WAVE GOODBYE TO SALT

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Statement of Disclaimer

Abstract

Our team of Cal Poly Mechanical Engineers ideated, designed, built, and tested a system to help combat the growing problem of widespread drought in coastal and island communities. We developed a proof-of-concept model of a wave powered, mechanical system to desalinate ocean water using a reverse osmosis process. From topical research, it was found that there are many ways to harness a portion of the huge amount of energy that the ocean provides. While large scale ocean water desalination plants are already in operation, smaller scale desalination units powered by ocean waves are largely underdeveloped. Our relatively small and inexpensive system proved to be effective in many aspects of our testing process, confirming the feasibility of our design concept as we exceeded a flowrate of 1 gallon per hour of desalinated water during ocean testing. In an era where global access to clean drinking water is a huge issue that has been unresolved for decades, this system may be able to make an impact in small coastal communities everywhere around the world.

Introduction

Our project seeks to design, build, and test a functioning proof-of-concept system to mechanically convert wave energy to a pressure differential that can be used to desalinate ocean water through a reverse osmosis system. This system will be geared primarily towards coastal and island communities that are severely affected by increasingly long global drought conditions.

This report includes the four separately prepared sections of our design process:

I. Scope of Work
   - In this introductory professional document, the problem is identified, and existing solutions are researched. Initial analyses are conducted to define our team's available resources and the time needed to complete the project for our sponsor Dr. Schuster.

II. Preliminary Design Review
   - This document presents our team's chosen design direction for the problem identified. The direction chosen is described in detail and justified with decision matrices, CAD designs, and preliminary mathematical analysis.

III. Critical Design Review
   - The first goal of this document is to provide a clearly defined summary of the system design and manufacturing process. Secondly, our team aims to convince our sponsor that our design will meet all our design specifications.

IV. Final Design Review
   - This final document outlines the progress our team made in our manufacturing and design process since the Critical Design Review. It is the culmination of all the data gathered from testing and describes the successes and shortcomings of the project.

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SCOPE OF WORK

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Abstract

According to the World Health Organization, one in three people globally do not have access to safe drinking water. The ocean is a seemingly endless volume of water, but the process of removing salt and other particulates from sea water has proven to be a difficult practice for decades. An efficient and environmentally friendly ocean water desalination process could be the solution to widespread water shortages. Current ocean water desalination plants are known to be highly expensive to construct and operate, as well as damaging to local aquatic ecosystems through sea water intake and brine byproduct expulsion. Considering these challenges, we seek to develop a desalination unit powered primarily by ocean waves to reduce energy costs and therefore the environmental impact of emissions from traditional power plants. Through diverse research, we have investigated the numerous forms of desalination and will focus on reverse osmosis systems due to their high efficiency relative to other methods. We also aim to capture the mechanical energy from ocean waves and apply it to our system without conversion to electrical energy, along with defining a more environmentally friendly method for introducing the brine byproduct back into the ocean. Globally, coastal communities in arid regions suffer from extremely long drought periods and saltwater intrusion; a desalination system with sole reliance on wave energy for operation would be an enormous advance in resource management and world health. A review of current water desalination techniques and products, as well as customer needs is presented. Furthermore, a quick analysis of next steps and design direction is introduced.

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1 Introduction

We are a team of mechanical engineers at California Polytechnic State University seeking an innovative way to integrate renewable ocean wave energy into ocean water desalination processes for our senior design project. Our sponsor, Dr. Peter Schuster, is looking for a new, small-scale wave-powered desalination system as a proof of concept.

The goal of this report is to inform our sponsor about the combinations of wave energy and desalination techniques that are optimal for constructing a small-scale prototype to produce fresh water. The application of larger scale desalination plants to be used in small coastal communities as a supplemental water source will be investigated as well, due to a growing demand for reliable fresh water sources. Small coastal communities will especially be able to benefit from this desalination unit as there will be a steady supply of drinkable water coming from the system, allowing for less rationing of water. Furthermore, the whole system is powered by renewable sources, reducing energy cost for small communities that can ill afford added expense.

The background of this report will encompass the design research conducted by all team members ranging from past senior projects to highly reviewed technical documents. The project scope will identify the parameters of this project, which include the boundary sketch, sponsor wants and needs, a functional decomposition, and the deliverables to be submitted before the end of the project. The objectives section will clearly define the design problem and specifications, including the problem statement and engineering specifications. Project management discusses the logistics of the project as a design process plan and assures the sponsor that the goals of this project will be met.

2 Background

The following sections give a comprehensive overview of the background research completed in desalination, wave power extraction, customer needs, environmental impacts, and existing solutions.

2.1 Technical Research: Desalination

Currently, there are three main types of desalination processes in the world. The three main types of desalination can be split into filtration, evaporation, and crystallization. Within these three areas of desalination, Figure 1 gives a brief overview of all the various methods. Filtration, the use of a filter to remove salt from water, is by far the most ubiquitous process in desalination. This is because the most common process used to desalinate water is reverse osmosis (a type of filtration) [1]. In fact, since reverse osmosis has gone through many design revisions due to industry feedback, it is now within a factor of two from the thermodynamic minimum [2]. However, just because a process is near the thermodynamic minimum does not mean that a process is energy efficient, as thermodynamic minimum in this case refers to exergy. In short, a process near the thermodynamic minimum can still be very energy consuming. This is the case with reverse osmosis, as it is not an energy efficient process.

Thus, other methods have also been researched to provide alternatives for reverse osmosis. In the evaporation process, saltwater is evaporated and then condensed in a separate chamber in order to remove impurities and salt, while in crystallization, other chemicals are added to the water that clumps together impurities which can then be removed easily [1]. One drawback of the evaporation process is the slow speed it takes to evaporate saltwater, and the systems involved are very massive. Crystallization involves adding chemicals to the water in the form of resins to perform ion exchange. This process involves water passing through a bed of exchange resin, where the undesirable ion is removed. However, the resin must be replaced periodically, and is not economically feasible given that seawater has very high concentrations of salt, so resin would have to be replaced very often.

Given that reverse osmosis (filtration) is a well-known process to the desalination industry and is a fairly optimized process, it is a very appealing method that has a less likelihood of failure as compared to the developing technologies in evaporation and crystallization. However, one well known drawback of reverse osmosis is the amount of energy it takes to power the system, as 24 bars of pressure are needed to overcome an industrial sized semi-permeable membrane. Typically, 24 bars of pressure will establish flowrates on the order of magnitude needed to supplement cities [3]. However, for small scale systems and proof of concept systems, this requirement can be reduced by using a household reverse osmosis system, which only requires three to four bars of pressure instead of 24 [4]. This discrepancy in pressure can be explained since industrial semi-permeable membranes are more robust, requiring significantly more pressure to overcome the membrane resistance. Even if parallel channels were utilized in order to attempt to use the household systems, household systems are generally capable of producing flowrates around 3 gallons per hour while industrial sized systems need to produce around 30 million gallons per day.

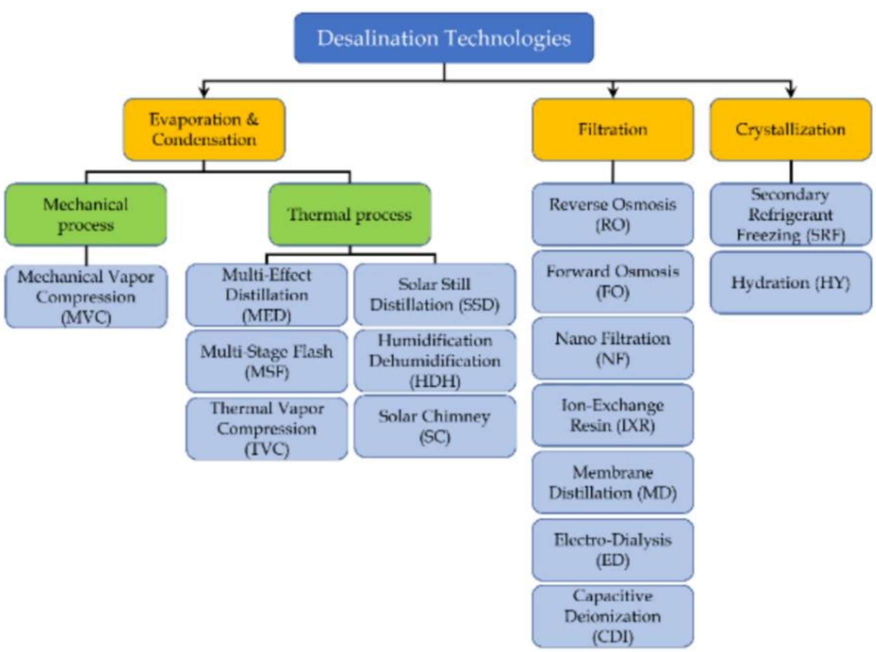

Fig 1. List of Desalination Categories and Processes [1].

2.2 Technical Research: Wave Energy Extraction

Due to the lower requirement of pressure needed if household reverse osmosis systems are leveraged, it becomes more feasible to power the system with renewable energy. Given that a desalination plant is close to the ocean, it is logical to use wave power to supply energy to the desalination system, creating an environmentally friendly desalination system. In fact, wave energy is a growing industry seeking to convert the estimated 29,500 TWhr/yr in untapped wave power [5]. For reference, last year, the United States generated an estimated 4,009 TWhr/yr of electricity [6]. Thus, there is sufficient wave power to power everything in the world abundantly, and the issue is figuring out how to utilize this vast amount of energy. To understand this, one must look at the different types of waves, separated into two categories, wind seas and swell [5]. Wind seas are waves generated locally, while swells are waves generated by distant winds. Out of these types, swells provide the most consistent wave energy. Locations where there are significant swells are found via satellite imagery; it was found that both coasts of the United States have a very consistent wave power potential waiting to be tapped [6]. In these conditions, wave energy extractors are utilized to generate power.

Wave energy extractors can generally be separated into three categories: nearshore, offshore, and near offshore. Nearshore refers to devices that are close to the shore, while near offshore refers to devices that are not yet in deep water. Finally, offshore represents devices that are very far away from shore in deep water [5]. In these categories, there are various technologies available. For example, for the onshore category, an oscillating water column with compressed water is suited for the application. In this case, the wave energy is used to move a piston that compresses an air column, driving a turbine to generate electricity [6]. Additionally, for near offshore categories, a point absorber or an oscillating wave surge converter can be used. A point absorber seeks to use the up and down motion of waves, coupled to a turbine to generate electricity. In contrast, an oscillating wave surge converter leverages the forward and backward motion of waves to power a turbine that generates electricity. Finally, for offshore situations, an overtopping device can be used, where waves crash over the device and funnel through an opening in the bottom, which powers a turbine to generate power [6]. See Figure 2 for a visual diagram of the various types of wave energy technologies currently proposed in literature. It is seen that in all these cases, existing products generate electricity with wave motion, not mechanical energy. If mechanical energy is not to be converted into electrical energy, a novel device will most likely have to be designed.

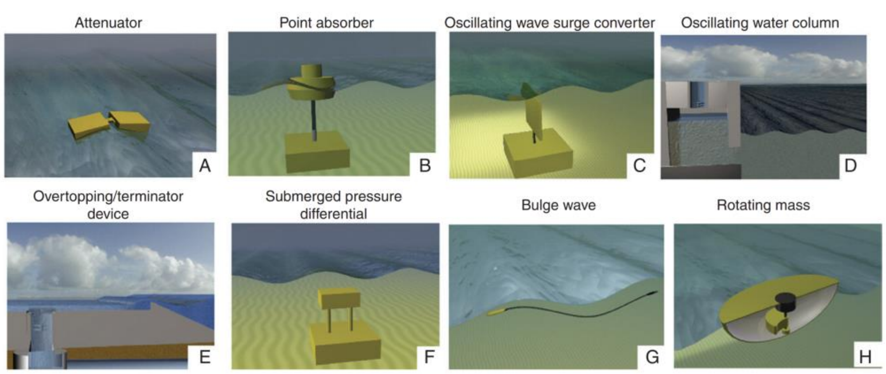

Fig 2. Visualization of types of wave energy extractors [5].

One of the main issues of wave energy conversion is the high associated capital cost in building the system, which is a contributing factor to why there are over thousands of patents issued every year regarding wave energy conversion devices but only around 200 prototypes. Part of this can be mitigated by tying the wave conversion devices to the construction of or existing infrastructure such as harbors and piers. [7]. That way, associated costs can be shared between both construction projects or minimized when tethered to existing infrastructure. In this case, the desalination system could be built alongside a breakwater system or pier for the cost of the wave conversion device to be shared or mitigated. However, this high cost can sometimes be justified as waves, due to the density of water, generally propagate significantly more energy than air that can be extracted [8]. As seen, if the construction costs are minimized, wave energy conversion devices provide a promising way to extract energy.

2.3 Environmental Effects

Desalination has been used around the world for decades and there are many arid countries who utilize desalination to supply fresh water for thousands of people living near the plants. Approximately 45% of the world's desalination is done in the Persian Gulf in the Middle East, and desalination is the primary source of fresh water for some of these regions [9]. Due to the large number of desalination plants present on the shores of the Persian Gulf, many studies have been conducted of the environmental impacts, energy use, and emissions produced. Brine is the most immediately detrimental byproduct of desalination in the Gulf, bringing the overall salinity of the water up from 45 ppm to 55 ppm, as well as containing significant levels of chlorine and heavy metals from treatment processes. This brine not only raises the salinity of the Gulf, but also kills many sea grasses and bottom feeders due to the brine being denser than sea water and flowing along the seabed, disrupting the ecosystem [9]. It is ideal for intake and outfall structures to encourage dispersion, so as not to harm fish and other organisms [2].

The seawater intake itself at these desalination plants can take in aquatic organisms and cause an alteration of the local seabed and sediment layers important to all local sea life. Multiple desalination plants raise the local ambient sea temperature of 35°C by 7 to 8°C, which is very significant. This is enough to completely change the habitat in the ocean, accelerating coral reef death and allowing invasive species to thrive. For these already established desalination plants, energy is the main cost factor, but energy costs are constantly being reduced by newer technologies such as energy recovery equipment, variable frequency pumps, and some use of renewable energy [9].

2.4 Stakeholders/Needs Research

We specified our stakeholders as small coastal communities, so we identified local coastal communities in the San Luis Obispo area that need water sources. We reached out to Cambria Community Service District and Morro Bay Community Center to interview them about their water sources and interest in desalination. The drought has immensely affected these communities by limiting their water supply and forcing them to come up with creative solutions to provide water to businesses and residents. A representative of the Cambria Community Service District Engineering Department states that Cambria has limited water supply due to their isolated location, weather conditions, and restricted budget. Their water supply comes from two shallow aquifers under creeks, which provide for the community, but resources are stretched thin during drought conditions. Residents are forced to limit water usage by restricting lawnwatering and other practices. Morro Bay's community center representative stated in our phone interview that the city gets its water supply from the California State Water Project (SWP), which causes problems for the community especially during drought periods. The water is prioritized to certain areas and restricts water usage in cities like Morro Bay. Therefore, the city is repurposing the wastewater treatment plant into a water reclamation facility (WRF). The WRF facility started construction in 2020 and is planned to be completed by 2023 so that the community can have an additional water source [10].

Cambria and Morro Bay have investigated both desalination systems and renewable energy sources. Cambria was working towards building a desalination unit for about ten years, but implementation was prevented due to environmental concerns, California Coastal Commission issues, and lack of finances. Morro Bay had a desalination unit which was built quickly in 1992 as an emergency project, which led to consequences [11]. Joe Mueller, the City's Utilities Division Manager, stated, "they built it and then put it in mothballs right away." The city of Morro Bay used it for an emergency, then shut it down, which led to rust from groundwater wells. The city attempted to revive the desalination plant multiple times by changing filtration systems, but the water was either not drinkable, or not enough water was produced. Morro Bay determined that recommissioning the desalination unit was not cost effective.

Other renewable energy sources have been considered by Cambria and Morro Bay, such as solar and wind power, and they have stated interest in utilizing renewable energy for their water source. The city of Morro Bay has a strong initiative to turn to more renewable energy sources and reduce their environmental impact as seen by their WFR project. While Cambria is more focused on saving money for the sake of their small community, they would be interested in renewable energy sources and have shown this by adding electric charging stations in the city.

There is a desalination unit at Diablo Canyon Power Plant in San Luis Obispo County which provides drinking water for employees and other plant needs [12]. We are currently working on getting in contact with employees at Diablo Canyon to ask about their desalination unit and potentially schedule an on-site tour of the facility. This would help us gain insight on an existing desalination unit in a coastal community, which is specific to our project scope. The power plant is in the process of getting decommissioned, but government officials, like Assembly Member Jordan Cunningham are working on redistributing the water supply from the desalination plant to local areas [13]. Morro Bay and Cambria community center representatives have expressed interest in repurposing the water from the Diablo Canyon desalination unit to their cities as a supplemental water source.

2.5 Existing Solutions

Here, existing solutions are researched and documented, starting with reverse osmosis systems. Afterwards, existing desalination plans and wave energy conversion devices will also be discussed.

2.5.1 Reverse Osmosis

Reverse osmosis is the most general and common solution for desalination. Single pass reverse osmosis systems are the cheapest for marketable consumer options. Prices can range from $100 to $6,000 for a small system. Figure 3 shows a generic example that can be placed on a shelf, counter, or floor in a household. They are sold with water storage tanks that range in size from 14 –120 gallons. However, they are generally slow to purify water and require a power source.

Fig 3. Single pass reverse osmosis system listed for $1722.60 [14].

Two pass systems function similarly to single pass reverse osmosis systems, but the system passes the brine through an additional filter. This produces a higher quality of water than a single pass system. Two pass configurations are generally most desirable when a single pass membrane does not filter as efficiently [15]. These systems tend to be more expensive. Products like the one shown in Figure 4 range in price from $500 to $10,000. These suffer from the same shortcomings as the one pass systems. It was found that the Navy and desalination units for boats also use a derivative of reverse osmosis systems, instead gaining energy to power the system by burning fuel.

Fig 4. Two Pass Reverse Osmosis System Listed for $5,860.00 [16].

2.5.2 Desalination Plants

The Carlsbad Desalination Plant built by Poseidon Water began operation in 2015 and can produce approximately 50 million gallons of water per day. Since this plant intakes approximately 100 million gallons of water a day, 50 million gallons of brine byproduct are released to the surrounding ecosystem as well. This massive output of high salinity water increased the salinity of the surrounding area (600m radius) from the plant by about 2.7 units above ambient levels [17]. Solutions to this environmentally detrimental practice include using diffusor systems or increasing the rate of dilution of the brine water before it is sent back to the ocean. Studies found that the release of the brine water from the Carlsbad plant influenced the local sea life but had almost no effect as the brine diluted further from the plant. This suggests that it may be beneficial for future desalination plants to have brine water rejection located at the same spot along a shoreline, preferably one that contains less sea life than a highly biodiverse ocean ecosystem [17].

2.5.3 Wave Energy

A study was conducted on the competence of wave energy in creating enough power to effectively produce enough fresh water from the ocean. The main concern with relying only on wave energy is not the consistency of power, but the amplitude of power received. There are constantly waves breaking on any given shoreline, but there can be weeks or months where there is not a substantial swell to create sufficient power. Wave energy readings taken off the coast of Kilifi, Kenya suggested that wave energy alone creates enough power to completely power a desalination plant of appropriate size, or one that produces about 540 Liters a day. Figure 5 shows various renewable energy sources that could possibly be applied to desalination processes. Two or three of these systems placed in close proximity with one another could potentially produce up to 400,000 gallons per year solely based on wave energy [18].

RE-Desalination process	Typical capacity (m^3/day)	Energy Demand (KW/m^3) for sea water	Water production cost (US$/$m^3$)
Solar stills	1–100	Passive	1.3–6.5
Solar pond	20,000–200,000	4–6	0.66–0.77
PV/RO	12–120	4–6	7.98–29
	40	5.5	9.5
	1–100	5.5	11.7–15.6
Geothermal Energy	80	12.4–24	2–2.8
Wind/RO	50–2000	4–6	6.6–9 small capacity 1.9–5.2 for 1000 m^3/day
	12	8	
	12	5	
	175–1400	2.28	
Wind/MVC	1–100	7–12	5.2–7.8

Fig 5. Parameters of varying renewable energy (RE) desalination processes [7].

Some existing solutions for wave generation of energy are in the protype phase, such as the Pontoon Power Converter (PPC) of the point absorber type and the Sea Power Attenuator. The PPC is still in the protype phase, is around 80 meters long with roughly a 3600 kW capacity. The Sea Power Attenuator is currently deployed in an Ireland test site and has a roughly 3600 kW capacity [1]. However, both devices do not fulfill the necessary requirements of generating a differential pressure, not electricity. For reference, both the point absorber and the attenuator types of wave capture devices are relisted in Figure 6.

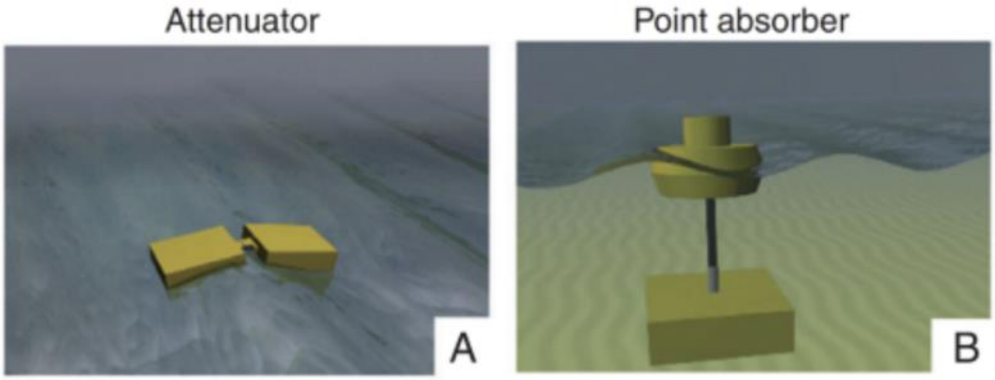

Fig 6. Wave energy conversion types-attenuator and point absorber as adapted from [1].

We researched multiple patents relating to wave power generation. One difference between the patents was the location at which the power generator collects water. Some devices such as US4672222A [19] rested on the surface of the water, while others like JP6101203B2 [20] and US3898471A [21] are attached to the ocean floor, typically in shallow water. Shallow water is typically preferable due to harsher conditions offshore. Many of the patents like US5359229 [22] had electrical energy conversion within their systems, which is traditional for large-scale desalination plants. The wave motor device, US4145885A, has a floating component with anchors to the ocean floor (shallow water application) [23]. There is a displaceable member attached to the float which moves with the waves, a pair of shafts, and a transmission. It is essentially a motor system which converts wave energy to mechanical work. Our project mission is to have a device that generates mechanical energy from waves, so this would be an interesting design to investigate. In general, most of the patents found had buoyant, rotational, and/or linear motion components.

3 Project Scope

The sponsor expects a final prototype that can be tested as proof-of-concept. Deliverables will include a report of research conducted, a functioning prototype of a small-scale desalination system, and analysis of how the system performs off the Avila Pier. Avila Pier was chosen as a testing location as it is a non-moving pier where there is still wave action around the pier, serving as an ideal testing ground for the wave energy converter.

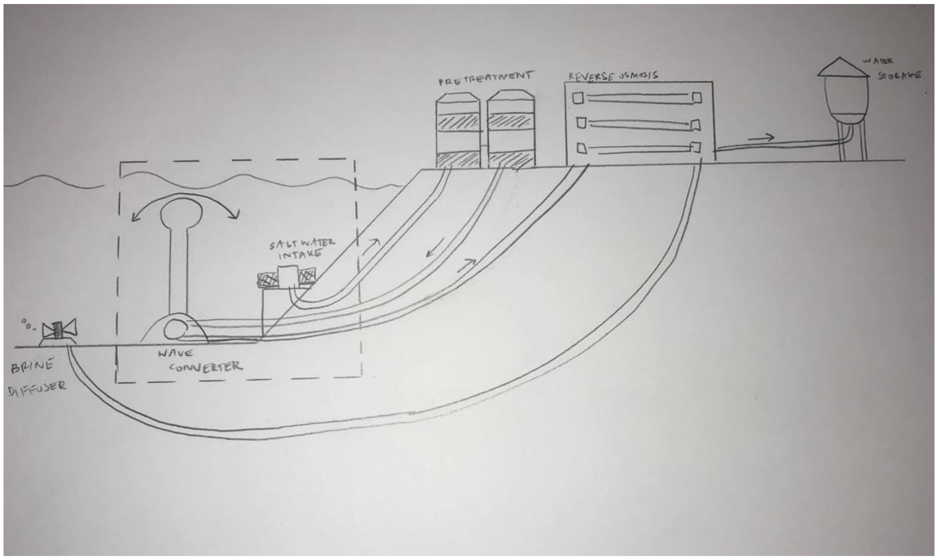

Fig 7. Boundary sketch highlighting the main focuses of the project.

The type of desalination system used in this project will be reverse osmosis, as it is currently the most used process on the market. From research above, evaporation is too slow and needs very large scale systems, while crystallization is economically infeasible. As visualized in Figure 7, the full process involves the following steps:

1. Generating energy to pump seawater through filters
2. Intaking seawater
3. Prepping the water for treatment
4. Running the water through reverse osmosis tubules
5. Storing the water produced
6. Disposing of the brine removed from the water

Due to limitations of our discipline, the scope of this project will be narrowed to the mechanical aspects. The design will only modify steps 1 and 2, and other subsystems will not be addressed. The subsystems we have chosen to modify may end up being interdependent based on what method is chosen, so our scope currently extends to both. If the energy generation method chosen does not end up involving one of the steps, it will then be excluded from the scope. As we are in the early stages of research and ideation, these choices cannot be explicitly confirmed.

This project will not involve creating every part of the desalination system but will involve assembling all components to create the system that will successfully desalinate water. While the majority of parts will be bought and assembled, a few parts will possibly designed, such as the wave energy conversion device. Deconstructing the functions of the different parts of the desalination system, as seen in Figure 8, it is seen that most functions already have existing products that can be purchased. For example, a tank can be bought to store water, while a reverse osmosis filter can be purchased to separate particles.

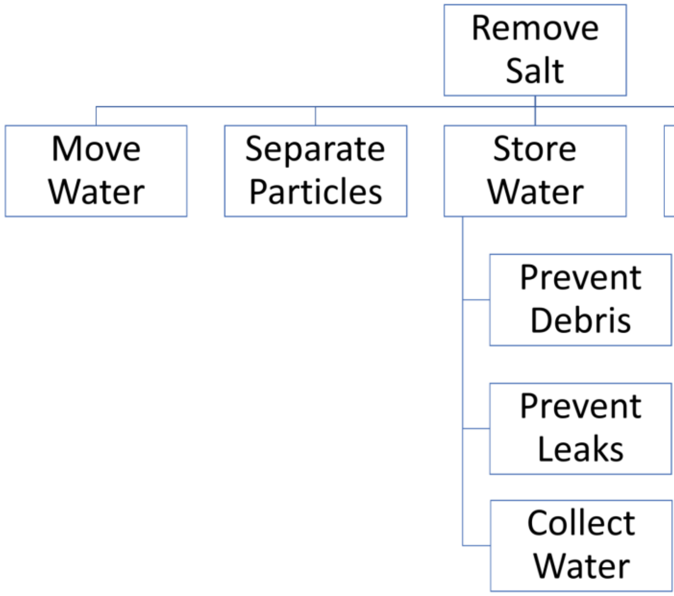

Fig 8. Functional Decomposition of the system.

To complete our design, thorough research will be conducted on viable tidal and wave energy sources. Local consumer needs have been and will continue to be investigated by contacting California coastal communities and local desalination plants to address the relevant areas of improvement. We will start ideating and designing a prototype for generating a pressure differential to pump water through the entirety of the system. The prototype will be small-scale due to cost constraints. Components that are not generated by our design process, for example the reverse osmosis system, will be bought to assemble a full desalination unit.

In summary, some of the important customer wants and needs from research are: inexpensive to run, wave powered to reduce environmental impact, non-toxic to both humans and the environment, and reliable. The common theme of the customer's wants and needs is a system that will efficiently desalinate water while being non-obtrusive and environmentally friendly. The full Quality Function Deployment (QFD) chart has all of the customer wants and needs from research, and can be found in Appendix A.

4 Objectives

Residents, specifically of arid climates and coastal locations, need a cost-effective, environmentally conscious, small-scale wave-powered saltwater desalination unit because climate change has created drought and water shortages in these areas. Our final project will be a small-scale prototype used for educational purposes and future senior projects to build upon.

To turn customer needs into engineering specifications, the QFD process was used, in which customer needs and specifications were ranked based on relationship and relative importance. Customer needs were written down, followed by matching engineering specifications to the needs to ensure that customer needs would be met. Refer to Appendix A for the full QFD chart.

As seen in Appendix A, each engineering specification is neatly aligned to at least one customer need. The engineering specifications that resulted from the QFD process are shown in Table 1.

Table 1. Engineering Specifications Table

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk*	Compliance**
1	Power generated by waves	Power required to generate 3-4 bars	+/- 1 bars	H	A,T
2	Size	2ft x 4ft	Max	M	I
3	Cost	$2000	Max	M	S
4	Materials	Non-Corrosive and Water-tight	Set	M	I,A
5	Codes/Standards	Meets EPA codes	Set	M	I
6	Vol. Flowrate	1 gal/hr	Min	H	A,T
7	Operation Noise	Below 85 dB	Max	L	T
8	Volume of Stored Water	0.5ft^3	Min	M	I,T
9	Water Quality	7 pH	+/- 0.7	L	T
10	Time to Process	20 minutes	Max	M	A,T

*Risk of meeting specification: (H) High, (M) Medium, (L) Low
**Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

1. Power generated by the waves must be able to create a differential pressure of three to four bars, with a tolerance of 1 bars. Too much pressure will rupture the membrane, while too little pressure and no desalination will take place. First, analysis such as Computational Fluid Dynamics (CFD) may be run, and testing in the ocean to measure power output will also be completed.
2. The size of the whole system must be less than 2ft by 4ft, which is around the size of a tabletop.
3. The cost must be less than 2000 dollars.
4. Materials used to create the system must be non-corrosive and water-tight, which will be enforced via inspection and analysis.
5. In order to be legal, the device must meet EPA standards for long term use in the future. Depending on which wave conversion device is selected, EPA standards will be found to ensure compliance as it is currently unknown what the device will look like and what codes apply.
6. The volumetric flowrate of the system must be greater than or equal to 1 gallon per hour, which will be tested by timing the system.
7. The operation of the system must be less than 85dB, which can be tested with a sound meter.
8. The volume of stored water must be a least 0.5 cubic feet, which can be tested.
9. The water quality must be between a pH of 6.3 and 7.7, and will be tested with Litmus paper.
10. The time to process water must be between 0 to 20 minutes, which will be tested by measuring the time it takes the system to make water and through analysis such as CFD if possible.

As seen, the first specification, power generated by the wave conversion device must be sufficient to generate three-four bars of osmotic pressure, is listed as “high” since this is something that has yet to be tried out anywhere in the world. Therefore, rigorous design, analysis, and testing will be necessary to ensure that the power requirement is met.

Furthermore, the volumetric flowrate of the system is also set to high as the household system that may be purchased is theoretically capable of 1gal/hr flowrate, but when used to desalinate water, may not actually give us that flowrate. This is because our team is utilizing the household system in a way that the designers did not envision, so rigorous testing will be needed to ensure that this flowrate is achieved. Just in case this system fails, alternate methods of approach will be planned out in advance.

5 Project Management

The initial project plan is arranged in Team Gantt to outline, assign, and keep track of tasks and major deliverables (Appendix B). A hierarchy of assignments are arranged in Team Gantt using groups of tasks, subgroups, and tasks. The group of tasks define major steps leading up to major deliverables (called milestones) including, “Problem Definition”, “Project Concept and Design”, “Concept Generation and Selection”, “Detailed Design and Analysis”, “Manufacturing”, “Testing”, and “Project Wrap-up”. A table of milestones is shown in Table 2.

Table 2. Project Milestones

Milestone	**Due Date**
Scope of Work	10/20/21
Preliminary Design Review	11/18/21
Interim Design Review	1/13/22
Critical Design Review	2/11/22
Manufacturing and Test Review	3/10/22
Verification Prototype Sign-Off	4/26/22
DVPR Sign-Off	5/17/22
Final Design Review	6/3/22

Below the major group tasks are subgroups like “Customer/Needs Research” and “Ideation”. Below the subgroups are tasks such as “Write Problem Statement” and “Create Specification Table”. The tasks have start dates and end dates so that the project can progress smoothly with a planned timeline. At least one individual in the group is assigned to each task and will receive notifications via email to remind them to complete certain tasks. Additionally, there are dependencies which relate tasks to other tasks so that we know that one task cannot be completed without the previous tasks. This will maintain the flow of the project. The ‘Boards’ function on Team Gantt will be utilized to account for weekly tasks and be reviewed by a member on the team at least once a week to ensure all members are on track for deliverables.

The design approach we are taking includes immense background research, ideation, conception, modeling, and prototyping. The bulk of the background research has been done prior to this report, but we will be continued throughout the project, especially during ideation. The ideation process will include brainstorming activities and discussing existing solutions. The next milestone of the project is the Preliminary Design Review (PDR) where we present our final concept. After our concept is selected and some prototyping is done, we will start testing. This testing may include performing fluids analysis, determining power generation, evaluating environmental impacts, and water quality testing after desalination treatment. Our desalination system will likely be an accumulation of existing products for desalination purposes.

6 Conclusion

The primary design challenge of this project is to design and prototype a functioning ocean water desalination system that draws from renewable wave-energy sources to reduce the costs associated with operating a desalination plant. This report was constructed to create a realistic scope with respect to our sponsor, containing our research within the boundaries of their wants and needs. From the research conducted, many different methods of desalination and wave energy collection have been ruled out, and the team ultimately elected to use the methods of reverse osmosis desalination and a form of pressure differential wave energy collection. The next major deliverable for this project will be the preliminary design review, due on November 16, 2021. This review will introduce the team’s ideation process and aim to achieve Dr. Peter Schuster’s approval for our comprehensive design direction.

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Appendix

A. Quality Function Deployment (QFD) House of Quality
B. Team Gantt Chart

Appendix A: Quality Function Deployment (QFD) House of Quality

Correlations	
Positive	+
Negative	–
No Correlation	

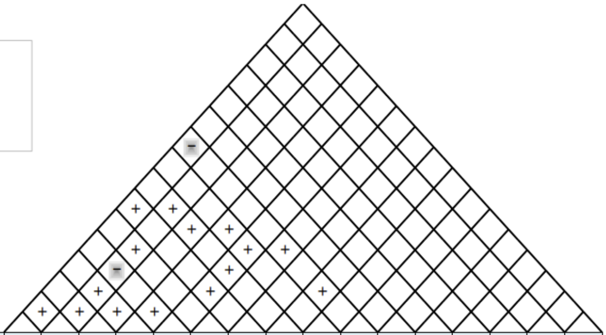
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: Wave Goodbye to Salt

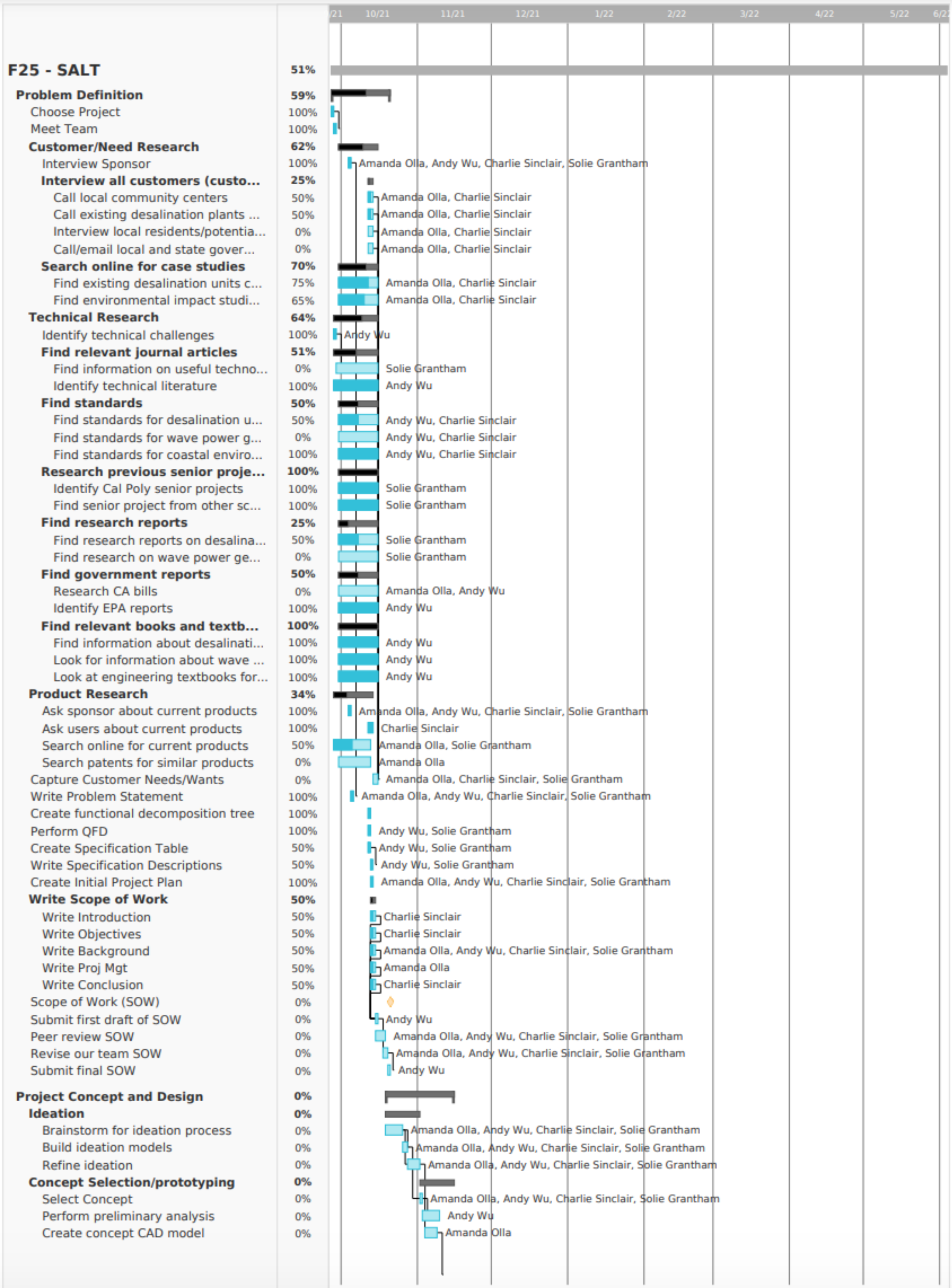
Revision Date: ______10/12/21_________

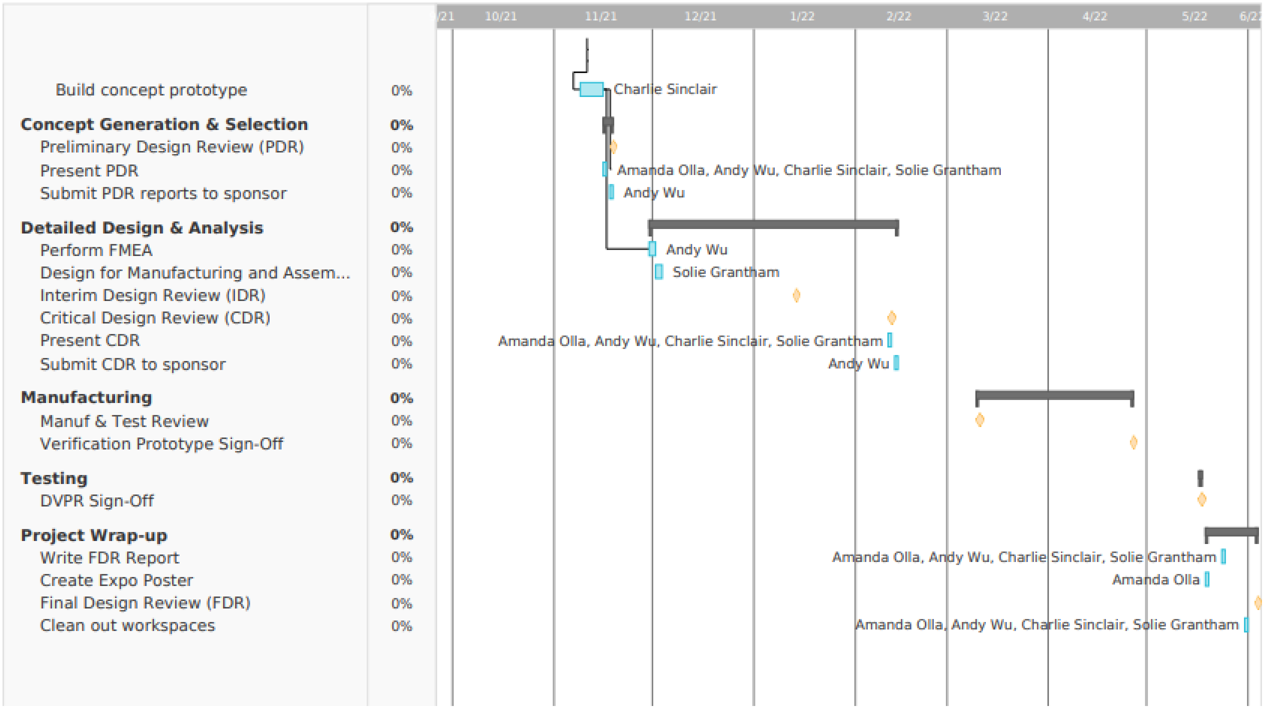


Row #	Weight Chart	Relative Weight	Coastal Residents	Commercial (i.e. powerplants, nu	Survivalist	Maximum Relationship	Column # → / WHAT: Customer Requirements (Needs/Wants) ↓ HOW: Engineering Specfications (Tests)	1 Power	2 Size	3 Cost	4 Materials	5 Codes/Standards	6 Flowrate	7 Operating Noise	8 Volume of stored water	9 Water Quality Test	10 Time to Process	Our Current Product	Competitor #1: Large Scale Desali	Competitor #2: Household RO Fil	Row #
							Direction of Improvement	▲	◇	▼	◇	◇	▲	▼	▲	◇	▼				
1	▮	8%	8	8	8	9	Inexpensive to run	○	○	●	▽							5	0	3	1
2	▮	6%	9	2	7	9	Wave powered	●	●	▽	▽	▽						5	0	0	2
3	▮	4%	4	4	4	9	Non-Toxic				●	○				○		5	4	5	3
4	▮	9%	9	9	9	9	Reliable	●			○		○		○	●	●	5	5	5	4
5	▮	8%	8	8	6	9	Established Safety Protocols					●				○		4	5	5	5
6	▮	9%	9	9	9	9	Efficient at desalinating water	▽							●		●	5	2	3	6
7	▮	8%	8	8	8	9	Withstands environmental stress		▽	▽	●	▽						4	5	0	7
8	▮	7%	8	6	6	9	Efficient Extraction of Energy	●					●	○				5	0	1	8
9	▮	6%	7	4	8	9	Non-Obstructive		●					●				5	0	3	9
10	▮	6%	9	3	7	9	Environmentally Conscious				●			○				5	3	2	10
11	▮	9%	9	9	9	9	Inexpensive to build			●	○	▽						5	0	3	11
12	▮	5%	8	3	5	9	Quiet operation						○	●				5	2	3	12
13	▮	6%	8	5	6	9	Safe for wildlife				●			○				5	2	4	13
14	▮	6%	9	2	8	9	Stores Water						○		●			5	2	3	14
15		0%																			15
16		0%																			16

HOW MUCH: Target Values	Power Required to generate 3-4 bars of	Size (2ft by 4ft)	Cost ($2500) +/- 500	Noncorrosive and watertight setup	Must meet Codes/Standards	Minimum flowrate of 1gph	Operating Noise under 85 dB	Volume of stored water minimum	Acceptable PH for Water Quality (6.3-7.7)	0-20 minutes time to process water						
Max Relationship	9	9	9	9	9	9	9	9	9	9						
Technical Importance Rating	233.3	143.4	174.1	297.6	105.4	124.2	163.7	168.3	120.3	169.3	0	0	0	0	0	0
Relative Weight	14%	8%	10%	18%	6%	7%	10%	10%	7%	10%	0%	0%	0%	0%	0%	0%
Curr. Products: Our Current Product	5	5	5	5	4	5	5	5	5	5						
#1: Large Scale Desalination Plant	5	0	0	5	5	5	3	5	5	5						
ompetitor #2: Household RO Filter	0	5	5	5	5	5	5	2	5	5						
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Appendix B: Team Gantt Chart




/21
10/21
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5/22
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Build concept prototype
0%
Charlie Sinclair
Concept Generation & Selection
0%
Preliminary Design Review (PDR)
0%
Present PDR
0%
Amanda Olla, Andy Wu, Charlie Sinclair, Solie Grantham
Submit PDR reports to sponsor
0%
Andy Wu
Detailed Design & Analysis
0%
Perform FMEA
0%
Andy Wu
Design for Manufacturing and Assem...
0%
Solie Grantham
Interim Design Review (IDR)
0%
Critical Design Review (CDR)
0%
Present CDR
0%
Amanda Olla, Andy Wu, Charlie Sinclair, Solie Grantham
Submit CDR to sponsor
0%
Andy Wu
Manufacturing
0%
Manuf & Test Review
0%
Verification Prototype Sign-Off
0%
Testing
0%
DVPR Sign-Off
0%
Project Wrap-up
0%
Write FDR Report
0%
Amanda Olla, Andy Wu, Charlie Sinclair, Solie Grantham
Create Expo Poster
0%
Amanda Olla
Final Design Review (FDR)
0%
Clean out workspaces
0%
Amanda Olla, Andy Wu, Charlie Sinclair, Solie Grantham

WAVE GOODBYE TO SALT
Preliminary Design Review

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Fall 2021

Abstract

According to the World Health Organization, one in three people globally do not have access to safe drinking water. The ocean is a seemingly endless volume of water, but the process of removing salt and other particulates from sea water has proven to be difficult. An efficient and environmentally friendly ocean water desalination process could be the solution to widespread water shortages. Current ocean water desalination plants are known to be highly expensive to construct and operate, as well as damaging to local aquatic ecosystems through sea water intake and brine byproduct expulsion. Considering these challenges, we seek to develop a desalination unit powered primarily by ocean waves to reduce energy costs and therefore the environmental impact of emissions from traditional power plants. A description of the ideation process and controlled convergence process is illustrated. Through that process, it was found that a diffuser grate was the best design choice for reintroducing brine back into the ocean. Furthermore, a hydraulic pump was found to be the best design choice for generating the differential pressure for the reverse osmosis system while still being able to be powered by wave energy. This will significantly help inform design direction as now specific parts can be purchased and tested. In order to reduce the likelihood of a high-risk specification failing, a concept model was created and tested to ensure successful function of the wave energy conversion device. It was found that a larger area and a mounting surface close to the waterline was needed to generate the most movement of the lever. From these results, we will be able to purchase the correct materials and design a better wave energy conversion device.

