates the salt and fresh water into two different components, freshwater ice and saltwater brine, in order to extract the freshwater. Our group hopes to design and build a proof of a concept prototype, then focus on optimizing and improving the prototype's efficiency so that a scaled-up model, no larger than a mini fridge, which can be employed worldwide.

III. Theory

Cryodesalination is a freeze desalination process based on a natural separation: ice frozen from a saltwater source will be free of salt. The process consists of three major components: the cryochamber, the separator, and the washer. The most critical component of the system is the separator, which it takes advantage of the different densities of saltwater brine, oil, and ice.

The cryochamber is where the freezing of the saltwater occurs. In order to accomplish the freezing process, we will be using compressed liquid CO2. In order to freeze saltwater, a lower temperature than what regular freezes at is needed. This is shown by the Blagden's law for freezing point depression, which shows that the decrease in the freezing point of a solution is proportional to the amount of solute added to the original solvent. Blagden's law explains why salt water has a lower freezing point in comparison to pure water, thus backing up the theory behind the cryodesalination process.

$$\Delta T_{\mathrm{F}} = \frac{\Delta H^{\mathrm{fus}}_{T_{\mathrm{F}}} - 2RT_{\mathrm{F}} \cdot \ln a_{\mathrm{liq}} - \sqrt{2\Delta C^{\mathrm{fus}}_{p} T^2_{\mathrm{F}} R \cdot \ln a_{\mathrm{liq}} + (\Delta H^{\mathrm{fus}}_{T_{\mathrm{F}}})^2}}{2\left(\frac{\Delta H^{\mathrm{fus}}_{T_{\mathrm{F}}}}{T_{\mathrm{F}}} + \frac{\Delta C^{\mathrm{fus}}_{p}}{2} - R \cdot \ln a_{\mathrm{liq}}\right)}.$$

Equation 1. Blagden's law

The separation process is designed based on the difference in densities of brine and ice, which are 1.23 g/cm^3 and 0.9167 g/cm^3 respectively. However, the density difference is not sufficient to prevent the formation of slurry. The oil separation reagent, with a density ranging from 0.9167 g/cm^3 to 1.23 g/cm^3 is therefore added to allow floatation of ice separated from brine completely. This same idea applies when separating the ice from oil. As ice melts, oil floats on top of the formed water, allowing separation of the freshwater and oil.

Ice floats in water due to its lower density caused by the crystalline structure that forms during freezing due to the nature of its intermolecular hydrogen bonding. Water sinks in oil due to its higher density, as well as the fact that they are immiscible fluids due to their molecular polarity differences. Because of this, the freshwater and oil layers are capable of reaching a high enough separation where it becomes possible to recover pure water.

Water purification via freeze crystallization is related to the difference in the concentrations of the solid and liquid components. The following diagram goes into detail of the phases of the elements involved in our design process:

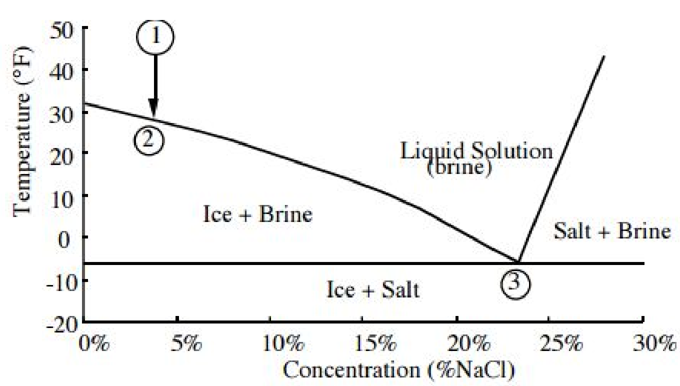

Figure 1. Phase diagram. Seawater at point 1 is first cooled to point 2, where water ice crystals begin to form. Further cooling results in increasing salt concentration until the eutectic at point 3 is reached. Further cooling from 3 results in a solid solution of ice and salt.

According to the diagram above, there are several phases pertaining to the components that relate to both the temperature and the concentration of the salt. As with crystallization, the beginning conditions of the process can selectively lead to the desired concentration or purification. Again, going back to the figure shown above, it conveys the starting process, in which the cooling of salt water promotes the formation of the brine. In addition, there is a presentation of a phase change, in which increased cooling leads to the ice slurry. The formation of the ice slurry serves as an indication to the next step of the cryodesalination process to be done: ice separation. However, as shown, if more cooling is done beyond the formation of the ice slurry will render a solid solution as the product.