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1 Introduction

We are a team of mechanical engineers at California Polytechnic State University seeking an innovative way to integrate renewable ocean wave energy into ocean water desalination processes for our senior design project. Our sponsor, Dr. Peter Schuster, is looking for a small-scale desalination system that will be powered solely by wave energy. The final objective will be to create a small-scale desalination system as a working proof-of-concept that is powered by wave energy.

In the Scope of Work (SOW), the plan for the project was to create a full desalination system powered by renewable wave energy. Due to the huge amount of background research necessary, this was a tentative plan, as we were unsure about the feasibility of doing so. However, after more research, we have definitively decided that we will design, build, and test a wave energy powered desalination system as a proof-of-concept. Furthermore, with our sponsor's consent, we have agreed to purchase existing subsystems instead of designing our own when possible. At our sponsor's request, we have also removed the specification requiring a specific amount of water to be made in 10 minutes.

The goal of this report is to inform our sponsor about the process from idea generation to a working concept, hopefully gaining approval to proceed in the end. First, the ideation process that led to a large-scale generation of ideas will be discussed, as well as the controlled convergence process where ideas were evaluated. Then, the concept prototype and the computer-aided design (CAD) model will be illustrated, along with showing preliminary test results and calculations. Finally, the concept will be evaluated against the specifications set by the SOW, and a review of upcoming deliverable dates will be discussed.

2 Concept Development

The following sections give a comprehensive overview of the ideation process and final concept decision process.

2.1 Ideation Process

Ideation was done with a series of brainstorming activities. We wrote and made drawings of ideas to generate as many ideas as possible, with some constraints, like no electrical components. The ideation process for this project was very open-ended, so we had to include constraints to hone our focus on mechanical energy generation. Utilizing these activities enhanced creative thinking and allowed ideas to build off each other to break the system down into its basic functions. During ideation, we strove for a breadth of ideas, without worrying to much about depth. This is illustrated in one of our activities where we wrote down different topics on separate pieces of paper. Then, we gave every team member two minutes to write down as many ideas as possible, and then switched papers until every topic was covered by every person. This activity allowed us to build upon each other's ideas without judgement and resulted in some very creative ideas. Our brainstorming activity ideas can be found in Appendix A.

After brainstorming ideas, we created physical ideation models to represent the wave-powered desalination system. Using household materials, basic prototypes were constructed for different functions of the system. Initial ideation model examples are shown in Figure 1.

Figure 1. Initial Ideation Models for Wave Energy Generation

These prototypes allowed us to physically represent and test the feasibility of our ideas. This process eliminated certain ideas and changed design aspects like shape, material, or orientation. Furthermore, by also bringing a tank of water to the prototyping session, we were able to quickly eliminate ideas that would not float or were too hard to control. See Appendix B for more examples of the ideation model prototypes.

2.2 Concept Decision Process

The top ideation concepts for each function were evaluated using Pugh matrices (see Appendix C). The functions of our system are wave energy generation, energy conversion, desalination, and brine rejection. Wave energy generation and energy conversion are divided into separate functions because they require different devices; one device turns the wave energy into a force and the other device turns the force into a different form of mechanical energy (i.e. pressure). The design direction of using a hydraulic pump for energy conversion for a proof-of concept solution was clear based on the background research from the SOW, therefore we did not use a Pugh matrix for this function. However, alternatives such as using the wave mechanical energy to drive a piston to create the pressure differential should be considered for a long-term solution. The desalination component was defined in the SOW report as a reverse osmosis system, so we did not include a Pugh matrix for that function.

The matrix has columns for concepts and rows for criteria including cost to build, environmental impact, and estimated efficiency. The ideas for each function are evaluated in a Pugh matrix by comparing them to a selected datum concept to determine if it is better, worse, or the same as the datum for each criterion. The sum of the "better", "worse", and "same" for each concept are totaled to eliminate the concepts with low scores. Negative scores indicate a higher number of "worse" qualities than "better", therefore, these concepts should be rejected from consideration or adjusted to improve the concept. Some ideas or parts of ideas were combined to come up with a new concept, which were evaluated again in the Pugh matrix. For the wave energy generation device, the Pugh matrix suggested that our datum idea was one of the best choices, which was interesting as we expected the combination idea to be the best choice. In this case, we believe the cost and complexity of the system ended up being detrimental. When it came to the choices of rejecting brine back into the ocean, we had less of an idea which one would be the clear winner, but it turned out that the diffuser grate was the best combination of efficiency and environmental friendliness.

The best concepts from the Pugh matrices for each function are put into a morphological matrix (see Appendix D). The functions represent components of the system that are pieced together to create a system-level concept. We voted on the top eight system-level concepts to put into a weighted decision matrix (see Appendix E for larger version, reproduced in Figure 2 as a condensed version).

		1111		1212		1311		2111		2311		4111		3111	
Criteria	Weighting	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Cost to Build	5	4	20	3	15	3	15	2	10	1	5	3	15	2	10
Environmental Impact	4	2	8	2	8	1	4	5	20	5	20	1	4	5	20
Estimated Efficiency	3	4	12	3	9	5	15	2	6	4	12	4	12	4	12
Maintenance	3	4	12	4	12	2	6	3	9	2	6	4	12	2	6
Estimated Consistency	4	3	12	4	16	5	20	3	12	5	20	3	12	3	12
Proximity to Shore	2	4	8	4	8	4	8	5	10	4	8	5	10	5	10
Current R&D	2	4	8	3	6	2	4	3	6	2	4	4	8	3	6
SUM			**80**		**74**		**72**		**73**		**75**		**73**		**76**

Figure 2. Final Weighted Decision Matrix

The weighted decision matrix has rows of criteria (same as Pugh matrix criteria) and columns of system-level concepts. We were able to select a concept based on stakeholder needs due to the weighted decision matrix, as the criteria column in the weighted decision matrix represented customer needs such as cost to build and environmental impact. Other criteria were based off of specifications, such as proximity to shore, which would indirectly impact the criteria of producing enough power to desalinate water. Scores for the eight system-level concepts were calculated by ranking each concept for each criterion on a scale of zero to five. Figures 3-7 depict the top five system-level designs as a result from the weighted decision matrix.

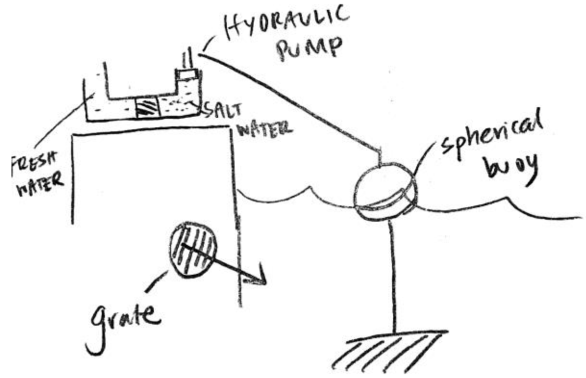


Figure 3. First System-level Concept Drawing (1111)

The system in Figure 3 consists of a buoy connected to a lever arm which provides a torque on the pump handle to generate hydraulic pressure. The water goes through a reverse osmosis desalination system and the excess brine is released back to the ocean through a grate which is specialized to disperse salt concentration more evenly by fanning out the brine when discharging. Due to the small scale nature of this system, many of these will be employed, each releasing a small amount of brine in a separate location, which will also reduce the amount of salt concentration in one location. Coupled with the grate, we hope to see minimal environmental impact.

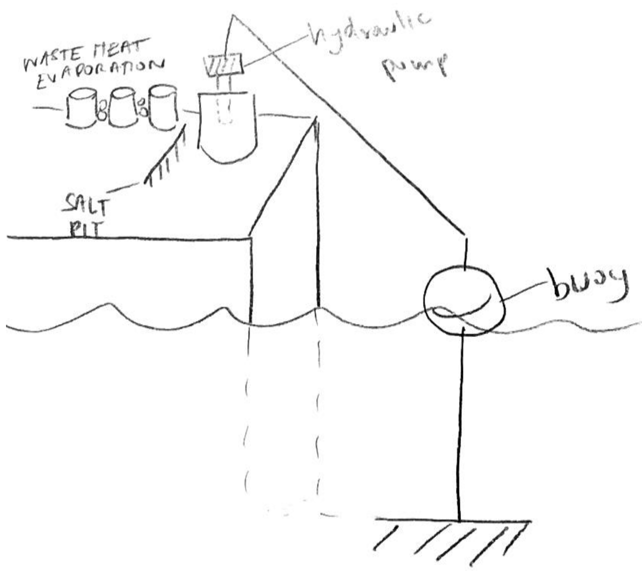


Figure 4. Second System-level Concept Drawing (3111)

Figure 4 shows a hydraulic pump powered by a buoy that moves vertically due to ocean waves, thus providing pressure to a reverse osmosis desalination system. Brine water is then evaporated with the help of waste heat from the desalination process, and this salt can be repurposed. The drawback of this system is that there is unlikely to be enough waste heat to evaporate the water. However, evaporation concerns would be less of a problem in tropical regions where the climate would handle the evaporation.

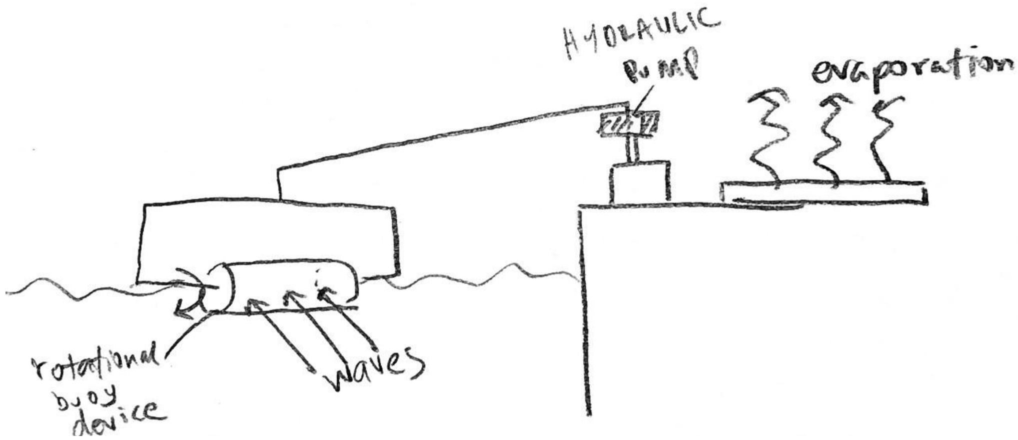


Figure 5. Third System-level Concept Drawing (2311)

Figure 5 shows how the system captures wave energy with both rotational and linear motion and the motion is used to power a hydraulic pump lever arm which generates the pressure required to operate a reverse osmosis desalination system. The rotational component would produce electric energy locally to provide more power while also allowing for the mechanical energy of the waves to power the pump. An evaporation field is also used to evaporate brine water into the atmosphere using solar radiation and leaves behind salt which can be repurposed. A drawback of this system is that it is more expensive to build, which would put more burden on the stakeholder. The evaporation pits require land purchases and the rotational buoy device is more costly to manufacture.

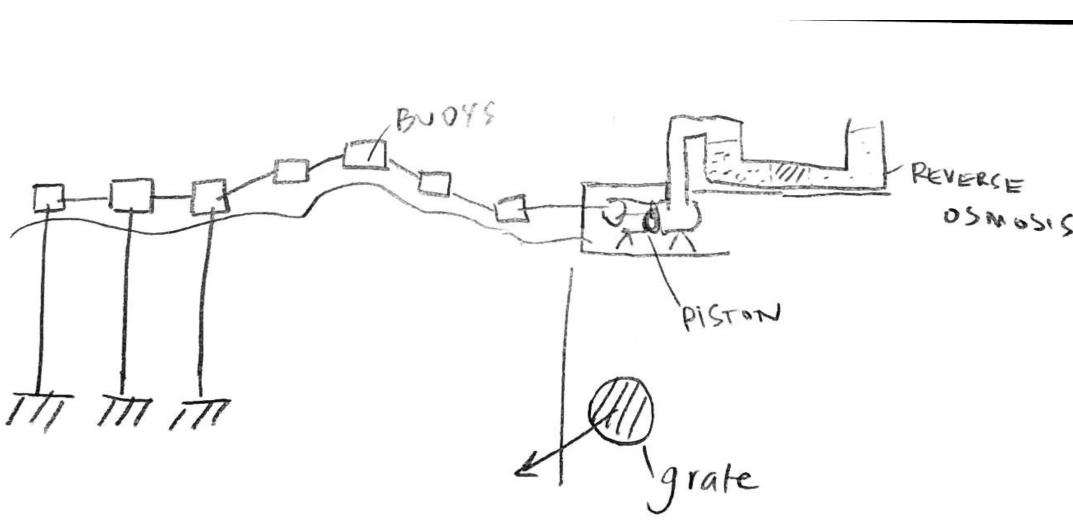


Figure 6. Fourth System-level Concept Drawing (1212)

The system depicted in Figure 6 is a buoy chain connected to a piston which converts the wave energy from the buoy motion to compress water or air. The pressure from the piston powers the reverse osmosis desalination system. The brine goes through the specialized grate which will help reduce environmental impacts. Due to the long length of buoys, this design would be less environmentally friendly as sea life can get caught between a long chain of buoys, making it less appealing to stakeholders.

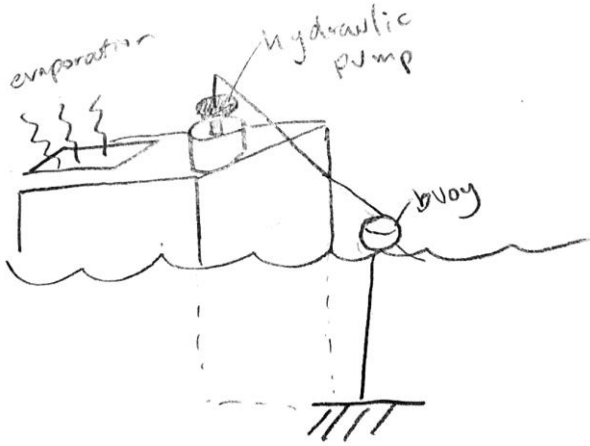


Figure 7. Fifth System-level Concept Drawing (2111)

The buoy wave energy generator moves the hydraulic pump handle vertically in the system-level concept depicted by Figure 7. The hydraulic pump creates a pressure differential that allows for the reverse osmosis desalination component to convert saltwater to fresh water. The design is similar to Figure 4, except the brine rejection method is different. The brine resulting from the reverse osmosis goes to evaporation pits where the liquid is evaporated, and the salt is extracted to be used elsewhere or sold for a profit. However, one drawback of the system is that the evaporating pits require expensive land purchasing, adding to building costs of the system, which would not be ideal for stakeholders.

The concept with the highest score represents the best option based on the criteria, which is the system depicted in Figure 3. Specifically, during this process, while it was hard to assign weights due to relative importance, our group was able to converge on the results after initial discussion. In the end, the results of the weighted matrix matched our intuition, as stated above, since we expected a less costly and complex system overall to be preferable for the stakeholders. In this case, the clear winner was the least complicated system that was still able to complete all the tasks well.

3 Concept Design

The concept direction, as established by the weighted decision matrix, leads into the concept design and prototyping phase of the project. The following section will explain our chosen concept through drawings, a CAD model, a concept prototype, and detailed descriptions.

3.1 Concept Design Description

Our results from the weighted decision matrix, as well as justification through team discussion, indicate that a system made up of a hydraulic pump powered by a marine buoy, a reverse osmosis desalination system, and a brine diffuser is the most viable option. Figure 8 depicts this system-level design.

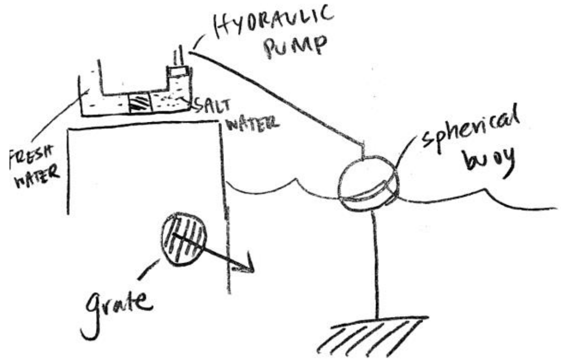


Figure 8. Final Design Concept Drawing

This system consists of a buoy connected to a lever arm which moves the pump handle to generate hydraulic pressure. The water goes through a reverse osmosis desalination system and the excess brine is released back to the ocean through a grate which is specialized to disperse the brine evenly.

The purpose of the buoy and pump system is to convert the bobbing motion from the waves to a differential pressure through the pump. A lever arm is attached to the buoy and pump by a fixed connection at the pump handle and a pin-joint connection at the buoy, allowing for full vertical motion of the buoy as it floats in the waves. The buoy is also spherical for better buoyancy. The lack of sharp edges minimizes environmental harm while enhancing aesthetics.

The hydraulic pump converts linear harmonic motion into a differential pressure. In this case, the motion of the buoy causes the pump handle to move, generating a pressure. Furthermore, the hydraulic pump rests on a stationary surface, such as the ground or a pier, and serves as an anchor to the buoy. As seen in Figures 9 and 10, the CAD model is constructed with anchoring constraints in mind but does not explicitly include the objects the model is anchored to. Figure 9 shows the isometric view of the design concept CAD model.

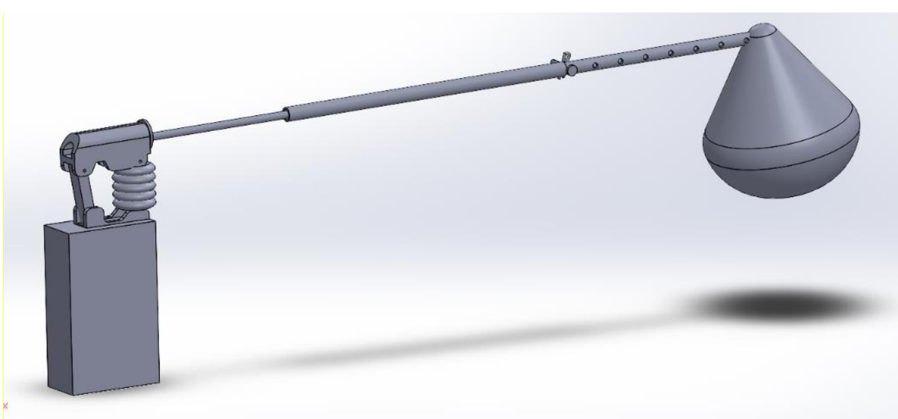


Figure 9. Isometric View of Final Design CAD

Figure 10 is a side view of the CAD model with annotations for each part in the assembly.

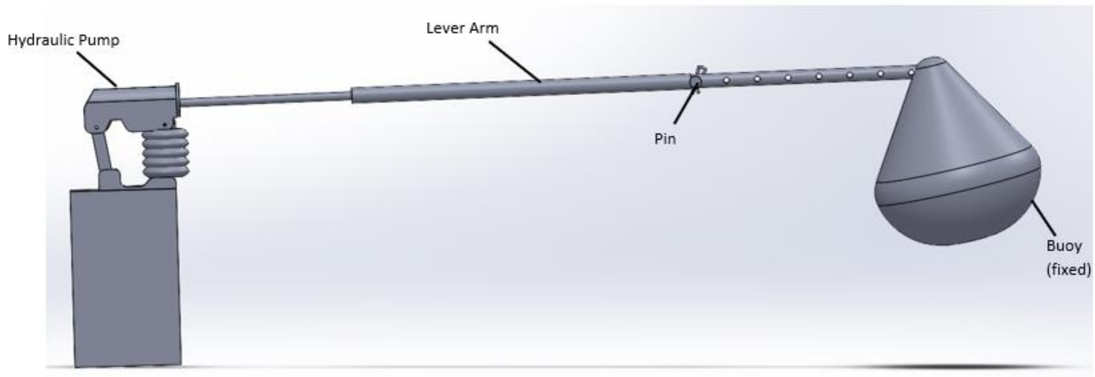


Figure 10. Annotated Side View of Final Design CAD Model

The final design will be built as a benchtop display, and the entire size of the system will not exceed that of a standard 2 ft by 4 ft table. In the current model, shown in Figures 9 and 10, the diameter of the cylinder of the piston is 2.99 inches. The lever arm has a length of 23 inches, and the buoy has a diameter of 3 inches.

Materials used will depend on final weight and flexibility of the system. The pump, lever arm, and buoy will likely all be separately purchased items and so the material of the mechanism is not yet determined.

The reverse osmosis filtration system consists of a semipermeable membrane in a pipe system. Saline water is added to the inlet and forced through the membrane at high pressure, leaving fresh water at the outlet. These systems can contain multiple reverse osmosis filtration steps to further purify water.

A specifically designed diffuser will fit onto a pipe for brine rejection. Before rejecting brine into the ocean, this diffuser will spread the brine out over a larger distance so one area will have less salt concentration. This way, there will be decreased environmental impacts with not much increase in cost.

3.2 Concept Prototype

The concept prototype's purpose is to test functionality of the wave energy generation component of the system. The wave generation component consists of the point-absorber buoy and lever arm. We made two versions of the prototype by changing the buoy size: one with a tennis ball and the other with a ping pong ball. Both the tennis ball and ping pong ball float which is required for testing. We simply attached the buoy to the lever arm by wrapping it in duct tape. The lever arm is modeled by a long wooden dowel (about 18 inches). The lever arm is attached to the "pump", which is modeled as a metal can, with a hinge so we can test if the buoy will move the lever arm. The two versions are attached to one can as depicted in Figure 11.

Figure 11. Concept Prototype

We tested the concept prototype in a pool and simulated the ocean waves as discussed in Section 4.2. This motion will determine if waves provide proficient vertical displacement of the buoy and move the lever arm. See Appendix F for testing details and photos. In the final prototype, the lever arm will be more securely attached to the buoy and the pump handle. This model is sufficient to demonstrate the motion of the lever arm, as the hydraulic pump has not yet been purchased.

The angle of the lever arm may have a factor on the effectiveness of energy generation, which will be discovered through future calculations and testing. Materials for a final prototype may include a lightweight and stiff metallic rod for the lever arm, a buoyant and sturdy buoy material, and anchor with a cable.

The other components (hydraulic pump, reverse osmosis desalination unit, and brine diffuser) are not modeled in the concept prototype and will be bought and assembled in the system once funds are available to purchase these items. Additionally, we didn't model an anchoring system in the prototype because it would require drilling a hole in the buoys which would ruin the buoyancy aspect of the system. To fix this issue in future prototyping, sealant or a different type of buoy will need to be used.

The sponsor expects a final prototype that can be tested as proof-of-concept. Deliverables will include a report of research conducted, a functioning prototype of a small-scale desalination system, and analysis of how the system performs in an ocean scenario. An ocean scenario could be simulated by using a wave generator in an aquarium tank or testing off a local pier [1]. Avila Pier is a potential testing location as it is a non-moving pier that is associated with Cal Poly for research needs. However, there is not much wave activity there, so we plan to investigate alternative pier locations where there is more wave action for ideal testing for the wave energy converter.

4 Concept Justification

When selecting the best system for our primary design concept, the parameters in Table 1 below must be taken into consideration. These parameters ensure that our design will generate enough fresh water, stay within a budget, and satisfy environmental guidelines.

Table 1. Engineering Specifications Table

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk*	Compliance**
1	Power generated by waves	Power required to generate 55-69 bars	+/- 1 bars	H	A,T
2	Size	2ft x 4ft	Max	M	I
3	Cost	$2000	Max	M	S
4	Materials	Non-Corrosive and Water-tight	Set	M	I,A
5	Codes/Standards	Meets EPA codes	Set	M	I
6	Vol. Flowrate	1 gal/hr	Min	H	A,T
7	Operation Noise	Below 85 dB	Max	L	T
8	Water Quality	7 pH	+/- 0.7	L	T

*Risk of meeting specification: (H) High, (M) Medium, (L) Low
**Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

1. Power generated by the waves must be able to create a differential pressure of 55-69 bars. Too much pressure will rupture the membrane, while too little pressure and no desalination will take place. First, analysis such as Computational Fluid Dynamics (CFD) may be run and testing in the ocean to measure power output will also be completed.
2. The size of the whole system must be less than 2ft by 4ft, which is around the size of a tabletop.
3. The cost of the prototype must be less than 2000 dollars.
4. Materials used to create the systems must be non-corrosive and water-tight (for systems containing fluids), which will be enforced via inspection and analysis.
5. In order to be legal, the device must meet EPA standards for long term use in the future.
6. The volumetric flowrate of the system must be greater than or equal to 1 gallon per hour, which will be tested by timing the system.
7. The operation of the system must be less than 85dB, which can be tested with a sound meter.
8. The water quality must be between a pH of 6.3 and 7.7 and will be tested with Litmus paper. The water quality will also be tested with salinity strips.

4.1 Design Specifications

As shown in Table 1, the first design specification listed is power generated by ocean waves. The scope of the project restricts the design to direct mechanical energy conversion, so common electrical conversion will be avoided. Our concept entails power generation via a hydraulic pump coupled with a spherical buoy. This conversion system must generate 55-69 bars of osmotic pressure in order to satisfy our desired flowrate specification. This power generation specification is listed as high risk since it has little to no testing anywhere else in the world. Further testing of pressure levels is planned to ensure that the pressure differential generated by the hydraulic pump system will be sufficient. The final pressure relies not only on the pump chosen, but also on the amount of wave energy captured and the design pressure of the system. Given promising initial testing results (see Section 4.2), we believe that there will be enough work generated to satisfy our pressure differential requirements. Additionally, a hydraulic pump will likely meet this specification since they are commonly used for loads that require 0-100 bars of pressure. We must also keep in mind that the pressure required by the reverse osmosis system determines the pressure and flowrate needed from the pump, which will likely vary. To achieve this, the pump will be implemented so that the flowrate can be varied to ensure the correct pressure is being supplied.

Furthermore, the volumetric flowrate of the system is also regarded as a high-risk specification since the reverse osmosis system is theoretically capable of a flowrate of over 1gal/hr, but it may not be achieved when the system is interfaced with the hydraulic pump. This discrepancy is caused by our team utilizing the reverse osmosis system in a way that the designers did not envision, so rigorous testing will be needed to ensure that this flowrate is achieved. We have confidence that this flowrate can be achieved since flowrates are determined by how much pressure is supplied to the system. If 3-4 bars of pressure are generated, the flowrate will likely be met. Like our first specification, this actual flowrate value can only be determined once we have acquired the hydraulic pump itself along with the desalination system due to the principles of fluid flow continuity. One advantage of using the household system is that the water output of the reverse osmosis system will likely be safe to drink, meaning that it will be simpler to meet the pH requirements of a pH between 6.3 and 7.7.

We are confident that we will be able to meet our $2000 budget limit as outlined in our Baker-Koob proposal. We have listed how much each material/system is going to cost, building in some leeway to ensure that we have enough funds to complete the project. Additionally, by using a household reverse osmosis system, not only will the desalination system itself will be very compact and able to meet the 2ft by 4ft size maximum, it will likely also meet the 85dB sound requirement as household systems are typically very quiet. Finally, the materials chosen for the design will be non-corrosive, and water-tight sealants like gaskets will be used to ensure system robustness, as well as ensuring that EPA codes are met. That way, all specifications will be met.

4.2 Preliminary Testing

Testing was conducted two times in different orientations, with both sides of the concept prototype apparatus in a swimming pool. Waves were simulated by maneuvering a wooden board to produce motion in the water. Figure 12 and 13 show two testing setups.

The initial setup suspended the metal can with its opposite lever arm held parallel to the ground by a large rock. In this position, the hinges attaching the lever arm to the can were approximately 7.75” from the pool’s water. There was not much motion for either the tennis ball or ping pong ball setup with the can in this position. While the tennis ball tended to become saturated with water and sink, it was generally more buoyant, proving that a larger sized buoy would increase the force generated by the system.

Figure 12. First Test of Concept Prototype with Ping Pong Ball

A second test yielded better motion for each side of the concept prototype. The new setup involved someone holding onto the metal can and holding the base flush with the surface of the pool, allowing for increased mobility of the lever arm. It was documented that in order for the lever arm to move freely, it must be close to the waterline. This may eventually impact our placement of the pump, as it may need to be closer to the water than previously envisioned.

Once the range of motion from the lever arm was improved, the waves were observed to create more rotational motion about the hinge when the tennis ball buoy was used as compared to the ping-pong ball buoy. It was concluded that less force was exerted on the lever arm due to a smaller spherical area, thus inducing less torque. The larger tennis ball provided much more smooth and consistent motion. This confirmed our inclination towards using a larger buoy for the final design. See Appendix F for further testing details.

Figure 13. Second Test of Concept Prototype with Tennis Ball

Even with the preliminary testing, the design of the wave energy conversion system which consists of the buoy connected to the hydraulic pump, is still a major concern. We are worried that we will be unable to make the design specification of generating 55-69 bars of pressure for the reverse osmosis system. To mitigate this, we plan on purchasing a hydraulic pump early in winter quarter to do initial testing, measuring quantities such as torque needed to move the hydraulic pump handle and its ability to generate 55-69 bars of pressure with inconsistent motion. Our lever arm movement may be impacted by the proximity to the ocean waterline and reduce the ability to capture wave energy. Furthermore, we plan on undergoing more testing by varying lever arm length and seeing if we can move the pump to a point higher than the waterline while still retaining significant lever arm motion. Additionally, we may need to test on a boat dock or floating platform instead of a pier. This will reduce our risk and allow us to move forward with more confidence.

4.3 Preliminary Calculations

Significant calculations cannot be conducted until we have acquired the pump and the rest of the fluid system. Product manufacturers can provide some calculations such as pressure and force requirements of the hydraulic pump. All baseline values will be taken from the design specifications of the components we plan to purchase for our complete design, as shown in Table 1.

Despite this, preliminary calculations based on our design concept were able to be made regarding buoyancy force of the tennis ball modeling the spherical buoy, and static torque generated by this surface force. The calculations also suggest that we need to take care in determining if the selected spherical buoy will still float when we maximize the surface area to produce the maximum force. The buoy must be buoyant enough to respond to ocean wave oscillations while still having enough weight to depress the lever on the hydraulic pump. An exact predicted value for the dimensions of this buoy will be difficult to determine before we receive the hydraulic pump for our system, as there are no published values of torque that will move the pump handle on the internet. For now, the buoyancy calculation will be based on our concept model. These calculations are included in Appendix G for reference.

4.4 Design Hazards and Challenges

Along with the proposed design, several safety considerations must be made to ensure safe operation and to secure environmentally friendly performance. During normal operation, there will be significant mechanical motion generated from the spherical buoy and the lever arm attached to the hydraulic pump. This system could potentially harm not only a human bystander, but also any surrounding sea life swimming along the shore, which is a common behavior of many marine mammals. To prevent any organisms from coming in to contact with the system, a protective fencing or cage system may be built around the buoy and lever arm.

Due to our system being in a marine environment, corrosion and biofouling are significant concerns when running sea water through any part of the apparatus. Maintenance on the wave energy capture components could be performed out of the water by detaching the lever arm from the hydraulic pump and bringing it to a safe location on land to be repaired. Since most other aspects of our design will be located on land, these can be repaired in place.

The hydraulic pump and reverse osmosis systems will also be subject to high levels of pressure, which could be prone to fail especially in a corrosive marine environment. While proper maintenance should prevent failures, a pressure release valve could be installed as a failsafe for any pressure related incidents. A completed checklist of all design hazards is located in Appendix H for reference. All significant hazards for our design and their respective solutions are neatly shown below in Table 2.

Table 2. Design Hazards and Corrective Actions

Description of Hazard	Planned Corrective Action
Large marine buoy and lever arm moving quickly in an oscillating vertical path.	Fencing or a cage system surrounding the lever mechanism to prevent people and sea life from being injured.
Pressurized fluids present in piping and reverse osmosis system.	Install pressure release valve for emergency use. Valve opens directly to ambient conditions and rapidly equalizes pressure.
System operated in close proximity to ocean environment, causing rapid corrosion of system components.	Regular and scheduled maintenance checks to ensure a high level of integrity across system components.

Many of our design specifications are dependent on each other such as the pressure generated from the hydraulic pump and the flowrate of fresh water out of the reverse osmosis system. Due to these dependencies, we have many unknowns in our design at this point in the project. This is a challenge and a concern as we are unable to state with full certainty that our design will be capable of generating enough pressure from wave energy to drive a reverse osmosis system effectively.

Another factor that generates uncertainty is the inconsistent nature of ocean waves. This project was currently planned to operate off the Cal Poly pier in Avila Beach, but Avila is shielded from deep ocean swells and may not provide the necessary consistency and size of waves. We plan to relocate to an area that receives strong and consistent swell and still allows for operation off a stationary platform such as a pier.

5 Project Management

We performed preliminary testing on our concept prototype to ensure feasibility and estimate effectiveness of our design. The concept prototype was tested in a pool where we manually generated waves to determine if the buoy would move the lever arm. The purpose of this test was to evaluate the effectiveness of the point absorber to translate vertical motion to move a pump handle and generate energy for the system. Further testing on our final concept prototype may include performing fluids analysis, determining power generation, evaluating environmental impacts, and water quality testing after desalination treatment. Our desalination system will likely be an accumulation of existing products for desalination purposes.

In order to perform better tests and do proper analysis, we plan to purchase testing and prototype materials. Wave-simulation can be done more effectively with a wave generator device which can be put in a tank to regulate the waves [1]. We did not purchase a hydraulic pump, reverse osmosis system, or brine diffuser for our concept prototype, but these components will be tested and included in the final prototype [2, 3]. Additionally, we looked into buoy materials for our final prototype that are for marine applications [4].

Table 3 outlines the next major milestones of our project.

Table 3. Project Milestones

Milestone	Due Date
Preliminary Design Review	11/18/21
Critical Design Review	2/11/22
Manufacturing and Test Review	3/10/22
Verification Prototype Sign-Off	4/26/22
DVPR Sign-Off	5/17/22
Final Design Review	6/3/22

The Gantt chart which outlines our full project plan with tasks and deliverables can be found in Appendix I.

The next milestone of the project is the Critical Design Review (CDR). The CDR provides the full details of our final design including design justification, a manufacturing plan, and design verification plan. Prior to CDR, we have the Interim Design Review (IDR) where we present our design description with our CAD model and updated prototype, analysis and testing plan, manufacturing plan, current issues, and project progress. After IDR, will use our planned purchases and final CAD model with detailed drawings to build our structural prototype which will presented for CDR.

6 Conclusion

The primary design challenge of this project is to design and prototype a functioning ocean water desalination system that draws from renewable wave energy sources to reduce the costs associated with operating a desalination plant. Through the ideation phase and prototyping phase, we were able to create a bank of ideas to draw upon, ultimately combining ideas together to create a working system. By using a weighted decision matrix, final systems could be chosen using a relatively objective method against stakeholder needs, resulting in a ranked list of top choices. Finally, in order to test a high-risk function, a concept prototype of the function was created in order to undergo preliminary testing. We hope we have convinced our sponsor to agree with us on our design direction.

References

[1] “Wave Generator, Adjustable Phase.” Flinn Scientific. https://www.flinnsci.com/wave-generator-adjustable-phase/ (accessed November 10, 2021).

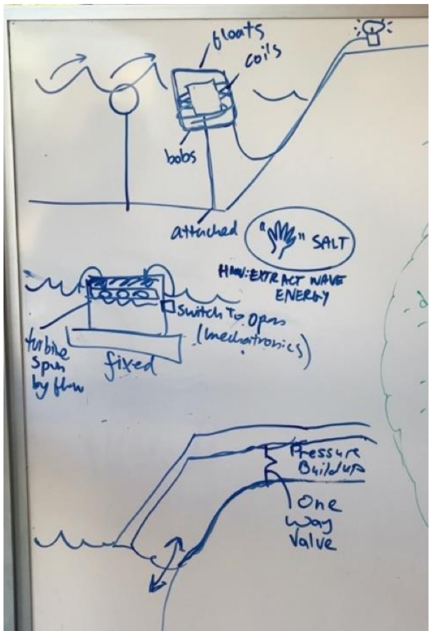
[2] "Chief Double Acting Hydraulic Pump". 2021. Amazon.com. https://www.amazon.com/gp/product/B07B9DBVDY (accessed November 9, 2021).

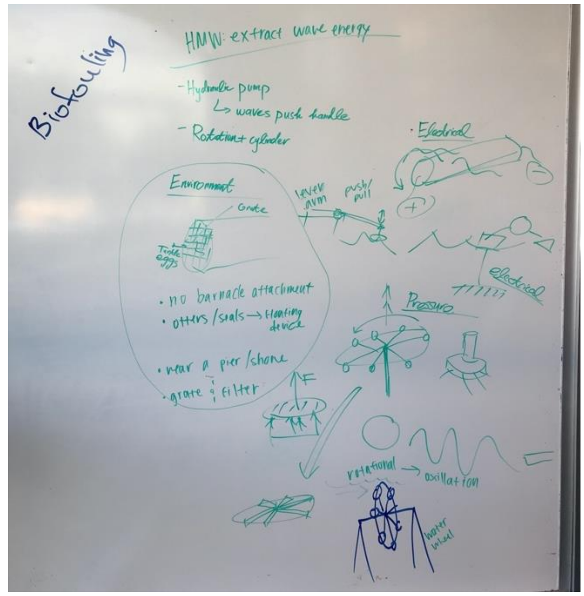
[3] “VEVOR Hydraulic Pressure Test Pump”. 2021. Amazon.com https://www.amazon.com/VEVOR-Hydrostatic-Hydraulic-Container-Irrigation/Q (accessed November 9, 2021)

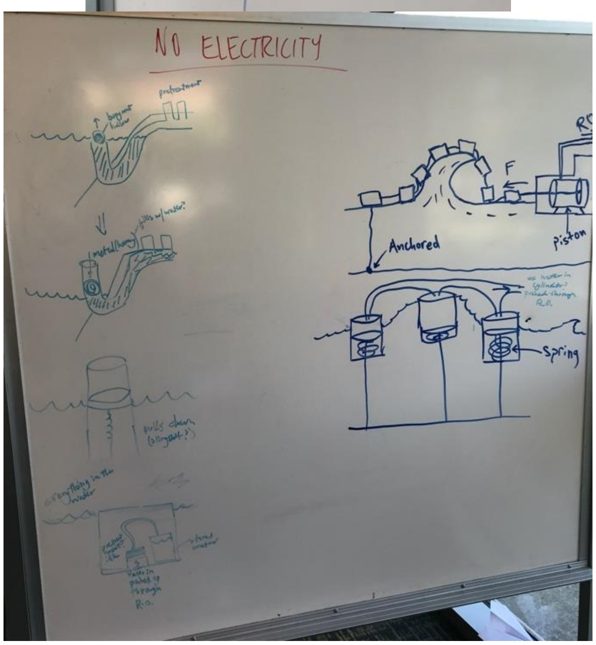
[4] “Essence Premium Quality 5-Stage Under Sink”. 2021. Home Depot. https://www.homedepot.com/p/APEC-Water-Systems-Essence (accessed November 9, 2021)

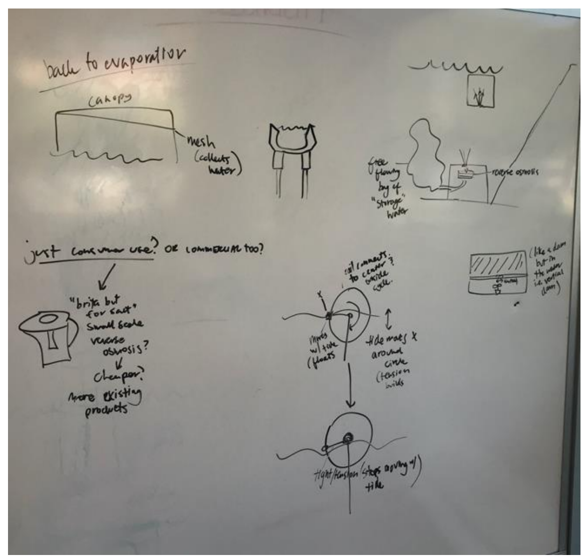
Appendix

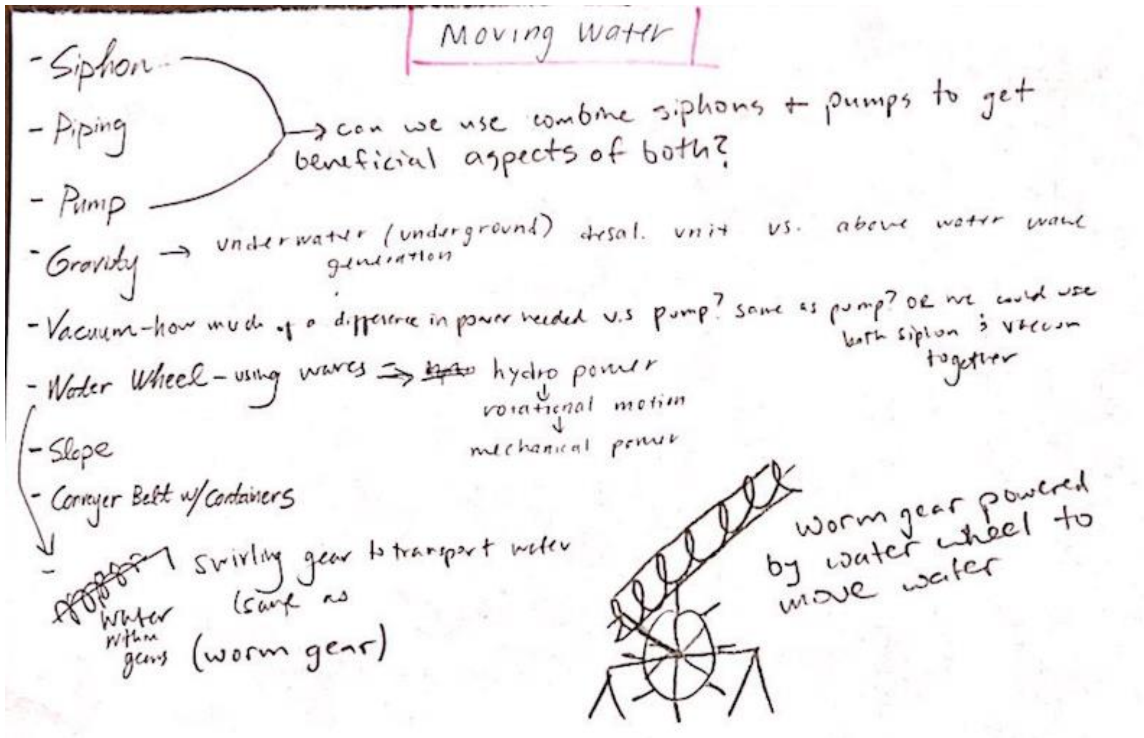
Appendix A: Idea Lists and Sketches



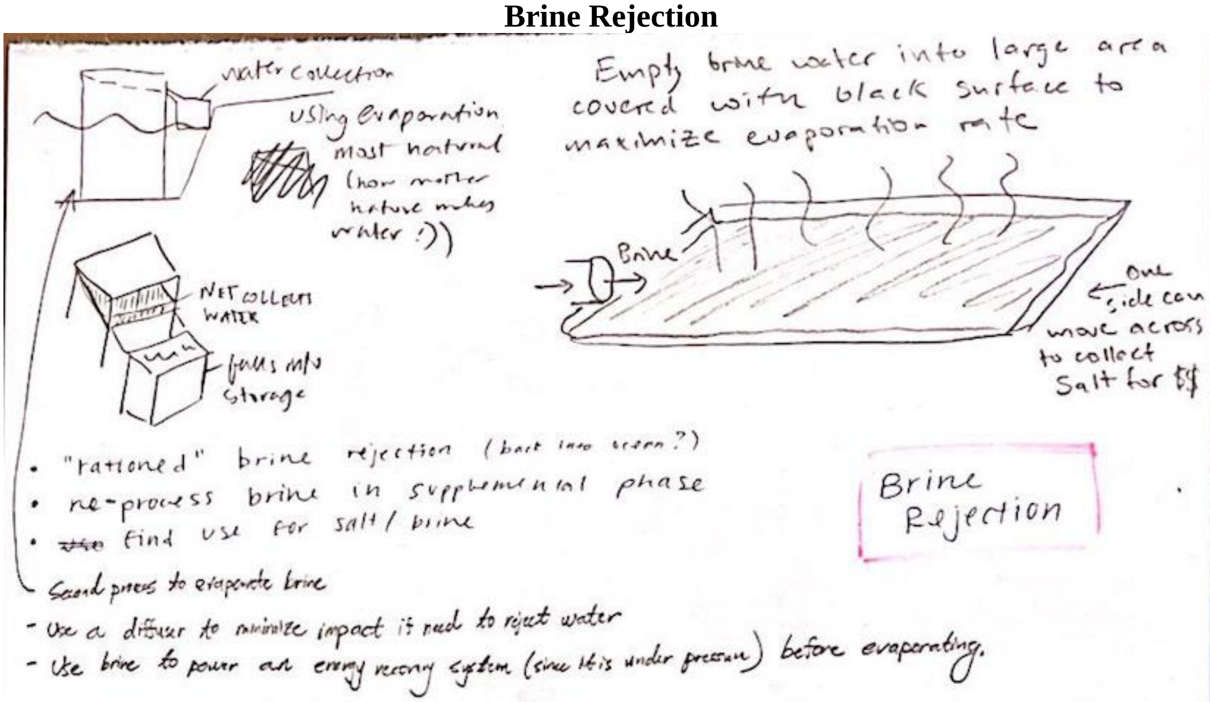








Brine Rejection

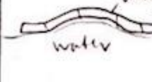


MECH ENERGY GENERATION

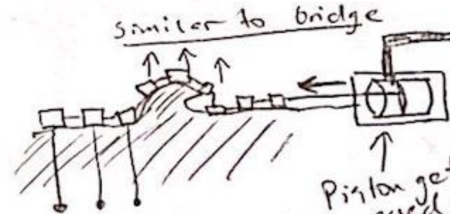
- hydraulic pump
- differential pressure
- rotational → translational motion → oscillations
- gears
  - ↳ gear ratio
    - ↳ power (mechanical pwr) amplifier

induction (we have other sensor projects to build off of)

- repetitive motion
- water motor
- Buoy / point absorber for motion
- Channels and turbines attached to hydraulic pump
- Create suction
- Use water pressure (Potrogh)
- "bridge" but modified has points that when they move create energy



Similar to bridge



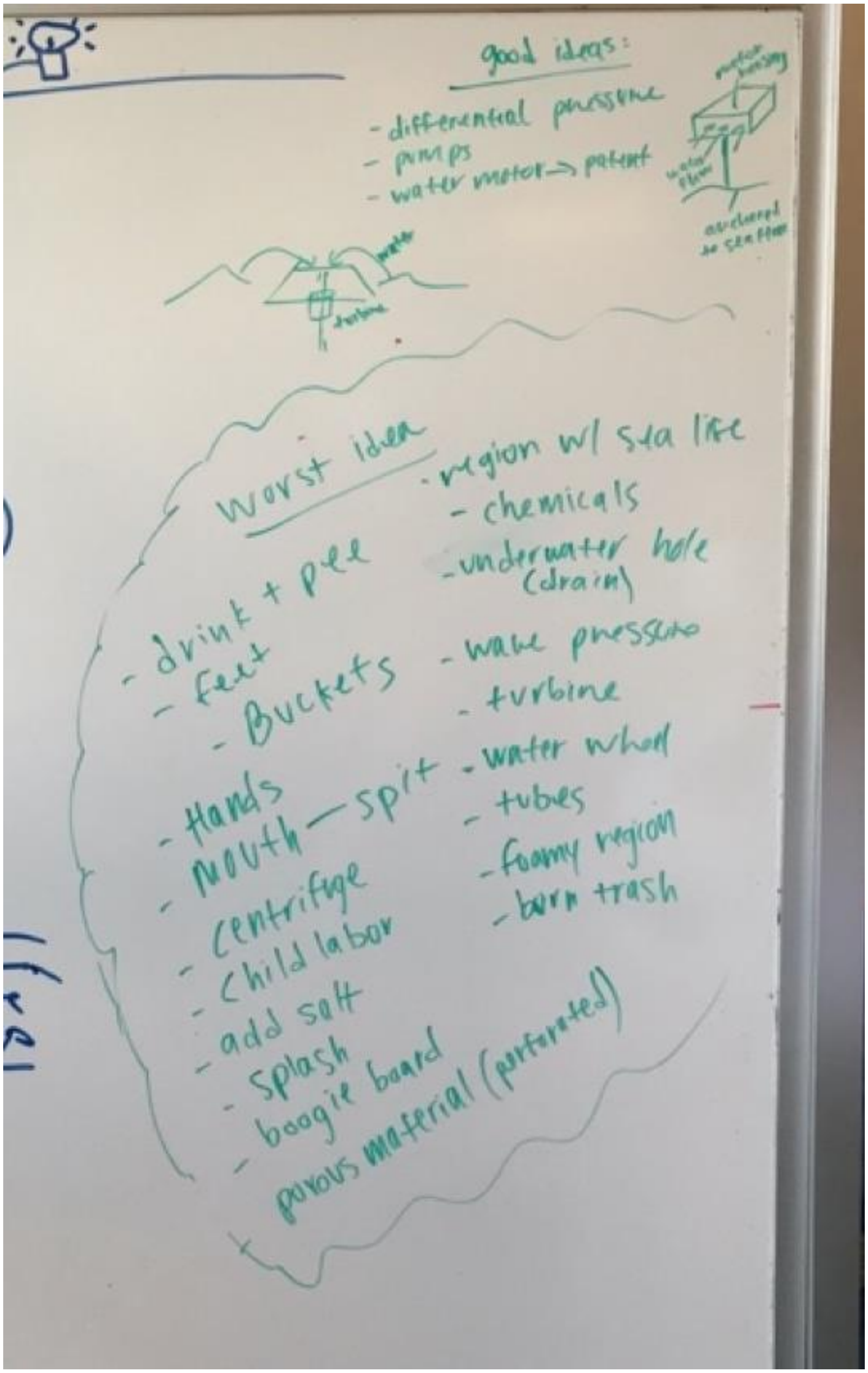
Piston gets compressed with tension on cord - pressure used to pump air or water

Bonus!

- Siphons - if used correctly, no required power input except for priming the siphon using suction
  - Use ocean wave powered pump for priming
  - Level of ocean water must be higher than collection tanks
- Locating portion of desalination plant underground?
  - Better for siphons :) ← can have water collection part underground
- sea life considerations
  - "fish" filters
  - attach system to the pier
  - floating not submerged device
- moveable components?
  - ↳ need to transport system? (small-scale)
- wind-aided power (not just wave power)
  - (or solar
- Control system if necessary to automate
- Noncorrosive Materials
- Diffuser if necessary

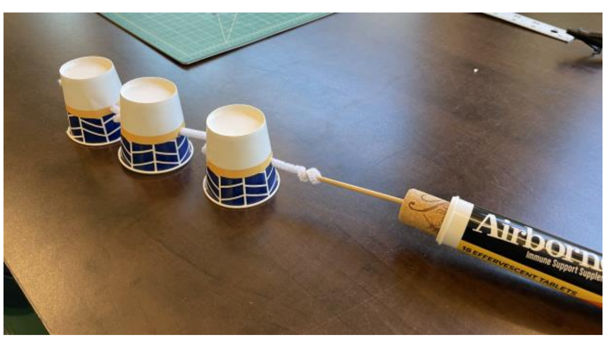
- pump pushes water through filter
- mechatronics to initiate some sort of switch?

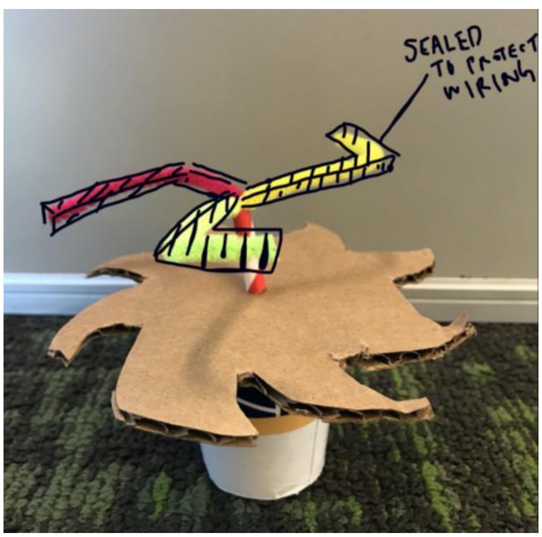
i.e.

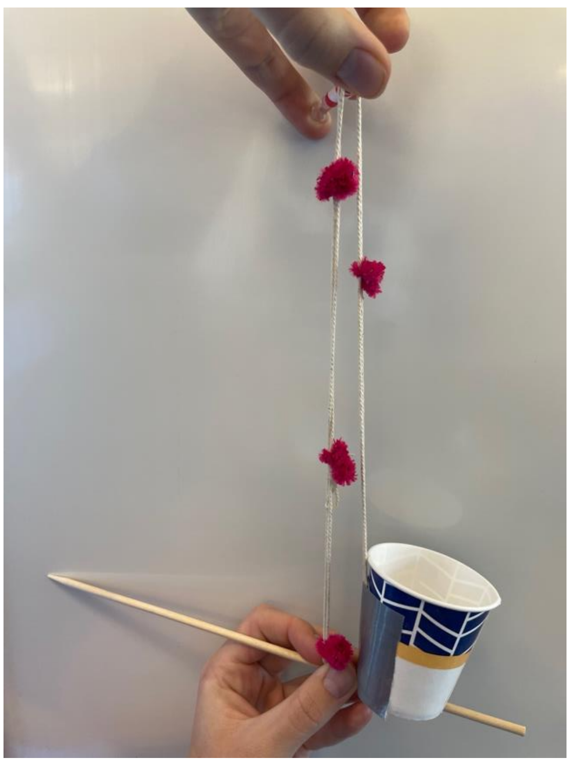

good ideas:
- differential pressure
- pumps
- water motor → patent
anchored to sea floor
worst idea
- drink + pee
- Feet
- Buckets
- Hands
- Mouth — spit
- centrifuge
- child labor
- add salt
- splash
- boogie board
- porous material (perforated)
- region w/ sea life
- chemicals
- underwater hole (drain)
- wave pressure
- turbine
- water wheel
- tubes
- foamy region
- burn trash

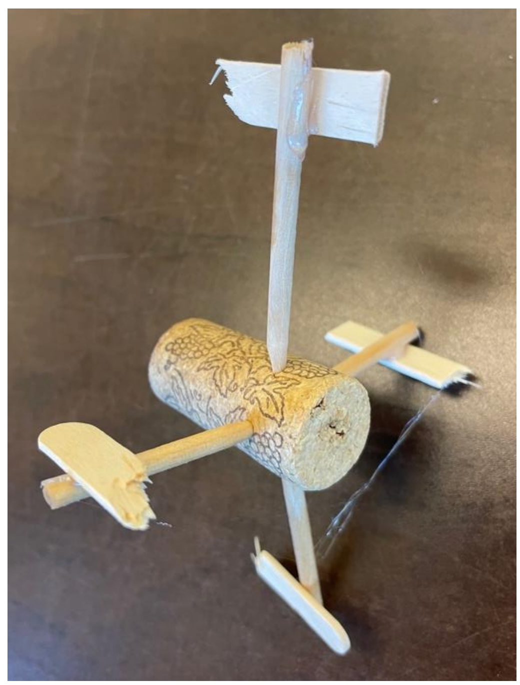
Appendix B: Ideation Model Pictures

When undergoing ideation with 3-D prototyping, water in buckets was brought, which allowed us to quickly create and evaluate concepts. During this process, we found many concepts were too unstable when floating in water or would become saturated with water and sink.




SEALED
TO PROTECT
WIRING





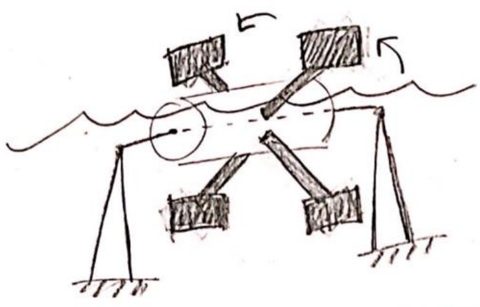
Appendix C: Pugh Matrices

Function: Generate wave energy

Concept Sketches

Function: Generate wave energy

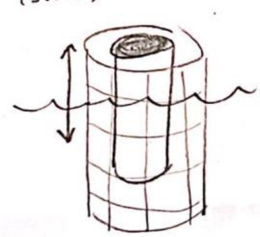
① Wheel / paddle:



function description:

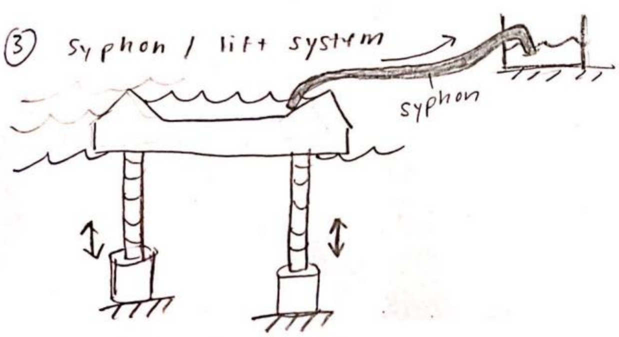
- Waves push paddles
- Paddles attached to arms attached to rotating body
- "body" is centerpiece which rotates along rod
- rod must be stable
- rod anchored to bottom of ocean (sea floor)
  - ↳ shallow water application
- rotation generates energy?
  - ↳ induces current → electrical

② buoy w/ cage:
(Solie)



- cage restricts buoy motion to vertical
  - ↳ cage needs to be anchored somehow?
- need to attach buoy to main sys. to transfer energy
  - ↳ sensor on top that measures displacement
  - ↳ lever arm to hydraulic pump

③ Syphon / lift system



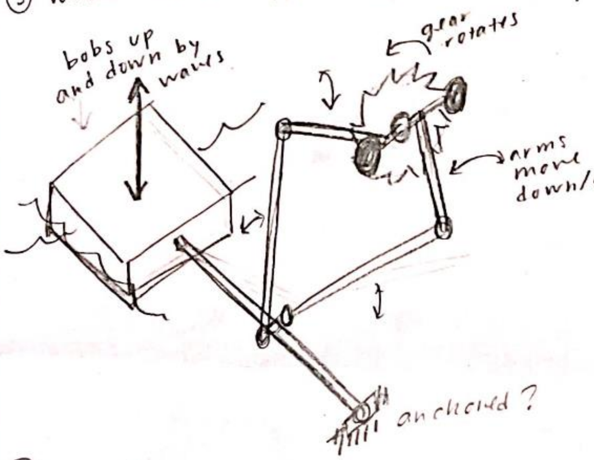
(charlie)

- syphon from low to higher elevation
- needs to be two bodies of water for water to move thru syphon
- notches on legs so waves push it up & locks
- needs a way to be moved back down... sensor / timer?
- legs anchored to bottom
- maybe 1 leg so both go up at the same time
  - ↳ or rod connecting legs

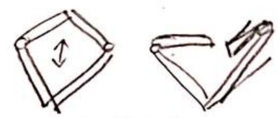
④ Buoy / spinning apparatus (patent)

- center rod anchored to ocean floor
  - ↳ shallow water application
- rod rotates
  - ↳ generates energy
  - ↳ don't have to worry about stiffness... (ish) moves w/ ocean waves
- arms attached to center rod
- bobbing devices hang from rods
  - ↳ vertical motion generates energy which goes back to center rod
- electricity ...

⑤ wave motor: (youtube)



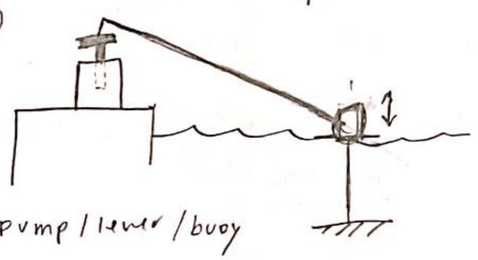
- bobbing device attached to lever arms
- arms :



like car adjuster?

- set of gears that rotate
- connect to transmission to convert to mechanical work

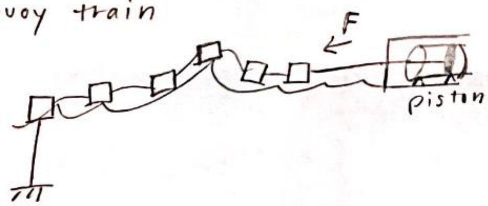
⑥



★pump / lever / buoy

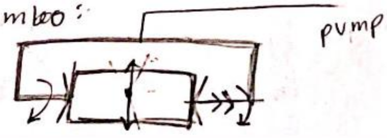
- bobbing device attached to lever arm
- anchored to bottom to keep in place (maintain vertical motion)
- bobbing motion moves lever arm and pushes hydraulic pump up and down

⑦ buoy train



- buoys attached by cord
- piston to push / pull ⇒ pressure turns to work
- front buoy anchored

⑧ combo:



- combo of ①, ②, ⑥
- rotating cylinder generating energy ... rotating wave
- power thru rotational motion to cords → translational w/ pump

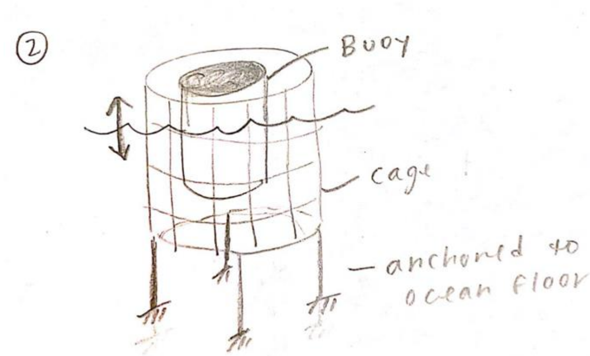
ME 428 : Pugh Matrix

concept / criteria	1	2	3	4	5	DATUM 6	7	combo 8	9	10
cost to build	−	−	−	−	−	D	S	−		
environ-mentally impact	−	S	−	S	−		−	−		
estimated efficiency	+	S	−	S	−	A	S	+		
maintan-ence	−	−	−	−	−		S	−		
estimated consistency of energy generation	−	S	−	−	−	T	S	+		
proximity of shore	−	−	S	S	−		S	S		
current research	−	S	S	−	−	U	S	−		
Σ+	1	0	0	0	0		0	1		
Σ−	6	3	5	4	7	M	1	3		
ΣS	0	4	2	3	0		6	3		
	X	↓			X	↓	↓	↓		
	-6	-3	-5	-4	-7	0	-1	-3		

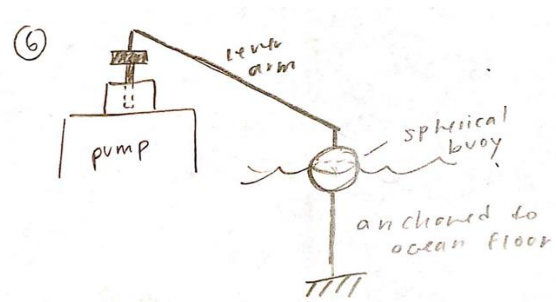
+ = better than

− = worse than

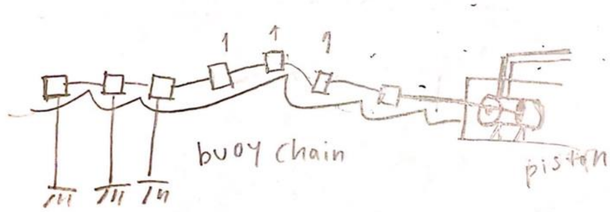
S = same



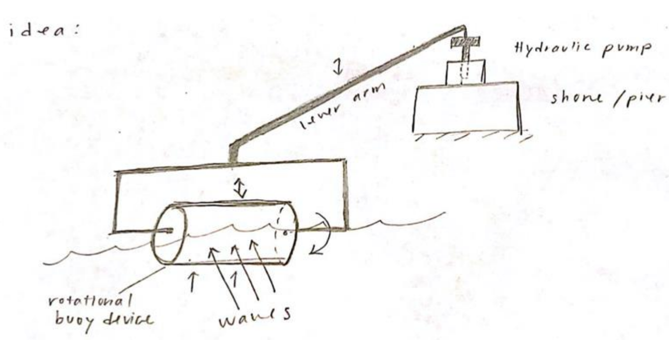
2. The device is a buoy with a cage surrounding it so that the buoy stays in place and has controlled vertical motion. The cage will be anchored to the ocean floor with cords or chains so that it can stay in place and it will allow the waves to pass through. The buoy will bob up and down in the water and have an attachment to return the wave energy to mechanical energy. This attachment could lead to a pump or other apparatus to convert energy.



6. This system has a buoy and pump to convert the bobbing motion from the waves to differential pressure through the pump. A lever arm attaches the buoy to the pump. The buoy is spherical so it can float easier and not have sharp edges to minimize environmental harm and enhance aesthetics. The buoy must be anchored to the ocean floor so it doesn't float around too much and can restrict the motion to just vertical to make it more efficient.

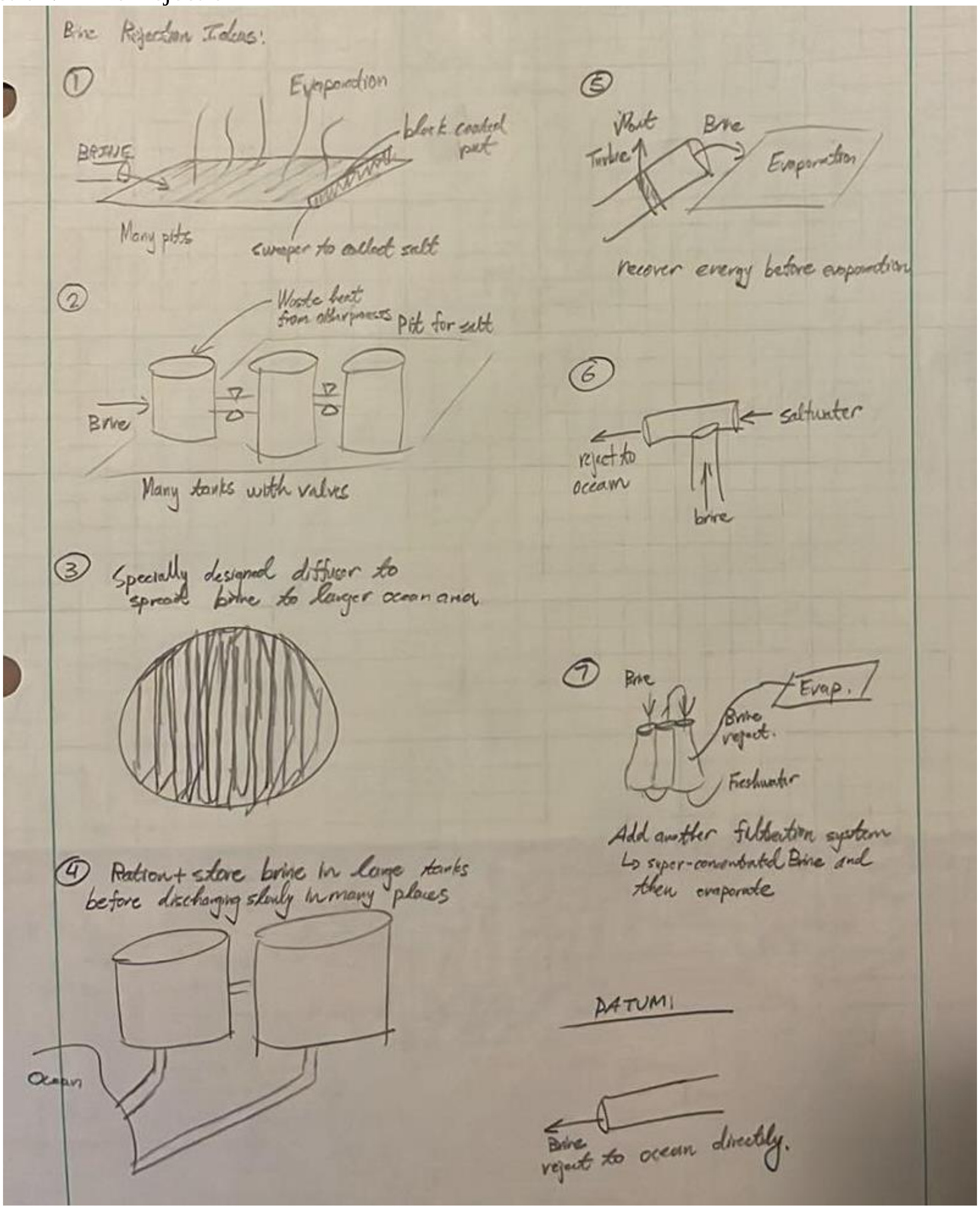


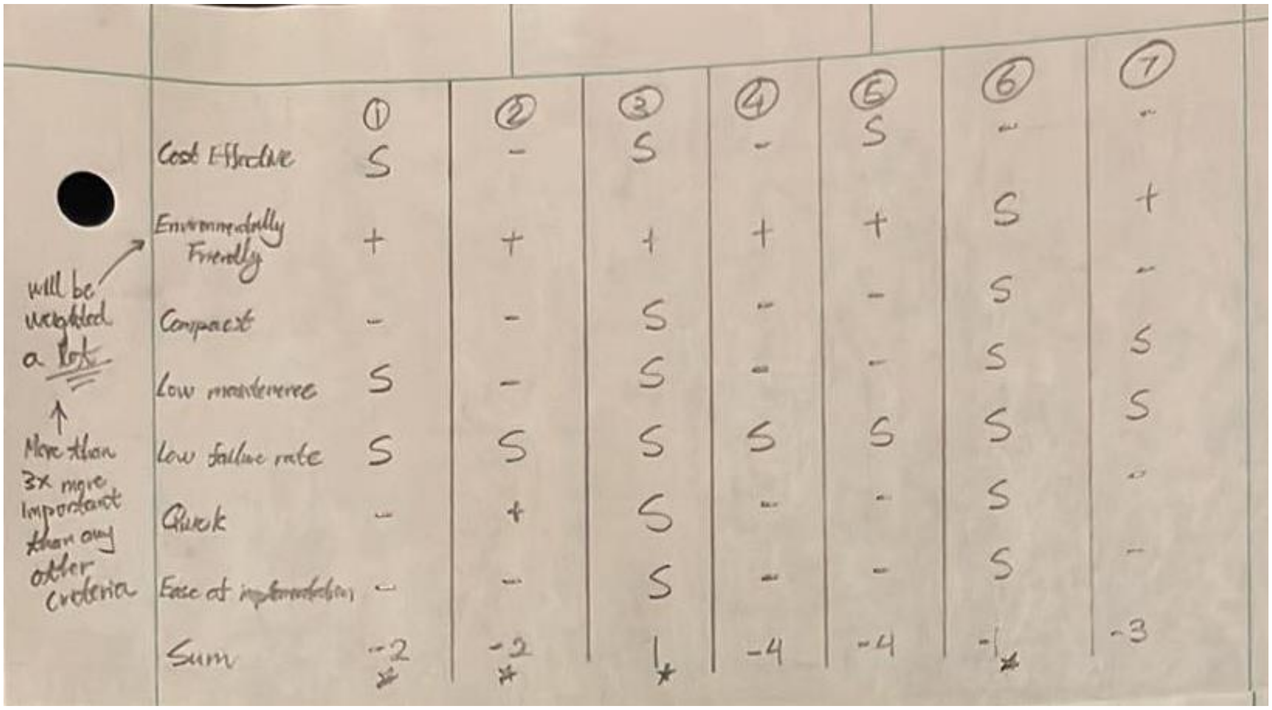
7. The apparatus is a buoy chain connected to a piston. The buoys move up and down with the waves created tension in the cord. The piston gets compressed with the tension from the cord and the pressure is used to pump air or water to generate energy. The front buoys are anchored to the ocean floor to restrict the movement of the chain so it doesn't float around.



8. This is a combination of multiple ideas, like 2 and 6, which take positive aspects of each and put them together. The floatation component is a rotational buoy which can also move up and down. The waves turn over the buoy and lift it up and down. The rotational motion can go through the center rod through the buoy and back to the main system to generate energy. The translational (up and down) motion will move the lever arm which presses the pump handle up and down which is another source of energy generation.

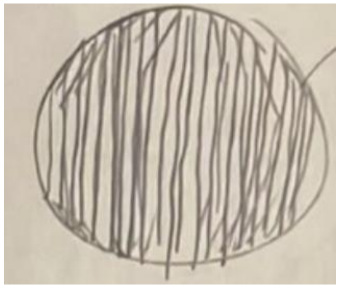
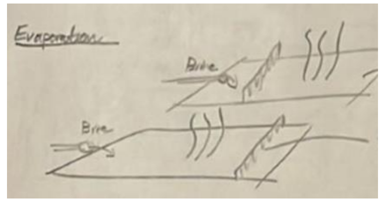
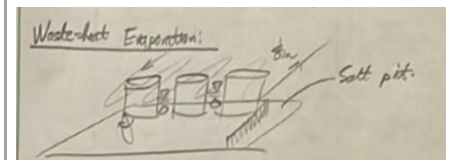
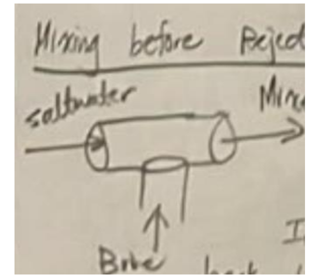
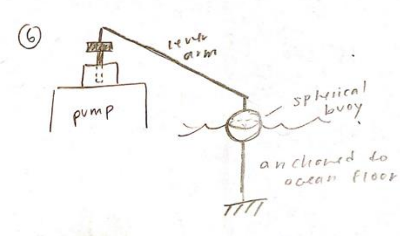
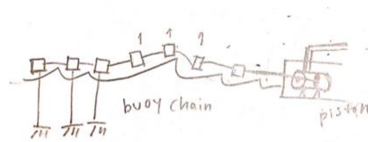
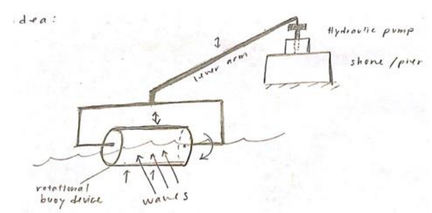
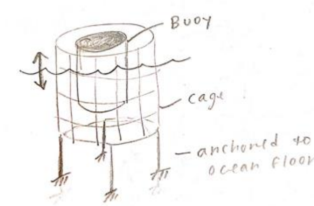
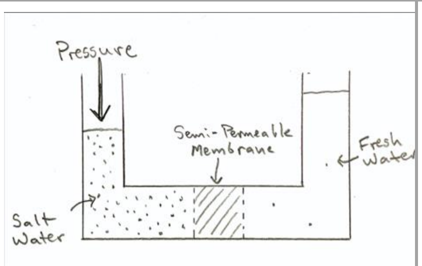
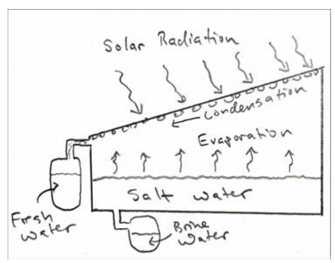
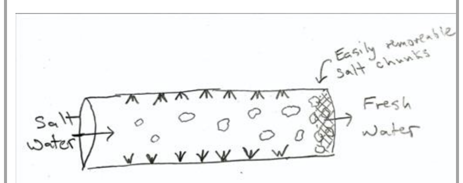
Function: Brine Rejection



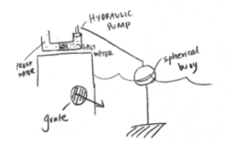
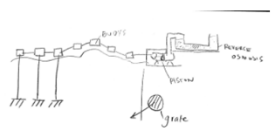
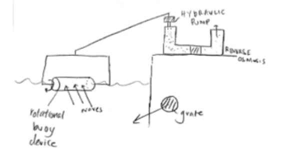


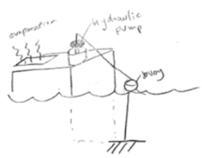
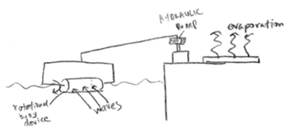
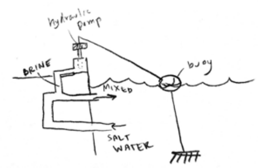
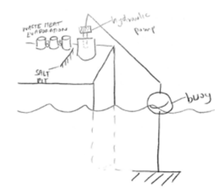
	①	②	③	④	⑤	⑥	⑦
Cost Effective	S	-	S	-	S	-	-
Environmentally Friendly	+	+	+	+	+	S	+
Compact	-	-	S	-	-	S	-
Low maintenance	S	-	S	-	-	S	S
Low failure rate	S	S	S	S	S	S	S
Quick	-	+	S	-	-	S	-
Ease of implementation	-	-	S	-	-	S	-
Sum	-2 *	-2 *	1 *	-4	-4	-1 *	-3

Appendix D: Morphological Matrix

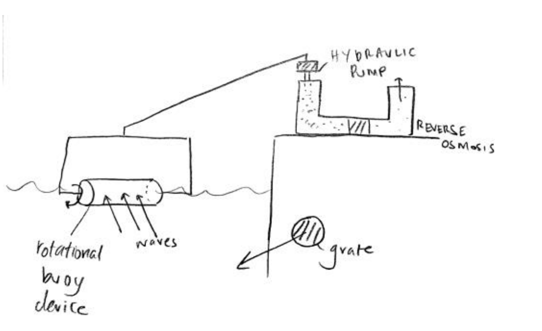
Functions	Ideas			
Brine Processing	 Diffuser/Grate, B1	 B2	 B3	 B4
Wave Energy Generation	 W1	 W2	 W3	 W4
Desalination	 Reverse Osmosis D1	 Evaporation D2	 Crystallization D3	
Energy conversion	Hydraulic Pump E1	Piston E2	Gear/transmission E3	

Appendix E: Weighted Decision Matrix

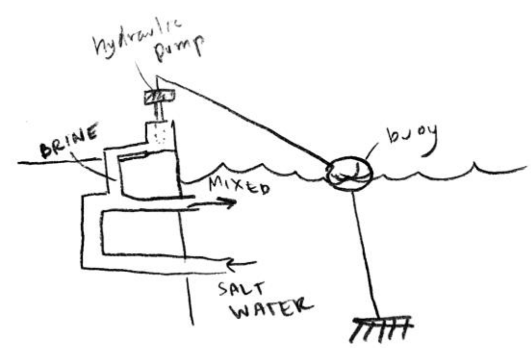
		 1111		 1212		 1311	
Criteria	Weighting	Score	Total	Score	Total	Score	Total
Cost to Build	5	4	20	3	15	3	15
Environmental Impact	4	2	8	2	8	1	4
Estimated Efficiency	3	4	12	3	9	5	15
Maintenance	3	4	12	4	12	2	6
Estimated Consistency	4	3	12	4	16	5	20
Proximity to Shore	2	4	8	4	8	4	8
Current R&D	2	4	8	3	6	2	4
SUM			80		74		72

 2111		 2311		 4111		 3111	
Score	Total	Score	Total	Score	Total	Score	Total
2	10	1	5	3	15	2	10
5	20	5	20	1	4	5	20
2	6	4	12	4	12	4	12
3	9	2	6	4	12	2	6
3	12	5	20	3	12	3	12
5	10	4	8	5	10	5	10
3	6	2	4	4	8	3	6
	73		75		73		76

Alternative designs:



1212

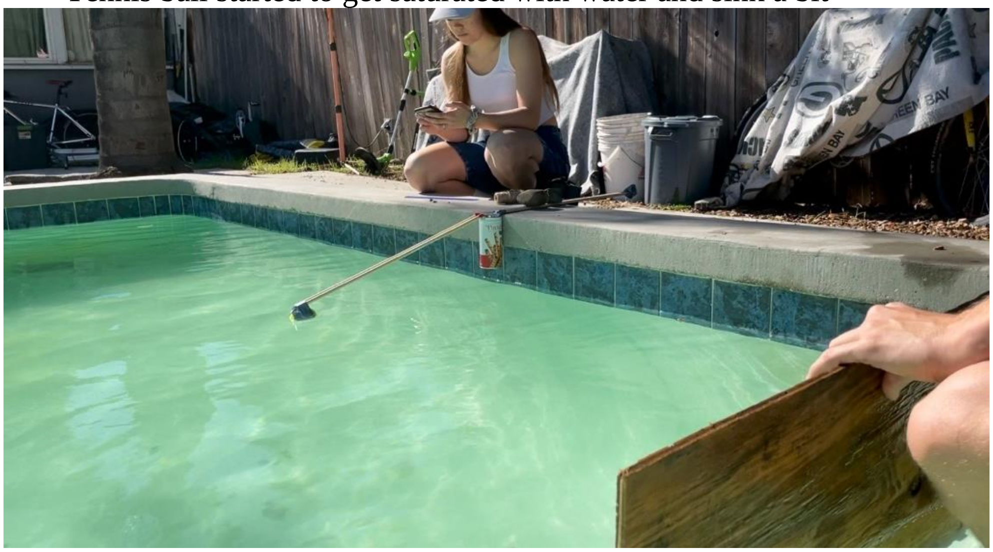


4111

Appendix F: Testing Details

Test 1: bottom of can located 7.75" from pool edge

- Tennis ball
    - Moved lever arm a good amount so function works
    - Refracted waves seem to have good effect on bobbing
    - Bigger size (larger area) of buoy leads to increased force
    - Tennis ball started to get saturated with water and sink a bit



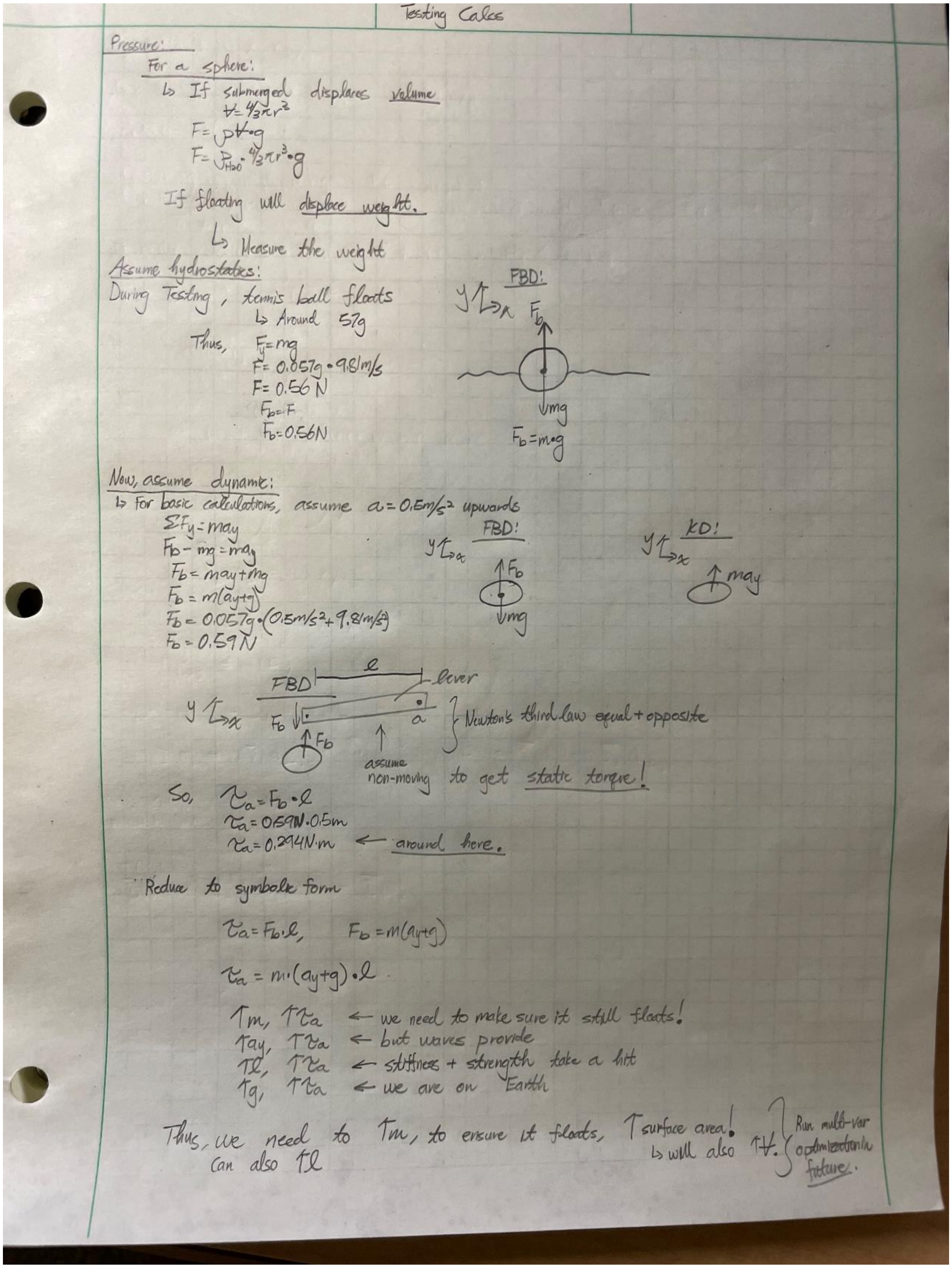
- Ping pong ball
    - Did not move lever arm very much
    - Small size didn't have great effect on bobbing
    - Ball is not well attached to lever arm
        - Buoy is in line with lever arm… should be below to be point absorber like tennis ball set up

Test 2: move pump lower (closer to water surface)
Test to see how pump height would effect motion

- Tennis ball
    - Still good motion
    - Lever arm moving to nearly horizontal position
    - Buoy below lever arm is better than in-line with lever arm

- Ping pong ball
    - Water is moving lever arm more than buoy
    - Better bobbing and vertical motion (compared to test 1)
    - Buoy is nearly submerged by waves
        - And part of lever arm connected to buoy

Appendix G: Preliminary Analysis


Testing Calcs

Pressure:

For a sphere:

↳ If submerged displaces volume

$\forall = \frac{4}{3}\pi r^3$

$F = \rho \forall \cdot g$

$F = \rho_{H_2O} \cdot \frac{4}{3}\pi r^3 \cdot g$

If floating will displace weight.

↳ Measure the weight

Assume hydrostatics:

During Testing, tennis ball floats

↳ Around 57g

Thus, $F_y = mg$

$F = 0.057g \cdot 9.81 m/s$

$F = 0.56\ N$

$F_b = F$

$F_b = 0.56N$

Now, assume dynamic:

↳ For basic calculations, assume $a = 0.5 m/s^2$ upwards

$\Sigma F_y = ma_y$

$F_b - mg = ma_y$

$F_b = ma_y + mg$

$F_b = m(a_y + g)$

$F_b = 0.057g \cdot (0.5 m/s^2 + 9.81 m/s^2)$

$F_b = 0.59\ N$

So, $\tau_a = F_b \cdot \ell$

$\tau_a = 0.59N \cdot 0.5m$

$\tau_a = 0.294 N \cdot m$ ← around here.

Reduce to symbolic form

$\tau_a = F_b \cdot \ell, \quad F_b = m(a_y + g)$

$\tau_a = m \cdot (a_y + g) \cdot \ell$

$\uparrow m, \uparrow \tau_a$ ← we need to make sure it still floats!

$\uparrow a_y, \uparrow \tau_a$ ← but waves provide

$\uparrow \ell, \uparrow \tau_a$ ← stiffness + strength take a hit

$\uparrow g, \uparrow \tau_a$ ← we are on Earth

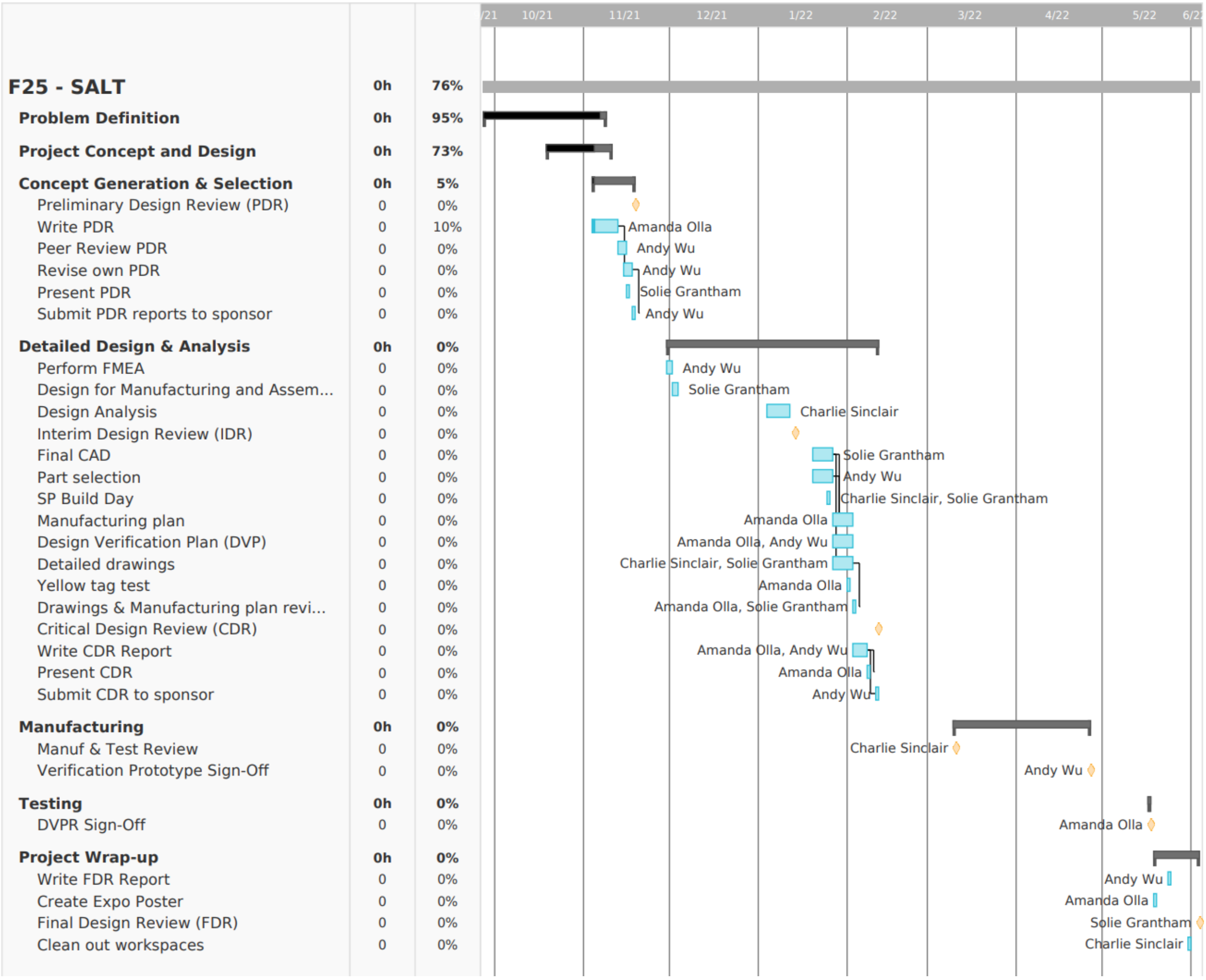
Thus, we need to $\uparrow m$, to ensure it floats, $\uparrow$ surface area! can also $\uparrow \ell$

↳ will also $\uparrow \forall$. } Run multi-var optimization in future.

Appendix H: Design Hazard Checklist

Y	N	
×		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
×		2. Can any part of the design undergo high accelerations/decelerations?
×		3. Will the system have any large moving masses or large forces?
	×	4. Will the system produce a projectile?
	×	5. Would it be possible for the system to fall under gravity creating injury?
	×	6. Will a user be exposed to overhanging weights as part of the design?
	×	7. Will the system have any sharp edges?
	×	8. Will any part of the electrical systems not be grounded?
	×	9. Will there be any large batteries or electrical voltage in the system above 40 V?
×		10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	×	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	×	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	×	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	×	14. Can the system generate high levels of noise?
×		15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
	×	16. Is it possible for the system to be used in an unsafe manner?

Appendix I: Team Gantt Chart



Task	Hours	% Complete
F25 - SALT	**0h**	**76%**
Problem Definition	**0h**	**95%**
Project Concept and Design	**0h**	**73%**
Concept Generation & Selection	**0h**	**5%**
Preliminary Design Review (PDR)	0	0%
Write PDR	0	10%
Peer Review PDR	0	0%
Revise own PDR	0	0%
Present PDR	0	0%
Submit PDR reports to sponsor	0	0%
Detailed Design & Analysis	**0h**	**0%**
Perform FMEA	0	0%
Design for Manufacturing and Assem...	0	0%
Design Analysis	0	0%
Interim Design Review (IDR)	0	0%
Final CAD	0	0%
Part selection	0	0%
SP Build Day	0	0%
Manufacturing plan	0	0%
Design Verification Plan (DVP)	0	0%
Detailed drawings	0	0%
Yellow tag test	0	0%
Drawings & Manufacturing plan revi...	0	0%
Critical Design Review (CDR)	0	0%
Write CDR Report	0	0%
Present CDR	0	0%
Submit CDR to sponsor	0	0%
Manufacturing	**0h**	**0%**
Manuf & Test Review	0	0%
Verification Prototype Sign-Off	0	0%
Testing	**0h**	**0%**
DVPR Sign-Off	0	0%
Project Wrap-up	**0h**	**0%**
Write FDR Report	0	0%
Create Expo Poster	0	0%
Final Design Review (FDR)	0	0%
Clean out workspaces	0	0%

WAVE GOODBYE TO SALT
Critical Design Review

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Sponsor
Dr. Peter Schuster

Mechanical Engineering Department
California Polytechnic State University
San Luis Obispo

Winter 2022

Abstract

According to the World Health Organization, one in three people globally do not have access to safe drinking water. The ocean is a seemingly endless volume of water, but the process of removing salt and other particulates from sea water has proven to be difficult. An efficient and environmentally friendly ocean water desalination process could be the solution to widespread water shortages. Current ocean water desalination plants are known to be highly expensive to construct and operate, as well as damaging to local aquatic ecosystems through sea water intake and brine byproduct expulsion. Considering these challenges, we seek to develop a desalination unit powered primarily by ocean waves to reduce energy costs and therefore the environmental impact of emissions from traditional power plants. A description of the detailed analysis and design is illustrated. Through that process, force analysis and structures calculations were done to size the lever arm and calculate the range of motion of the lever arm. These calculations will help ensure that the lever arm is sized properly for the maximum loading condition the system will experience in the ocean. Furthermore, the force analysis completed will ensure that the hydraulic pump arm will move sufficiently when it is disturbed by a three-foot wave. In order to reduce the likelihood of a high-risk specification failing, a structural prototype was created to ensure that it could be built successfully, with testing planned to find the optimal lever arm length by the end of the quarter.