IV. Design/Materials

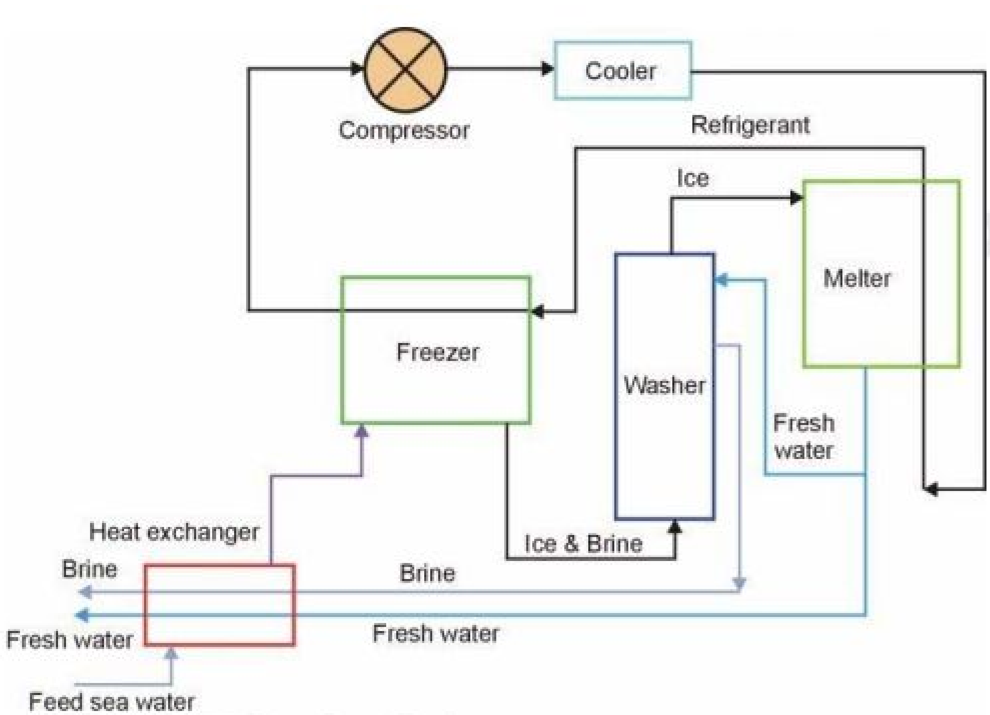

Figure 2. Sample Cryodesalination System

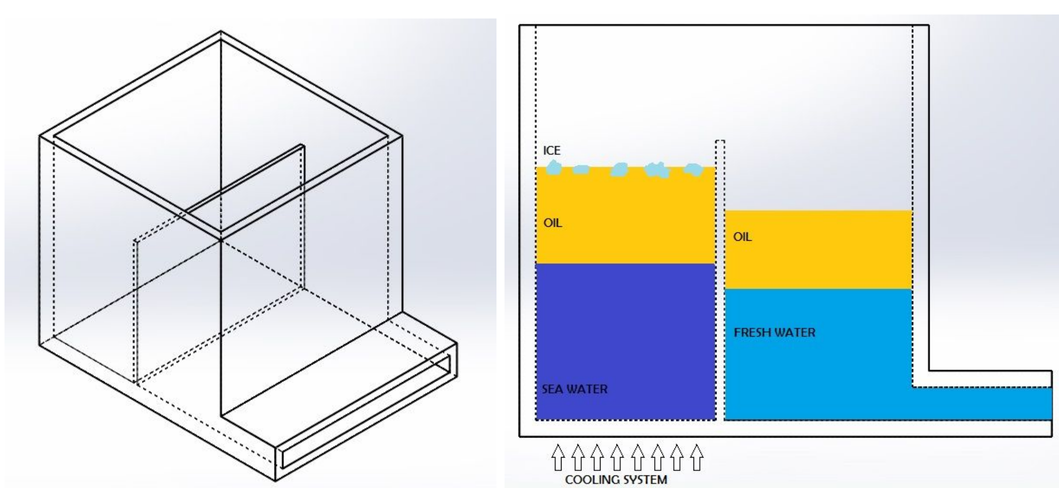

Figure 3. Design Outline

Materials:
The tank that will be 3D printed will contain all the chemicals required for the cryodesalination process. The transition temperature of materials must be kept in mind to prevent brittle behaviour from occurring and causing cracking or dismantling of the system. It must also be able to withstand chemicals such as brine, carbon dioxide, and oil used in the process to avoid corrosion. Possible 3D printing materials are outlined below:

Plastics				
Material	**Glass Transition Temp.**	**Chemically Resistant?**	**Is a 3D Printing material?**	**If so, Cost per 1kg spool?**
PVDF	-45 °C	Yes	Yes	$1,135
PP	-20 °C	Yes	Yes	$62.50
PLA	60 °C	Yes	Yes	$21.99
ABS	105 °C	Yes	Yes	$29.15
PC	145 °C	Yes	Yes	$39.99
Metals				
Material	**Ductile-Brittle Transition Temp.**	**Chemically Resistant?**	**Is a 3D Printing material?**	**If so, Cost per 1kg spool?**
Aluminum	N/A	Fair	Yes	$51.98
Copper	N/A	Fair	Yes	$73.25
Inconel 718	N/A	Yes	Yes	$40,000
Austenitic Stainless Steel	N/A	Yes	Yes	$99.99

Due to limited access to resources, PLA will be used for the design of the prototype. UCSD's EnVision Studio generously provides the 3D printing machine, the Makerbot 5th Edition, and the material, PLA.

V. Cryodesalination System Process Description/Methodology

Before any calculations were performed, several key assumptions were made:

- Batch System is at Steady State
- Negligible energy loss
- Brine Temperature (T_H)
- Temperature of CO_2 vapor (T_C)
- Feed salinity (X_f) = constant
- All heat capacities ($C_{p,i}$) are known for each stream
- Thermal Conductivity of PLA is 0.13 W/m-K (k)
- T_{cw} (feed seawater temperature before heating) is known

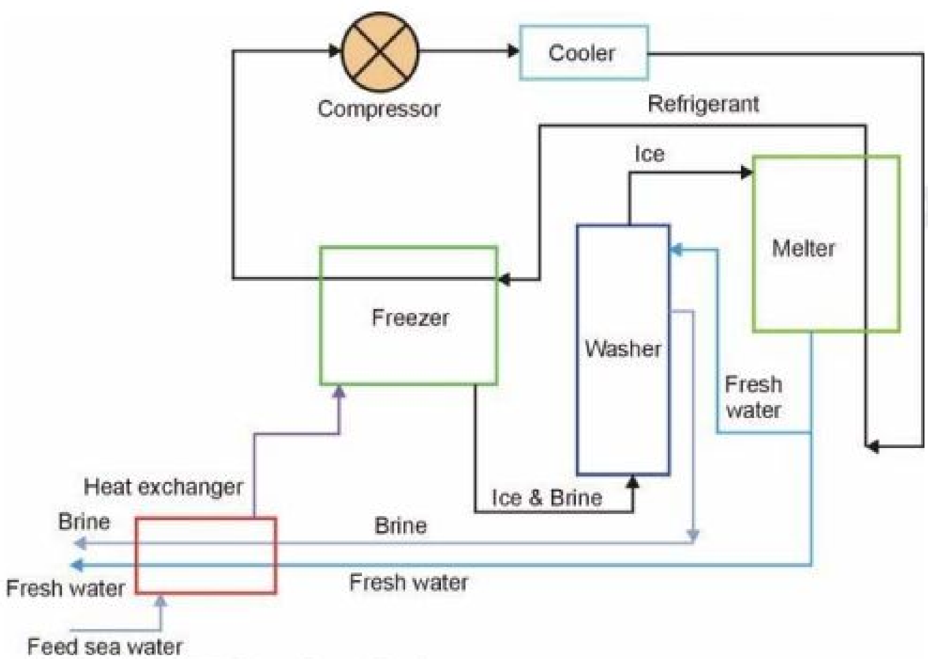

Figure 4: Sample Cryodesalination System

First, the saltwater is sent into the cryochamber, where it will be in contact with a freezing agent that is below the freezing point of saltwater. From there, the interaction between the saltwater and the freezing agent will form salt-free ice and float on the surface, while the extra-concentrated saltwater brine will be at the bottom. If left alone, the ice will interact with the brine and form a slurry mixture that will make separation very difficult. Therefore, a separator compound, in the form of an oil, will be added to the slurry and create separation between the brine and ice, preventing the slurry mixture from mixing with the brine. From there, the ice and the brine are separated, and the ice is run through a wash to get rid of any contaminants and excess oil that may be on it; this wash stream could be recycled as to not waste the oil. Afterwards, the isolated ice can be sent to a heating chamber where it will melt into fresh water and can be extracted for human consumption.