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1 Introduction

We are a team of mechanical engineers at California Polytechnic State University seeking an innovative way to integrate renewable ocean wave energy into ocean water desalination processes for our senior design project. Our sponsor, Dr. Peter Schuster, is looking for a desalination system that will be powered solely by wave energy. The final objective will be to create a desalination system as a working proof-of-concept that is powered by wave energy.

Through the Preliminary Design Review (PDR), we evolved the project from idea generation to a working concept. The ideation process led to a large-scale generation of ideas which were evaluated in a controlled convergence process to select our final concept. We built a concept prototype and computer-aided design (CAD) model, along with preliminary test results and calculations. Our sponsor approved our design direction, leading into the next phase of our project of constructing a structural prototype, performing more analysis, and creating a working final CAD model.

Feedback from our sponsor and peers from PDR suggested that we investigate structural analysis of our design, specifically regarding the lever arm and its attachments to the buoy and hydraulic pump. These are key components in our design and with the force from waves and joints, we need to check for stiffness, yielding, and buckling. Additionally, we are holding off on testing our device in a stock tank with a wave generator because the buoy size has increased such that a stock tank testing set-up may be insufficient. We are also reconsidering an anchor or structure to restrict the motion of the lever arm and buoy to just up-and-down movement. The brine rejection function of our design has been deemed unnecessary in our design; therefore, we are neglecting that function from now on.

In this report we will describe our system design, explain analysis and calculations, provide manufacturing plans, and review upcoming deliverable dates. We will provide a final CAD model and structural prototype depicting our system design with corresponding descriptions of details and functions. Further testing and analysis have been done for structural analysis, determining forces and sizing and components, and physically testing the wave-energy generation component functionality on the structural prototype. Safety, maintenance, and other concerns will also be discussed. The manufacturing plans include an Indented Bill of Materials (iBOM) and describe how the components will be assembled. Additionally, the Design Verification Plan will provide an overview of our test plans.

2 System Design

The following section will provide the details of our design and explain how it will function.

2.1 Design Description

The system consists of a buoy connected to a lever arm which provides a torque on the pump handle to generate hydraulic pressure. The water goes through a reverse osmosis (RO) desalination system where the filtered water is separated from the brine, which is released back into the ocean. Due to the small-scale nature of this system, many of these devices will be employed, each releasing a small amount of brine in a separate location, which will help reduce the amount of salt concentration in one location. The initial system hand sketch is depicted in Figure 1.

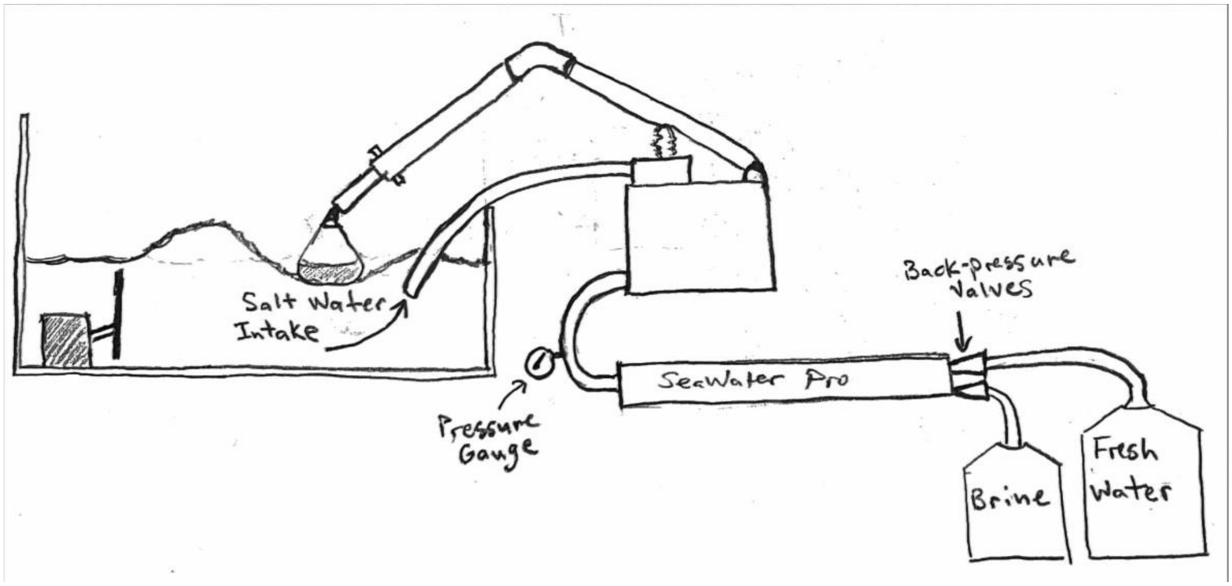

Figure 1. Schematic of Design Concept

The system is modeled in Solidworks to demonstrate the functionality of the design and ensure the appropriate dimensions. All the components including the buoy, lever arm, hydraulic pump, reverse osmosis system, and additional piping and connection components are included in the CAD model shown in Figure 2.

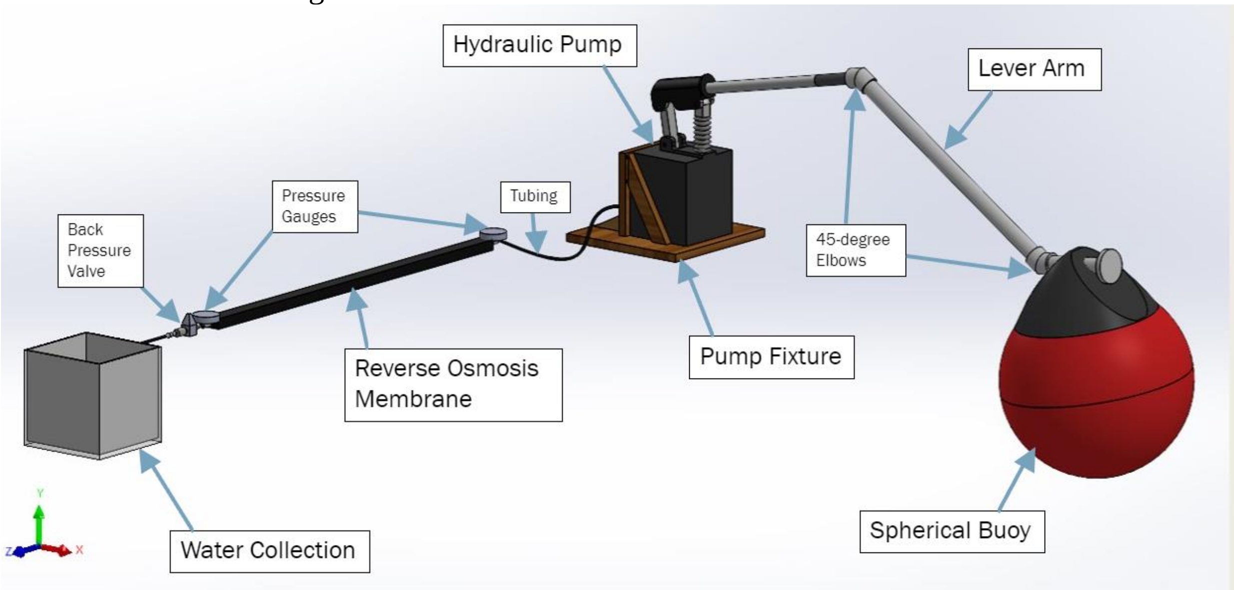

Figure 2. Annotated Isometric View of Final CAD Model

The buoy, hydraulic pump, and reverse osmosis components will be purchased, so the only part we are building and modifying is the pump fixture and lever arm.

The final design will be built as a benchtop display, and the entire size of the system, not including the lever arm and buoy, will not exceed that of a standard 2 ft by 4 ft table. In the current model, shown in Figure 2, the lever arm has a diameter of 1.5 in and the buoy has a diameter of 18 in. The length of the lever arm is currently 32 in, but this dimension will be solidified after further testing to determine the optimal length for the function.

See Appendix A for the final assembly detailed drawing with a corresponding bill of materials and specifications for the other system components in the Drawing & Specifications Package. Appendix B shows a larger version of the Indented Bill of Materials (iBOM).

2.2 Design Function

The purpose of the buoy and pump system is to convert the bobbing motion from the waves to a differential pressure through the pump. A lever arm is attached to the buoy and pump by a fixed connection at the pump handle and a fixed connection at the buoy, allowing for full vertical motion of the buoy as it floats in the waves. The buoy is spherical because the lack of sharp edges minimizes environmental harm while enhancing aesthetics.

The hydraulic pump converts linear harmonic motion into a differential pressure. In this case, the motion of the buoy causes the pump handle to move up and down, pushing the water from the pump inlet through the pump to the outlet, generating a pressure for the RO system. The hydraulic pump rests on a stationary surface, such as the ground or a pier. As seen in Figure 2, the CAD model is constructed with anchoring constraints in mind but does not explicitly include the objects the model is anchored to (i.e. pier or dock). The anchoring constraints include the pump fixture which will be anchored to the dock or pier with clamps. These constraints are necessary so that the pump doesn’t move around due to the motion from lever arm apparatus.

The reverse osmosis filtration system consists of a semipermeable membrane in a pipe system. Saline water is added to the inlet and forced through the membrane at high pressure, leaving fresh water at the outlet. These systems can contain multiple reverse osmosis filtration steps to further purify water. The excess brine is separated from the filtered water through a different pipe released into a separate collection container from the freshwater container.

2.3 Major Subsystems and Components

The final assembly is broken down into subassemblies corresponding to the system functions. These subassemblies are the wave energy generation subassembly, reverse osmosis, brine and freshwater collection, tubing, tube reducers, pipe fittings, pressure gauges, and sealant. Since many of these subassemblies only consist of one component that is purchased, the only sub-assembly that has many components is the wave energy generation assembly. Therefore, in the drawing and specification package, only the final assembly is shown.

The wave energy generation assembly includes the buoy, lever arm, hydraulic pump, and pump fixture. The buoy and hydraulic pump will be purchased and the lever arm and pump fixture will need to be constructed. The buoy purchased has a diameter of 18 in [1]. The hydraulic pump is double acting, has a 2.6 gallon tank, and is rated for 45 cm^3 flow rate [2]. This will ensure that we are getting enough flow rate and that we can meet the required pressure differential for the reverse osmosis membrane to function. The purchased components (buoy and pump) are shown in Figure 3.

Figure 3. Marine Buoy and Hydraulic Pump

The pump fixture will be a base to anchor the hydraulic pump to a pier, dock, or other stationary foundation. This component will be manufactured for the Verification Prototype after CDR. We plan to use wooden pieces including 2x4s and plywood to construct the fixture and attach it to the hydraulic pump with wooden screws or bolts. The prototype fixture will be made with wood as a cheaper solution for testing purposes, but the final design will be made with material that is suitable for water applications like steel. We couldn't construct this part for CDR because our pump has not arrived, and we needed it for proper sizing of the fixture. The CAD model with component labels for the pump fixture is shown in Figure 4.

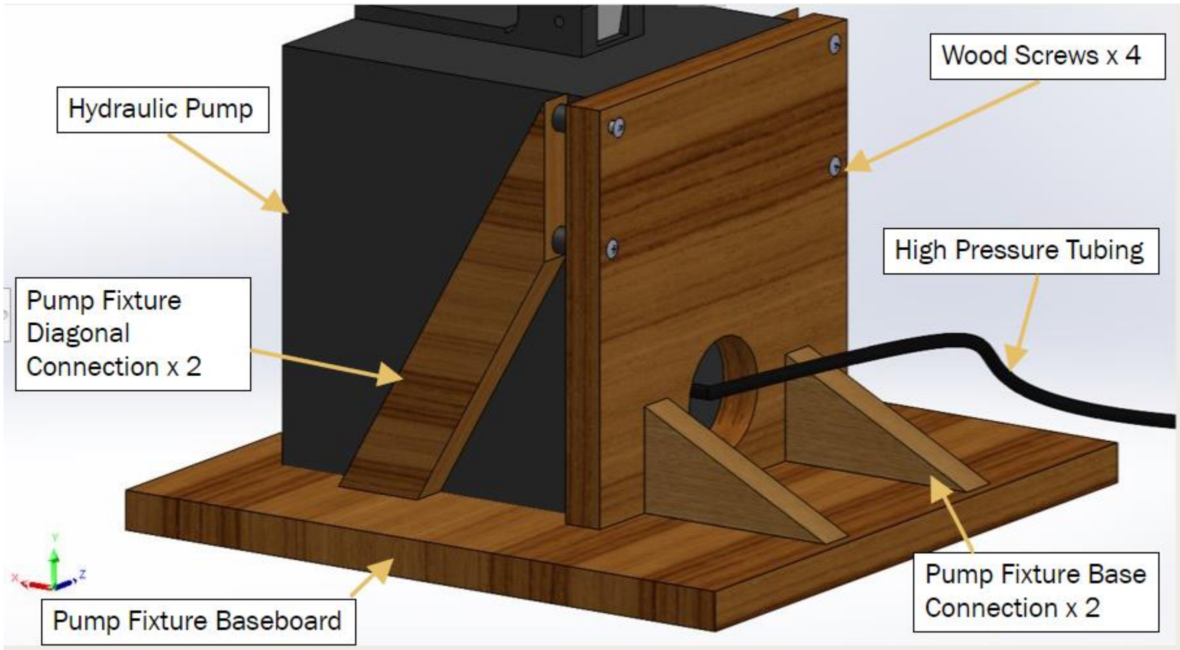

Figure 4. Annotated Model of Pump Fixture

There are many sizing and fitting differences between the parts in the tubing assembly and between the hydraulic pump and the collection containers. Figure 5 depicts the tubing, pipe fittings, and pressure gauge set up in our system.

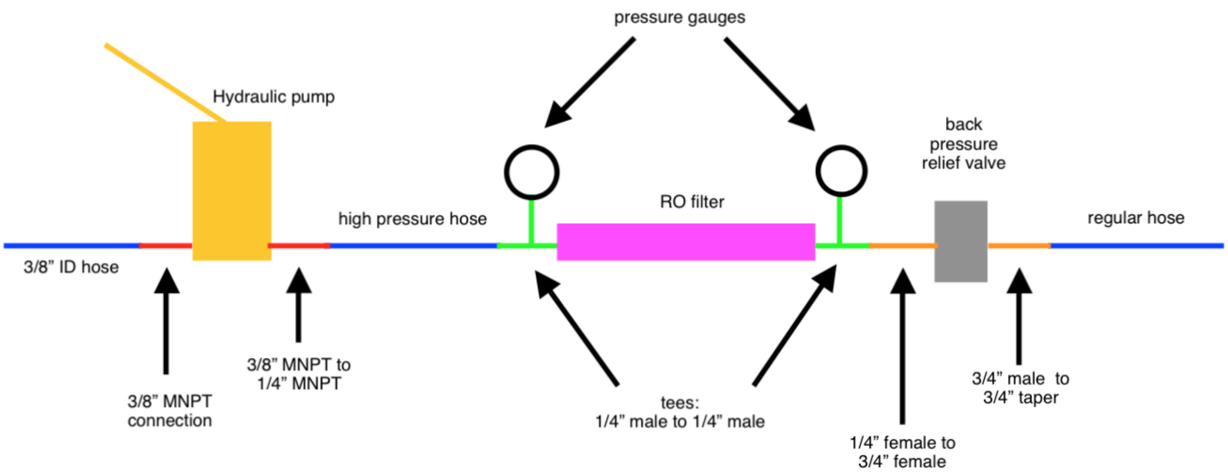

Figure 5. Tubing System Assembly

The tubing we need to get water from the ocean to the hydraulic pump then from the pump to the RO filter is braided steel hosing from Airgas [3]. It has ¼" NPT female attachments which will work with the pump that has NPT threading. See Figure 6 for an image of the product we plan to purchase for the tubing.

Figure 6. Braided Steel Tubing with ¼" NPT Female Attachments

We will need to purchase tube reducers as well to fit the diameters at each connection. These reducers are a 3/8" NPT to 1/4" NPT and ¼" NPT to ¾" NPT; both will be purchased from Amazon.com [4] [5]. Pipe fittings will also be purchased; an NPT to JIC connector and ¾" Barb connector from Hydraulics Direct and Amazon, respectively [6], [7].

The reverse osmosis assembly consists of a purchased RO filter from SeaWater Pro and a back pressure valve. The filter membrane is 40 in in length and the bursting (maximum) pressure is 5000 psi. Figure 7 provides a picture of the RO filter from SeaWater Pro's website [8].

Figure 7. SeaWater Pro RO Filter Membrane

The RO filter requires a pressure differential of 55-69 psi from the hydraulic pump and the pressure drop throughout the membrane cannot exceed 15 psi. Pressure gauges are from Toolots and will be used to inspect the pressure throughout the system, specifically in the RO filter since there is a restriction per the manufacturer [9]. If the pressure drop is greater than the value recommended, the membrane of the filter will rupture and not work properly for long-term applications. Furthermore, the pressure gauges will allow for efficient debugging of the system during the testing phase to see what pressures the water is being pumped at.

The back pressure valve is imperative to the system to ensure the pressure drop is not exceeded by regulating the water pressure released.   The back pressure valve, as shown in Figure 8, is a high-pressure relief valve from Bailey Hydraulics and is rated for a flow rate of 20 gpm and is adjustable for 1000-2500 psi [10].

Figure 8. High Pressure Relief Valve

The brine and freshwater collection assembly consists of collection containers; one container for brine and one container for fresh water. The containers will be clear with volumetric measurement markings so we can evaluate the amount of fluid being released from the system. These will be purchased from Home Depot [11].

We are also purchasing polymer tape from Home Depot as a sealant to reduce leakage in our system because there are multiple connection points where leakage could occur.

See Appendix B for the Indented Bill of Materials (iBOM) that includes all the assembly components described.

2.4 Summary Cost Breakdown

We received $2000 for our prototype from the Baker Koob grant which we plan on spending about half on our structural and verification prototypes and the remaining funds will be spent on making alterations and finalizing our prototype.

All the assembly components described in Section 2.3 and in the iBOM are included in the Project Budget. The main items we are purchasing are the buoy, lever arm materials, hydraulic pump, RO system, tubing, pressure gauges, seals and fittings, and corrosion resistant spray. The total cost of these items is $1100, which leaves $890 left to spend on improving our prototype by making changes and buying better materials after analysis and testing. Other potential items to be purchased are a flowmeter, water tank, and wave generator for prototype testing purposes.

Table 1 shows a condensed version of the project budget including the major components and their corresponding prices.

Table 1. Condensed Project Budget

Components	Price
Buoy	$67.12
Hydraulic Pump	$619.00
Pressure Gauges (2)	$10.78
Seals/Fittings	$50.81
Corrosion Resistant	$53.61
Total Cost	$1110.26
Remaining Funds	$890

See Appendix C for the Project Budget with specific costs for each item, including the costs of the smaller components.

3 Supporting Analyses

The following section provides evidence that our design will meet all specifications outlined by the PDR and Statement of Work (SOW) through engineering analyses and similarity to existing designs.

3.1 Structural Prototype

The structural prototype models the wave energy generation component of our system as seen in Figure 9. The wave energy generation component consists of an 18in marine buoy, PVC adjustable lever arm, 1/2in PVC rod and "stopper" (3-way PVC elbow) to secure buoy, and PVC elbow connections (one 45-degree with 1/2in to 1/2in diameters elbow and one 90-degree 1in to 1/2in elbow). This sub-system is the most crucial component of the whole system, as it will take the wave mechanical energy and convert it to a differential pressure. Since few people in the world have done this before, we are the most uncertain about this sub-system. Therefore, it is good to build a model of this system early in order to start testing as soon as possible, giving us time to debug and improve this subsystem.

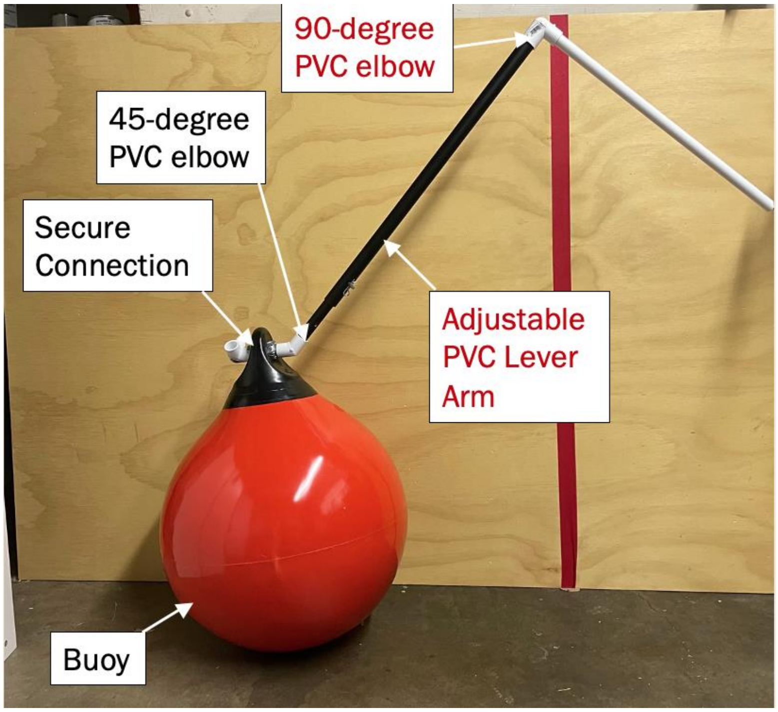

Figure 9. Structural Prototype

The lever arm has two concentric rods; the outer rod has a single hole and the inner rod has multiple holes spaced 2 in apart. The two rods are held together by a clevis pin. The lever arm is adjustable for testing purposes so we can determine the optimal length the lever arm needs to extend to extract wave energy for the final prototype. Figure 10 shows the lever arm for structural prototype which is made of PVC.

Figure 10. Structural Prototype Lever Arm

The next iteration of our structural prototype will have a lever arm with a defined length made of different material that meets our structural needs (see Section 3.2.3 for Structural Analysis) and is non-corrosive. We will likely need to add other support components to prevent deflections of the lever arm. Additionally, the updated prototype will have 45-degree stainless steel elbows rather than the current PVC ones. Due to purchasing delays, we were not able to assemble or test our full system which includes the hydraulic pump, reverse osmosis system, and other connection components described in Section 2.3.

3.2 Specifications

The specifications and corresponding parameters are listed in Table 2. These parameters ensure that our design will generate enough fresh water, stay within a budget, and satisfy environmental guidelines.

Table 2. Engineering Specifications Table

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk*	Compliance**
1	Power generated by waves	Power required to generate 55-69 bars	+/- 1 bars	H	A,T
2	Size	2ft x 4ft	Max	M	I
3	Cost	$2000	Max	M	S
4	Materials	Non-Corrosive and Water-tight	Set	M	I,A
5	Codes/Standards	Meets EPA codes	Set	M	I
6	Vol. Flowrate	1 gal/hr	Min	H	A,T
7	Operation Noise	Below 85 dB	Max	L	T
8	Water Quality	7 pH	+/- 0.7	L	T

*Risk of meeting specification: (H) High, (M) Medium, (L) Low
**Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

1. Power generated by the waves must be able to create a differential pressure of 55-69 bars. Too much pressure will rupture the membrane, and if there is too little pressure, no desalination will take place.
2. The size of the whole system must be less than 2ft by 4ft, which is around the size of a tabletop (excluding buoy and lever arm).
3. The cost of the prototype must be less than 2000 dollars.
4. Materials used to create the systems must be non-corrosive and water-tight (for systems containing fluids).
5. In order to be legal, the device must meet EPA standards for long term use in the future.
6. The volumetric flowrate of the system must be greater than or equal to 1 gallon per hour, which will be tested by timing the system.
7. The operation of the system must be less than 85dB, which can be tested with a sound meter.
8. The water quality must be between a pH of 6.3 and 7.7 and will be tested with Litmus paper. Salinity strips will also be used.

3.3 Justification for Meeting the Specifications

In order to justify that the design will meet the required specifications, engineering analysis and similarity to existing designs will be used. In this section, each subsection corresponds to an engineering specification, conveniently listed in the order it was presented in Table 2.

3.3.1 Specification #1-Differential Pressure Requirement

From the specification sheet, we found out that the membrane functions optimally at around 68 bars of pressure. After contacting the pump manufacturer and obtaining pump curves, it was determined that the hydraulic pump will meet this specification. In particular, the manufacturer explained that a hydraulic pump functions by varying the flowrate of the liquid, keeping the required pressure constant. The pressure required is determined by the reverse osmosis membrane. If the membrane requires 68 bars of pressure to function optimally, the pump will supply 68 bars, varying the force required at the pump handle to ensure that correct pressure is supplied. Since the pump purchased can pump against a maximum load that requires around 300 bars, the pressure differential we need will be satisfied.

However, even if the pressure differential is satisfied, the waves may not be able to move the buoy enough to generate sufficient lever arm movement. For this analysis, a Matlab script was created that could analyze the range of motion of the buoy, as explained in Section 3.2.2. See Appendix D and E for full details. Appendix F shows the Matlab script.

In order to determine if waves would generate sufficient lever arm movement, force analysis was performed where the static equilibrium of the buoy was calculated. At equilibrium, approximately 54.7% of the buoy will be underwater, with the water level rising until 85% of the buoy is underwater before the buoyancy force is sufficient to overcome the torque at the hydraulic pump handle. When the water is receding, the water level will decrease until 24.3% of the buoy is underwater before the buoy will start moving downwards. In the script, it was determined that in order to move the hydraulic pump handle down, the buoy needs to be weighed with an additional 55 pounds. If the buoy was unweighted, the waves will push the hydraulic pump up but then the hydraulic pump handle will be stuck in an upright position as the buoy is not heavy enough to push the hydraulic pump lever down. In the end, after running the script and trying different combinations, an 18in buoy was needed, which nominally will provide 112 pounds of buoyancy force. Factoring in a 3-foot wave, the buoy is expected to move around 20 inches, providing an angular displacement of around 37 degrees to the hydraulic pump handle. Given that the waves around the Central Coast are all at least 3 feet, the waves will generate sufficient hydraulic pump handle movement. As seen, the spherical buoy will be able to provide significant lever arm movement. Given that all inexpensive buoys on the market are spherical, the choice of a spherical buoy is appealing. With the lack of sharp edges, a spherical buoy may also provide additional safety for wildlife. See Appendix F for the Matlab Script.

Given that we now need to weigh the buoy down with a huge mass, structure calculations are needed to ensure that the lever arm will not fail.
We performed structural analysis on the wave-energy generation component of our design. Stresses we are concerned about are the forces from the joints from the lever arm to the buoy and hydraulic pump handle, and the stress on the lever arm rod. In our calculations, we statically fixed the handle to perform analysis that could treat each section as a cantilever beam. Then,

statics was applied to calculate the stresses at the joints, and then the stress equations such as the Bending Moment Equations were used to calculate final stresses. This was then implemented in a Matlab script to vary various parameters and undergo trade studies.

In our final prototype, we plan to use an Acetal copolymer rod with a diameter of 1.5 in. This material and diameter were determined in force analysis, with corresponding factors of safety of around 1.56. For the metal joint connecting the lever arm to the pump handle, after calculating the stresses, we found that the metal joint will have a factor of safety of 2.02. Therefore, we are confident that both the metal elbow connection and the lever arm rod will not yield, especially since the forces acting on the system are overestimated. It is likely that the true factors of safety are slightly higher. Since both the Flexural Modulus and Elastic Modulus of the Acetal Copolymer rod are both over 2.5 GPa while the stresses are on the order of magnitude of 0.2 GPa, we are not very worried about displacements.

See Appendix E for the hand calculations and Appendix F for the Matlab Script.

3.3.2 Specification #2-System Size must fit within 2ft by 4ft

The largest component we have is the reverse osmosis membrane, measuring 40 inches long and a few inches wide. Therefore, this element will be able to make the 4ft maximum requirement, giving us confidence that the rest of the components will also fit on a benchtop display. Since the buoy and lever arm will not be included in this restriction, the only components that need to fit on the benchtop are the reverse osmosis membrane, the hydraulic pump, and a variety of hoses and fittings. We are confident that the pump will fit on the table-top display alongside the reverse osmosis filter and believe that the hoses and fittings will only add a relatively small amount of area.

3.3.3 Specification #3-Prototype Cost must be less than $2000

Given that we have purchased most of our components and found vendors for the rest of the components, we are highly confident that our system will cost less than $2000. Currently, we project to have around $890 left for replacing components during a second design iteration after all parts are purchased.

3.3.4 Specification #4-Non-corrosive and watertight

We are confident that we will be able to meet this specification since our reverse osmosis membrane is meant to desalinate water, and all of our selected fittings and piping that we plan on purchasing are all advertised to be non-corrosive. We contacted the manufacturer of the pump, who stated that the pump will corrode in the presence of sea water. Thus, we have purchased a food-grade, anticorrosive spray to use on the hydraulic pump to ensure that it will not corrode. Since all our fittings are the JIC or NPT standard, we do not anticipate water leakage to be an issue.

3.3.5 Specification #5-Meets EPA Standards

Since the buoy purchased is meant for marine applications and is the only aspect of the system that will come into significant contact with the water, we do not have to worry about EPA standards there.

3.3.6 Specification #6-Flowrate of the System

Since the reverse osmosis membrane is advertised to run at a maximum of 20 gallons per hour, a 1 gallon per hour flowrate will not be challenging to this component at all. The amount of times the pump handle moves, and how much the pump handle moves, will be the integral factor in determining this flowrate. Since this is unable to be analyzed or tested until the whole system is completed, it is a major concern for us. Since the manufacturer was unable to provide many concrete answers on the flowrate of the pump if the full range of the handle displacement was not utilized, we are unable to actually calculate a flowrate of the pump until rigorous testing. However, our sponsor has stated that flowrate is not too important for this proof-of-concept design.

3.3.7 Specification #7-System Operation Noise

Since there are no motors, and the hydraulic pump does not make any noise when pumping water, we do not expect to come anywhere close to the 85dB limit. In reverse osmosis systems where the membrane we purchased was used, the membrane itself did not make significant noise when in use, according to the videos we watched.

3.3.8 Specification #8-Water Quality

While we are unable to test this until the full system is created, we are confident that this specification will be met as the reverse osmosis membrane we purchased is meant for desalination applications, so it would be highly unlikely that the water at the output of the reverse osmosis membrane was not drinkable (pH of around 7).

3.4 Safety, Maintenance, and Repair Considerations

Along with the proposed design, several safety considerations must be made to ensure safe operation and to secure environmentally friendly performance. During normal operation, there will be mechanical motion generated from the spherical buoy and the lever arm attached to the hydraulic pump. This system could potentially harm surrounding sea life swimming along the shore. To prevent any organisms from coming in to contact with the system, a bright color was chosen for the buoy to deter animals, and a protective fencing or cage system may be built around the buoy and lever arm in the future.

Due to our system being in a marine environment, corrosion and biofouling are significant concerns when running sea water through any part of the apparatus. Maintenance on the wave energy capture components could be performed out of the water by detaching the lever arm from the hydraulic pump and bringing it to a safe location on land to be repaired. Since most other aspects of our design will be located on land, these can be repaired in place. Thankfully, the lever arm material, Acetal Copolymer, is non-corrosive and meant for outdoor applications, so the lever arm itself will see minimal rusting. This is important since it will need to continue to bear load, so it would be highly impacted if it started rusting, as this would make the lever arm significantly weaker.

The hydraulic pump and reverse osmosis systems will also be subject to high levels of pressure, which could be prone to fail especially in a corrosive marine environment. While proper maintenance should prevent failures, a pressure release valve could be installed as a failsafe for any pressure related incidents. The valves selected are all stainless-steel valves, so they should be able to withstand the required pressure while simultaneously not corroding. A completed checklist of all design hazards is located in Appendix H for reference. All significant hazards for our design and their respective solutions are neatly shown below in Table 3.

Table 3. Design Hazards and Corrective Actions

Description of Hazard	Planned Corrective Action
Large marine buoy and lever arm moving in an oscillating vertical path.	Bright buoy colors, possible fencing or a cage system surrounding the lever mechanism to protect sea life from being injured.
Pressurized fluids present in piping and reverse osmosis system.	Install pressure release valve for emergency use. Valve opens directly to ambient conditions and rapidly equalizes pressure.
System operated in close proximity to ocean environment, causing rapid corrosion of system components.	Regular and scheduled maintenance checks to ensure a high level of integrity across system components.

Many of our design specifications are dependent on each other such as the pressure generated from the hydraulic pump and the flowrate of fresh water out of the reverse osmosis system. This is a challenge and a concern as we are unable to state with full certainty that our design will be capable of generating enough pressure from wave energy to drive a reverse osmosis system effectively.

See Appendix F for the Failure Modes & Effects Analysis (FMEA) and Appendix H for the Design Hazard checklist for further details on safety considerations.

3.5 Other Concerns

A factor that generates uncertainty is the inconsistent nature of ocean waves. This project was currently planned to operate off the Cal Poly pier in Avila Beach, but Avila is shielded from deep ocean swells and may not provide the necessary consistency and size of waves. We plan to relocate to an area that receives strong and consistent swell and still allows for operation off a stationary platform such as a pier.

4 Manufacturing Plan

When designing the system for the ocean wave powered reverse osmosis system, it was kept in mind that many of the components themselves were to be purchased to keep fabrication at a minimum. All of our desired components are used extensively in a vast range of applications and when dealing with pressurized systems; it is ideal to use components that have gone through commercial safety vetting. The majority of manufacturing to be done for our system will be connecting our different components together and anchoring our hydraulic pump to a fixed surface.

4.1 Procurement of Materials and Components

As mentioned above, most of the components for this system will be purchased from third-party manufacturers. The buoy, hydraulic pump, and tubing reducers are all to be purchased from Amazon.com while our reverse osmosis membrane and housing will be purchased from SeaWaterPro.com, a marine vessel desalination company. High pressure tubing will be purchased from AirGas.com, back pressure valves will be purchased from baileyshydraulics.com, NPT to JIC adapters will be purchased from hydraulicsdirect.com, and pressure gauges will be purchased from toolots.com. Raw materials including PVC components and lumber will be purchased from a local Home Depot.

4.2 Manufacturing

Before having completed any testing on our prototype, we are certain that we will need to manufacture a lever arm from the pump handle to the buoy as well as a base for the pump to attach to a solid surface.

4.2.1 Lever Arm

The lever arm will be implemented as an interface between the hydraulic pump handle and the buoy; it will include adapters at each end to allow for compatibility between components. Due to the corrosive nature of a coastal environment, a solid cross section polymer lever arm was selected as the best option for our purposes. After structural analysis, a polymer lever arm with a diameter of 1-½ inches was found to be a strong enough member to transmit our desired loads to the hydraulic pump. However, there are concerns with using a polymer material for applications exposed to solar radiation for long-term applications. While a polymer material will resist corrosion, the solar radiation will cause the material to be brittle, leading to failures like cracking and breaking. Therefore, we are investigating other lightweight, strong, durable, corrosion-resistant materials such as steel and fiberglass. Virtually all the manufacturing required for the lever arm will include sizing, cutting, and adhering the arm to the connection points on either end.

The lever arm will connect to the buoy since the buoy has a thru-hole which the lever arm can slide through, and the end will be affixed with a PVC stopper in order to prevent the buoy from sliding off. The lever arm connects with the pump handle with a 1.5 in adjustable steel elbow.

4.2.2 Pump Fixture

The pump is the only component of our design that is required to be fixed in place. To fulfill this requirement, a fixture must be manufactured to ensure there are no losses in energy transmission to the pump from the waves.

The pump itself has four connection points on its rear surface, shown in Figure 11, these will be the points from which a fixture will be attached. The bottom surface of the pump must be anchored, so that the bottom plane will be attached to a fixed surface using multiple clamps. In order to do this, 2 x 4 in lumber sections will be cut at an angle to attach the eyelets on the back of the pump to a ¾ in plywood sheet parallel to the bottom surface of the pump. The lumber sections will be measured and cut with a bandsaw to proper length, before drilling the pieces. Then, they will be connected with screws and wood glue for extra robustness.

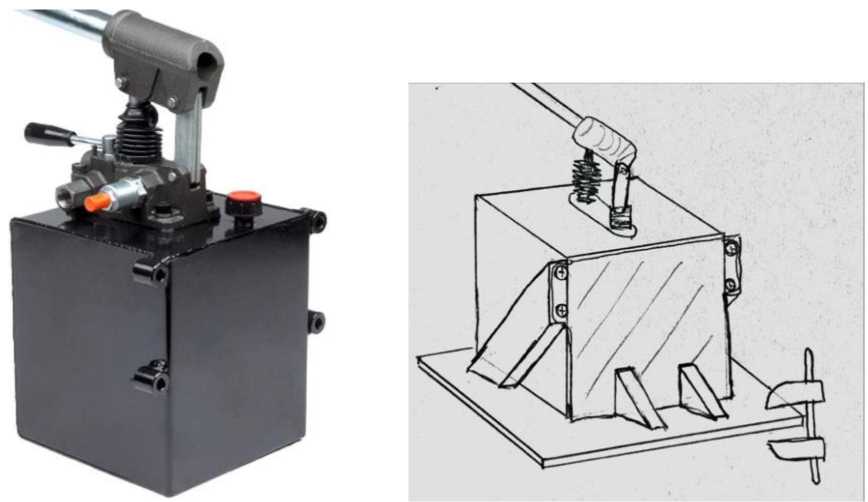

Figure 11. Hydraulic Pump Rear View and Fixture Design Concept

In future iterations of this aspect of the assembly, we will likely switch to a corrosion resistant aluminum or stainless-steel design. The wooden design is prone to warping and liquid absorption, a metal design would be stiffer and more resistant to negative effects caused by nearby liquids.

4.3 Assembly

This system consists of 3 main subsystems: the buoy/lever arm, the hydraulic pump, and the reverse osmosis system. Attachment from the buoy to the lever arm will consist of a PVC stopper attached to a 3 in section of 1-1/2 in diameter steel. A 1-½ in to 1-½ in elbow will then attach to the lever arm, from which a 1-½ in to 1 in elbow will be needed between the lever arm and the pump handle. The following connections will all involve pressurized fluids.

The outlet of the hydraulic pump is 3/8 in NPT, we will be using a 3/8 in NPT to ¼ in NPT reducer from the pump, where we will connect ¼ in tubing into a ¼ in pressure gauge. The inlet and outlet of the reverse osmosis system is a ¼ in JIC connection, but we need all NPT connections, so we will connect ¼ in JIC to NPT adapters to each end of the reverse osmosis system. The pressure gauge will connect to the inlet JIC to NPT adapter, and another pressure gauge will connect to the outlet of the reverse osmosis membrane. Our back pressure valve has an inlet and outlet size of ¾ in NPT, so after the pressure gauge at the outlet of the membrane, a ¾ in NPT to ¼ in NPT reducer will allow for flow into the back pressure valve. Lastly, a ¾ in barb connector will attach to a hose to the collection containers.

5 Design Verification Plan

Our system will require a series of tests in order to determine if our components will properly work together to achieve our desired power generation from the waves, water pH, and flowrate. We also hope to keep our entire design under a certain size. The spreadsheet including our Design Verification Plan is included in Appendix I.

5.1 Power Generated by Waves

We will conduct two separate tests on power generated at two different times over our design timeline. The first will include the use of our prototype adjustable length lever arm in a pool to help decide what length our final lever arm should be. In this test, waves will be generated by hand and will reach a height of about 1 ft. From this test, we wish to achieve at least 15 degrees of lever arm movement for a 1 ft wave at the shortest possible lever arm length. Data collected will be analyzed to determine how to increase the lever arm movement. Here, we will be using a backyard pool and a board to generate the waves.

The second test to be conducted for power generation will take place in the ocean and will use a solid cross section polymer lever arm at a fixed length to test our power output. The acceptance criterion for this test is any amount of freshwater flow at the outlet of the system. This test will take place approximately two months after the first test to ensure we have selected the proper lever arm length and achieved other system parameters. In order to properly test this specification, a testing trip to a pier will need to be done so that we can test the prototype in the ocean.

5.2 Freshwater pH

It is imperative that the water generated from our system achieves an acceptable pH for human consumption, so the water generated from the second power generation test will be tested with litmus paper for salinity and pH levels. This water from our system must have a pH between 6.3 and 7.7 and a salinity less than 1000 ppm to pass our acceptance criteria for this test. This water will be directly from the ocean, so additional treatments may be required to consume it in larger quantities. Most likely, this test will also be done at the same time as the test mentioned in Section 5.1.

5.3 System Size

The design of our system is to be designed as a table-top display for educational purposes. To fit on a table-top, our design must be no more than 2 ft by 4 ft, excluding the buoy and lever arm assemblies. This test will be conducted with a simple measurement and can be completed once we have fully constructed our pump and reverse osmosis systems.

5.4 Flowrate

One of the most important outcomes of our design is the freshwater flowrate. This test will take place simultaneously with the second power generation test from ocean water. The desalination system will run for 30 minutes in an ocean environment, and the freshwater output will be collected in measurement containers. The goal of this test is to achieve 0.5 gallons of freshwater in 30 minutes, or 1 gallon per hour. If this test fails, all components of the system will need to be reevaluated since all components contribute to the flowrate of the system. We would also perform this test at the same time as the test described in Section 5.1.

6 Project Management

The progress we have made on our project and structural prototype will lead into our next tasks for the quarter. We will continue improving our structural prototype by assembling a full model of our design and perform additional testing and analysis. The next major milestone is the Manufacturing and Test Review where we will report the status of manufacturing details and test plans for our structural prototype. Following this will be the Verification Prototype Sign-Off where we get our Verification Prototype with our Design Verification Plan (DVP), Design Hazard Checklist, and more safety items approved by our faculty coach, Professor Harding, and safety technicians. Our final prototype will be completed by the Final Design Review (FDR).

Table 4 outlines the next major milestones of our project.

Table 4. Project Milestones

Milestone	Due Date
Critical Design Review (CDR)	2/10/22
Manufacturing and Test Review	3/10/22
Project Update Memorandum	4/1/22
Verification Prototype Sign-Off	4/26/22
Design Verification Plan & Report (DVPR)	5/17/22
Final Design Review (FDR)	6/3/22

The Gantt chart which outlines our full project plan with tasks and deliverables can be found in Appendix J.

7 Conclusion

The primary design challenge of this project is to design and prototype a functioning ocean water desalination system that draws from renewable wave energy sources to reduce the costs associated with operating a desalination plant. Through building our structural prototype, final

CAD model, and performing force and structural analysis, we are able to update our prototype and perform testing. Our manufacturing plan, drawing and specification package, and design verification plan will enable us to construct a verification prototype which will be evaluated in a testing environment mainly for functionality of our design. We hope we have convinced our sponsor to agree with us on our design direction.

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[9] "2.5 Inch Pressure Gauge ¼" NPT 0-1500Psi / 0-100Bar Back Entry SS304". Toolots. https://www.toolots.com/2-5-inch-pressure-gauge-1-4-npt-0-1500psi-0-100bar-back-entry-ss304.html (accessed February 3, 2022).

[10] "Chief SL Series High Pressure Relief Valve: 20 GPM, 1000-2500 psi Adj, Range". Bailey Hydraulics. https://www.baileyhydraulics.com/CHIEF-High-Pressure-Relief-Valves-SL-Series-20-GPM-1500-PSI (accessed February 3, 2022).

[11] "2.5 qt. HDX All Purpose Mixing Container". Home Depot. https://www.homedepot.com/p/HDX-2-5-qt-All-Purpose-Mixing-Container-05M3HDX/204286575 (accessed February 3, 2022).

Appendix

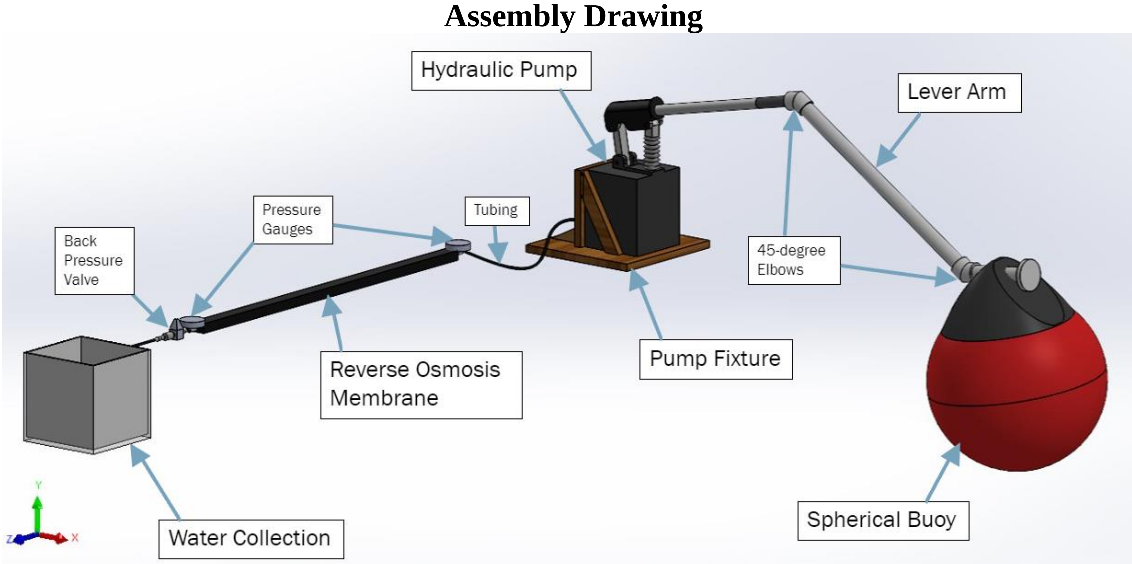
Appendix A: Drawings & Specification Package

Reverse Osmosis Freshwater Generator Powered by Mechanical Wave Energy

Indented Bill of Material (iBOM)

Assy Level	Part Number	Descriptive Part Name				Qty	Mat'l Cost	Shipping/tax Costs	Total Cost	Part Source	More Info
		Lvl0	*Lvl1*	*Lvl2*	*Lvl3*						
0	100	Final Assy									
1	200		Wave Generation Assembly								
2	210			Spherical Buoy		1	$67.12	$5.87	$72.99	Amazon.com	Spherical polymer buoy with mooring loop
3	220				PVC Connection	1	$3.00	$0.22	$3.22	Home Deopt	PVC stopper to fix buoy to lever arm
2	230			Lever Arm		1	$27.35	$20.17	$47.52	Home Depot	Acetal Copolymer 1.5" diameter shaft
2	240			Hydraulic Pump		1	$281.41	$27.58	$308.99	Amazon.com	Double acting, 1.8 gallon tank, 25cm3 rated flow
	250				1.5" to 1" Reducer	1	$9.50	$27.38	$36.88	jmesales.com	1.5" to 1" concentric stainless steel butt weld reducer
3	260				Stainless Steel Elbow	1	$28.99	$19.68	$48.67	Kegworks.com	Adjustable stainless steel 1.5" OD elbow
2	270			Pump Fixture		1	$74.17	$5.37	$79.54	Home Depot	Constructed from 2"x4" lumber and 3/4" plywood
1	300		Reverse Osmosis Assembly								
2	310			SeaWater Pro RO FIlter		1	$595.00	$23.95	$618.95	SeaWaterPro.com	40" membrane, 5000 psi bursting pressure housing
3	320				Back Pressure Valve	1	$66.94	$24.12	$91.06	baileyhydraulics.com	20 GPM, 1000-2500 psi adjustable range
1	400		Water Collection Assy								
2	410			Collection Containers		2	$2.48	$0.18	$2.66	Home Depot	Clear containers with volumetric measurement markings
1	110		Tubing			2	$43.62	$13.17	$56.79	Airgas.com	1/4" NPT female attachments, braided steel hosing
1			Tube Reducers			2					
2	130			3/8" NPT to 1/4" NPT		1	$8.99	$0.79	$9.78	Amazon.com	Connection from hydraulic pump to 1/4" tubing
2	140			1/4" NPT to 3/4" NPT		1	$11.79	$0.91	$12.70	Amazon.com	Connection from RO membrane to back pressure valve
1			Pipe Fittings			3					
2	150			NPT to JIC		2	$2.02	$13.36	$15.38	hydraulicsdirect.com	Adapters from JIC RO membrane to NPT system
2	160			3/4" Barb Connector		1	$12.49	$0.97	$13.46	Amazon.com	Connection from back pressure valve to water collection
1	170		Pressure Gauges			2	$5.39	$10.53	$15.92	toolots.com	1/4" NPT pressure valve 0-1500 psi
1	180		Sealant			1	$0.98	$0.07	$1.05	Home Depot	Polymer tape to reduce leakage
					Total Parts:	26					

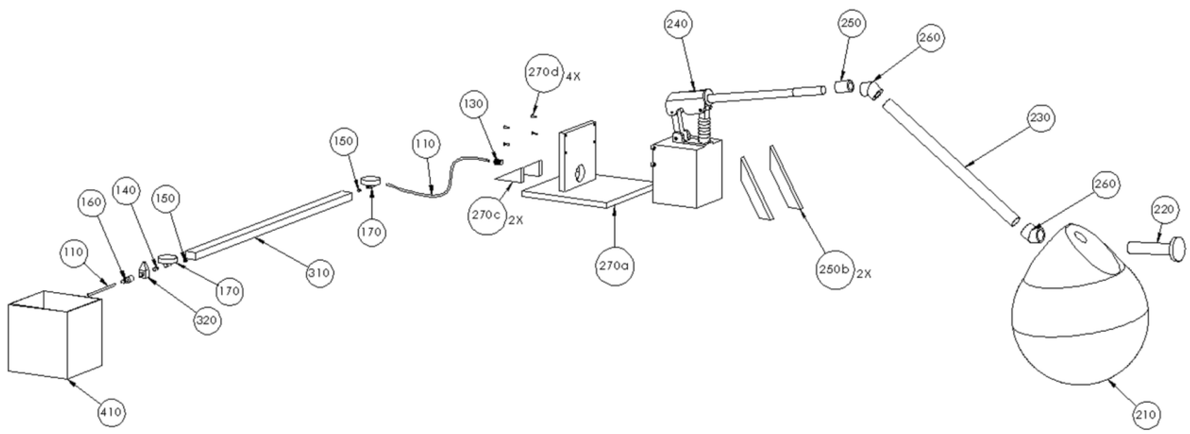
Assembly Drawing



Exploded Assembly View Drawing

PART #	110	130	140	150	160	170	210	220	230
ITEM DESCRIPTION	Tubing	3/8" NPT to 1/4" NPT	1/4" to 3/4"	1/4" NPT to JIC	3/4" Barb Connector	Pressure Gauge	Spherical Buoy	PVC Connection	Lever-arm
QUANTITY	2	1	1	4	1	2	1	1	1

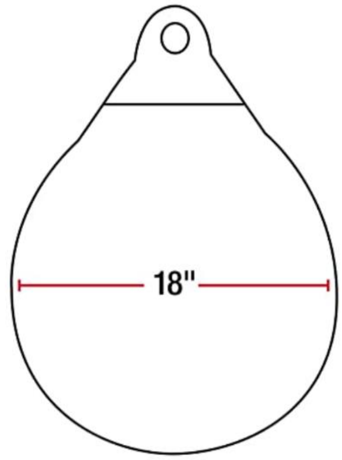
PART #	240	250	260	270a	270b	270c	270d	310	320	410
ITEM DESCRIPTION	Pump	1.5" to 1" Reducer	Stainless Steel 45 degree Elbow	Base-board	2x4 Connection	2x4 Connection	Wood Screw	R.O. Membrane	Back Pressure Valve	Water Collection
QUANTITY	1	1	1	1	2	2	4	1	1	1

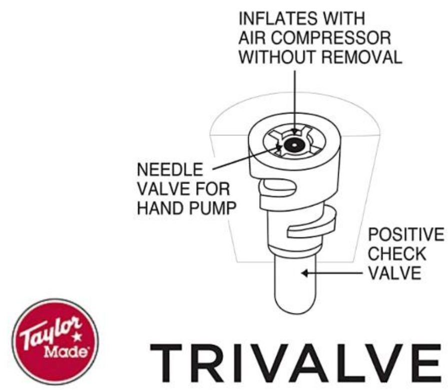


CAL POLY ME 429	Lab Section:02	Senior Project	Title: Wave Generated RO	Drwn. By: Solie Grantham
	Dwg. #:01	Nxt Asb:	Date: 2/3/22 / Scale: 1:10	Chkd. By: ME STAFF

Buoy, Part number: 210

Taylor Made Products 61149 Tuff End Inflatable Vinyl Boat Buoy, Orange, 18 inch Diameter





Features:

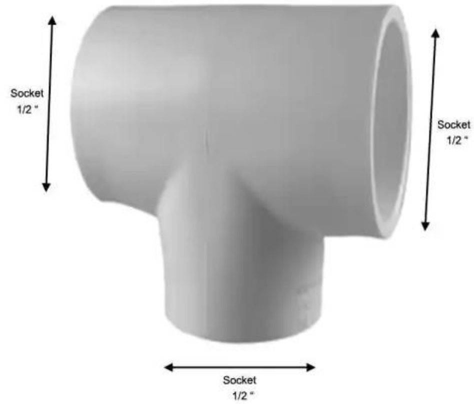
- 1 year warranty
- Valve located on the side of the buoy for easy inflation
- Dia: 18"
- Circumference: 57"
- Line Hole: 1-1/2"
- Approx. Buoyancy (lbs): 112

Product : TAYLOR MADE TUFF END 18" ORANGE INFLATABLE VINYL BUOY
Manufacturer : TAYLOR MADE
Manufacturer Part No : 61149
UPC : 040011316493

PVC Connection, Part Number 220

Charlotte Pipe

1/2 in. PVC Schedule 40 S x S x S Tee

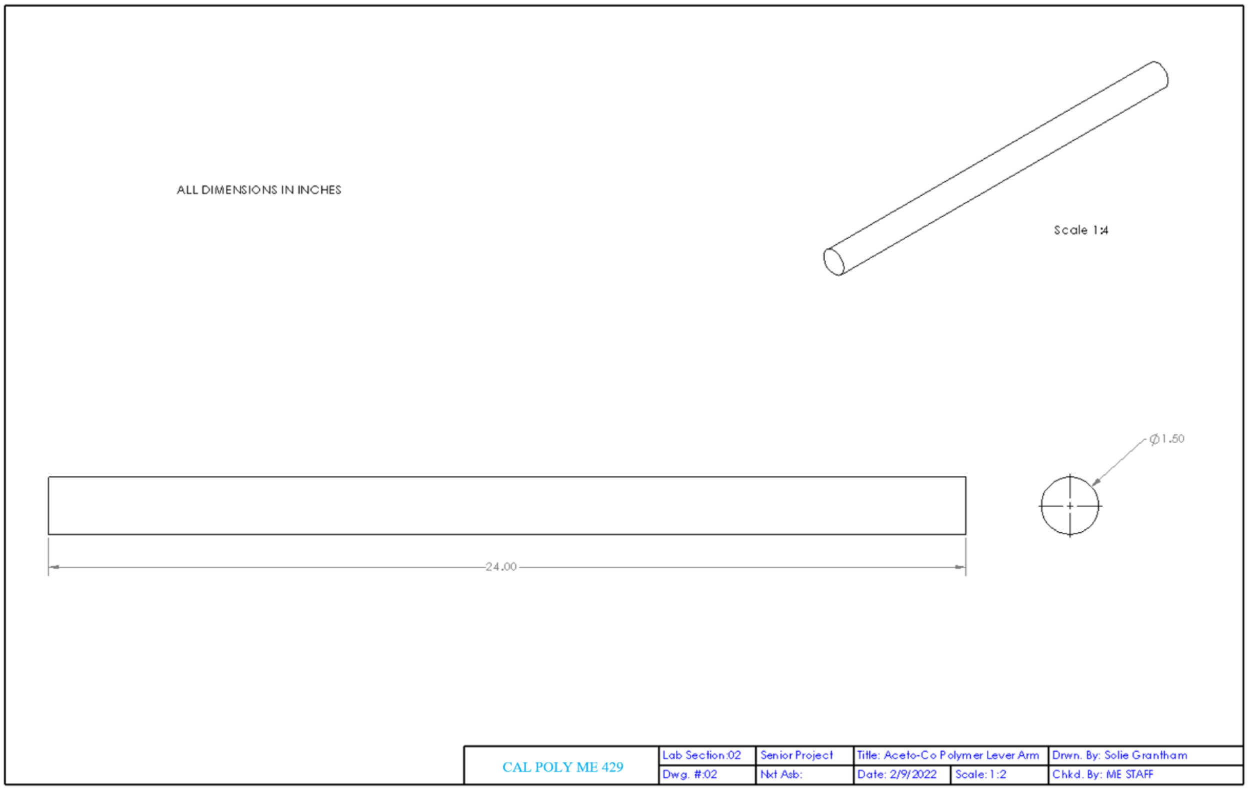


Product Overview

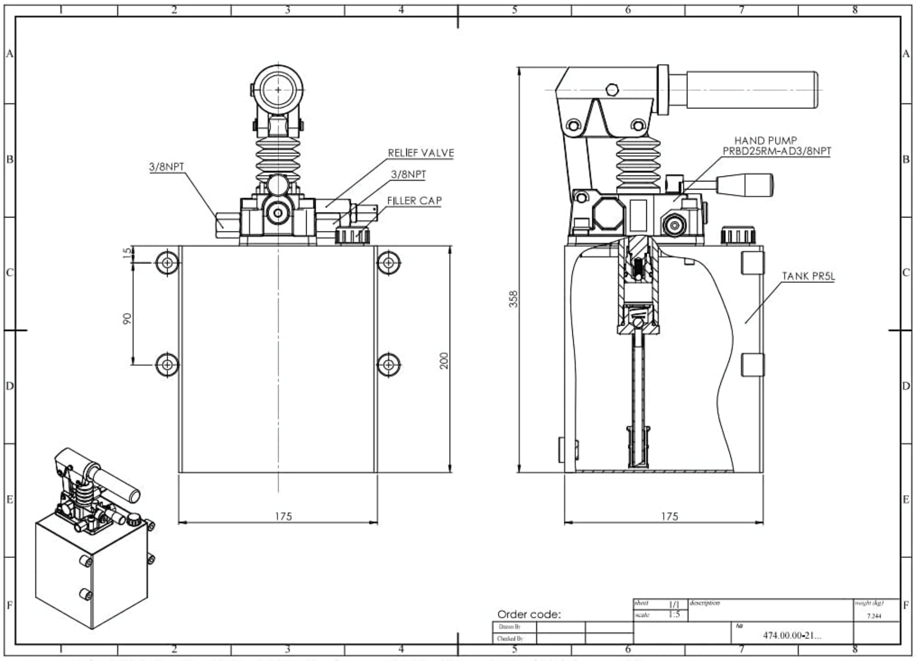
PVC Sch. 40 fitting are for pressure systems where temperatures will not exceed 140°F. They are highly resilient, with high-tensile and high-impact strength. PVC Sch. 40 has better sound deadening qualities than PVC Sch. 40 DWV Foam Core and ABS Foam Core. Installation requires the use of primer and solvent cement.

- Conforms to meet standards: ASTM D 1784, ASTM D 2466, NSF 14 and 61
- White fittings that are used in potable water applications only
- Intended for pressure use
- PVC schedule 40 pipe and pressure fittings are used in irrigation, underground sprinkler systems, swimming pools, outdoor applications and cold water supply lines
- Maximum working temperature of 140°F
- Require no special tools for cutting and to be installed with solvent cement
- +/-0.623" ID and 0.84" OD

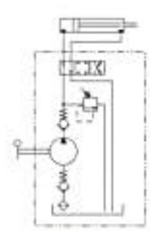
Lever Arm, Part number: 230



Hydraulic Pump, Part number: 240



Double Acting for Double Acting Cylinder – Tank Mounting



Order Code	Description	Displacement (cm³)	Max. Pressure (bar)	Outlet Ports
PRBD-4093000	PRBD12RM	12	380	G 3/8 (Male)
PRBD-4092990	PRBD25RM	25	350	
PRBD-4105087	PRBD45RM	45	280	

Note:

- *Displacement is per cycle. One cycle is extend and retract of the handle.*
- *Relief Valve factory set to Max. Pressure.*
- *All Hand Pumps are supplied with an Adjustable Relief Valve, Bellows over piston shaft, Handle, Suction Filter, Suction Tube, Rubber Gasket, SHCS & Spring Washers for mounting to our tank or yours.*
- *Prices **do not** include a tank. They are sold separately. Refer to Page 3.04.*
- *RP Tanks are supplied with the correct length suction tube.*
  Do not use the one supplied with the hand pump. Fit the serrated end of hose inside the suction strainer.
- *When using RP Tanks hand pump can only be mounted with the handle horizontal.*
- *Hand Pumps can be mounted to your tank with the handle vertical. Ensure you use sealed nuts or thread sealant and take care not to kink and block the Suction Tube.*

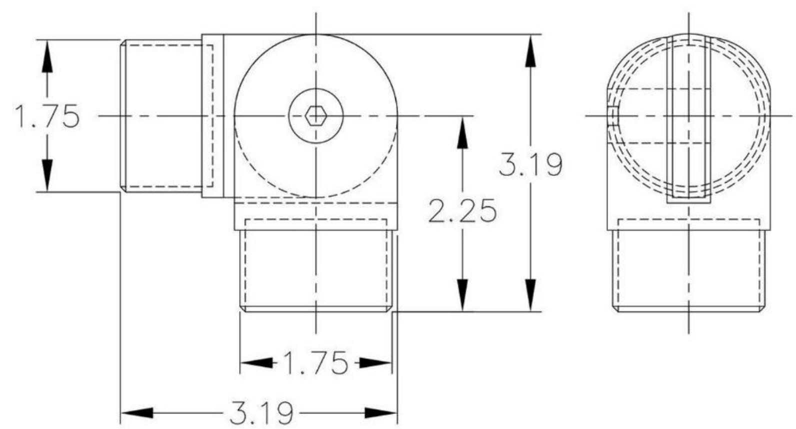
1.5” to 1” Concentric Butt Weld Reducer, Part Number 250

1-1/2 in. x 1 in. Unpolished Concentric Weld Reducer (31W-UNPOL) 316L Stainless Steel Tube OD Buttweld Fitting

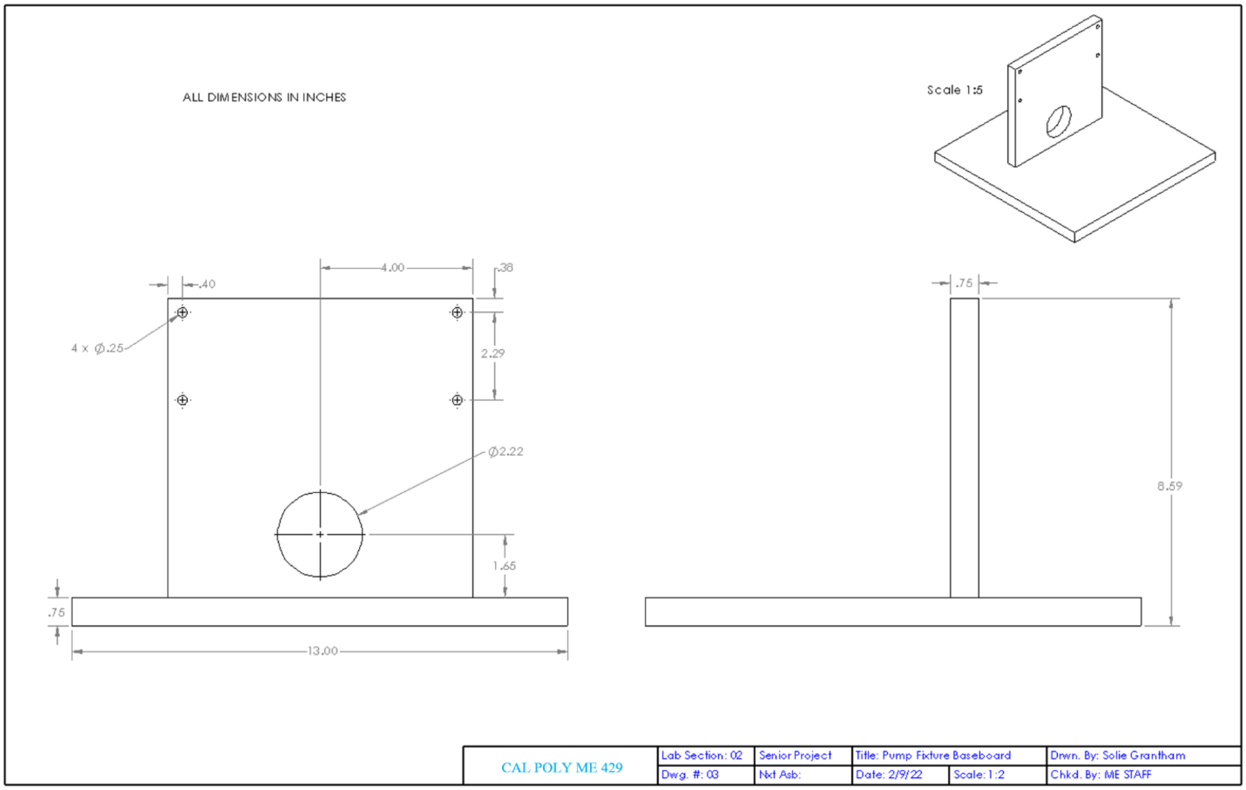
SIZE (INCHES):	1.50 (1-1/2")
SIZE (INCHES):	1.00 (1")
MATERIAL TYPE:	316L Stainless Steel
PRODUCT TYPE:	Concentric Reducer
CATEGORY:	Tube OD Fittings
STYLE:	31W
WEIGHT (LBS):	0.12

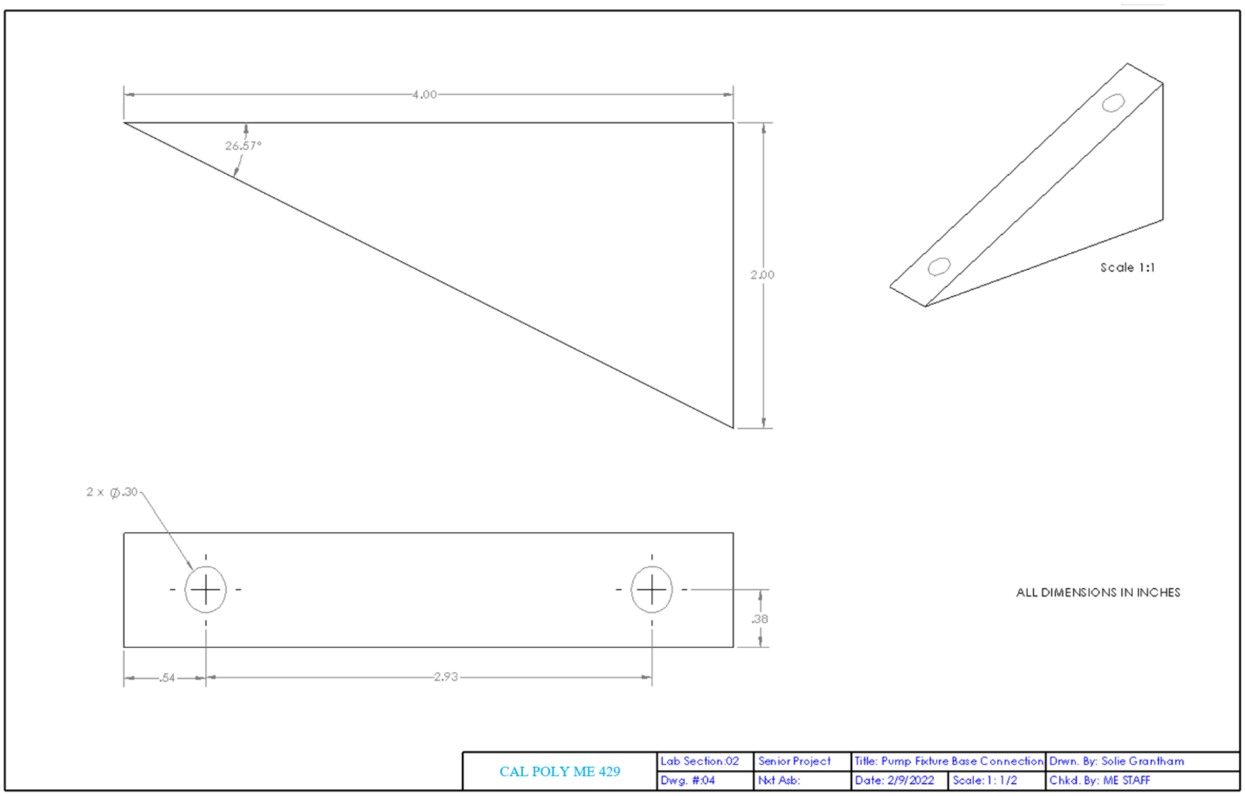
Adjustable Stainless Steel Elbow, Part number: 260

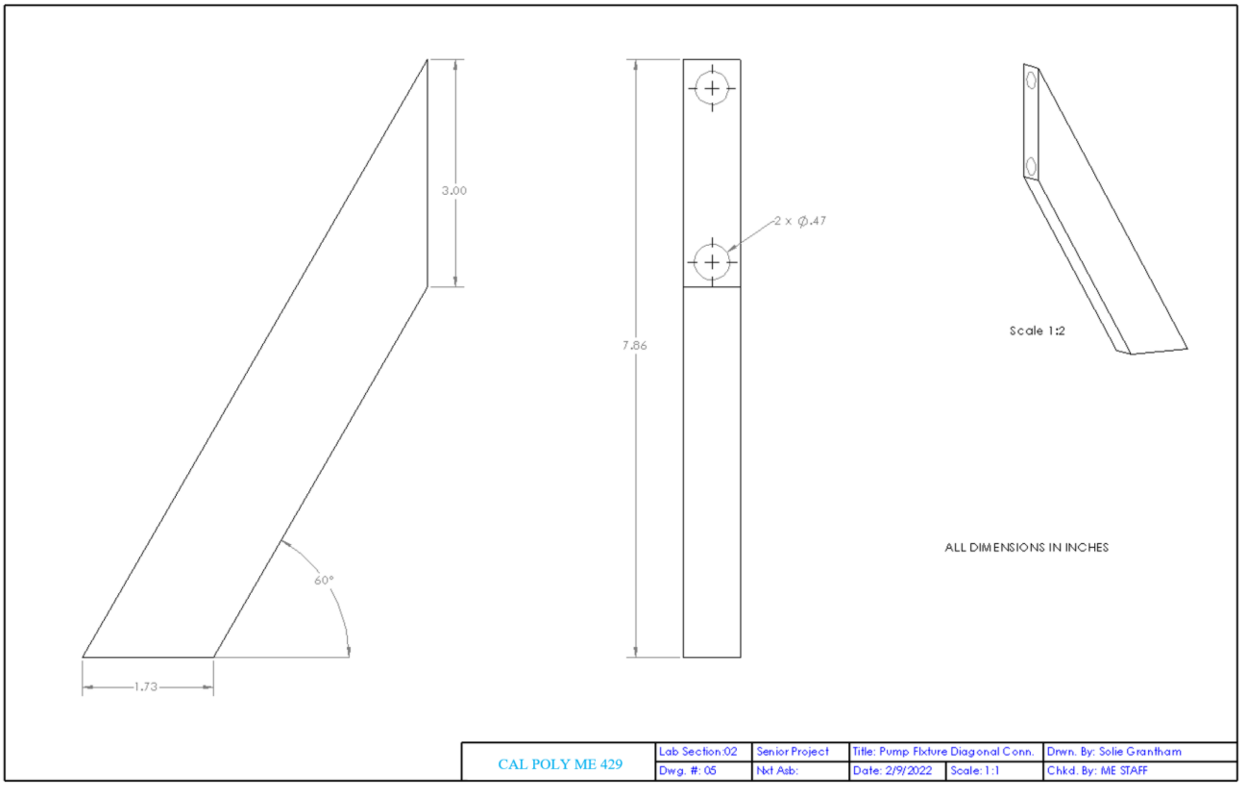
Adjustable Flush Elbow Fitting - Brushed Stainless Steel - 1.5" OD



Fixture, Part number: 270






3.00
7.86
2 x ∅.47
Scale 1:2
60°
1.73
ALL DIMENSIONS IN INCHES
CAL POLY ME 429
Lab Section:02
Senior Project
Title: Pump Fixture Diagonal Conn.
Drwn. By: Solie Grantham
Dwg. #: 05
Nxt Asb:
Date: 2/9/2022
Scale: 1:1
Chkd. By: ME STAFF

SeaWater Pro Reverse Osmosis Filter, Part number: 310

Back Pressure Valve, Part Number 320

Specifications

GPM	20
Action	Adj. 1000-2500 PSI
PSI	2500
Port Size	3/4” NPTF
Weight	3 lb
Brand	Chief
Type	Inventory Item

Collection Containers, Part Number: 400

Product Overview

The 2.5 qt. Versa-Tainer Plastic Bucket is calibrated for measuring liquids. This plastic bucket is opaque and has graphics so you can easily see what you are pouring.

- Plastic
- Multi-purpose mixing pail is calibrated for measuring liquids
- Safe for food storage
- 2.5 qt.
- Opaque with graphics so you can easily see what you are pouring
- Ratios around the back for easy mixing
- Convenient size for easy mixing

Tubing, Part Number 410

Features

- Core consists of Teflon (polytetrafluoroethylene) with two outer reinforcing jackets of stainless steel braid (Teflon is inert to most chemicals and solvents, except molten alkali metals and fluorine at elevated temperatures and pressures)
- 1/4" nominal ID
- Braid consists of Type 304 full hard drawn stainless steel wire
- Teflon withstands temperatures from -65°F (54C) through +450°F (232C)
- Burst pressure rating at room temperature: 12000 psig
- Minimum bend radius of 3 inches provides for maximum life and safe performance
- All pigtails 100% tested before shipping and labelled for gas service and pressure rating
- Pressure ratings limited by CGA connection standards–the lowest pressure rating prevails
- 3" minimum bend radius

Product Attributes

Product Type
» Pigtail

Gas Service
» Oxygen

Length
» 24"

Material
» Stainless Steel

Thread
» 1/4" NPT Female

Maximum Inlet Pressure
» 3000 psi

3/8" NPT to 1/4" NPT Tube Reducer, Part Number: 130

Brand: Avanty

Avanty Stainless Steel 304 Forged Pipe Fitting Reducing Adapter 3/8" NPT Female x 1/4" NPT Male 2000psi

Product Specifications

Color	Stainless Steel
Connector Type	Adapter
Item Shape	reducer adapter
Measurement System	inch
Model Number	SS304-3200CB
Number of Items	1
Part Number	SS304-3200CB
Size	3/8" NPT Female x 1/4" NPT Male
Thread Type	NPT

1/4" NPT to 3/4" NPT Tube Reducer, Part Number: 140

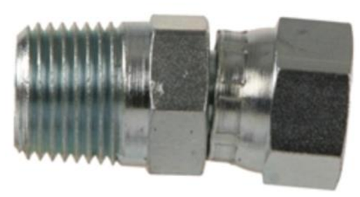
TAISHER 2PCS Forging of 304 Stainless Steel Reducer Hex Bushing, 3/4" Male NPT to 1/4" Female NPT, Reducing Forging Pipe Adapter Fitting

Product Specifications

Connector Type	Reducer
Exterior Finish	Stainless Steel
Finish Type	Stainless Steel
Installation Type	Screw-In
Material	Stainless Steel
Maximum Operating Pressure	2800.00 pounds_per_square_inch
Measurement System	inch
Number of Items	2
Part Number	FC-243S
Size	3/4" MNPT x 1/4" FNPT
Thread Type	NPT
Warranty Description	1 year Warranty

NPT to JIC, Part Number: 150

6505 -NPTF MALE PIPE X 37° JIC FEMALE SWIVEL NUT ADAPTER



NPTF Male Pipe x 37° JIC Female Swivel Nut Adapter

6505 JIC equivalent to the following:

* Parker 0106
* Parker Hydraulics F6X
* Weatherhead 9100
* Aeroquip 2018

Available in stainless steel: SS-6505

Dash Size	Inch Size	Thread Size	Male Thread (O.D.)	Female Thread (I.D.)
4	1/4"	7/16-20*	.44	.39

3/4" Barb Fitting, Part Number: 160

ZIMFLEX 304 Stainless Steel 3/4" Hose Barb to 3/4" Male NPT Pipe Fitting, Home Brew Connector Fitting Water Fuel Air

Product Specifications

Material	Stainless Steel
Number of Items	2
Part Number	6jpj-3/4"-3/4"
Size	3/4" Hose Barb-3/4" NPT
Thread Type	NPT

Pressure Gauge, Part Number: 170

2.5 Inch Pressure Gauge 1/4" NPT 0-1500Psi / 0-100Bar Back Entry SS304

Qty: 1

Product Information

Technical Details

Code	YQ-2.5 Inch Glycerin Gauge	**Pressure Unit**	Psi / Bar
Diameter / Inch	63 mm / 2-1/2"	**Pressure Range**	0-1500 Psi / 0-100 Bar
Cover Material	SS304	**Precision Grade**	1.6
Thread Material	Brass	**Temperature**	Enviroment Temp: -50°F~+158°F Medium Max. Temp: +194°F
Thread Size	1/4"	**Feature**	Shock-proof
Thread Type	NPT	**Box Size (inch) L×W×H**	2.84 × 2.76 × 2.25
Installation	Back direction	**Weight (KG)**	0.196
Fill Oil	Yes	**Weight (LB)**	0.432

Sealant, Part Number: 180

Supply Giant I34 PTFE Thread Seal Tape for Plumbers 3/4 Inch x 260 Inch, Single, White

Technical Details

Manufacturer	Supply Giant
Part Number	I34
Item Weight	0.16 ounces
Product Dimensions	0.75 x 2 x 2 inches
Item model number	I34
Is Discontinued By Manufacturer	No
Size	Single
Color	White
Style	Single
Material	Plastic
Item Package Quantity	1
Included Components	Actual Item
Batteries Included?	No
Batteries Required?	No

Appendix B: Indented Bill of Materials (iBOM)

Reverse Osmosis Freshwater Generator Powered by Mechanical Wave Energy

Indented Bill of Material (iBOM)

Assy Level	Part Number	Descriptive Part Name				Qty	Mat'l Cost	Shipping/tax Costs	Total Cost	Part Source	More Info
		Lvl0	*Lvl1*	*Lvl2*	*Lvl3*						
0	100	Final Assy									
1	200		Wave Generation Assembly								
2	210			Spherical Buoy		1	$67.12	$5.87	$72.99	Amazon.com	Spherical polymer buoy with mooring loop
3	220				PVC Connection	1	$3.00	$0.22	$3.22	Home Deopt	PVC stopper to fix buoy to lever arm
2	230			Lever Arm		1	$27.35	$20.17	$47.52	Home Depot	Acetal Copolymer 1.5" diameter shaft
2	240			Hydraulic Pump		1	$281.41	$27.58	$308.99	Amazon.com	Double acting, 1.8 gallon tank, 25cm3 rated flow
	250				1.5" to 1" Reducer	1	$9.50	$27.38	$36.88	jmesales.com	1.5" to 1" concentric stainless steel butt weld reducer
3	260				Stainless Steel Elbow	1	$28.99	$19.68	$48.67	Kegworks.com	Adjustable stainless steel 1.5" OD elbow
2	270			Pump Fixture		1	$74.17	$5.37	$79.54	Home Depot	Constructed from 2"x4" lumber and 3/4" plywood
1	300		Reverse Osmosis Assembly								
2	310			SeaWater Pro RO Filter		1	$595.00	$23.95	$618.95	SeaWaterPro.com	40" membrane, 5000 psi bursting pressure housing
3	320				Back Pressure Valve	1	$66.94	$24.12	$91.06	baileyhydraulics.com	20 GPM, 1000-2500 psi adjustable range
1	400		Water Collection Assy								
2	410			Collection Containers		2	$2.48	$0.18	$2.66	Home Depot	Clear containers with volumetric measurement markings
1	110		Tubing			2	$43.62	$13.17	$56.79	Airgas.com	1/4" NPT female attachments, braided steel hosing
1			Tube Reducers			2					
2	130			3/8" NPT to 1/4" NPT		1	$8.99	$0.79	$9.78	Amazon.com	Connection from hydraulic pump to 1/4" tubing
2	140			1/4" NPT to 3/4" NPT		1	$11.79	$0.91	$12.70	Amazon.com	Connection from RO membrane to back pressure valve
1			Pipe Fittings			3					
2	150			NPT to JIC		2	$2.02	$13.36	$15.38	hydraulicsdirect.com	Adapters from JIC RO membrane to NPT system
2	160			3/4" Barb Connector		1	$12.49	$0.97	$13.46	Amazon.com	Connection from back pressure valve to water collection
1	170		Pressure Gauges			2	$5.39	$10.53	$15.92	toolots.com	1/4" NPT pressure valve 0-1500 psi
1	180		Sealant			1	$0.98	$0.07	$1.05	Home Depot	Polymer tape to reduce leakage
					Total Parts:	26					

Appendix C: Project Budget

Total Budget:		$2,000			
Components Purchased				Price	
Buoy				67.12	
Lever arm materials				TBD	6
Hydraulic Pump				$308.99	
RO system				$619	
Wave Generator				TBD	93.55
Water trough/tank				TBD	
Tubing				TBD	
Pressure Gauge				10.78	
Flowmeter				TBD	
Seals/Fittings				50.81	
Corrosion Resistant				$53.61	
			Total:	1110.26	
		Remaining Funds:		$890	

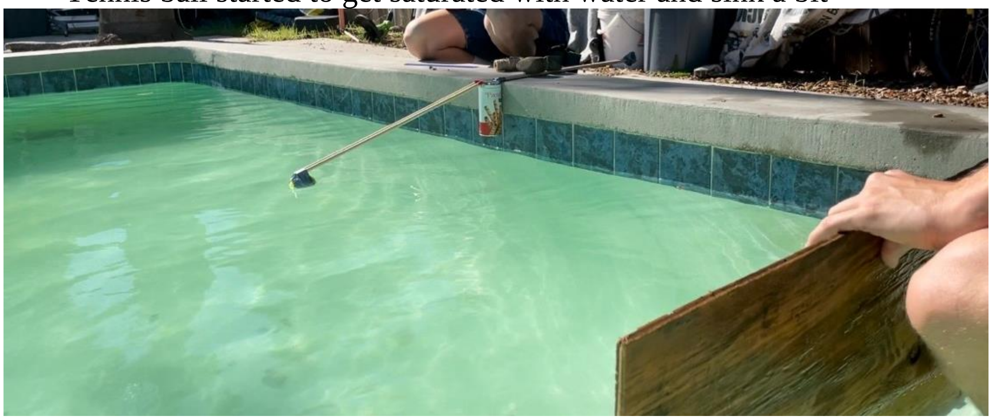
Item Description	Vendor	Vendor Part #	Our Part #	Material Price	Shipping/Handling /Tax Estimates	How Material Will be Purchased	Account Used	Date Purchased	Current Location of Material
Hydrualic Pump	Chief	220996	1	$281.41	$27.58	On Amazon		1/14/22	
Spherical Buoy	Taylor Made	61149	2	$67.12	$5.87	On Amazon			
Lever Arm Materials	Home Depot	n/a	3	$6.00	n/a	In Store			
RO System	SeaWater Pro	not given	4	$595.00	$23.95	SeaWater Pro Website		1/14/22	
Wave Generator			5						
Water Trough/Tank			6						
Tubing (1/4")	SeaWater Pro		7	$10.00					
Pressure Gauge			8	$5.39					
Flowmeter			9						
Seals			10						
Corrosion Resistant Spray	Rust-Oleum	273992	11	$49.99	$3.62	On Amazon		1/14/22	
Back Pressure Valve			12	$16.20					
PVC Fittings			13						
Tubing Reducer 3/8" to 1/4"			14	$8.99					
Tubing Reducer 3/4" to 1/4"			15	$11.79					
			16						
			17						
			18						

Appendix D: Preliminary Analysis

Preliminary Testing:

Test 1: bottom of can located 7.75" from pool edge

- Tennis ball
    - Moved lever arm a good amount so function works
    - Refracted waves seem to have good effect on bobbing
    - Bigger size (larger area) of buoy leads to increased force
    - Tennis ball started to get saturated with water and sink a bit



- Ping pong ball
    - Did not move lever arm very much
    - Small size didn't have great effect on bobbing
    - Ball is not well attached to lever arm
        - Buoy is in line with lever arm… should be below to be point absorber like tennis ball set up

Test 2: move pump lower (closer to water surface)

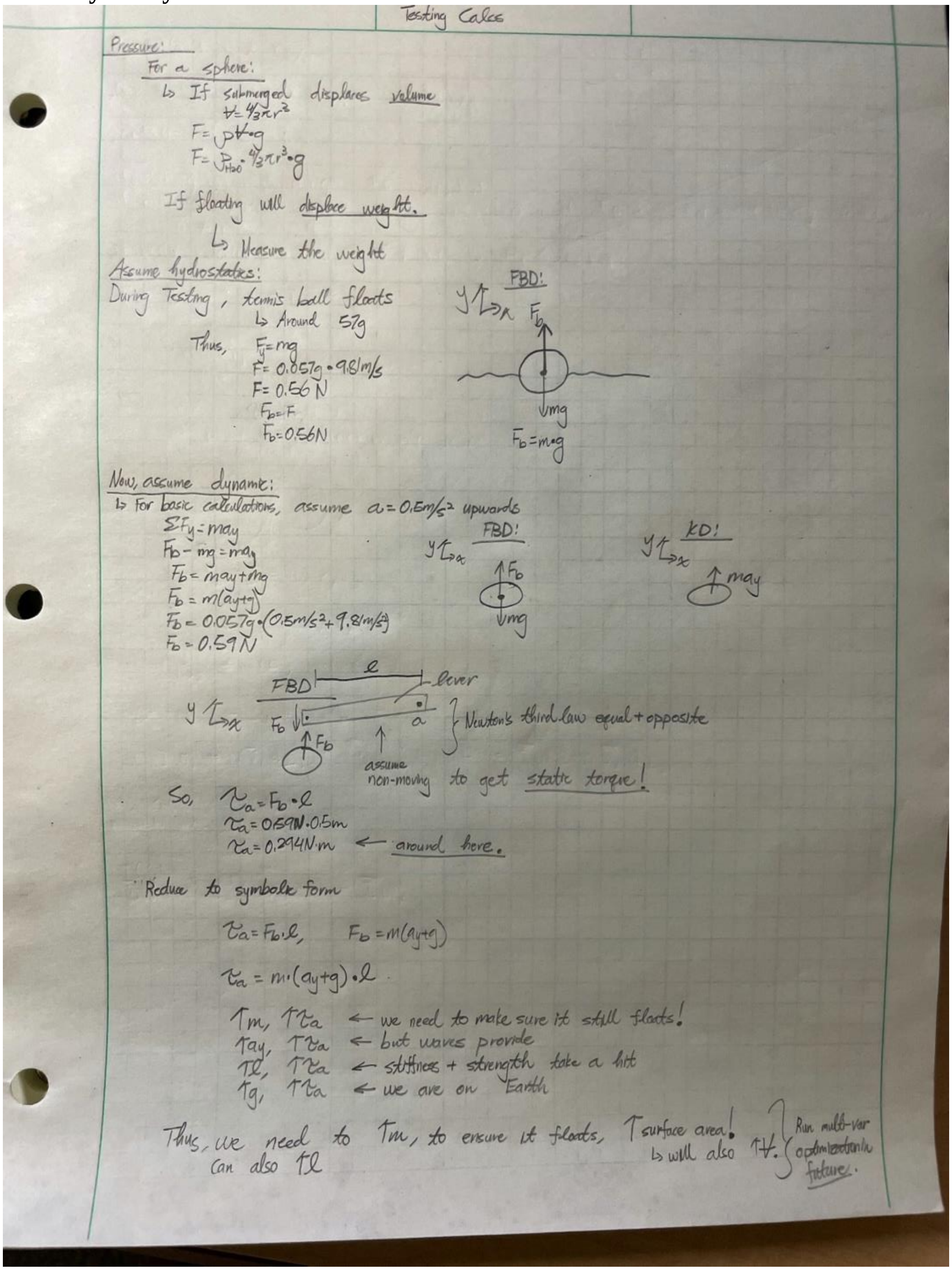
Test to see how pump height would effect motion

- Tennis ball
    - Still good motion
    - Lever arm moving to nearly horizontal position

- Buoy below lever arm is better than in-line with lever arm

- Ping pong ball
  - Water is moving lever arm more than buoy
  - Better bobbing and vertical motion (compared to test 1)
  - Buoy is nearly submerged by waves
    - And part of lever arm connected to buoy

Preliminary Analysis:



Testing Calcs

Pressure:

For a sphere:

↳ If submerged displaces volume

$V = \frac{4}{3}\pi r^3$

$F = \rho V g$

$F = \rho_{H_2O} \cdot \frac{4}{3}\pi r^3 \cdot g$

If floating will displace weight.

↳ Measure the weight

Assume hydrostatics:

During Testing, tennis ball floats

↳ Around 57g

Thus, $F_y = mg$

$F = 0.057g \cdot 9.8 m/s$

$F = 0.56 N$

$F_b = F$

$F_b = 0.56N$

Now, assume dynamic:

↳ For basic calculations, assume $a = 0.5 m/s^2$ upwards

$\Sigma F_y = ma_y$

$F_b - mg = ma_y$

$F_b = ma_y + mg$

$F_b = m(a_y + g)$

$F_b = 0.057g \cdot (0.5 m/s^2 + 9.8 m/s^2)$

$F_b = 0.59 N$

to get static torque!

So, $\tau_a = F_b \cdot \ell$

$\tau_a = 0.59N \cdot 0.5m$

$\tau_a = 0.294 N \cdot m$ ← around here.

Reduce to symbolic form

$\tau_a = F_b \cdot \ell, \quad F_b = m(a_y + g)$

$\tau_a = m \cdot (a_y + g) \cdot \ell$

$\uparrow m, \uparrow \tau_a$ ← we need to make sure it still floats!

$\uparrow a_y, \uparrow \tau_a$ ← but waves provide

$\uparrow \ell, \uparrow \tau_a$ ← stiffness + strength take a hit

$\uparrow g, \uparrow \tau_a$ ← we are on Earth

Thus, we need to $\uparrow m$, to ensure it floats, $\uparrow$ surface area! ↳ will also $\uparrow V$. } Run multi-var optimization in future.

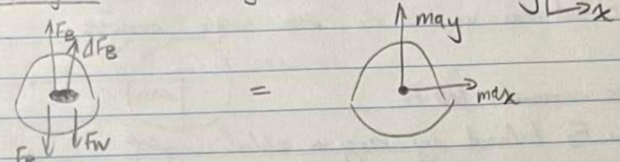
Can also $\uparrow \ell$

Appendix E: Structures and Force Analysis

Force Analysis:

Final Version:

FBD Analysis: *Buoy wants to move upwards



F_B, F_W cancel since floating

↑ only appears during movement

$F_W = F_g$ on buoy

F_B = buoyancy force

F_R = resistance due to pump at buoy

From pump graph, 69bar → 275 N of force, end of 550mm handle.

L = length of lever arm + pump handle (horizontal)

$$F_R = \frac{275N \cdot 0.55m}{L}$$

Assume $L = 1m$ for now

$F_R = 151.25N$

$\Sigma F_y = m \cdot a_y$

$\Delta F_B + F_B - F_R - F_W = m\ddot{y}$

$-\rho g A \cdot y - F_R = m\ddot{y}$

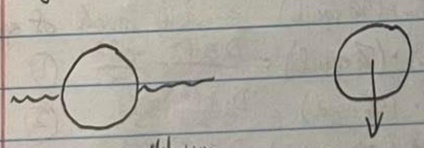
m in buoy mass, found in online specification sheet

$A(D, y) \Rightarrow$ cross sectional area depends on diameter + y (position)

Initial conditions?

Which Regime is this valid for?

Regime 1: Regime 2:



Buoy in equilibrium, moving upwards

Buoy moving downwards ✕

↑ Only to the extent that water level rising w/respect to buoy ($\Delta F_B = -\rho g A y$)

Not valid when water has risen enough relative to equilibrium that buoy starts moving

Very complicated analysis!

Let's switch gears

↳ Still use FBD, but now we will do more unique analysis

During equilibrium + no movement: No F_r

Thus, at equilibrium F_B balanced by $m_B g$ + added weight

↑ Need this b/c need buoy to move downwards!

↑ F_r always resists motion

Calculate % of buoyant force used during equilibrium

$\% equil = \frac{F_{extra} + mg}{F_B} \times 100$ } For $D_B = 18in$, w/ 24.6kg weight on buoy, buoy provides 112lb of buoyancy fo

$\% equil = 54.65\%$

When also opposing F_R, buoyant force used

$\% used = \frac{F_r + F_{extra} + mg}{F_B} \times 100$

$\% used = 85.01\%$

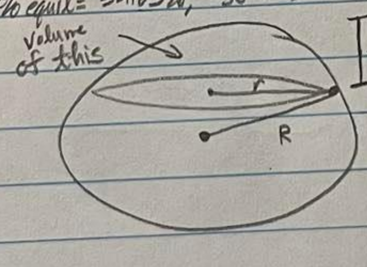
When buoy moving down, F_r opposing motion

$\% Downstroke = \frac{-F_r + F_{extra} + mg}{F_B} \times 100\%$

$\% Downstroke = 24.29\%$ ← % buoyancy Force used.

Where is water level in these situations?