VI. Project Timeline

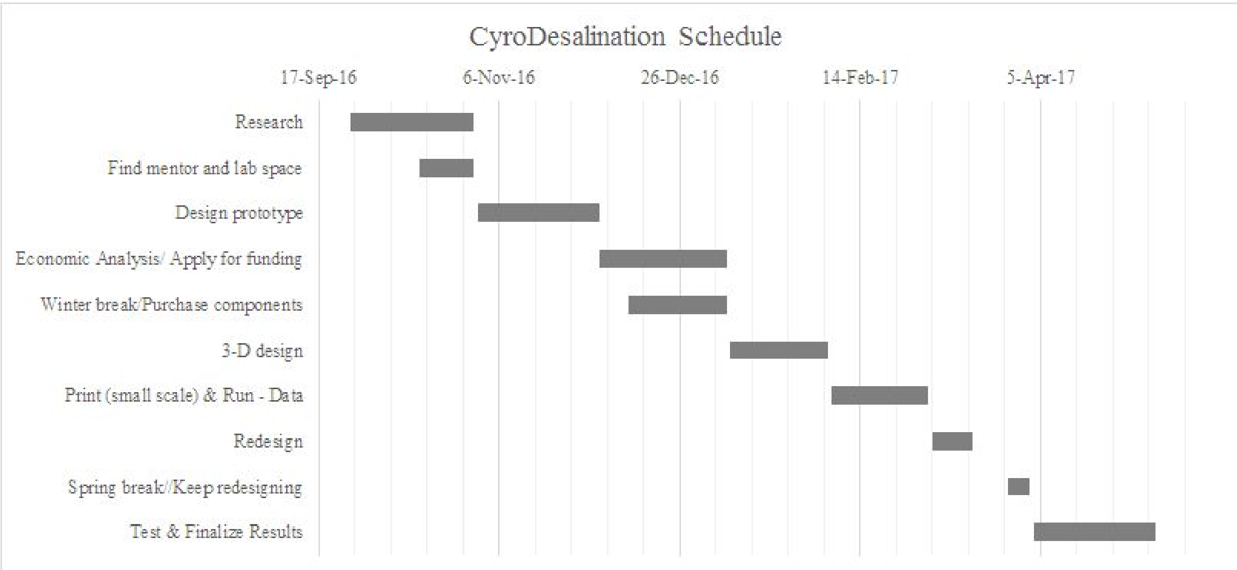

Figure 5. Schedule of 2016-2017

VII. Budget/Feasibility

Below is a list of materials that will be required to run a test:

Cryodesalination Cycle		
Component	**Quantity**	**Total Cost**
48 oz. Cottonseed Oil	1	$21.51
16 oz. Flaxseed Oil	1	$19.50
80 oz. CO_2 Tank	1	$61.83
24 oz. CO_2 Refill	15	$81.00
Black ABS Filament	1	$29.15
Mesh Strainer	1	$1.08
Total Including Tax		$214.08

VIII. Expected Results/Conclusion

Seawater desalination, as a source for potable water, will continue in the future due to the decline of pure water resources. Current conventional desalination technologies, ranging from distillation to vapor compression to reverse osmosis, have different elements that account for notable benefits and drawbacks. In regards to our freeze desalination method, it is a relatively new thermal technique that offers certain benefits.

For our project, we propose a simplified, small-scale hybrid desalination process that utilizes freezing, filtration, separation, and melting systems. Using the characterization of the two desalination processes, freezing and filtration, we look to analyze and evaluate the energy consumption, pure water recovery, and other overall performance factors that will serve to prove the potential of the freezing process for the cryodesalination system. In addition, throughout our scientific research, detailed experiments, and results and findings, we hope to ascertain the applications of our design process and system in terms of small-scale utilizations. Depending on the outcome of our experiments, such a design process as this could serve to be integrated into other desalination processes that could increase efficiency and lower energy requirements. On the other hand, different results or unexpected failures that occur will serve as ample evidence that renders the design in need for more evaluation and review.

IX. References

[1] Buchsbaum, Norbert. "CryoDesalination: Oceans of Fresh Water." *St Andrews Prize for the Environment*. Mearns and Gill, 2013. Web. 26 Oct. 2016. <http://cryodesalination.com/>.

[2] Boundless. "Water's States: Gas, Liquid, and Solid." Boundless Biology. Boundless, 26 May. 2016. Web. 30 Oct. 2016. <https://www.boundless.com/biology/textbooks/boundless-biology-textbook/the-chemical-foundation-of-life-2/water-51/water-s-states-gas-liquid-and-solid-282-11415/>.

[3] "Charles Blagden." *Wikipedia*. Wikimedia Foundation, n.d. Web. 30 Oct. 2016. <https://en.wikipedia.org/wiki/Charles_Blagden>.

[4] Lu, Z. and L. Xu. "Freezing Desalination Process." *Encyclopedia of Life Support Systems (Eolss): V.2: Desalination and Water Resources (Desware): Thermal Desalination Processes*. Vol. 2. Oxford: EOLSS, 2010. N. pag. Print.

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