$\% equil = 54.65\%$, so 54.65% of buoy volume underwater



$V_{cap} = \frac{D \cdot \pi \cdot h^2}{2} - \frac{\pi h^3}{3}$

$V_{cap} = V_{sphere} \cdot (\% equil)$ ← how much of sphere is underw

$\frac{4}{3}\pi (D/2)^3 \cdot (\% equil) = \frac{D \cdot \pi \cdot h^2}{2} - \frac{\pi h^3}{3}$ ①

$\frac{4}{3}\pi (D/2)^3 \cdot (\% used) = \frac{D \cdot \pi h^2}{2} - \frac{\pi h^3}{3}$ ②

$\frac{4}{3}\pi (D/2)^3 \cdot (\% Downstroke) = \frac{D \cdot \pi h^2}{2} - \frac{\pi h^3}{3}$ ③

①,②,③ solve for h

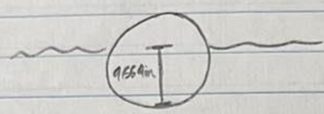
① ⇒ $h = 9.554in$

② ⇒ $h = 16.17in$

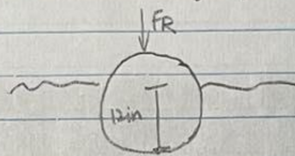
③ ⇒ $h = 5.77in$

Now, Assume buoy in equilibrium, $h = 9.554in$

* Assume 3ft (so amplitude = 1.5ft) wave



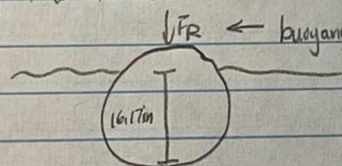
Water wants to move buoy up



when water level gets to 16.17in, will be able to provide upwards force.

Thus, the (16.17in − 9.554in) water moved, buoy is stationary
↳ 6.616in

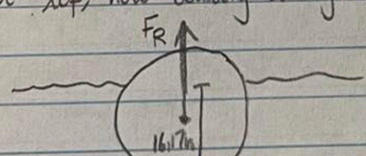
Now, buoy starts to rise:



← buoyancy can now counteract this!
↳ buoy will now rise w/waterline.

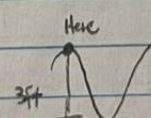
$1.5ft$ amplitude ⇒ $1.5ft \times \frac{12in}{1ft} - 6.516in = 11.484in$ of buoy rise

At top, now wanting to go down, no velocity



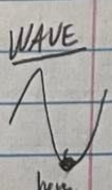
water level needs to drain to ③ $h = 5.77in$ for buoy to move down.

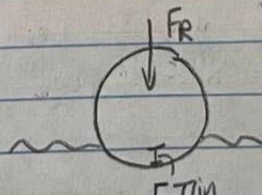
$16.17in - 5.77in = 10.4in$



Buoy motion ⇒ $3ft \times \frac{12in}{1ft} - 10.4in$
$= 25.6in$

Now at bottom, wanting to go up





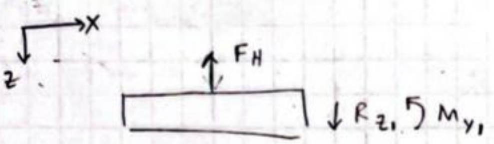
Water rise to 16.17in before rising w/water.

$16.17in - 5.77in = 10.4in$

Buoy motion ⇒ $3ft \times \frac{12in}{1ft} - 10.4in$
$= 25.6in$ ← how much we expect buoy to move.

Structural Analysis

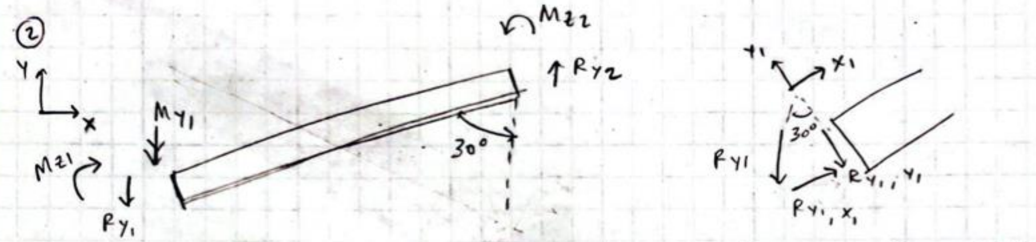
①



$F_z: \; -F_H + R_{z1} = 0$

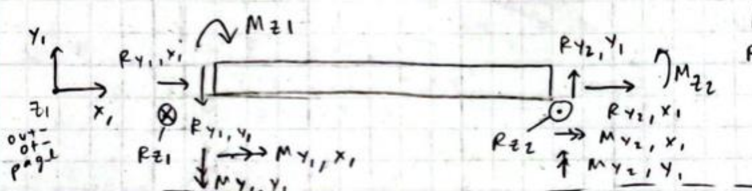
$(+)\; M_y: \; -F_H\left(\frac{L_1}{2}\right) + M_{y1} = 0$

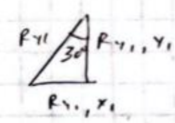
②



$R_{y1,y1} = R_{y1}\cos 30°$

$R_{y1,x1} = R_{y1}\sin 30°$





$F_{x1}: \; R_{y1,x1} + R_{y2,x1} = 0$

$F_{y1}: \; -R_{y1,y1} + R_{y2,y1} = 0$

$M_{z1}: \; -M_{z1} + M_{z2} + R_{y1,y1}(L_2) = 0$

$+ F_D\left(\frac{L_1}{2}\right) + M_{z2} + R_{y1,y1}(L_2) = 0$

$M_{y1,y1} = M_{y1}\cos 30°$

$M_{y1,x1} = M_{x1}\sin 30$

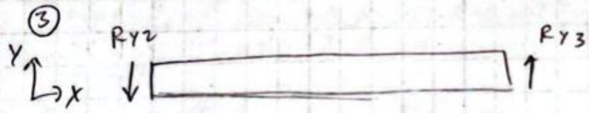
$M_{x1}: \; M_{y1,x1} + M_{y2,x1} = 0$

$M_{y1}: \; -M_{y1,y1} + M_{y2,y1} - R_{z1}(L_2) = 0$

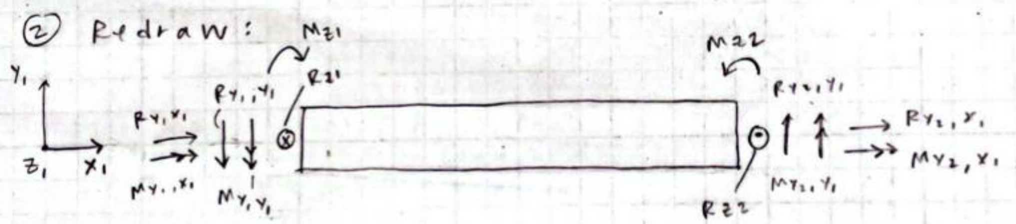
$F_{z1}: \; -R_{z1} + R_{z2} = 0$

$R_{y2} = \sqrt{R_{y2,x1}^2 + R_{y2,y1}^2}$ in $+\hat{y}$ dir.

③



② Redraw:



Define Parameters:

$L_1 = 3$ in
$L_2 = 32$ in
$F_D = 121$ N
$F_H = 217.73$ N
$D_o = 1.004$"
$D_i = 3/4$"

Solve:

① $F_y: -F_D + R_{y_1} = 0$
$R_{y_1} = F_D$
$R_{y_1} = 121$ N

$M_z: M_{z1} = -F_D(L_1/2)$
$= -121(3/2)$ N-in
$M_{z1} = -181.5$ N-in

$F_z: R_{z1} = F_H$
$= 217.73$ N

$M_y: M_{y1} = F_H(L_1/2)$
$= (217.73)(3/2)$
$= 326.6$ N-in

② $R_{y_1,y_1} = R_{y_1}\cos 30°$
$= (121\text{ N})\cos 30°$
$= 104.79$ N

$R_{y_1,x_1} = R_{y_1}\sin 30°$
$= 60.5$ N

$F_{x_1}: R_{y_2,x_1} = -R_{y_1,x_1}$
$= -104.79$ N

$F_{y_1}: R_{y_2,y_1} = R_{y_1,y_1}$
$= 60.5$ N

$F_{z_1}: R_{z2} = R_{z1}$
$= 217.73$ N

$\Rightarrow R_{y2} = \sqrt{R_{y_2,x_1}^2 + R_{y_2,y_1}^2}$
$= 120.88$ N ✓ ≈ 121
in positive $\hat{y}$-dir.

$M_{y_1,y_1} = M_{y_1}\cos 30°$
$= (326.6\text{ N-in})\cos 30°$
$= 282.84$ N-in

$M_{y_1,x_1} = (326.2\text{ N-in})\sin 30°$
$= 163.3$ N-in

$M_{x_1}: M_{y_2,x_1} = -M_{y_1,y_1}$
$= -282.84$ N-in

$M_{y_1}: M_{y_2,y_1} = M_{y_1,y_1} + R_{z1}(L_2)$
$= 163.3 + (217.73\text{ N})(32")$
$= 7130.66$ N-in

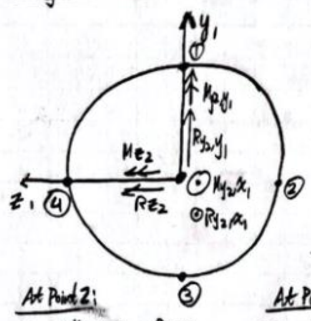
$M_{z_1}: M_{z2} = M_{z1} - R_{y_1,y_1}(L_2)$
$= -181.5 - (104.79)(32")$
$= -3534.78$ N-in

* convert N-in to N-m

<u>From above</u>

$R_{y_2,x_1} = -104.79N$
$R_{y_2,y_1} = 60.5N$
$R_{z_2} = 217.73N$
$M_{y_2,y_1} = 282.84$ N-in
$M_{y_1,x_1} = 162.3$ N-in
$M_{y_2,x_1} = -282.84$ N-in
$M_{y_2,y_1} = 7130.66$ N-in
$M_{z_2} = -3534.78$ N-in

<u>At very end:</u>



<u>At Point 1:</u>

$\sigma_{xx} = \frac{-M_{z_2} \cdot r_o}{I} + \frac{R_{y_2,x_1}}{A}$

$\tau_{xz} = \frac{R_{z_2} \cdot Q}{It}$ } Transverse shear → neglect

$\tau_{xy} = \frac{R_{y_2,y_1} \cdot Q}{It}$

$\tau_{xz} = \frac{M_{y_2,x_1} \cdot r_o}{J}$

<u>At Point 2:</u>

$\sigma_{xx} = \frac{-M_{y_2,y_1} \cdot r_o}{I} + \frac{R_{y_2,x_1}}{A}$

$\tau_{xy} = \frac{M_{y_2,x_1} \cdot r_o}{J}$

<u>At Point 3:</u>

$\sigma_{xx} = \frac{M_{z_2} \cdot r_o}{I} + \frac{R_{y_2,x_1}}{A}$

$\tau_{xz} = -\frac{M_{y_2,x_1} \cdot r_o}{J}$

<u>At Point 4:</u>

$\sigma_{xx} = \frac{M_{y_2,y_1} \cdot r_o}{I} + \frac{R_{y_2,x_1}}{A}$

$\tau_{xy} = -\frac{M_{y_2,x_1} \cdot r_o}{J}$

Since PVC all same diameter, this cross-section governs.

$A = \pi\left(\left(\frac{D_o}{2}\right)^2 - \left(\frac{D_i}{2}\right)^2\right)$

$I = \frac{\pi}{64}(D_o^4 - D_i^4)$

$J = \frac{\pi}{32}(D_o^4 - D_i^4)$

<u>Once through by hand:</u>

$A = \pi\left(\left(\frac{D_o}{2}\right)^2 - \left(\frac{D_i}{2}\right)^2\right)$
$A = \pi \cdot \left(\left(\frac{1.004in}{2}\right)^2 - \left(\frac{0.75in}{2}\right)^2\right)$
$A = 0.3499 in^2$

$I = \frac{\pi}{64}(D_o^4 - D_i^4)$
$I = \frac{\pi}{64}((1.004in)^4 - (0.75in)^4)$
$I = 0.03435 in^4$

$J = \frac{\pi}{32}(D_o^4 - D_i^4)$
$J = \frac{\pi}{32}((1.004in)^4 - (0.75in)^4)$
$J = 0.06869 in^4$

<u>Point 1:</u>

$\sigma_{xx} = \frac{-M_{z_2} \cdot r_o}{I} + \frac{R_{y_2,x_1}}{A}$

$\sigma_{xx} = \left(\frac{-(-3534.78N\text{-}in) \cdot \left(\frac{1.004in}{2}\right)}{0.03435 in^4} + \frac{(-104.79N)}{0.349 in^2}\right) \cdot \frac{1 in^2}{(2.54cm)^2} \cdot \frac{(100cm)^2}{(1m)^2}$

37.9 MPa
~54.8 MPa

$\sigma_{xx} = 79.6 MPa$

$\sigma' = (\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2)^{1/2}$

$\tau_{xz} = \frac{M_{y_2,x_1} \cdot r_o}{J}$

$\tau_{xz} = \frac{-282.84N\text{-}in \cdot \left(\frac{1.004in}{2}\right)}{0.06869 in^4} \cdot \frac{1 in^2}{(2.54cm)^2} \cdot \frac{(100cm)^2}{(1m)^2}$

$\tau_{xz} = -3.2 MPa$

<u>Von Mises:</u> $\sigma' = (\sigma_x^2 + \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2)^{1/2}$ ($\sigma_y = \sigma_z = 0$, τ_{xz})

$\sigma' = (\sigma_x^2 + 3\tau_{xy}^2)^{1/2}$

$\sigma' = \sqrt{(79.6MPa)^2 + 3 \cdot (3.2MPa)^2}$

$\sigma' = 79.8 MPa$

<u>Point 2:</u>

$\sigma_{xx} = \frac{-M_{y_2,y_1} \cdot r_o}{I} + \frac{R_{y_2,x_1}}{A}$

$\sigma_{xx} = \left(\frac{-7130.66N\text{-}in \cdot \left(\frac{1.004in}{2}\right)}{0.03435 in^4} + \frac{(-104.79N)}{0.349 in^2}\right) \cdot \frac{1 in^2 (100cm)^2}{(2.54cm)^2 \cdot 1m^2}$

$\sigma_{xx} = -162 MPa$

$\tau_{xy} = \frac{M_{y_2,x_1} \cdot r_o}{J}$

$\tau_{xy} = \frac{-282.84N\text{-}in \cdot \left(\frac{1.004in}{2}\right)}{0.06869 in^4}$

$\tau_{xy} = -3.2 MPa$

<u>Von Mises:</u> $\sigma' = (\sigma_x^2 + \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2)^{1/2}$

$\sigma' = ((162MPa)^2 + (3.2MPa)^2)^{1/2}$

$\sigma' = 162.1 MPa$

Point 3:

$$\sigma_{xx} = \frac{M_{z_2} \cdot r_o}{I} + \frac{R_{y_2 x_1}}{A}$$

$$\sigma_{xx} = \left(\frac{-3534.78\ N\text{-}in \cdot \left(\frac{1.004 in}{2}\right)}{0.03435 in^4} + \frac{(-104.79 N)}{0.3494 in^2}\right) \cdot \frac{1 in^2}{(2.54 cm)^2} \cdot \frac{(100 cm)^2}{(1 m)^2}$$

$$\sigma_{xx} = -80.5\ MPa$$

$$\tau_{xz} = -\frac{M_{y_2, x_1} \cdot r_o}{J}$$

$$\tau_{xz} = \frac{+282.84\ N\text{-}in \cdot \left(\frac{1.004 in}{2}\right)}{0.06869 in^4} \cdot \frac{1 in^2}{(2.54 cm)^2} \cdot \frac{(100 cm)^2}{(1 m)^2}$$

$$\tau_{xz} = 3.2\ MPa$$

Von Mises:

$$\sigma' = \sqrt{(-80.5 MPa)^2 + 3 \cdot (3.2 MPa)^2}$$

$$\sigma' = 80.7\ MPa$$

Point 4:

$$\sigma_{xx} = \frac{M_{y_2, y_1} \cdot r_o}{I} + \frac{R_{y_2 x_1}}{A}$$

$$\sigma_{xx} = \left(\frac{7130.66\ N\text{-}in \cdot \left(\frac{1.004 in}{2}\right)}{0.03435 in^4} + \frac{-104.79 N}{0.3494 in^2}\right) \cdot \frac{1 in^2 \cdot (100 cm)^2}{(2.54 cm)^2 \cdot 1 m^2}$$

$$\sigma_{xx} = 161\ MPa$$

$$\tau_{xy} = \frac{-M_{y_2, x_1} \cdot r_o}{J}$$

$$\tau_{xy} = \frac{+282.4\ N\text{-}in \cdot \left(\frac{1.004 in}{2}\right)}{0.06804 in^4} \cdot \frac{1 in^2}{(2.54 cm)^2} \cdot \frac{(100 cm)^2}{(1 m)^2}$$

$$\tau_{xy} = 3.2\ MPa$$

Von Mises:

$$\sigma' = \sqrt{(161 MPa)^2 + (3.2 MPa)^2 \cdot 3}$$

$$\sigma' = 161.2\ MPa$$

$$\eta = \frac{S_y}{\sigma'}$$

For PVC, $\eta = \frac{37.9 MPa}{161.2 MPa}$

$\eta = 0.235$ **Not good**

Appendix F: Matlab Scripts

Force Calculations

Editor - C:\Users\andyw\Desktop\All The Stuff\Cal Poly\ME 429\Buoy_diameter.m

Buoy_diameter.m | Audio.m | HighPassstuff.m | Audiomin.m | AudioProcTurb.m | AudioProcLam.m

```matlab
m = 6.903*0.454; % mass of the buoy [kg]
D = 0.457; % Diameter of the Buoy [m]
Wave_height = 3; % in feet!!!
L = 1; % horizontal length, in feet of lever arm and pump handle in meters
F_b = 112*4.4482; % Max buoyancy force---spec sheet [N]
F_r = 275*.550/L; % Resisting Hydraulic Pump force, assume 1m horizontal length[N]
g = 9.81; % acceleration due to gravity [m/s^2]
rho = 1026; % density of seawater[kg/m^3]
FS = 1.8; % factor of safety


Force_extra = F_r*FS - m*g % extra weight to add to end of lever arm to ensure downward stroke
mass_extra = Force_extra/g; % in kg, extra mass to add to lever arm
Percent_used = (F_r+Force_extra+m*g)/F_b % amount of buoyancy force "used" in order to overcome F_
Percent_equilibrium = (Force_extra + m*g)/F_b; % equilibrium amount of buoyant force used
Downstroke = (-F_r+Force_extra+m*g)/F_b % amount of buoyancy force "used" for resisting Fr
F_downstroke = -F_r+Force_extra+m*g; % net force in downwards direction during downstroke
a_downstroke = F_downstroke/(m+Force_extra/g); % needs to be around 0.5g

S = roots([-pi/3,D*pi/2,0,-4/3*pi*(D/2)^3*(Percent_equilibrium)])
h_equilbrium = S(2)*3.28084*12; % in inches
S = roots([-pi/3,D*pi/2,0,-4/3*pi*(D/2)^3*(Percent_used-0.5)])
h_max = S(2)*3.28084*12+D/2*3.28084*12; % in inches
S = roots([-pi/3,D*pi/2,0,-4/3*pi*(D/2)^3*(Downstroke)])
h_min = S(2)*3.28084*12; % in inches

h_moving = h_max-h_min; % height water has to transverse to get buoy moving [in]
amplitude_buoy = Wave_height*12-h_moving;
angular_displacement = amplitude_buoy/(L*3.28084*12)*180/pi;

%[t,y] = ode45(@buoy_up,[0 10],[0.2; 0]);
%[t,y] = ode45(@buoy_up,[0 20],[0;0],1.4,1026,9.81,96.25,0.3048,1);
```

Workspace

Name	Value
a_downstroke	4.3600
amplitude_buoy	25.6055
angular_displac...	37.2640
D	0.4570
Downstroke	0.2429
F_b	498.1984
F_downstroke	121
F_r	151.2500
Force_extra	241.5058
FS	1.8000
g	9.8100
h_equilbrium	9.5542
h_max	16.1687
h_min	5.7742
h_moving	10.3945
L	1
m	3.1340
mass_extra	24.6183
Percent_equilib...	0.5465
Percent_used	0.8501
rho	1026
S	[0.6588;0.1467;-0.12...
Wave_height	3

Structures Calculations

Editor - C:\Users\andyw\Desktop\All The Stuff\Cal Poly\ME 429\Structures.m

AudioProcessing.m | AudioProcessingTurbulent.m | LMSNConlyrun.m | Sensitivity.m | PostProc.m | Structures.m

```matlab
%% Input Parameters
l_1 = 3; %in
l = 32; %in
theta = 30;
F_d = 303.8; %[N] changed for worst case scenario, 1g acceleration downwards
F_h = 217.73; %[N]
D_o = 1.5; % in 1.75in for metal component
D_i = 0; % in 1.62in for metal component
Yield = 65; % MPa
k = 0.25;
E_c = 400000; %psi

%% Statics Calculations
R_y1 = F_d;
M_z1 = -F_d*l_1/2;
R_z1 = F_h;
M_y1 = F_h*l_1/2;


R_y1y1 = R_y1*cosd(theta);
R_y1x1 = R_y1*sind(theta);
M_y1y1 = M_y1*cosd(theta);
M_y1x1 = M_y1*sind(theta);


R_y2x1 = -R_y1x1;
R_y2y1 = R_y1y1;
M_z2 = M_z1-R_y1y1*l;
M_y2x1 = -M_y1x1;
M_y2y1 = M_y1y1+R_z1*l;
R_z2 = R_z1;
```

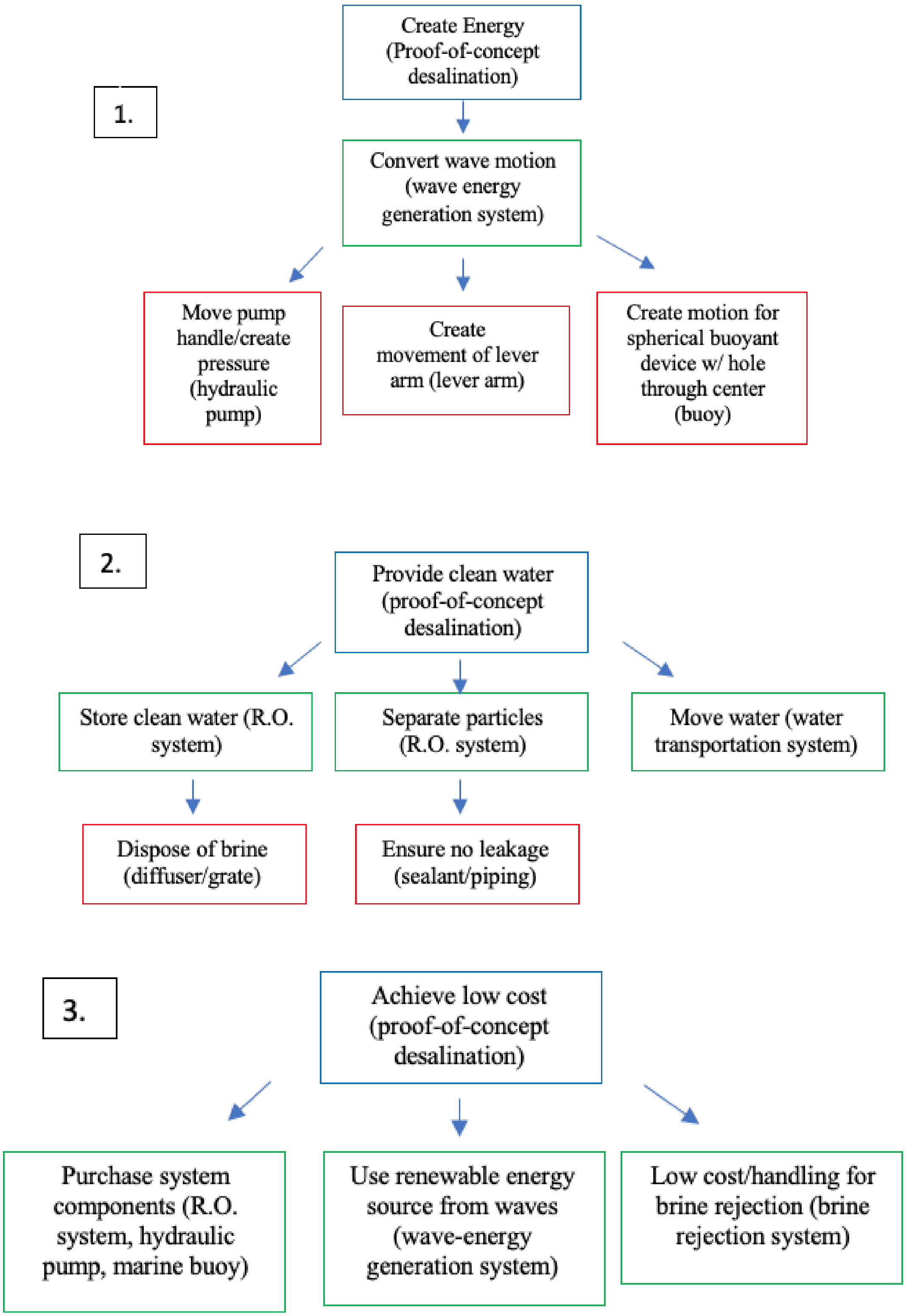
Workspace

Name	Value
a_downstroke	4.3600
amplitude_buoy	25.6055
angular_displac...	37.2640
D	0.4570
Downstroke	0.2429
F_b	498.1984
F_downstroke	121
F_r	151.2500
Force_extra	241.5058
FS	1.8000
g	9.8100
h_equilbrium	9.5542
h_max	16.1687
h_min	5.7742
h_moving	10.3945
L	1
m	3.1340
mass_extra	24.6183
Percent_equilib...	0.5465
Percent_used	0.8501
rho	1026
S	[0.6588;0.1467;-0.12...
Wave_height	3

AudioProcessing.m | AudioProcessingTurbulent.m | LMSNConlyrun.m | Sensitivity.m | PostProc.m | Structures.m

```
%% Cross Section Calculation
A = pi*((D_o/2)^2-(D_i/2)^2);
I = pi/64*(D_o^4-D_i^4);
J= pi/32*(D_o^4-D_i^4);

%% Point 1
sigma_xx_1 = (-M_z2*D_o/2/I+R_y2x1/A)*1/2.54^2*100^2;
Tau_xz = M_y2x1*D_o/2/J*1/2.54^2*100^2;
sigma_prime_1 = sqrt(sigma_xx_1^2+3*Tau_xz^2);

%% Point 2
sigma_xx_2 = (-M_y2y1*D_o/2/I+R_y2x1/A)*1/2.54^2*100^2;
Tau_xy = M_y2x1*D_o/2/J*1/2.54^2*100^2;
sigma_prime_2 = sqrt(sigma_xx_2^2+3*Tau_xy^2);

%% Point 3
sigma_xx_3 = (M_z2*D_o/2/I+R_y2x1/A)*1/2.54^2*100^2;
Tau_xz = M_y2x1*D_o/2/J*1/2.54^2*100^2;
sigma_prime_3 = sqrt(sigma_xx_3^2+3*Tau_xz^2);

%% Point 4
sigma_xx_4 = (M_y2y1*D_o/2/I+R_y2x1/A)*1/2.54^2*100^2;
Tau_xy = M_y2x1*D_o/2/J*1/2.54^2*100^2;
sigma_prime_4 = sqrt(sigma_xx_4^2+3*Tau_xy^2);

%% Find maximum stress and FS
sigma_prime_max = max([sigma_prime_1,sigma_prime_2,sigma_prime_3,sigma_prime_4]);
FS = Yield/(sigma_prime_max*10^-6);

P_cr = k*pi^2*E_c*I/l^2*4.44822; % in newtons
```

Appendix G: FMEA



												Action Results				
System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Detection	RPN
Wave Energy Generation System / Move Pump Handle	Too little pressure is generated	No fresh water is produced	5	1) Hydraulic pump does not generate enough pressure 2) RO system requires too much pressure	Testing to ensure sufficient lever arm movement	8	pressure gauge	1	40							
	Too much pressure is generated	RO system can no longer produce fresh water	6	1) Hydraulic pump generates too much pressure 2) RO system membrane ruptures	Testing to ensure sufficient lever arm movement	1	pressure gauge	1	6							
	Corrosion from salt water conditions	Seizing or fractures of mechanical components	3	1) Hydraulic Pump/other system components corrodes	1) Checking with manufacturer for salt water applications 2) Analysis of materials used 3)Regular checks on system components	7	visual inspection, water quality test	4	84	1) Spray non-toxic water corrosion resistant formula on the system components more likely to corrode (hydraulic pump, piping) 2) Analyze feasibility of plastic piping	Andy 1/10/22	This will reduce the occurrence of corrosion and also the severity since less corrosion will happen after treatment	2	4	4	32
Wave Energy Generation System / Lever Arm Movement	Lever arm too heavy or too long/short	Too little or no clean water	4	1) Heavy lever arm doesn't allow for sufficient buoy rebound 2) Wrong torque and frequency values achieved from wave motion	1) Early and often testing 2) CAD model analysis	2	visual inspection stifled buoy or pump handle motion, pressure gauge	6	48							
	Not enough motion in lever arm	Too little or no clean water	4	1) Pin connection is stuck 2) Lever arm yield or fractures	1) Early and often testing 2) CAD model analysis	7	visual inspection of stifled pump handle motion, pressure gauge	5	###.	Add additional simulation (creation of matlab script with inputs for force and lever arm length) and analysis time (dynamics analysis) to ensure that the lever arm will move	Amanda 2/1/22	This will reduce the likelihood that the motion of the lever arm is insufficient with extra analysis	4	2	5	40
Wave Energy Generation System / Buoy Motion	Seizing of buoy motion	Too little or no clean water	4	1) Biofouling 2) Wear or failure of buoy connections	regular maintance	2	visual insection	1	8							
	Buoy Sinks	Too little or no clean water	4	1) Not enough surface area 2) Buoy gets punctured 3) Insufficient buoyancy of buoy to raise lever arm	test floation capabilites of buoy	1	visual insection	1	4							
R.O. System / separate particles	leakage in pipes	a) maintance and clean-up issue b) less clean water to be stored for user	2	1) Sealant fails 2) Pipe has a hole 3) Bad connection between pipe junctions or system components	1) regular leak/maintance checks 2) ensure no leaks in pipe connections	4	visual inspection, pressure gauge, flowrate checks	5	40							

												Action Results				
System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Detection	RPN
R.O. System / purchase system components	components don't meet needs/specifications	User will need to purchase new components since system won't work	4	1) Filter does not desalinate water 2) System leaks chemicals into the water 3) Desalinates water too slowly	1)check specs online 2) email companies for additional specs/analysis	5	comparing manuf. Specs to own analysis of parts/components	5	###.							
	broken upon arrival	User will need to purchase new components	4	1) Components are fragile	n/a	1	visual insection	2	8							
	user mishandling	a) re-purchase components b) try to fix component	4	1) Defective parts (hydraulic pump, lever arm, RO system) 2) Parts arrive not as expected	read user manual	2	visual insection, compare specs	3	24							
Brine rejection system / facilitate brine through pipes	leakage in pipes	maintance and clean-up issue	2	1) Poor piping material 2) Sealant fails 3) Pipe has a hole 4) Bad connection between pipe junctions and components	1) regular leak/maintance checks 2) ensure no leaks in pipe connections	4	visual inspection, pressure gauge, flowrate checks	5	40							
	overflow/build up of brine in pipes	a) maintance and clean-up issue b) backup R.O. system and user will get gunky water	4	1) Build up of gunk in piping 2) Pipe materials (friction factor too high) 3) RO system doesn't desalinate as expected	regular maintance	5	visual inspection, pressure gauge, flowrate checks	4	80	Eventually, a filter will be installed at the inlet	Solie 2/1/22	This will reduce the occurance of build up of material in the pipe, nd if it does happen, will reduce the severity	3	2	4	24
Brine rejection system / release brine back into ocean	environmental damage	a) damage ecosystem by introducing too much salt b) sealife gets caught in grate	2	1) Diffuser grating is too large 2) Grating is placed in a precarious situation (near turtle egg hatching ground)	1) Early and often testing 2) check quality of desalination products	2	water quality tests, salinity test on brine rejection	7	28							
	doesn't perform desired diffusion	areas with highly-concentrated salt, so marine life may be injured	2	1) Diffuser doesn't spread out salt	1) Early and often testing 2) check quality of desalination products	3	water quality tests, salinity test on brine rejection, simulation	7	42							
	blockage in grate	a) maintance and clean-up issue b) no brine rejection, backup in pipes/R.O. system	3	1) Diffuser grate spacing is too small 2) Sea-life grows on the diffuser (biofouling)	1) regular maintance 2) early and often testing	3	visual inspection, pressure gauge, flowrate checks	3	27							
Water Transportation / Move Water	Leakage in piping	a) maintance and clean-up issue b) less clean water to be stored or clean water will leak	2	1) Bad piping material 2) Bad connections or sealant	1) regular leak/maintance checks 2) ensure no leaks in pipe connections	4	visual inspection, pressure gauge, flowrate checks	5	40							

Appendix H: Design Hazard Checklist

Y	N	
×		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
×		2. Can any part of the design undergo high accelerations/decelerations?
×		3. Will the system have any large moving masses or large forces?
	×	4. Will the system produce a projectile?
	×	5. Would it be possible for the system to fall under gravity creating injury?
	×	6. Will a user be exposed to overhanging weights as part of the design?
	×	7. Will the system have any sharp edges?
	×	8. Will any part of the electrical systems not be grounded?
	×	9. Will there be any large batteries or electrical voltage in the system above 40 V?
×		10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	×	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	×	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	×	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	×	14. Can the system generate high levels of noise?
×		15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
	×	16. Is it possible for the system to be used in an unsafe manner?

Appendix I: Design Verification Plan

DVP&R - Design Verification Plan (& Report)

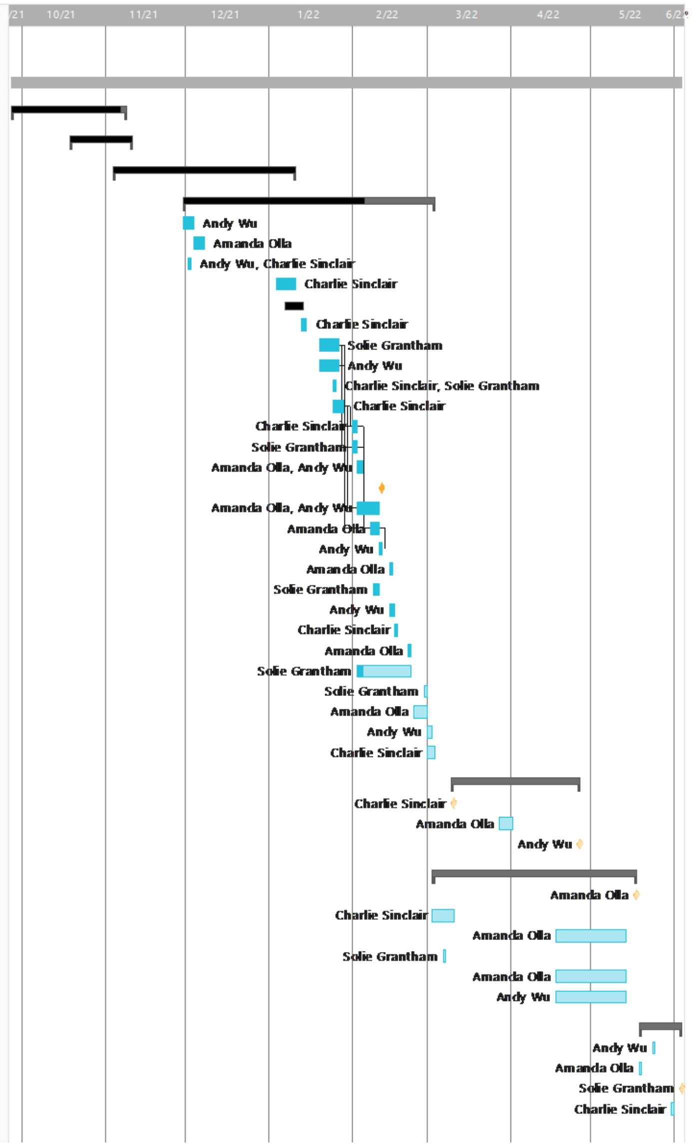
Project: F25 | Sponsor: Dr. Schuster | Edit Date: 2/3/22

TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING Start date	Finish date	Numerical Results	Notes on Testing
1	Power generated by the waves must be sufficient to create 55-69 bars of pressure	In this test, the lever arm and buoy system will be placed in a pool, with waves created by hand in order to determine the movement of the buoy and if it is sufficient to move the hydraulic pump handle.	Angular displacement of the lever arm handle	For a 1 foot wave, the lever arm moves at least 15 degrees	Charlie's Pool	SP--wave energy conversion system	Charlie	2/18/22			
2	Power generated by the waves must be sufficient to create 55-69 bars of pressure	The newly constructed lever arm from the final prototype (fixed length and larger diameter) will be placed with the buoy in an ocean. The pier location has yet to be specified	Amount of water at the outlet of the system	Water is generated at the outlet of the system (any amount is ok for this test)	Pier near the ocean	FP	Amanda	4/2/22			
3	Size must be 2 by 4 feet (exluding the buoy and lever arm)	For a table-top display, the whole system (minus the lever arm and buoy) must fit on a 2 ft by 4 ft benchtop display. Thus, the whole system will be rearranged so that it fits on the benchtop display	Area needed for all components	All components fit on the benchtop display	2 ft by 4 ft table	FP	Solie	4/2/22			
4	Flowrate must be greater than or equal to 1 gallon per hour	This test will happen simultaneously with test number 2, at the pier. The lever arm and buoy will be placed in the water, while the rest of the system is on the pier.	Amount of water produced in 30 minutes	0.5 gallons/30 minutes or greater	Pier near the ocean	FP	Amanda	4/2/22			
5	The pH of the water must be between 6.3-7.7, and the water salinity must be acceptable	This test will occur right after test 2, after the water has been desalinated at the pier. We will go to the collection tank and use litmus paper and salinity strips to test the water	pH, salinity in ppm	pH: Between 6.3 and 7.7 Salinity: less than 1000 ppm	Pier near the ocean	FP	Andy	4/2/22			

Complete these columns when you conduct the tests.

Appendix J: Team Gantt Chart

Task	Work	% Complete
F25 - SALT	0h	78%
Problem Definition	0h	95%
Project Concept and Design	0h	100%
Concept Generation & Selection	0h	100%
Detailed Design & Analysis	0h	72%
Perform FMEA	0	100%
Peer review FMEA	0	100%
Assign final ME 428 team tasks	0	100%
Manufacturing plan summary table	0	100%
Interim Design Review (IDR)	0h	100%
Structural Prototype plans	0	100%
Final CAD	0	100%
Part selection	0	100%
SP Build Day	0	100%
Indented Bill of Materials (iBOM)	0	100%
Manufacturing plan	0	100%
Part Layout and assembly drawings	0	100%
Design Verification Plan (DVP)	0	100%
Critical Design Review (CDR)	0	100%
Write CDR Report	0	100%
Present CDR	0	100%
Submit CDR to sponsor	0	100%
Yellow tag test	0	100%
Drawing and Spec Package	0	100%
Risk Assessment	0	100%
Safety Review	0	100%
Experimental design plan	0	100%
Structural prototype	0	10%
What-if scenario (solo task)	0	0%
CDR Report updates	0	0%
Preliminary experiment test procedu...	0	0%
Write test procedure (solo task)	0	0%
Manufacturing	0h	0%
Manuf & Test Review	0	0%
Project Update Memo	0	0%
Verification Prototype Sign-Off	0	0%
Testing	0h	0%
DVPR Sign-Off	0	0%
Test angular displacement of lever a...	0	0%
Test: measure water produced from ...	0	0%
Measure dimensions of full aparatus	0	0%
Measure flowrate	0	0%
Test pH level and salinity	0	0%
Project Wrap-up	0h	0%
Write FDR Report	0	0%
Create Expo Poster	0	0%
Final Design Review (FDR)	0	0%
Clean out workspaces	0	0%



WAVE GOODBYE TO SALT

Final Design Review

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Spring 2022

Table of Contents

1. Design Updates

Since Critical Design Review (CDR), one major design change we made was finding a new backpressure valve. While the original valve would probably have worked, we were unable to figure out how it might operate since there was no documentation online. Thus, we decided to purchase a different backpressure valve from McMaster-Carr that had robust documentation. Furthermore, upon receiving the Reverse Osmosis (RO) system right after CDR, we discovered that the pressure needed to operate the RO system was lower than the documentation suggested. Due to this, we decided to operate the system at 300psi. By operating at a lower pressure, there would be even less combined stress on the lever arm, resulting in an even higher factor of safety on the lever arm than previously analyzed. Since the factor of safety will be higher than previously analyzed, we are confident that the lever arm will not fail, and no new structures analysis needs to be completed.

2. Manufacturing

The following section describes the part procurement process, as well as manufacturing the verification prototype.

2.1 Part Procurement

From CDR, most of the components for assembly were in the process of being shipped. The tube reducer from the lever arm to pump handle was bought from McMaster-Carr, as well as the back pressure valve. Most of our procurement process thereafter involved buying parts as needed from various suppliers. Bolts for lever arm connections and for the securement of the hydraulic pump to the pump fixture were purchased at Home Depot along with wood screws for the front support of the pump fixture. After a failed assembly, where leaking was present within the system, a coupling component was replaced at Ferguson Plumbing Supply. This leaking failure was caused by the tapered design of the two male fittings being incompatible with the non-tapered coupling. Another failure within the pumping mechanism itself warranted another trip to Home Depot where hydraulic oil was purchased to keep the pump from corroding any further. The high-pressure tubing was purchased from Airgas, which is a company that specifically manufactures high pressure tubing for medical applications. The final list of expenses is found in Appendix A.

When purchasing the parts, great care was taken to ensure that all components would fit together for easy assembly, as fittings were all purchased that fit the NPT standard, and various diagrams were drawn to ensure that all pipes of various diameters had the proper fittings. Apart from a leak due to a faulty coupling, the whole assembly process was smooth.

2.2 Verification Prototype Manufacturing

The lever arm and pump fixture were the main components that required manufacturing. All manufacturing of the pump fixture was done in Mustang 60, where 2x4 lumber was cut at the appropriate angles and ¾ inch plywood was cut to form the fixture base and vertical support plate. Holes were then drilled through the 2x4s and the support plate to allow for a bolted connection between the pump and the fixture itself. Each joint was glued before being screwed together using wood screws. See Figure 1 for a photo of the completed pump fixture.

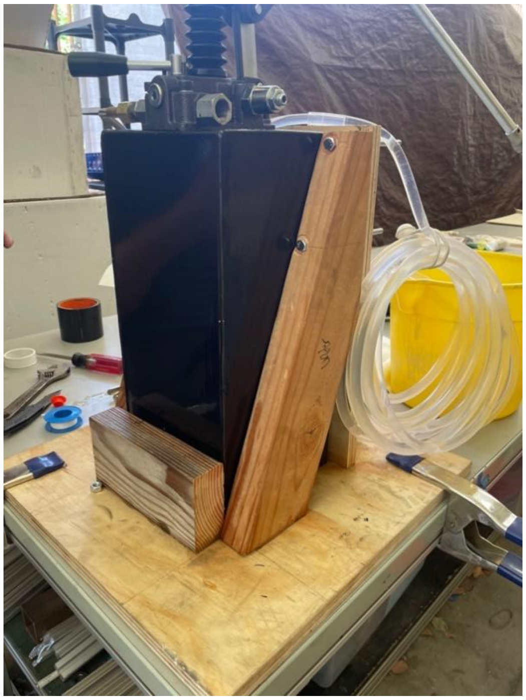


Figure 1. Pump fixture

The lever arm required many steps to manufacture, which were all completed at Mustang 60. First, the aluminum tubing was cut into two parts, with one part being 4 inches and the other part consisted of what was left of the tube. Afterwards, extensive deburring was needed to ensure that the tube was safe to touch. The ends of the tubes were fitted into their proper fittings. From there, we outsourced our welding to a shop tech at the Hangar to mate the tubes and the fittings. Next, at the end of the pump lever arm, one through hole was drilled for a bolt to be placed through. The weld joint purchased from McMaster-Carr also had a through hole drilled to put a bolt through both components, locking them into place. The pump lever arm is zinc-coated and the weld joint is stainless steel - making it a difficult welding process, so a bolted connection was determined to be the best option. Figure 2 shows the bolted connection.

Figure 2. Lever arm to pump handle connection

Finally, to ensure that the buoy would stay in place, two extra through holes were drilled in the portion of the lever arm that the buoy would attach to. A hole was also drilled through the buoy so that a bolt could be put through the buoy and the lever arm to secure the buoy robustly to the lever arm as seen in Figure 3. Bolts were placed through both of the through holes.

Figure 3. Buoy to lever arm connection

Then, the manufactured parts and purchased components are assembled for the full verification prototype as seen in Figure 4. See Appendix B for the User Manual.

Figure 4. Full verification prototype assembly

The full verification prototype built is able to test the whole system functionality. The waves will cause the buoy to move up and down, resulting in the pump pressurizing the fluid and forcing it through the RO system (which satisfies the customer need of fresh water). The inlet tubing is also installed onto the inlet of the pump so that water can be transported from the bucket, and the RO system's outlet is installed with the backpressure valve to ensure the water coming out of the system is at atmospheric pressure. Furthermore, as there are no electrical components in the system, it is safer for the customer to operate as there is no risk of electrocution and the system is more efficient.

2.3 Challenges and Lessons Learned

During the manufacturing process of the lever arm, our team had to overcome some issues, some being self-inflicted and others being products of slight clearance connections between parts. Firstly, when welding the lever arm into its fixed position, the lever arm was accidentally welded into the reverse position, placing the hole to secure the buoy in an upside-down position. To account for this, a new hole was welded in the correct position, resolving the problem.

Another issue with the lever arm was the bolted connection from the pump handle to the lever arm itself. This connection had a noticeable clearance fit which resulted in an energy loss from the wave motion to the hydraulic pump. To remedy this loss, aluminum tape was wrapped around the pump handle to occupy the open space between the concentric pipe connection. Approximately four wraps of tape were applied until it was a tight fit and the team was satisfied with the results.

The pump fixture was improved by adding a back support so that the pump would not move around during operation. The base of the pump would move around when the pump handle was in action (moving up and down). The purpose of the pump fixture was to hold the pump in place as well as having an attachment mechanism to a table or platform. The fixture was not doing a sufficient job of holding the pump in place, so an additional component was added. The component is a piece of 2x4 wood that fits securely between the two diagonal 2x4s on the backside of the pump. The new component is screwed into the wood board base from the bottom up. This piece was successful in securing the pump while the pump handle is in action which prevents loss of energy and increased difficulty of moving the pump handle. The 2x4 added is seen in Figure 1 (front piece of wood that goes across the bottom of the pump).

3. Design Verification

3.1 Design Specifications

The nine specifications and corresponding parameters are listed in Table 1. These parameters ensure that our design will generate enough fresh water, stay within a budget, and satisfy environmental guidelines. When testing, we designed tests to be able to see if the verification prototype would be able to meet these specifications. Some, such as operation noise, were not tested since during ocean testing it was obvious that the wave noise was louder than the operation noise of the system. Furthermore, the buoy that was purchased met the EPA codes and was the only item in the water. Thus, our system automatically meets those two specifications.

Table 1. Engineering Specifications Table

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk*	Compliance**
1	Power generated by waves	Power required to generate 55-69 bars	+/- 1 bars	H	A,T
2	Size	2ft x 4.5ft	Max	M	I
3	Cost	$2000	Max	M	S
4	Materials	Non-Corrosive and Water-tight	Set	M	I,A
5	Codes/Standards	Meets EPA codes	Set	M	I
6	Vol. Flowrate	1 gal/hr	Min	H	A,T
7	Operation Noise	Below 85 dB	Max	L	T
8	Water Quality	8 pH	+/- 1.5	L	T
9	Water Quality	Less than 1000 ppm salinity	Max	L	T

*Risk of meeting specification: (H) High, (M) Medium, (L) Low

**Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

1. Power generated by the waves must be able to create a differential pressure of 55-69 bars. Too much pressure will rupture the membrane, and if there is too little pressure, no desalination will take place.
2. The size of the whole system must be less than 2ft by 4.5ft, which is around the size of a tabletop (excluding buoy and lever arm).
3. The cost of the prototype must be less than 2000 dollars.
4. Materials used to create the systems must be non-corrosive and water-tight (for systems containing fluids).
5. In order to be legal, the device must meet EPA standards for long term use in the future.
6. The volumetric flowrate of the system must be greater than or equal to 1 gallon per hour, which will be tested by timing the system.
7. The operation of the system must be less than 85dB, which can be tested with a sound meter.
8. The water quality must be between a pH of 6.5 and 9.5 and will be tested with Litmus paper.
9. The water quality testing also includes salinity, which must test less than 1000 ppm using salinity test strips.

3.2 Tests

Testing was performed in three phases to verify the viability of the design and ensure specifications were met. The three phases include: Mustang 60 testing, pool testing, and ocean testing. The risks associated with these tests, use, and maintenance are detailed in Appendix C. See Appendix D for the Design Verification Plan & Results (DVP&R) and Appendix E for all test procedures and results. A short table summary of tests can be seen in Table 2.

Table 2. Test Summary Table

Test	Specification	Result	Pass/Fail
Size	<(4.5' x 2')	4.25' x 1.5'	Pass
RO pressure differential	<15psi	Max: 40 psi	Fail
Lever arm cycles	< 3 cycles for tests on separate days	0 cycles	Pass
Flowrate with angular displacement of lever arm	>1 gph for ±10-40°	4.94-10.88 gph ±10-40°	Pass
Flowrate (ocean test)	>1 gph	1.295 gph	Pass
Salinity	<1000 ppm	1640 ppm	Fail
pH	6.5-9.5	9.0	Pass

3.2.1 Mustang 60 Tests

At Mustang 60, we performed testing without water to evaluate the size of the system, pressure in the RO filter, flowrate due to varied angular displacements, and the force required on the pump handle. This was a logical first step to ensure all components of the system were working.

The size of the system was evaluated by measuring the length and width of the assembled system from the hydraulic pump to the end of the back pressure valve. The wave generation subsystem consisting of the lever arm and the buoy were not considered in the size measurements because it will hang off the table. The inlet and outlet buckets and tubing are also not included in the size measurement. The specification for this test was to be less than 2ft x 4.5ft to fit on a table for display as a proof-of-concept system. The measured dimensions were 1.4ft x 4.25ft; therefore, the system size meets the specifications.

The pressure in the RO filter was tested by determining the pressure differential and number of lever arm cycles to achieve pressure and flow. The purpose of the pressure differential test was to ensure the RO filter creates a pressure differential but does not exceed the maximum pressure differential of 15 psi, as specified by the manufacturer. Sufficient pressure is necessary to push water through the filter, but too much pressure differential will rupture the membrane and the filter will be ineffective. The full system must be assembled for this test with the back pressure valve tightened and pressure should already be established by manually moving the buoy up and down. The back pressure valve needs to be slightly opened to relieve some pressure until a reasonable flow rate is achieved, which we determined was approximately 300psi. This pressure value of 300psi was the standard or stabilizing pressure for all our tests. See Appendix E for more details. The pressure differential was below 15psi for most cycles, except the initial cycles where we measured differences in pressure of 40 psi and 30 psi. Despite the exceeded pressure differential, we were still able to achieve flowrate at the desired pressure and later desalinate the water. However, this high-pressure differential could have caused some damage to the membrane, but we would have to take apart the RO filter to affirm this.

We determined the number of lever arm cycles to generate pressure, achieve the desired pressure, and produce water flow. The system was fully assembled for this test except the buoy and lever arm. We can determine the lever arm cycles by moving the pump handle up and down. After 6 cycles, we started seeing pressure on the pressure gauges and at 7 cycles the desired pressure of 300psi was achieved. Additionally, we counted 10 cycles to get water flow through the system. We performed the same tests on a different day for repeatability and got the same results which indicates consistency. The pass criteria for this test was that the lever arm cycles must be within 3 cycles on separate days. Thus, we passed this test by having no differential.

The next test aimed to determine the impact of various angular displacements on the flowrate of desalinated water in the system. We assembled the full desalination system for this test and used tap water for ease of testing and less clean-up. The angular displacements from +40° to -40° in increments of 10° were drawn on posterboard and attached to the hydraulic pump where 0° was parallel to the table and the axis was at the pump handle pin joint (point of motion). The pump handle was moved up and down at a constant rate to the measured angular displacement markings from ±10° to ±40° in increments of ±10°. The flowrates achieved were from 4.94gph to 10.88gph for ±10° to ±40°. Our desired flowrate was at least 1gph; therefore, this test passed. See Section 3.3 for more results and error propagation.

The final Mustang 60 test was finding the maximum force necessary to move the pump handle from a stationary position. We obtained a force gauge from the ME Equipment Room which attached to the pump handle by hooking the force gauge to the hole at the very end of the pump handle arm (hole where screw should be to connect pump handle to lever arm). The rest of the system was assembled from the pump handle to the outlet bucket for this test. We read the force from the force gauge for both the upward and downward motion of the pump handle and recorded the range of values. This test was run five times, then we evaluated the maximum upward force to be 31 lbf and maximum downward force to be 24 lbf. Our initial calculations in Matlab indicate a force of 15 lbf required by the waves. The discrepancy between our results and calculations was due to the acceleration applied to the force gauge, which manifests as an increased force.

3.2.2 Pool Tests

The system prototype was initially tested using manually generated waves in a swimming pool. These tests were done to confirm functionality and filtered water flowrate of the design. The manually generated waves were made by displacing water at two ends of the pool using boards. We were able to create a 1 ft wave (trough to peak) which we used to produce an angular displacement in the lever arm. We anticipated this would displace the buoy enough to generate a flowrate through the system.

After running the system with the 1 ft waves for approximately 3 minutes (see Appendix E for this procedure), we were able to achieve a trickling flowrate, which was enough to satisfy the flowrate specification for this test. Running the system also verified the functionality of the design for the first time, confirming that the different aspects of our design could work together to achieve a freshwater flowrate.

Figure 5. View of outlet tubing to show flowrate through system

From pool testing, we noticed that our lever arm had some significant energy losses due to a loose connection due to the bolted connection from the lever arm to the pump handle. We also determined that we needed to attach the pump fixture to the table using multiple clamps due to the lever arm having a large amount of leverage on the pump. Lastly, we decided it would be best to attach all components to the table for further testing using tape and clamps to avoid components falling off and being lost or damaged during ocean testing.

3.2.3 Ocean Tests

The full system was set up and tested in the ocean at Morro Bay. In order to prevent the system from being clogged with sand, the inlet to the system was a controlled element, and saline water was generated to pump through the system. The final setup can be seen in Figure 6.

Figure 6. Full System assembled at Morro Bay

The system was taken into the ocean and held steady by members of the group as ocean waves passed over the buoy, driving the system. The testing is shown in Figure 7.

Figure 7. Testing in the water

The test enabled the team to evaluate overall design function. Time held in the water and the amount of water collected were recorded to find the flowrate of the system. Water collected in the inlet and outlet containers were tested for salinity and pH and compared. The side-by-side comparison of these tests can be seen in Figure 8, where the left-hand side corresponds to the inlet test and the right-hand side corresponds to the outlet test. Specifications for water quality required a maximum ppm of 1000 and a target of 8 pH +/- 1.5. The outlet had a pH value of 9, which met the requirement specified.

Figure 8. Test strips from ocean testing (inlet on left, outlet on right)

There was a clear general decrease in salinity based on the test strips used, as seen in Figure 8, but the resulting salinity did not meet specifications set for testing. The system removed approximately 85% of salt from the saline water run through the system, with a final salinity of

1640 ppm. Figure 9 shows the amount of salt removed as read from the test strip as it follows the trendline found on the back of the bottle of test strips.

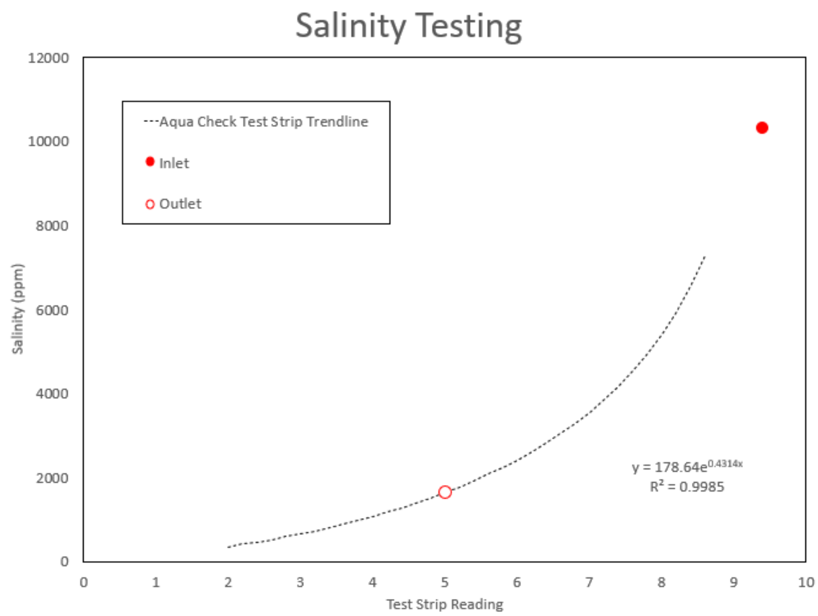


Figure 9. Salinity test strip reading

3.3 Numerical Data Collection and Error Propagation

In the Flowrate vs Angular Displacement test, we were able to collect numerical data on the time it took for the system to output 0.25 gallons. See Table 3. for numerical data collection results.

Table 3. Flowrate vs Angular Displacement testing results

Angular Displacement (degrees)	Total Angular Displacement (degrees)	Time to get to 0.25 gallons (sec)	Flowrate (gph)
± 10	20	182.29	4.94
± 20	40	126.79	7.10
± 30	60	86.27	10.43
± 40 (max)	80	82.71	10.88

When the flowrate is graphed versus total angular displacement, it is seen that the pump flowrate starts saturating at over 60 degrees of angular displacement, as the flowrate no longer increases significantly. This phenomena is seen in Figure 10. This impacts the overall curve fit, which is evidenced by the low R-squared value. In this case, it is better to create two curve fits, one before the pump saturates and one after the pump saturates. As seen in Figures 11 and 12, this provides better curve fits.

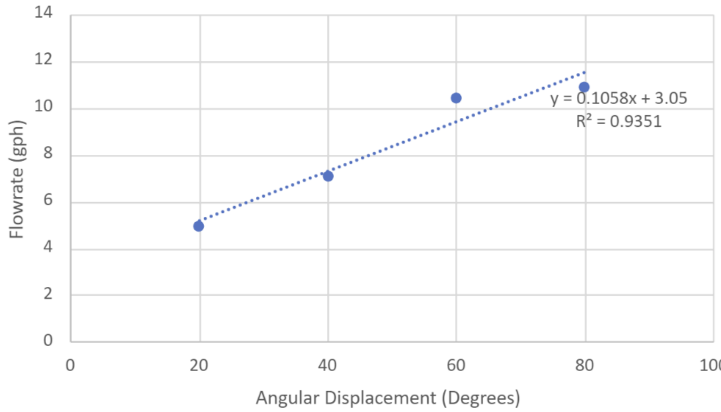


Figure 10. Overall curve fit of the data.

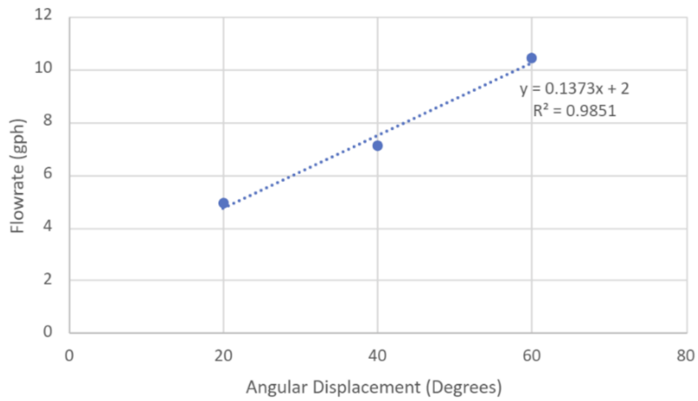


Figure 11. Curve fit of the data before pump saturation

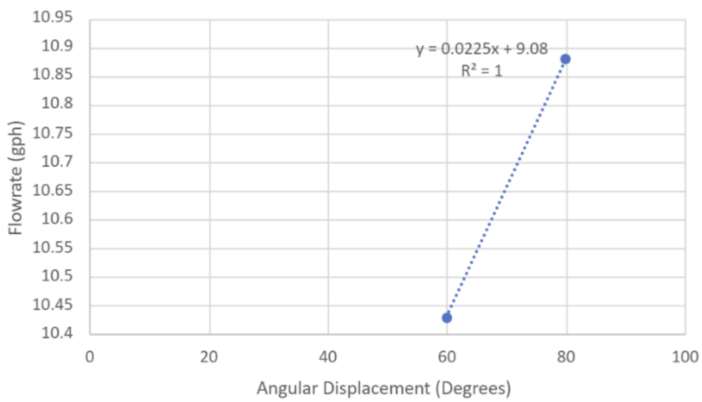


Figure 12. Curve fit of the data after pump saturation

The angular displacement uncertainty is 5 degrees, which is one half of the finest resolution (10 degrees). Furthermore, the volumetric uncertainty is plus or minus 0.03125 gallons, which is one half of the finest resolution (0.5 pints). As seen, the stopwatch resolution is small (reads to one hundredth of a second) and thus, its uncertainty is very small compared to the angular displacement and the volumetric uncertainty. Therefore, the uncertainty will be dominated by the volumetric and the angular displacement uncertainty, which means that the stopwatch's uncertainty can be neglected. As seen in Table 4, only the angular displacement and volumetric uncertainty is shown. Furthermore, when propagating uncertainty, as seen in column six of Table 4, the function evaluations are done with the curve fits distinguishing between before and after saturation, as illustrated in Figures 11 and 12. The function in column seven is as follows:

$$gph = \frac{gallons}{time\,(\text{sec})} \cdot \frac{3600\,(sec)}{1\,(hour)} \quad [1]$$

In equation one, gallons per hour is calculated, where "gallons" and "time" would be inserted with gallons measured and time it took to obtain that specific volume. Afterwards, sensitivities were calculated and root sum squared to obtain the actual uncertainty, as seen in Table 4 in the "uc" column.

Table 4. Uncertainty propagation of the completed test

x1	x2	ux1	ux2	f(xm)	f(x1+ux1)	f(x2+ux2)	s1	s2	uc
Angular Displacement (Deg)	Gallon Reading	(+/- Degrees)	+/- Gallons	gph	gph	gph	gph	gph	gph
20	0.25	5	0.03125	4.746	5.433	5.554	0.687	0.808	1.061
40	0.25	5	0.03125	7.492	8.179	7.986	0.687	0.494	0.846
60	0.25	5	0.03125	10.43	10.543	11.736	0.113	1.306	1.311
80	0.25	5	0.03125	10.88	10.993	12.242	0.113	1.362	1.366

As seen, after propagating the uncertainty, the uncertainty in the flowrate is approximately plus or minus 1 gallon per hour for all tests, and is well within the acceptable range of uncertainty for experimental tests.

3.4 Challenges and Lessons Learned

The journey from ideation to the final design prototype brought upon a number of challenges and valuable lessons.

A major challenge we had was corrosion in the internal cavities of the hydraulic pump. The hydraulic pump is rated for water applications, but it recommends using non-corrosive hydraulic fluid. Our project requires flow of water through the system, so we wanted to avoid damaging or seizing our pump as much as possible. We ran into the corrosion issue when we were trying to perform testing, but the pump was not generating any water flow from the inlet to the outlet. We had tested a few days prior and dried out the components, but there must have been some remaining water in the pump which clogged up the internal cavities. At the Hangar, we took apart and evaluated the components of the pump. We resolved the issue by spraying pressurized air through the small holes inside the pump and wiping down the components to clear out the corroded material. As a short-term solution for testing, we procured hydraulic oil to flush the system of water after every testing day was completed. The formal procedure for pumping oil through the pump is listed in Appendix B. It should be noted that the RO membrane is not suitable for fluids other than water, so we must isolate the hydraulic pump to pump oil through the system without disrupting the other components in the system. The hydraulic oil pushes out the water and coats the pump's internal cavities so that it will not corrode. A better long-term solution to the corrosion issue could be finding a more suitable corrosion-resistant fluid to coat the vital system components or getting a hydraulic pump that is designed for water and/or seawater applications.

Another issue with the verification prototype is the elbow and bolt connections on the lever arm. The elbows become loose when the buoy and lever arm are in motion; therefore, there is a loss of energy. The bolts through the elbow joints need to be securely tightened to prevent loosening due to motion and subsequent energy losses. After performing our first ocean test, it was immediately obvious that an ocean setting would require the welding of the adjustable connections to a fixed position. The constant presence of cold ocean water resulted in a loosening of the elbow joint, which refused to lock back into place using the screw connection. We solved this problem by welding both of our steel elbow joints at specific angles instead of leaving them adjustable to account for the variability of test sites. While it would be beneficial to be able to adjust these angles, we chose an "all-purpose" angle that can be used for most test situations. The bolted connection point on the lever arm also experiences unwanted motion and loss of energy. The bolt through the pump handle and tube reducer had some clearance due to the difference in diameters of the two components. The tube reducer was purchased from McMaster-Carr with the closest dimensions we could find to fit both the lever arm and pump handle, but there was some clearance on both sides. The connection from the tube reducer to the lever arm is welded so it is not a sizing issue, but the bolted connection to the pump handle was somewhat loose. We resolved this problem by putting aluminum tape around the end of the pump handle where it goes into the tube reducer. We applied about four rounds of tape until it was a tight fit into the tube reducer and cut out the holes for the bolts before attaching the components.

4. Discussion & Recommendations

During the project, we decided as a team to refine our scope to focus on a proof-of-concept design. These refinements included cutting out the brine rejection function from our initial design and limiting our ocean testing.

4.1 Recommendations for Future Iterations

If we were continuing the design, we would manufacture a water-resistant pump fixture and design and build a system to restrict horizontal motion of the buoy and lever arm. The pump fixture is currently made of wood, which is not an appropriate material for long-term applications. We discussed making a pump fixture of metal, but decided wood was acceptable for the limited pool and ocean testing we performed. The buoy and lever arm will be most effective in translating energy to the pump handle if their motion is restricted to purely vertical.

The design could be improved in many aspects including changing the buoy shape and weight, purchasing a different hydraulic pump, and developing a more effective method for the inlet and outlet for water. The spherical shape of the buoy was decided because of the aesthetics, availability, and ease of calculations. The shape could be reevaluated to be flat or cylindrical, use different material, adjust the weight, or anchor it to the ocean floor. The hydraulic pump had corrosion issues even though it was rated for water applications. This required us to take apart the system and pump hydraulic oil through the pump, which would not work for long term applications. Therefore, we would advise getting pump that will work for ocean applications or trying a different mechanism for pressure generation. The inlet and outlet for the saltwater was out of the scope for this project but should be investigated for future iterations so the system could be fully functioning in the ocean. We simply used buckets and plastic tubing for the inlet and outlet for the system which was effective for short-term testing. Also, exploring the brine rejection and clean water distribution aspects of the system could be another option in a later iteration of this project.

At full scale, the desalination system will need to be placed in the ocean or off a pier or dock. For testing, we clamped and taped the system to a table, but for actual use as a working system, a better solution would have to be designed. We suggest placing the system close to shore in shallow water because it will be easier to do maintenance on the system and the desalinated water will not have to travel far from the ocean to land. It might be favorable to have a stable platform that is anchored or floating. With a floating device that is not anchored, the relative motion of the waves may dissipate the wave energy through the lever arm, but it could potentially help.

A full working wave energy powered desalination system would require major updates to our proof-of-concept design including improving the wave-energy generation function, dealing with intake and distribution of water, and ensuring ocean-safe components. Our sponsor envisions multiple of these along the shore on platforms and running all day with little maintenance required.

4.2 Verification Prototype

Our verification prototype was effective for our testing, but we have some recommendations for setting it up and running the system. First, the hydraulic pump should be dealt with by pumping out the hydraulic oil that is in the pump so that it will not corrode while being stored. The testing can be done with water and saltwater, but it should be ensured that oil is pumped through the system again once testing is complete. The buoy seal was not very effective and would deflate after being stored, so have a hand pump available to fill it with air. For pool and ocean testing, we had to make sure the system was secure on the table using multiple clamps and duct tape. In the ocean it was especially important that the table and components were secure so they wouldn't fall into the ocean. We made wood pieces for the table legs so that the table would have more stability in the ocean. During testing, we monitored the systems pressure, checked for leaks, and evaluated each component for its effectiveness, especially on the lever arm for its effectiveness in converting wave energy. The User Manual in Appendix B discusses the assembly, disassembly, and maintenance for the verification prototype.

5. Conclusion

From this project we received insight into the intricacies of desalination systems as well as into the general process of troubleshooting a concept prototype. The final model achieves an adequate flowrate for generating fresh water from a reverse osmosis membrane for a table-top size, but does not reach the specified pressure we designed for. Most tests were therefore passed save for those pertaining to the pressure differential across the membrane and the resulting salinity in water collected from the output of the system.

While the system was verified to run properly, and does perform desalination, anticipated design goals for the project were not fully met. This was unfortunately due to a lack of understanding of the reverse osmosis membrane. When manufacturers were contacted, their help was limited and the component arrived with little instructions both physically and online. These issues that arose may not have been resolved by changes on our behalf. Communication with manufacturers was often difficult, and when we were able contact them, their understanding of the products was sometimes limited. To have avoided this would have meant avoiding these manufacturers in the first place and ordering from separate suppliers, but this was an issue given that reverse osmosis membranes were not sold as a separate entity by most retailers we found. And similarly the hydraulic pump was said to be able to handle water but eventually corroded.

If our team were to do this project again, it would be beneficial to have more time for ideation and prototyping stages. Due to the open-ended nature of this project, many ideas were lost as a result of crunched timelines and limiting criteria. Thankfully, future teams can learn from our project and make improvements with this insight or go a new direction altogether. This first iteration acts as a first step into this type of arena.

Appendix

A. **Final Project Budget**
B. **User Manual**
C. **Risk Assessment**
D. **Design Verification Plan & Report (DVP&R)**
E. **Test Procedures**

Appendix A. Final Project Budget

Baker Koob Funds	$2,000
Total Spent	$1,433.35
Baker Koob Funds Spent	$1,376.93
Funds Remaining	$623.08

Item Description	Vendor	Vendor Part #	Our Part #	Material Price	Shipping/Handling/ Tax Estimates	Total Cost	How Material Will be Purchased	Account Used	Date Purchased	Current Location of Material
Hydrualic Pump	Chief	220996	1	$281.41	$27.58	$308.99	On Amazon	Baker-Koob	1/14/22	Bldg 13 Storage
Corrosion Resistant Spray	Rust-Oleum	273992	2	$49.99	$3.62	$53.61	On Amazon	Baker-Koob	1/14/22	Bldg 13 Storage
RO Membrane Housing with Membrane Installed	SeaWater Pro		3	$595.00	$23.95	$618.95	SeaWater Pro Website	Baker-Koob	1/14/22	Bldg 13 Storage
Tuff End Inflatable Vinyl Boat Buoy	Taylor Made	61149	4	$67.12	$5.87	$72.99	On Amazon	Baker-Koob	2/2/22	Bldg 13 Storage
304 SS 3/4" Hose Barb to 3/4" Male NPT Pipe Fitting, Home Brew Connector Fitting Water Fuel Air	Zimflex		5	$12.49	$0.91	$13.40	On Amazon	Baker-Koob	2/3/22	Bldg 13 Storage
1/4" NPTF Male x 1/4" JIC (7/16"-20 thread) Female Swivel	Hydraulics Direct	6505-04-04	6	$2.20	$0.33	$2.53	Hydraulics Direct Website	Baker-Koob	2/3/22	Bldg 13 Storage
Branch Tee, 1/4" NPTF Male x 1/4" NPTF Male x 1/4" NPTF Female	Hydraulics Direct	5601-04-04-04	7	$7.36	$1.10	$8.46	Hydraulics Direct Website	Baker-Koob	2/3/22	Bldg 13 Storage
SS 304 Forged Pipe Fitting Reducing Adapter 3/8" NPT Female x 1/4" NPT Male 2000psi	Avanty	SS304-3200CB	8	$9.49	$0.69	$10.18	On Amazon	Baker-Koob	2/3/22	Bldg 13 Storage
1/2" x260" PTFE Tape	Home Depot	78864178500	9	$0.98		$0.98	In-store purchase	Baker-Koob	2/3/22	Bldg 13 Storage
#020 SS Clamp 3/4"x1-3/4" DIA	Home Depot	78575172057	10	$3.22		$3.22	In-store purchase	Baker-Koob	2/3/22	Bldg 13 Storage
80Z PVC Cement Red Hot Low VOC	Home Depot	44752110082	11	$8.93	$1.86	$10.79	In-store purchase	Baker-Koob	2/3/22	Bldg 13 Storage
1/2"x2' PVC Pipe	Home Depot	811000012159	12	$2.48		$2.48	In-store purchase	Baker-Koob	2/3/22	Bldg 13 Storage
3/4"x1/2" PVC EL 90D SXS	Home Depot	49081140663	13	$1.97		$1.97	In-store purchase	Baker-Koob	2/3/22	Bldg 13 Storage
1/2" PVC EL 90 D W Side Outlet SXSXS	Home Depot	49081142681	14	$2.46		$2.46	In-store purchase	Baker-Koob	2/3/22	Bldg 13 Storage

1/2" PVC EL 45D SXS	Home Depot	49081140229	15	$1.26		$1.26	In-store purchase	Baker-Koob	2/3/22	Bldg 13 Storage
2.5 Inch Pressure Gauge 1/4" NPT 0-1500Psi / 0-100Bar Back Entry SS304	ToolOts	BRYBZDABE	16	$5.39		$5.39	on ToolOts website	Baker-Koob	2/11/22	Bldg 13 Storage
BC Plywood: 3/4in thick, 2ftx4ft	Home Depot	813952011228	17	$26.64	$2.59	$29.23	In-store purchase	Baker-Koob	2/12/22	Bldg 13 Storage
Adjustable Pressure-Relief Valve for Water, 3/4 NPT, 1 to 1200psi	Mcmaster Carr	9763K65	18	$137.41		$137.41	McMaster Carr website	Baker-Koob	3/2/22	Bldg 13 Storage
2PCS 304 SS Cast Pipe Fitting, Coupling, 3/4", 3/4" Female Threaded	Taisher	FC-243S	19	$10.79		$10.79	On Amazon	Baker-Koob	3/2/22	Bldg 13 Storage
2PCS Forging of 304 SS Reducer Hex Bushing, 3/4" Male NPT to 1/4" Femail NPT, Reducing Forging Pipe	Taisher	FC-225	20	$12.79		$12.79	On Amazon	Baker-Koob	3/2/22	Bldg 13 Storage
5ft x 3/4" ID Clear Vinyl Tubing, Flexible Hybrid PVC Tubing Hose, Lightweight Plastic Tube UV Chemical Resistant Vinyl Hose, BPA Free and Non Toxic	Eastrans	737504987451	21	$12.99		$12.99	On Amazon	Baker-Koob	3/2/22	Bldg 13 Storage
Clear Vinyl Tubing Flexible PVC Tubing, Hybrid PVC Hose, Lightweight Plastic Tubing, by 3/8 Inch ID, 25-Feet Length	Eastrans	711414430122	22	$18.69	$5.77	$24.46	On Amazon	Baker-Koob	3/2/22	Bldg 13 Storage
Stainless steel 3/8" Hose Barb x 3/8" NPT Male - Home Brew Pipe Fitting Pack of 2	Dernord	DERNORD-642	23	$8.89		$8.89	On Amazon	Baker-Koob	3/2/22	Bldg 13 Storage
Premium Hydraulic Oil	Home Depot		24	$18.00		$18.00	In-store purchase	Andy Wu	4/1/22	Bldg 13 Storage
Stainless steel coupling 3/4"	Ferguson Enterprises, LLC	IS4CTCF	25	$6.20	$0.54	$6.74	In-store purchase	Amanda Olla	4/9/22	Bldg 13 Storage
Thin-Wall Butt-Weld Unthreaded Pipe Fitting, 304/304L SS, Straight Reducer 1-1/4 x 1 Pipe Size	Mcmaster Carr	45735K414	26	$46.14	$6.92	$53.06	McMaster Carr website	Baker-Koob	4/12/22	Bldg 13 Storage
Hex Nut Zinc 1/4 (AAB) (x4)	Home Depot		27	$0.36		$0.36	In-store purchase	Solie Grantham	4/19/22	Bldg 13 Storage
Hex Bolt Zinc 5/16 x 2 (x2)	Home Depot		28	$0.68		$0.68	In-store purchase	Solie Grantham	4/19/22	Bldg 13 Storage
Hex Nut Zinc 5/16 (AAB) (x2)	Home Depot		29	$0.28		$0.28	In-store purchase	Solie Grantham	4/19/22	Bldg 13 Storage
Hex Bolt Zinc 1/4 x 5-1/2 (x4)	Home Depot		30	$2.24		$2.24	In-store purchase	Solie Grantham	4/19/22	Bldg 13 Storage
Wood Screw Zinc PHL FLT #10 x 3 50PC	Home Depot	887480019421	31	$12.58	$1.41	$13.99	In-store purchase	Solie Grantham	4/19/22	Bldg 13 Storage
pH Test strips	Miners ACE Hardware		32	$14.13		$14.13	In-store purchase	Charlie Sinclair	5/24/22	Bldg 13 Storage
Donated/Borrowed Items										
Salinity and pH test strips			33	$0.00		$0.00	Dr. Schuster			Bldg 13 Storage
3/4" PVC			34	$0.00		$0.00	Charlie Sinclair			Bldg 13 Storage
1/2" PVC			35	$0.00		$0.00	Charlie Sinclair			Bldg 13 Storage
Clevis pin			36	$0.00		$0.00	Charlie Sinclair			Bldg 13 Storage
2x4 Lumber	Home Depot		37	$0.00		$0.00	Amanda Olla			Bldg 13 Storage
Mixing Bucket (x2)	Home Depot		38	$0.00		$0.00	Amanda Olla			Bldg 13 Storage

*Blue highlighted cells on project budget sheet indicate components purchased by team members and not included in Baker Koob funds

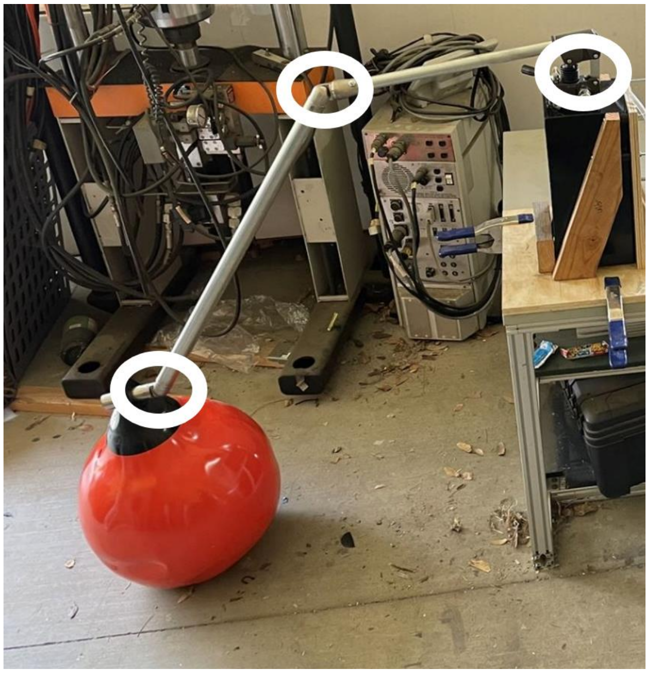
Appendix B. User Manual

F25 User Manual

Safety Hazards

Before discussing the assembly steps for the system and the method of placing the system in the water, safety hazards are discussed to ensure safe assembly and operation.

There are three main pinch points in our system, all of which are part of the wave energy conversion components of our system. Two of the pinch points are welded but could possibly fail – the user should be wary of these two connection points. The third pinch point is between the lever arm and the pump, this point also offers the most force and should be avoided to prevent injury during operation.



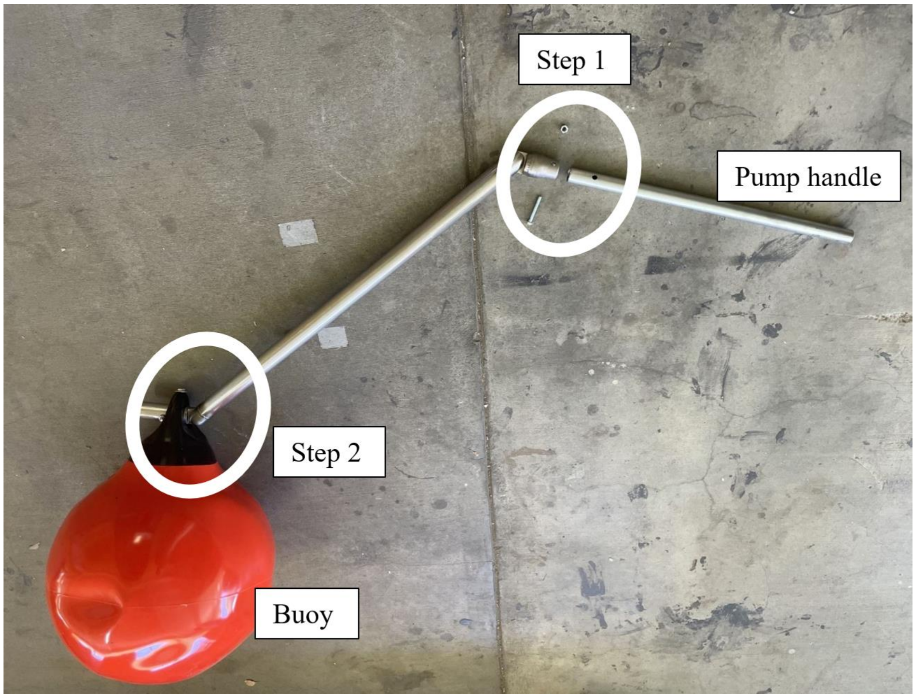
Furthermore, the system operates at a nominal pressure of 300 psi and will likely oscillate around this value. Given these high-pressure conditions, all connections should be checked prior to operation to guarantee the safest operation. Teflon tape should be used at each fitting connection to prevent leaking between components. Users should be wary of the pressure gauges on either side of the reverse osmosis membrane to ensure that the difference in pressure does not exceed 15 psi to avoid membrane failure or damage.

In order to bring the lever arm back to its lower position, the flotation buoy will be filled with water, making it a heavy moving object to avoid during operation. The buoy will weigh approximately 25lbs and will be moving considerably during normal operation.

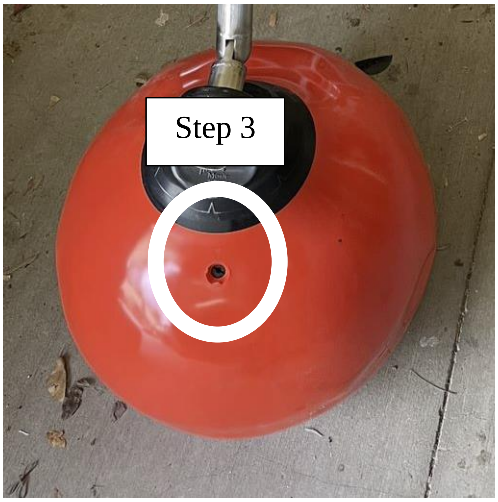
If the system is placed on a slick surface, users should wear proper footwear and be wary of fluid spilling (water, oil, etc.) to reduce the chance of injury from slippage. Users sho

Assembly Procedure

1. To assemble the lever arm, first, take the pump handle and place it inside the elbow joint. Then, line up the holes and insert a 5/16" bolt through all the holes. Tighten a nut to the bolt.
2. Next, slide the buoy onto the other end of the lever arm. Slide it in so that the buoy through hole is aligned with the through hole closest to the metal elbow. Place a 5/16" bolt through all the holes and tighten a nut to the end of the bolt. Also place a 5/16" bolt through the second through hole and tighten a nut to the end of the bolt. This serves as an additional restraint just in case the first bolt fails.



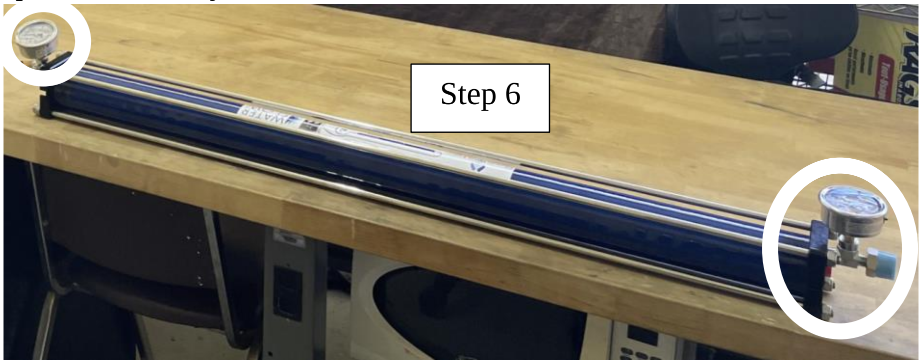
3. Next, fill the buoy with 25 pounds of water and then pump air into the buoy until it is full



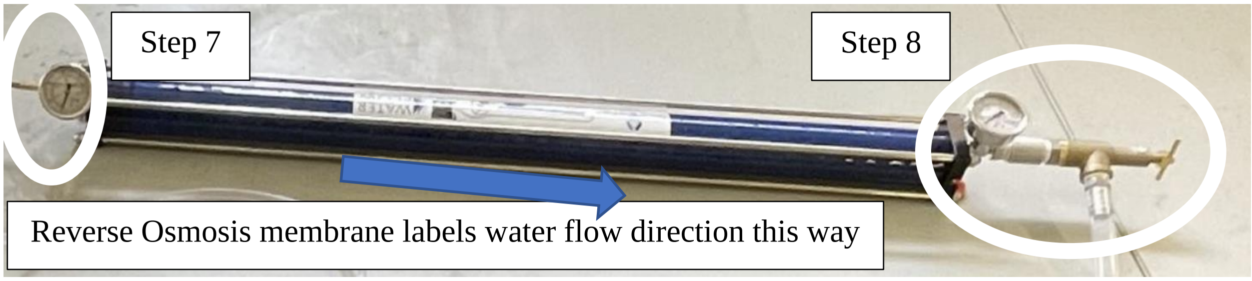
4. Connect the pump handle to the pump

5. Wrap both sides in Teflon tape and screw in a 3/8” Male NPT to 1/4” Male NPT to the left side of the hydraulic pump, then attach one end the high pressure tubing to the 1/4” Male NPT fitting.

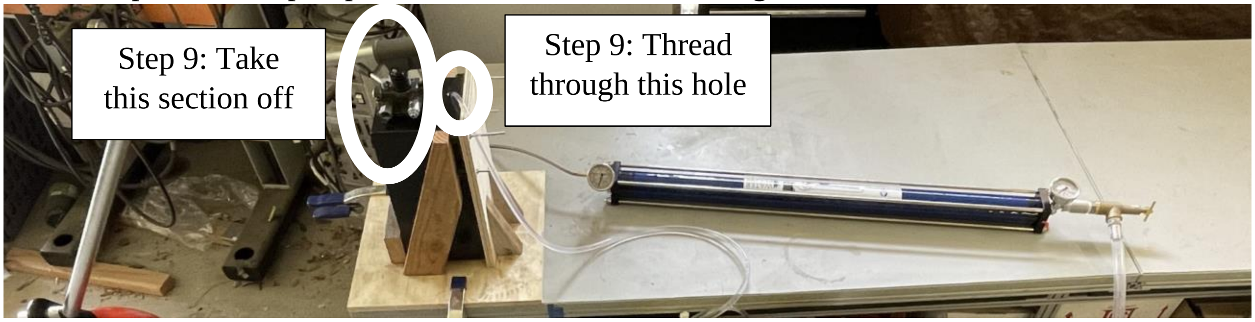
6. Wrap pressure gauges and 1/4" T-joints with Teflon tape. Take the reverse osmosis system, and screw in the 1/4" T-joints to both ends, then screw in the pressure gauges into the top side of the T-joint.



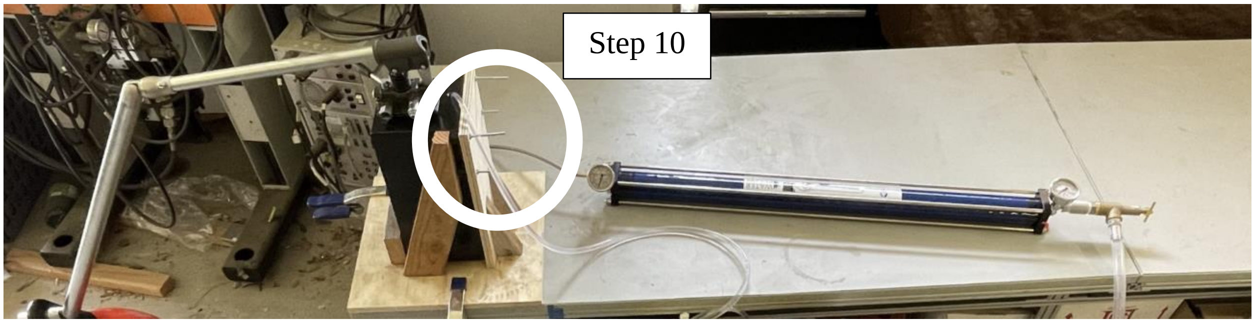
7. Next, screw in the high pressure tubing, ensuring that the water will flow as labeled on the reverse osmosis filter.



8. Wrap the 1/4" Female NPT to 3/4" Male NPT fitting with Teflon tape on the Male end, and then install the Female end to the end of the T-joint. Next, install the 3/4" coupling to the 3/4" Male NPT end. Then, wrap the backpressure valve with Teflon tape and install into the other end of the coupling. Finally, insert the 3/4" diameter clear hose on top of the barb.
9. Insert the smaller diameter clear hose tubing into the pump inlet (take the pump off the enclosure by unscrewing the 4 Allen head screws) and thread the clear tubing through the hole on top. Place the pump back onto the enclosure and tighten the 4 Allen head screws.



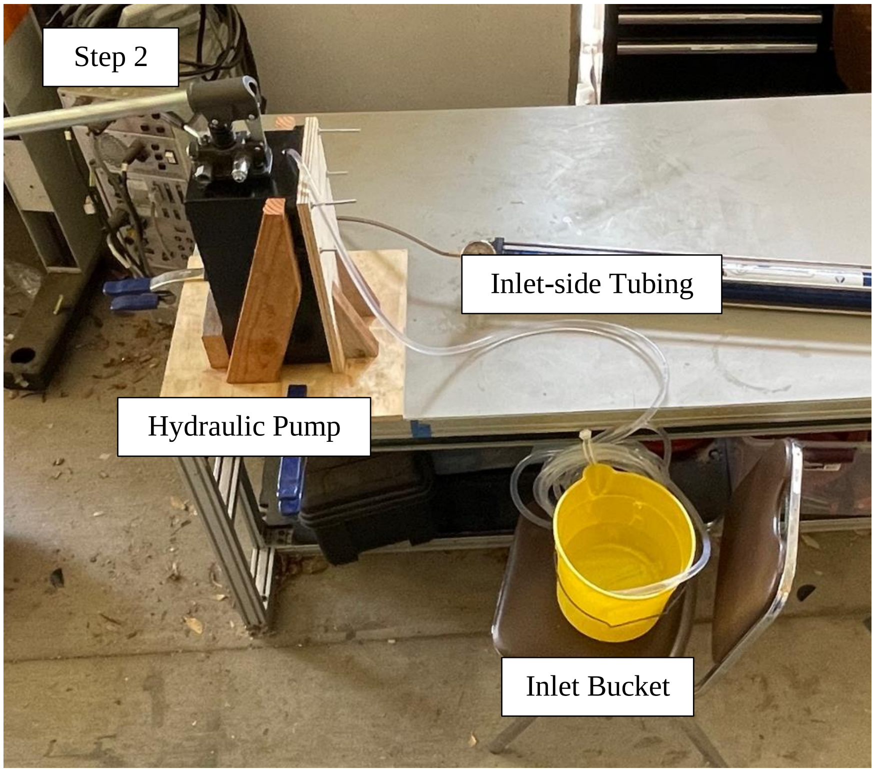
10. Mount the pump onto the enclosure with four 1/4" bolts, and tighten nuts onto the bolt.



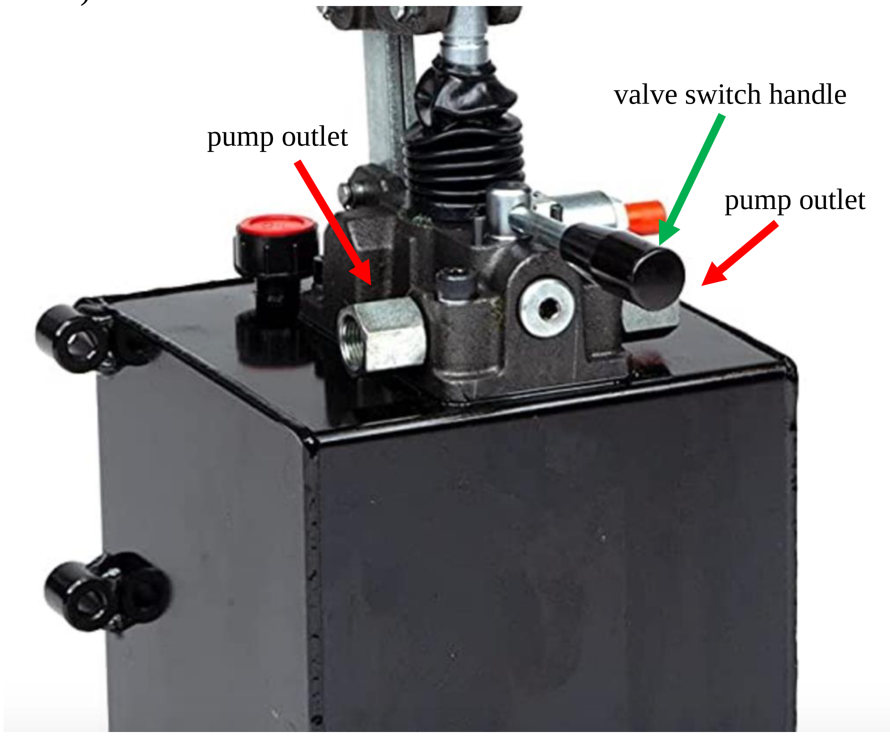
Corrosion Prevention:
There is a need to flush the hydraulic pump after running water through the system because the pump is made for non-corrosive fluids. Thus, after use, hydraulic oil will be pumped in order to coat the pump internals with hydraulic oil to ensure that there is no corrosion taking place. The oil will prevent corrosion and this procedure will work for a short-term solution, perfectly compatible with our proof-of-concept design for Senior Project. The procedure starts with the testing protocol and corrosion prevention method with hydraulic fluid.

Prototype Use Procedure

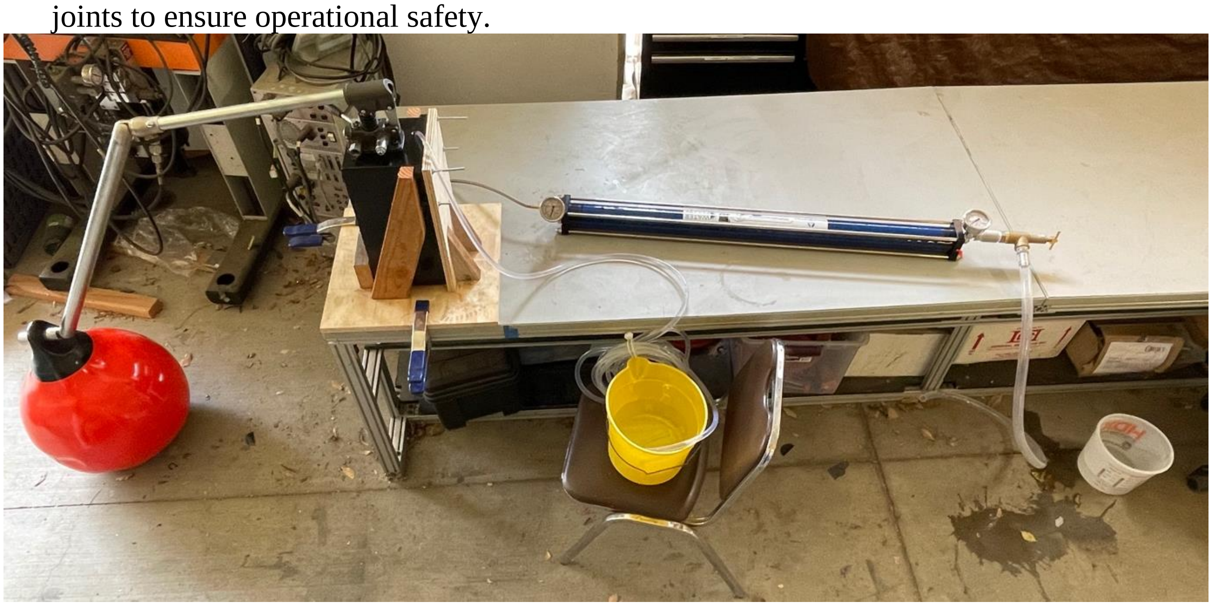
1. Fill inlet bucket with distilled water.
2. Attach one end of inlet-side tubing to tube in hydraulic pump and other end to inlet bucket.



3. Turn valve switch handle on top of the hydraulic pump towards one pump outlet side (right or left)



4. Move lever arm up and down so distilled water runs through hydraulic pump.
5. Repeat previous step (step 4) until hydraulic fluid is visibly gone (fluid is clear). This will take approximately 4 cycles.
6. Turn handle on top of the hydraulic pump towards other pump outlet side.
7. Repeat steps 4 and 5.
8. Assemble full desalination system (attach pump to tubing to RO system, etc.) Before running the test, ensure that all fittings are tightly in place and Teflon tape is used in the joints to ensure operational safety.



9. For testing, run distilled water or saltwater through full desalination system (from inlet bucket to outlet bucket).
10. When testing is done…
    a. If testing was done with distilled water, skip to step 11.
    b. If testing was done with saltwater, put distilled water in inlet bucket and run distilled water through full system by moving the pump handle up and down 10 times to clear out saltwater.
11. Detach hydraulic pump from rest of assembly.
12. Add hydraulic fluid to separate bucket.
13. Attach one end of inlet-side tubing to tube in hydraulic pump and other end to hydraulic fluid bucket.
14. Turn small handle on top of the hydraulic pump towards one pump outlet side (right or left)
15. Move lever arm up and down so hydraulic fluid runs through hydraulic pump for 5 cycles (or until no excess hydraulic fluid come out).
16. Turn handle on top of the hydraulic pump towards other pump outlet side.
17. Repeat steps 14 and 15.
18. Put orange stoppers on hydraulic pump outlets.
19. Clean excess hydraulic fluid from components and workspace.
20. Store components in dry area.

Saltwater testing example

If parts sustain damage or break with use, the system should be taken apart so that the broken component can be replaced. A full parts list with part sources if procurement of new parts is necessary can be found in the indented Bill of Materials.

Reverse Osmosis Freshwater Generator Powered by Mechanical Wave Energy

Indented Bill of Material (iBOM)

Assy Level	Part Number	Descriptive Part Name				Qty	Mat'l Cost	Shipping/tax Costs	Total Cost	Part Source	More Info
		Lvl0	*Lvl1*	*Lvl2*	*Lvl3*						
0	1000	Final Assy									
1	2000		Wave Generation Assembly								
2	2100			Spherical Buoy		1	$67.12	$5.87	$72.99	Amazon.com	Spherical polymer buoy with mooring loop
3	2200				Bolted stopper	2	$1.16	$0.22	$1.38	Home Depot	Bolted connections to fix buoy in place
2	2300			Lever Arm		1	$24.94	$12.72	$37.66	Amazon.com	1.5" OD stainless steel tubing, 16 gauge
2	2400			Hydraulic Pump		1	$281.41	$27.58	$308.99	Amazon.com	Double acting, 1.8 gallon tank, 25cm3 rated flow
3	2500				1.25" to 1" Reducer	1	$41.23	$27.38	$68.61	McMaster-Carr	1.25" to 1" concentric stainless steel butt weld reducer
3	2600				Stainless Steel Elbow	2	$28.99	$17.29	$75.27	Kegworks.com	Adjustable stainless steel 1.5" OD elbow
2	2700			Pump Fixture		1	$74.17	$5.37	$79.54	Home Depot	Constructed from 2"x4" lumber and 3/4" plywood
1	3000		Reverse Osmosis Assembly								
2	3100			SeaWater Pro RO FIlter		1	$595.00	$23.95	$618.95	SeaWaterPro.com	40" membrane, 5000 psi bursting pressure housing
3	3200				Back Pressure Valve	1	$137.41	$24.12	$161.53	McMaster-Carr	3/4" NPT inlet and outlet, 0-1200 psi adjustable range
1	4000		Water Collection Assembly								
2	4100			Collection Containers		2	$2.48	$0.18	$2.66	Home Depot	Clear containers with volumetric measurement markings
2	4200			3/4" ID Clear Vinyl Tubing		1	$12.99	$1.14	$14.13	Amazon.com	3/4" ID Clear vinyl tubing, BPA free, UV resistant
1	1100		Braided Tubing			2	$43.62	$13.17	$56.79	Airgas.com	1/4" NPT female attachments, braided steel hosing
1	1200		Inlet Tubing			1	$10.99	$0.96	$11.95	Amazon.com	3/8" ID Clear vinyl tubing, BPA free, UV resistant
1	1300		Tube Reducers								
2	1310			3/8" NPT to 1/4" NPT		1	$8.49	$0.74	$9.23	Amazon.com	Connection from hydraulic pump to 1/4" tubing, 2000 psi
2	1320			3/8" barb to 3/8" M NPT		1	$8.99	$0.79	$9.78	Amazon.com	Connection from inlet tubing to hydraulic pump
2	1330			3/4" M NPT to 1/4" F NPT		1	$12.99	$1.14	$14.13	Amazon.com	Connection from the membrane outlet to the back presssure valve
1	1400		Pipe Fittings			3					
2	1410			3/4" Stainless coupling		1	$8.99	$0.96	$9.95	Ferguson Plumbing	Connection from RO membrane to back pressure valve
2	1420			3/4" Barb Connector		1	$12.49	$0.97	$13.46	Amazon.com	No longer needed!
1	1600		Pressure Gauges			2	$5.39	$10.53	$15.92	toolots.com	1/4" NPT pressure gauge 0-1500 psi
2	1610			1/4" Stainless T-Joints		2	$8.56	$6.22	$14.78	hydraulicsdirect.com	1/4" NPT T-Joints for in-line pressure gauges
1	1700		Teflon Tape			1	$0.98	$0.07	$1.05	Home Depot	Polymer tape to reduce leakage
					Total Parts:	30		**Total Cost:**	$1,598.75		

Appendix C. Risk Assessment

designsafe Report

Application:	F25 Risk Analysis	Analyst Name(s):	Andy, Amanda, Charlie, Solie
Description:	F25 Deasalination System	Company:	Cal Poly
Product Identifier:	Verification Prototype	Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			
Risk Scoring System:	ANSI B11.0 (TR3) Two Factor		

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

Item Id	Sub-process / User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-1-1	Wave Energy Generation System adult first use / test	mechanical : pinch point	Minor Likely	Low		Minor		
1-1-1-2	Wave Energy Generation System adult first use / test	mechanical : product instability	Moderate Likely	Medium		Moderate		
1-1-1-3	Wave Energy Generation System adult first use / test	slips / trips / falls : slip	Minor Unlikely	Negligible		Minor		
1-1-1-4	Wave Energy Generation System adult first use / test	ergonomics / human factors : lifting / bending / twisting	Moderate Likely	Medium		Moderate		
1-1-1-5	Wave Energy Generation System adult first use / test	environmental / industrial hygiene : corrosion	Minor Unlikely	Negligible		Minor		
1-1-1-6	Wave Energy Generation System adult first use / test	fluid / pressure : hydraulics rupture	Serious Unlikely	Medium		Serious		
1-1-1-7	Wave Energy Generation System adult first use / test	fluid / pressure : surges / sloshing	Serious Remote	Low		Serious		

Item Id	Sub-process / User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-1-8	Wave Energy Generation System adult first use / test	fluid / pressure : fluid leakage / ejection	Moderate Very Likely	High	Ensure all fittings are properly in place, pressure gauges are installed in order to determine if there is a leak in pressure that needs to be addressed.	Moderate Likely	Medium	
1-1-2-1	Wave Energy Generation System adult normal use	mechanical : pinch point	Minor Likely	Low		Minor		
1-1-2-2	Wave Energy Generation System adult normal use	slips / trips / falls : slip	Minor Unlikely	Negligible		Minor		
1-1-2-3	Wave Energy Generation System adult normal use	environmental / industrial hygiene : corrosion	Moderate Likely	Medium		Moderate		
1-1-2-4	Wave Energy Generation System adult normal use	fluid / pressure : hydraulics rupture	Serious Unlikely	Medium		Serious		
1-1-2-5	Wave Energy Generation System adult normal use	fluid / pressure : surges / sloshing	Serious Remote	Low		Serious		
1-1-2-6	Wave Energy Generation System adult normal use	fluid / pressure : fluid leakage / ejection	Moderate Likely	Medium		Moderate		
1-1-3-1	Wave Energy Generation System adult maintenance / lubrication	mechanical : pinch point	Minor Likely	Low		Minor		
1-1-3-2	Wave Energy Generation System adult maintenance / lubrication	mechanical : product instability	Moderate Likely	Medium		Moderate		

Item Id	Sub-process / User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-3-3	Wave Energy Generation System adult maintenance / lubrication	slips / trips / falls : slip	Moderate Unlikely	Low		Moderate		
1-1-3-4	Wave Energy Generation System adult maintenance / lubrication	ergonomics / human factors : lifting / bending / twisting	Moderate Likely	Medium		Moderate		
1-1-3-5	Wave Energy Generation System adult maintenance / lubrication	environmental / industrial hygiene : corrosion	Moderate Unlikely	Low		Moderate		
1-1-3-6	Wave Energy Generation System adult maintenance / lubrication	fluid / pressure : hydraulics rupture	Moderate Unlikely	Low		Moderate		
1-1-3-7	Wave Energy Generation System adult maintenance / lubrication	fluid / pressure : fluid leakage / ejection	Moderate Unlikely	Low		Moderate		
1-1-4-1	Wave Energy Generation System adult repair tasks	mechanical : pinch point	Moderate Likely	Medium		Moderate		
1-1-4-2	Wave Energy Generation System adult repair tasks	mechanical : product instability	Moderate Likely	Medium		Moderate		
1-1-4-3	Wave Energy Generation System adult repair tasks	slips / trips / falls : slip	Moderate Unlikely	Low		Moderate		
1-1-4-4	Wave Energy Generation System adult repair tasks	ergonomics / human factors : lifting / bending / twisting	Moderate Likely	Medium		Moderate		

Item Id	Sub-process / User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-4-5	Wave Energy Generation System adult repair tasks	environmental / industrial hygiene : corrosion	Moderate Unlikely	Low		Moderate		
1-1-4-6	Wave Energy Generation System adult repair tasks	fluid / pressure : hydraulics rupture	Moderate Unlikely	Low		Moderate		
1-1-4-7	Wave Energy Generation System adult repair tasks	fluid / pressure : fluid leakage / ejection	Moderate Remote	Negligible		Moderate		
1-1-4-8	Wave Energy Generation System adult repair tasks	wastes (Lean) : correction / defective parts	Minor Likely	Low		Minor		
1-1-5-1	Wave Energy Generation System adult assemble	mechanical : pinch point	Minor Likely	Low		Minor		
1-1-5-2	Wave Energy Generation System adult assemble	ergonomics / human factors : lifting / bending / twisting	Moderate Likely	Medium		Moderate		
1-1-5-3	Wave Energy Generation System adult assemble	fluid / pressure : fluid leakage / ejection	Minor Very Likely	Medium		Minor		
1-1-5-4	Wave Energy Generation System adult assemble	wastes (Lean) : moving material / transport	Moderate Likely	Medium		Moderate		
2-1-1-1	Reverse Osmosis System adult first use / test	mechanical : pinch point	Moderate Likely	Medium		Moderate		

Item Id	Sub-process / User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-1-1-2	Reverse Osmosis System adult first use / test	slips / trips / falls : slip	Moderate Unlikely	Low		Moderate		
2-1-1-3	Reverse Osmosis System adult first use / test	ergonomics / human factors : lifting / bending / twisting	Moderate Likely	Medium		Moderate		
2-1-1-4	Reverse Osmosis System adult first use / test	fluid / pressure : hydraulics rupture	Serious Unlikely	Medium		Serious		
2-1-1-5	Reverse Osmosis System adult first use / test	fluid / pressure : explosion / implosion	Serious Unlikely	Medium		Serious		
2-1-1-6	Reverse Osmosis System adult first use / test	fluid / pressure : fluid leakage / ejection	Moderate Likely	Medium		Moderate		
2-1-1-7	Reverse Osmosis System adult first use / test	wastes (Lean) : correction / defective parts	Moderate Likely	Medium		Moderate		
2-1-2-1	Reverse Osmosis System adult normal use	biological / health : mold	Minor Unlikely	Negligible		Minor		
2-1-2-2	Reverse Osmosis System adult normal use	fluid / pressure : hydraulics rupture	Serious Unlikely	Medium		Serious		
2-1-2-3	Reverse Osmosis System adult normal use	fluid / pressure : explosion / implosion	Serious Unlikely	Medium		Serious		

Item Id	Sub-process / User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-1-2-4	Reverse Osmosis System adult normal use	fluid / pressure : fluid leakage / ejection	Moderate Unlikely	Low		Moderate		
2-1-3-1	Reverse Osmosis System adult repair tasks	mechanical : pinch point	Moderate Likely	Medium		Moderate		
2-1-3-2	Reverse Osmosis System adult repair tasks	slips / trips / falls : slip	Moderate Unlikely	Low		Moderate		
2-1-3-3	Reverse Osmosis System adult repair tasks	ergonomics / human factors : lifting / bending / twisting	Moderate Likely	Medium		Moderate		
2-1-3-4	Reverse Osmosis System adult repair tasks	biological / health : mold	Minor Unlikely	Negligible		Minor		
2-1-3-5	Reverse Osmosis System adult repair tasks	fluid / pressure : hydraulics rupture	Moderate Unlikely	Low		Moderate		
2-1-3-6	Reverse Osmosis System adult repair tasks	fluid / pressure : explosion / implosion	Moderate Unlikely	Low		Moderate		
2-1-3-7	Reverse Osmosis System adult repair tasks	fluid / pressure : fluid leakage / ejection	Moderate Unlikely	Low		Moderate		
2-1-4-1	Reverse Osmosis System adult assemble	mechanical : pinch point	Moderate Likely	Medium		Moderate		

Item Id	Sub-process / User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-1-4-2	Reverse Osmosis System adult assemble	slips / trips / falls : slip	Moderate Unlikely	Low		Moderate		
2-1-4-3	Reverse Osmosis System adult assemble	ergonomics / human factors : lifting / bending / twisting	Moderate Unlikely	Low		Moderate		

Appendix D. Design Verification Plan & Report (DVP&R)

DVP&R - Design Verification Plan (& Report)

Project: F25 | Sponsor: Dr. Schuster | Edit Date: 5/15/22

TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING Start date	TIMING Finish date	Numerical Results	Notes on Testing
1	Power generated by the waves must be sufficient to create 55-69 bars of pressure	In this test, the pump lever arm will be displaced by hand to determine the flowrate and angular displacement relationship. The number of cycles to establish initial flowrate in the system will also be recorded (may be done as separate tests)	Angular displacement of the lever arm handle, water flowrate, number of cycles	1 gph flowrate with maximum angular displacement	Outside Mustang '60	SP–wave energy conversion system	Charlie	2/18/22	4/21/22	4.94 to 10.88 gph for +/-10 to 40 degree angular displacement; 10 cycles to achieve pressure (on test day 1 and 2)	During the test, efforts were made to keep angular velocity constant, and both tests will be completed again on another day to test for repeatability. 6 lever arm cycles to establish initial flowrate in the system. Pump curves are drawn and analysis is in completed
2	Power generated by the waves must be sufficient to create 55-69 bars of pressure	The newly constructed lever arm from the final prototype (fixed length and larger diameter) will be placed with the buoy in an ocean. The pier location has yet to be specified	Amount of water at the outlet of the system	Water is generated at the outlet of the system (any amount is ok for this test)	Ocean (Morro Bay)	FP	Amanda	4/2/22	5/12/22	26.3oz	The system produced 26.3oz of water at the outlet which indicates our system worked!
3	Size must be 2 by 4 feet (exluding the buoy and lever arm)	For a table-top display, the whole system (minus the lever arm and buoy) must fit on a 2 ft by 4 ft benchtop display. Thus, the whole system will be rearranged so that it fits on the benchtop display	Area needed for all components	All components fit on the benchtop display	2 ft by 4 ft table	FP	Solie	3/2/22	3/8/22	Currently, all our components fit in a 2ft by 4.25 ft enclosure.	The backpressure valve is larger than expected, making the reverse osmosis system stick out further. However, a benchtop display of 2ft by 4.25 ft is also sufficient, so we are not worried about this extra length.
4	Flowrate must be greater than or equal to 1 gallon per hour	This test will happen simultaneously with test number 2, at the ocean. The lever arm and buoy will be placed in the water, while the rest of the system is on a table.	Amount of water produced in 9.5 minutes	20.3oz/9.5 minutes (or greater)	Ocean (Morro Bay)	FP	Amanda	4/2/22	5/12/22	26.3oz/9.5min (1.295 gph)	The ocean flowrate tests passed our expectations for 1 gph. It should be noted that the pressure gauges did not indicate any pressure which could be a result of our back pressure valve being faulty.
5	The pH of the water must be between 6.5-9.5, and the water salinity must be acceptable	This test will occur right after test 2, after the water has been desalinated at the pier. We will go to the collection tank and use litmus paper and salinity strips to test the water	pH, salinity in ppm	pH: Between 6.5 and 9.5 Salinity: less than 1000 ppm	Ocean (Morro Bay)	FP	Andy	4/2/22	5/17/22	pH: 9.0; salinity: 1640ppm	The pH value is acceptable, but the salinity is over our desired limit for drinkable water. The pH did not change between the inlet and outlet bucket which was expected since the RO filter doesn't adjust it.The salinity was reduced from 10300ppm (inlet) to 1640 (outlet), but it was still over 1000ppm. This could be caused from possible membrane rupture or issues with the back pressure valve.

Appendix E. Test Procedures

1. **Desalination System Assembly Sizing**
2. **R.O. Filter Pressure Differential**
3. **Lever Arm Cycles to Establish Pressure**
4. **Flowrate with Angular Displacement of Lever Arm**
5. **Flowrate, pH, and Salinity from Ocean Testing**

TEST 1

Test Name: Desalination System Assembly Sizing

Purpose: The purpose of this test is to ensure the system assembly meets size specifications of 4.5ft x 2ft for "table-top" design.

Scope: Our project scope is for a proof-of-concept, so we want to display our final design as a demonstration on a table. The design is a small-scale desalination system so all our components purchased should meet our size specification. The desalination component of our full system assembly includes the hydraulic pump, tubing, reverse osmosis filter, pressure gauges, outlet containers for brine and water rejection, and other fittings. The wave generation component made up of the lever arm and the buoy will not be considered in the size measurements because it will hang off the table.

Equipment:

- measuring tape
- 4.5ft x 2ft table (or larger)
- complete desalination system (hydraulic pump to outlet bucket)

Hazards: The only hazards would be lifting and pinch points from moving and assembling the desalination system.

PPE Requirements: N/A

Facility: Mustang 60

Procedure:

1) Assemble full desalination system (from hydraulic pump to outlet bucket)
2) Set assembly on table
3) Measure length and width of fully assembled system with measuring tape
4) Record width and length values

Results:

Length = 4.25 [ft]

Width = 1 [ft], 5 [in]

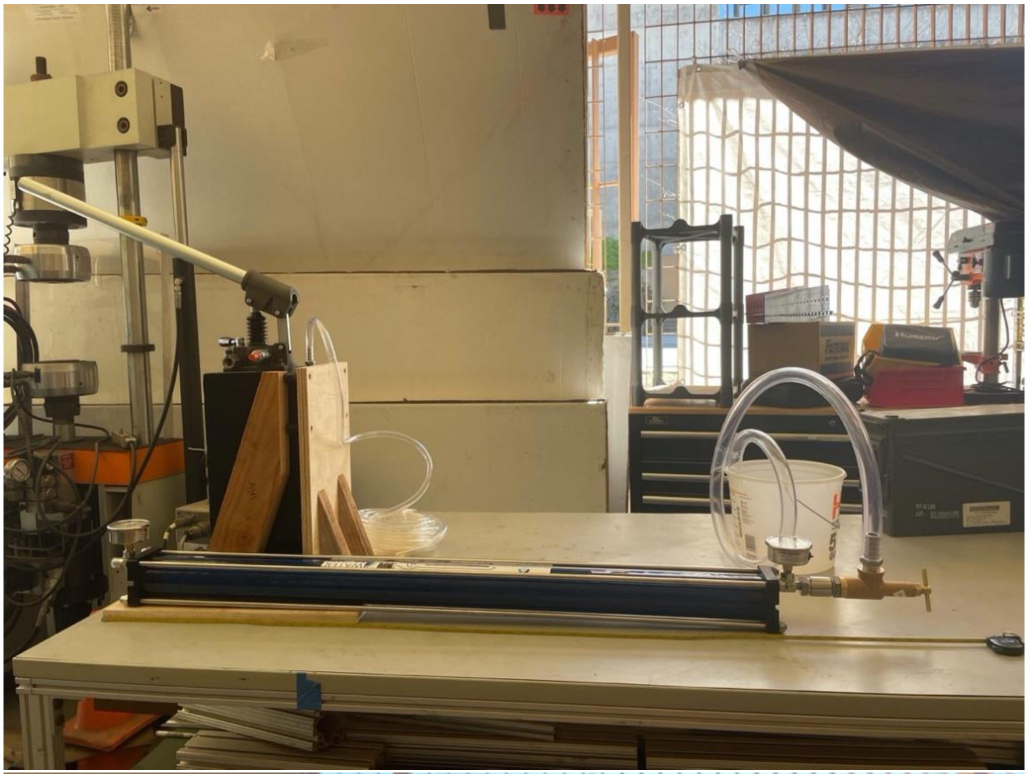
Pass Criteria: length is less than 4.5ft and width is less than 2ft

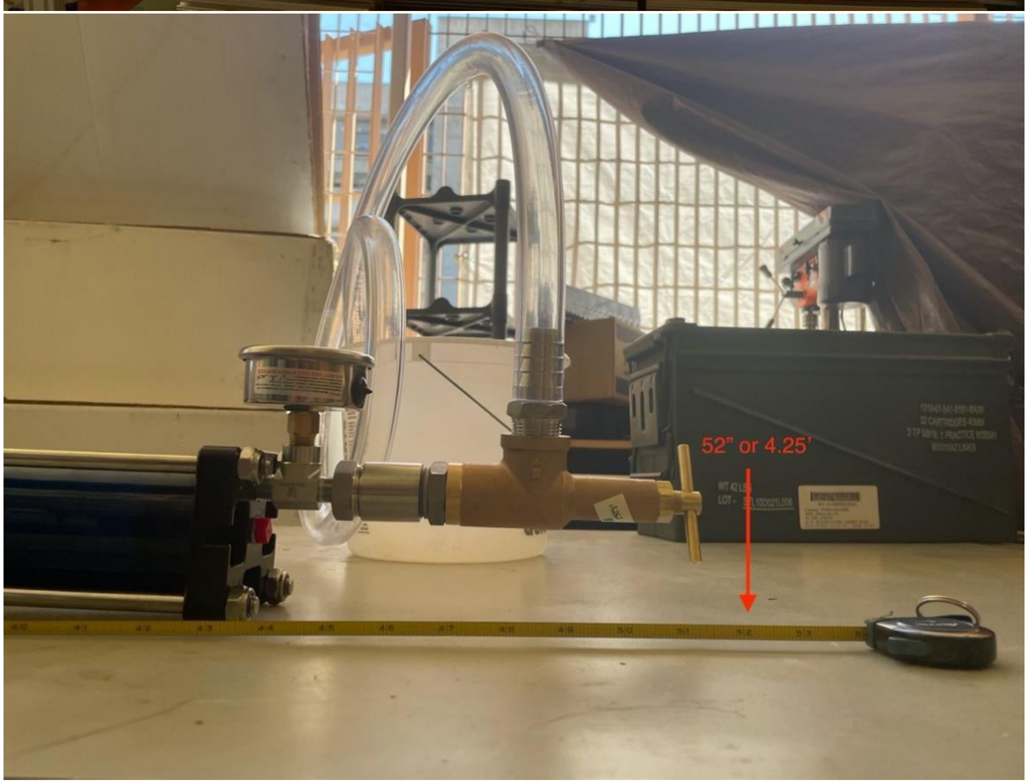
Fail Criteria: length is more than 4.5ft and width is more than 2ft

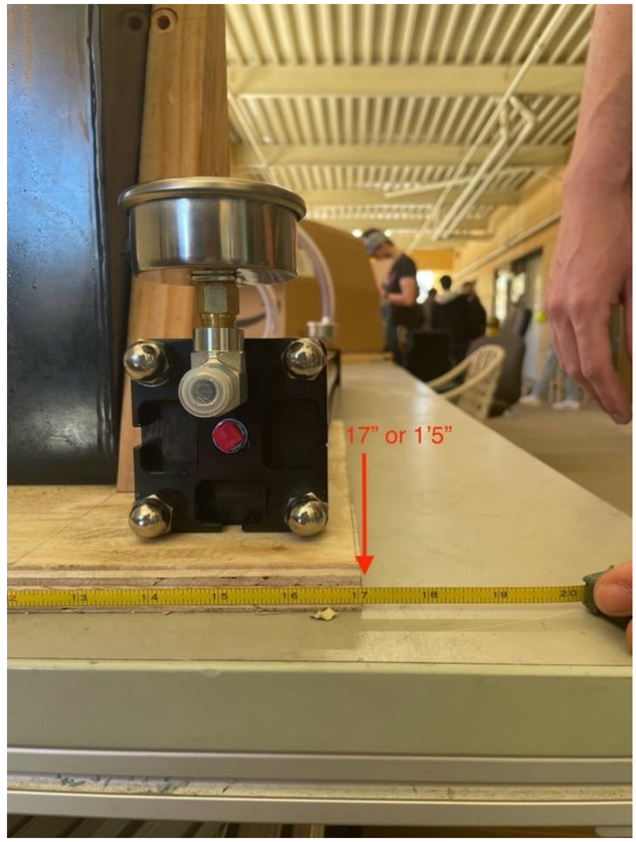
Test Date(s): 3/8/22

Test Results: Passed

Performed By: Amanda Olla






17" or 1'5"

TEST 2

Test Name: RO Filter Pressure Differential Test

Purpose: The purpose of this test is to ensure the reverse-osmosis (RO) filter creates a pressure differential but does not exceed the maximum pressure differential of 15 psi, as specified by the manufacturer.

Scope: Our desalination system includes a hydraulic pump that provides pressure to force water through a reverse-osmosis (RO) membrane to filter the ocean water and produce drinkable water. The RO filter we purchased from SeaWater Pro cannot exceed a pressure differential of 15 psi otherwise the membrane will rupture and the filter will be ineffective. We need enough pressure to push water through the filter, but not too much to destroy the membrane, therefore, this test will monitor the pressure differential across the filter.

Equipment:

- Two pressure gauges
- Complete desalination system (hydraulic pump to outlet bucket)

Hazards: Potential rupture of system (in tubing or RO filter) or leaks at connection points

PPE Requirements: Safety goggles

Facility: Mustang 60

Procedure: (List number steps of how to run the test, can include sketches and/or pictures):

1) Assemble full desalination system (from hydraulic pump to outlet bucket) on table
2) Tighten back pressure valve on outlet side of RO system (to restrict pressure differential level for exceeding 15 psi)
3) Place inlet tubing in water bucket (or ocean)
4) Apply force to hydraulic pump handle (appropriate force determined in previous test)
5) After 7 cycles of pumps (number of cycles determined in lever arm cycles test), visually observe water moving through inlet tubing and outlet tubing.
6) Relieve back pressure valve in small increments (15 degrees CCW at a time), until reasonable flow is achieved (over 0.5 gal/hr)
7) Record initial pressure reading on each pressure gauge (one on pump side and one on outlet side)
8) Manually move pump handle up and record pressure reading on each pressure gauge (one on pump side and one on outlet side)
9) Move pump handle down and record pressure reading on each pressure gauge (one on pump side and one on outlet side)
10) If pressure differential approaches 15 psi, stop applying force to pump handle and relieve pressure in back pressure relief valve
11) Repeat steps 5-10 for 5 cycles (cycle includes upstroke and downstroke)

Results:

	Initial Pressure		Intermediate Pressure		
Cycle	Inlet	Outlet	Inlet	Outlet	Pressure differential
0	300	300	490	450	40
1a	260	260	490	460	30
1b	220	240	310	300	10
2a	240	270	460	460	0
2b	260	280	370	360	10
3a	310	320	480	460	20
3b	250	280	390	390	0
4a	320	350	460	470	-10
4b	200	240	310	310	0
5a	280	280	490	490	0
5b	210	240	320	320	0

*Pressures in psi
**a=upstroke; b=downstroke

Pass Criteria: Pressure differential is below 15 psi.
Fail Criteria: Pressure differential is greater than 15 psi.

Test Date(s): 4/14/22
Test Results: Fail
Performed By: Amanda Olla

TEST 3

Test Name: Lever Arm Cycles to Establish Pressure

Purpose: In this test, the number of lever arm cycles will be counted once the system is assembled in order to determine how much time it takes to establish the pressure and flowrate needed for desalinated water to be output from the system.

Scope: Here, the functionality of the hydraulic pump and reverse osmosis system will be tested. In addition to the number of lever arm cycles counted, this number will be multiplied by the average period of the waves (13 seconds). This will determine the approximate amount of time it takes from putting the system into the ocean to when water is output from the system.

Equipment: Hydraulic pump, reverse osmosis system and proper connections. Tap water in the hydraulic pump reservoir.

Hazards: Pinch points due to the hydraulic pump lever arm, needs a person who can exert around 55 pounds of force. High pressure water: ensure that the high pressure tubing is not kinked.

PPE Requirements: Safety goggles.

Facility: This test can occur outside Mustang ’60 on the tables near a sewer.

Procedure:

1) Assemble the hydraulic pump with the reverse osmosis system. Do not attach the buoy or the lever arm. Only use the pump lever arm that was initially installed on the pump. Ensure that the high pressure tubing is not kinked.

2) Using the maximum angular displacement, count the number of complete cycles needed until the system starts outputting water.

4) Repeat this again on a different day to test for repeatability.

Results:

Pass Criteria: Lever arm cycles must be within 3 cycles on separate days.

Measured: Number of lever arm cycles

Day 1:

Lever arm cycles for pressure to start rising: 6 cycles

Lever arm cycles to establish 300si pressure: 7 cycles

Lever arm cycles for water output: 10 cycles

Day 2:

Lever arm cycles for pressure to start rising: 6 cycles

Lever arm cycles to establish 300si pressure: 7 cycles

Lever arm cycles for water output: 10 cycles

As seen, within two days, the lever arm cycles for each are the same. They are all within three cycles of each other on separate days. Our prototype passes this test.

Test Date(s): 4/15/2022

Test Results: Passed

Performed By: Andy Wu

TEST 4

Test Name: Flowrate with Angular Displacement of Lever Arm

Purpose: This test seeks to determine the impact of various angular displacements towards the flowrate of desalinated water in the system. By varying the angular displacement of the lever arm and recording the flowrate, an angular displacement versus flowrate curve can be established.

Scope: This test seeks to vary the input of the wave energy conversion system and determine how the final output of the entire system responds. The lever arm angular displacement will be varied from plus or minus 10 degrees all the way to the maximum displacement allowed by the lever arm in increments of 10 degrees. The final increment may not be ten degrees as the maximum displacement achieved by the lever arm may be less than the 10-degree increment. The flowrate will be measured by recording the time it takes to reach the 1 quart (0.25-gallon) mark on the bucket. In this case, the frequency of the lever arm will be set to 0.25 cycles per second no matter what the angular displacement is in order to obtain an accurate comparison of the flowrates for various angular displacements. The uncertainty in angular displacement will also be propagated to see how it impacts the flowrate.

Equipment: Poster board with angular displacements marked out with a protractor, two stopwatches, complete desalination system connected to the hydraulic pump, bucket with gallon markings.

Hazards: Moving lever arm may cause pinch points. Use of improper equipment connections in the system may result in serious injury (when assembling the system to not confuse the low-pressure hose with the high-pressure tubing). DO NOT drink desalinated water. Requires someone able to exert around 55 pounds of force.

PPE Requirements: Safety goggles

Facility: Musting ‘60 Outside Tables

Procedure: (List number steps of how to run the test, can include sketches and/or pictures):

1) Fill the hydraulic pump reservoir with water, and hand pump the hydraulic pump a few times while the system is unconnected in order to remove any foreign substances (dust from storage). Ensure that the hydraulic pump handle is parallel to the ground. Everyone must be wearing safety goggles.

2) Connect the hydraulic pump with the whole system, ensuring that the high-pressure tubing connects to the hydraulic pump outlet.

3) Take the poster board marked with angular displacements, and tape it so that it is level with the pump/horizon.

4) Using one or two hands, grab the hydraulic pump handle and have someone else start the first stopwatch. Have another person start the second stopwatch. Start moving the hydraulic pump handle upwards. Ensure that the frequency of the lever arm is 0.25 cycles per second. This can be achieved by ensuring that it takes two seconds to move the hydraulic pump handle from the level position, upwards to the maximum angular displacement as determined by the poster, and down again to the level position). Then, it should take another two seconds to move the hydraulic pump handle from the lever position, downwards to the maximum angular displacement as determined by the poster, and then back to the level position. Have someone reset the stopwatch after each cycle.

5) Once the desalinated water fills up to 0.25 gallons, record the time on the second stopwatch. Then, reset both stopwatches and repeat steps 4 and 5 for the other angular displacements. Ensure that the lever arm starts parallel to the ground every time.

Results:

Angular Displacements (Deg)	Time to get to 0.25 gallons (sec)	Flowrate (gph)
± 10	182.29	4.94
± 20	126.79	7.10
± 30	86.27	10.43
± 40 (max)	82.71	10.88

*results taken at constant rate of angular displacement

** uncertainty: angles +/- 2.5 degrees; water bucket +/- 0.25pts

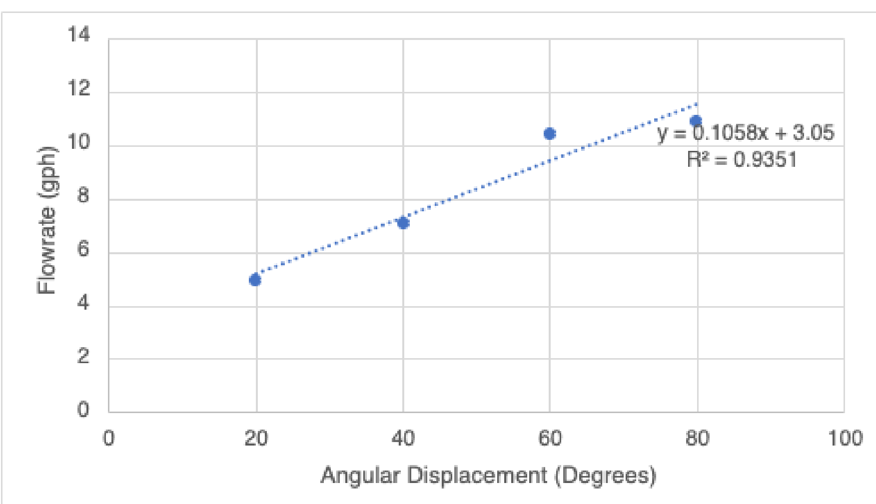


Figure E1. Flowrate vs. Angular Displacement from Test Results

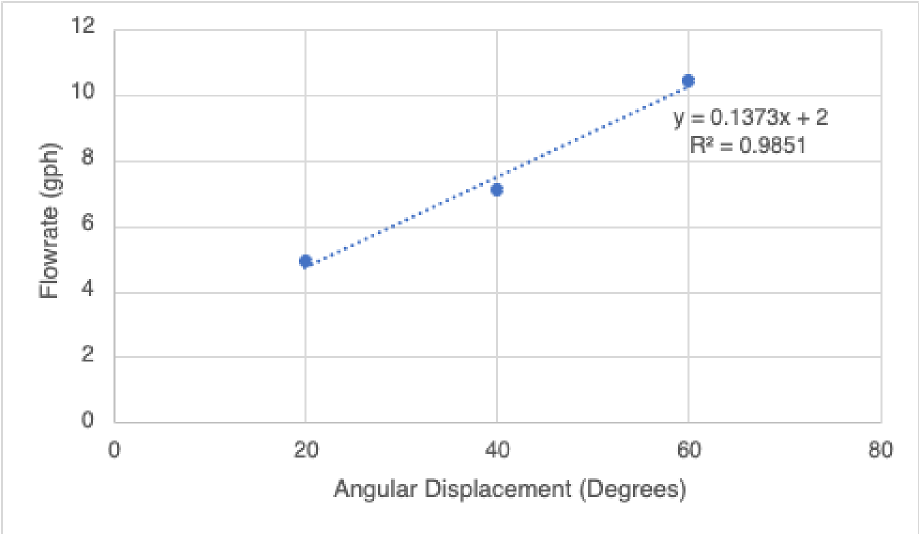


Figure E2. Adjusted Test Results (80deg removed)

Pass criteria:

At least 1 gallon per hour!

Test Date(s): 4/21/22

Test Results: Passed

Performed By: Andy Wu

TEST 5

Test Name: Flowrate, pH, and Salinity from Ocean Testing

Purpose: This test seeks to determine the final function of the system. Waves from the ocean will push the buoy as the mechanical energy input, while the system output, the flowrate of the system, will be measured. Furthermore, the water quality will be determined.

Scope: This test seeks to quantify the real-world performance of the whole system. The buoy will be placed in the water, and the hydraulic pump will be bolted onto the pier with the fixture. The time will be measured to determine the flowrate of the desalinated water, and the pH and salinity of the water will be tested in order to determine the quality of the water.

Equipment: Whole system, litmus paper, salinity strips, stopwatch, bucket with gallon markings

Hazards: Moving lever arm may cause pinch points. Use of improper equipment connections in the system may result in serious injury (when assembling the system to not confuse the low-pressure hose with the high-pressure tubing). DO NOT drink desalinated water.

PPE Requirements: None

Facility: Pier near an ocean

Procedure: (List number steps of how to run the test, can include sketches and/or pictures):

1. Connect the whole system together, and place the buoy into the water.
2. Place the pump fixture and pump on the pier, clamping the fixture to the pier.
3. Start the stopwatch and operate the system. Calculate the flowrate using the volume of water collected divided by the time recorded on stopwatch.
4. Test the desalinated water with litmus paper and salinity strip.

Results:

9.5 min operation time

26.3 ounces of filtered water collected

Flowrate-Trial 1 (gph): 1.295 gal/hr

Test Strips Results

	Salinity [ppm]	pH	Alkalinity [ppm]	Hardness [ppm]	Chlorine [ppm]
Before filtering	10300	9	180	450	1
After filtering	1640	9	180	250	1

Pass criteria:

At least 1 gallon per hour! **PASS**

pH between 6.5 and 9.5! **PASS**

Less than 1000 ppm for salinity! **FAIL**

Test Date(s): 4/22-5/10

Performed By: Amanda Olla

TEST 6

Force Criteria for Pump Handle

Test Purpose: *Find maximum force necessary to move pump handle from stationary position.*
Scope: Hydraulic Pump Handle
Test Equipment:

- Force Gauge
- Hydraulic Pump with handle attached

Hazards:

Safety Concern	Mitigation
Heavy Lift Items	• 1 person lift <40 lbs • 2 person lift <70 lbs
Pinch Points	• Hands must be out of the way before pulling gauge

PPE Requirements: Safety glasses
Facility: Mustang 60
Procedure:

1. Secure the base of the wooden pump fixture to the table using clamps.
2. Hook the force gauge into the hole at the very end of the pump handle arm (hole where screw should be to connect pump handle to lever arm).
3. Configure the pump handle to be in its lowest downward position.
4. Pull the gauge upwards until the handle moves and record the highest force observed in the corresponding table below. Repeat 5 times.
5. Configure the pump handle to be in its highest upward position and repeat step 4 with a downward motion.
6. Record the maximum value observed for both directions in the results table below

Results:
Pressure increase from 260 to 300 psi

Test #	Upward Motion (lbf)	Downward Motion (lbf)
1	26-31	14-24
2	26-31	18-24
3	28-31	18-24
4	25-30	18-24
5	26-31	19-23

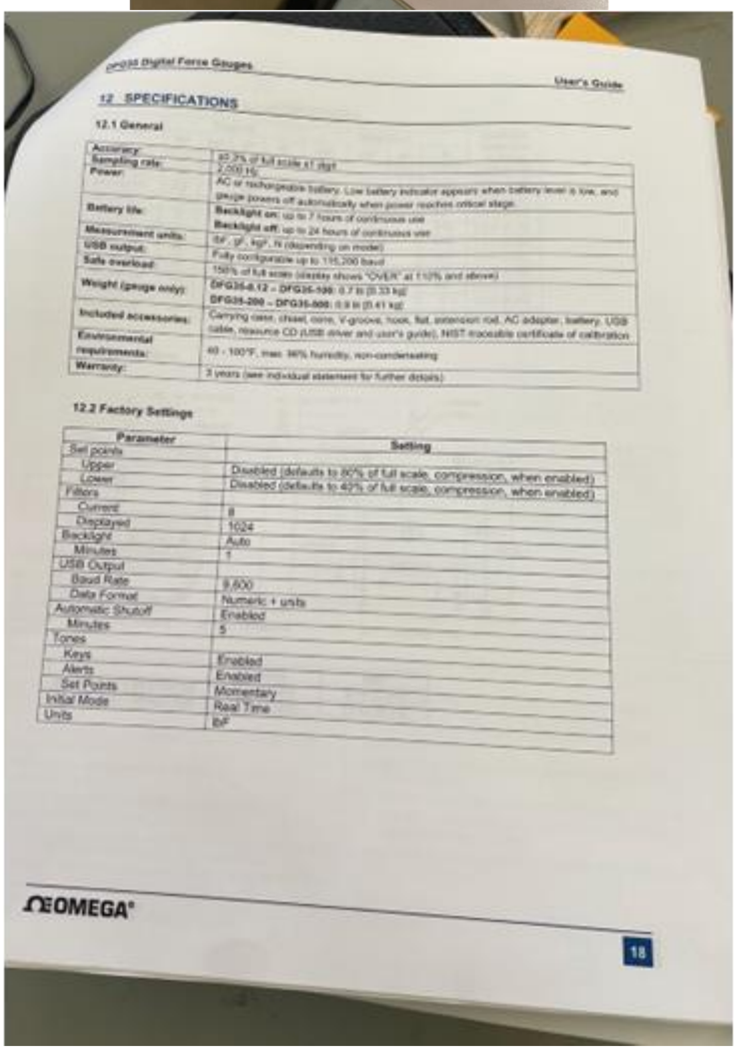
Highest Force Observed:

MAXIMUM UPWARDS FORCE	MAXIMUM DOWNWARDS FORCE
31	24

Performed By:

Name(s)	**Charlie Sinclair**
Test Date(s):	**5/3/22**

Force Gauge Specs:



DFG35 Digital Force Gauges

User's Guide

12 SPECIFICATIONS

12.1 General

Accuracy:	±0.2% of full scale ±1 digit
Sampling rate:	2,000 Hz
Power:	AC or rechargeable battery. Low battery indicator appears when battery level is low, and gauge powers off automatically when power reaches critical stage.
Battery life:	**Backlight on:** up to 7 hours of continuous use **Backlight off:** up to 24 hours of continuous use
Measurement units:	lbF, gF, kgF, N (depending on model)
USB output:	Fully configurable up to 115,200 baud
Safe overload:	150% of full scale (display shows "OVER" at 110% and above)
Weight (gauge only):	**DFG35-0.12 – DFG35-100:** 0.7 lb [0.33 kg] **DFG35-200 – DFG35-500:** 0.9 lb [0.41 kg]
Included accessories:	Carrying case, chisel, cone, V-groove, hook, flat, extension rod, AC adapter, battery, USB cable, resource CD (USB driver and user's guide), NIST traceable certificate of calibration
Environmental requirements:	40 - 100°F, max. 96% humidity, non-condensating
Warranty:	3 years (see individual statement for further details)

12.2 Factory Settings

Parameter	Setting
Set points	
Upper	Disabled (defaults to 80% of full scale, compression, when enabled)
Lower	Disabled (defaults to 40% of full scale, compression, when enabled)
Filters	
Current	8
Displayed	1024
Backlight	Auto
Minutes	1
USB Output	
Baud Rate	9,600
Data Format	Numeric + units
Automatic Shutoff	Enabled
Minutes	5
Tones	
Keys	Enabled
Alerts	Enabled
Set Points	Momentary
Initial Mode	Real Time
Units	lbF

OMEGA

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