Project Number: MQP 4501_MQF_B11

A STUDY OF THE FLUID DYNAMICS INVOLVED IN WATER PURIFICATION METHODS WITH REVERSE-OSMOSIS

by

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A Major Qualifying Project

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

in Mechanical Engineering

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APPROVED: DECEMBER 2011

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ABSTRACT

The purpose of the report is to analyze the most promising methods for distilling pure water from otherwise unusable water: reverse osmosis with several stages of preprocessing. By forcing the intake water through a fine membrane the system removes the need for heat, hence combustion, to be used to purify the water. High pressures in the filtration process allow a person to utilize salt water, which comprises almost all of the available water on the planet, and also waste water to create a distillate which is safely consumable by a human and for use in electronic cooling systems. Eliminating fuel consumption in the system decreases cost significantly and creates an environmentally friendly system out of a process usually responsible for the release of large quantities of greenhouse gases. Preprocessing allows even the most polluted waters to safely be passed through the membranes without the destruction normally caused by chemical pollutants found in many freshwater areas. To increase the efficiency of the system, the fluid dynamics through the pipes and pump were analyzed to search for areas of weakness in the design. A significant goal of the project was to decrease electricity consumption and increase the total water output of the system. These improvements are vital as they will make fresh water more readily available throughout the third world as well as decreasing the environmental impact of a lifesaving process. The final computer-aided design utilizes both carbon filtration to remove organic impurities as well as a multiple-pass reverse osmosis array to optimize purification. The availability of fresh water is one of the greatest challenges facing many developing nations all over the world and the improvement of these systems shows the greatest potential for making fresh water available virtually anywhere in the world both cheaply and efficiently.

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ACKNOWLEDGMENTS

We would like to extend our appreciation to Professor Mustapha Fofana for his assistance throughout the development of this project. We also would like to express our gratitude for his expertise in MathCad as a way to assist us throughout the computational portions of this report.

NOMENCLATURE

D	Diameter of pipes	[ft]
D_h	Hydraulic diameter	[ft]
f	Darcy frictional factor	[dimensionless]
g	Gravity	[ft/s^2]
h_L	Head loss	[ft]
L	Length	[ft]
m’	Mass flow rate	[lbm/s]
P_{atm}	Atmospheric pressure	[psi]
Re	Reynold’s number	[dimensionless]
T_W	Inlet temperature of water	[^{o}F]
V	Volume	[gallons]
V’	Volume flow rate	[gallons/s]
v_2	Velocity	[ft/s]
W’	Power	[Btu/hr]
z_2	Distance water traveled	[ft]
ε	Mean surface roughness	[ft]
μ	Dynamic viscosity	[lbm/ft*s]
ρ	Density	[lb/ft^3]

CHAPTER 1. INTRODUCTION TO REVERSE OSMOSIS

In the normal osmosis process, two solutions of different solute concentrations are separated by a semipermeable membrane. The solvent, generally water, travels through the membrane in order to naturally balance the solute concentrations. This movement of water generates osmotic pressure. Applying an external pressure to reverse the natural flow of solvent is therefore called “reverse osmosis.”

The topic of clean water is one that effects people throughout the world, from third world war-torn regions to the most modern nations, such as the United States of America or throughout the United Kingdom. For some, clean drinking water is not difficult to obtain: it is as easy as turning on a faucet and filling a glass for drinking. This is not the case for others, in places where obtainable water is filled with contaminants or debris. When the need for consumable water on Naval vessels was brought up, there was a realization that even though the people on these vessels are surrounded by water, and in many cases entirely submerged in it, they do not have immediate access to clean water for drinking or cooking, or even bathing. Taking this into consideration, our project first examined current methods available for water purification. The single most promising method was reverse osmosis because of its superior ability to remove a wide range of harmful microscopic contaminants from water.

Purifying water using the principles reverse osmosis, our most significant objective is to provide a method of providing clean water anywhere in the world. When there are droughts or strife in a large region, there will be a very large need for clean water, affecting as much as hundreds of thousands of people. In addition, these instances arose in the wake of natural disasters, such as in the aftermath of hurricane Katrina. Considering the staggering populations without clean drinking water, there must be a way to provide suitable and safe water on a very large scale, minimizing the environmental impact and waste. Considering austere events during which access to clean water is not easily tangible, the scale of people who may find themselves in need of clean water may be on the scale of hundreds. Remote villages without a reliable power supply serve as a prime example, which can be considered a medium scale water necessity. On a small scale level, water may become necessity for someone on a hike or a small group of people who are away from a clean water source. In all cases, reverse osmosis systems are capable of providing varying amounts of water relative to the scale on which it is needed. Additionally, the situations in which clean water is required may involve change of location which could require that the reverse osmosis system be portable or have the ability to be disassembled for transport. It is our intention to provide a generic reverse osmosis water purification system which we will be able to scale based on the amount of clean water required, whether small, medium, or large scale. The ability to transport the system is paramount, either from site to site in the event of a natural disaster (large scale), or outdoor event (medium scale) in which the water purification system is only temporarily required, or a reverse osmosis unit that can be placed in a backpack and carried for several days while hiking or for our soldiers in the field of battle.

Throughout this paper the process of reverse osmosis will be discussed, evaluated, and manipulated to fit the goals of the project. The current chapter introduces the concept of reverse osmosis and discusses its applications. The following chapter discusses the multiple concepts used to make the process a reality, ranging from the use of high pressure pumps to the many filters which prevent destructive chemicals from destroying the fragile membranes. Chapter two also discusses the many different alternatives that exist to using reverse osmosis and both the "pros and cons" associated with each. The chapter concludes with a summation of MIRAD Laboratory's goals and how the project addresses each of them to create a better tomorrow.

Chapter three contains the mathematics behind the concept using basic fluid dynamic concepts. Chapter four contains the group's conclusions and recommendations for furthering the project. The appendices at the end contain the 3D designs for parts as well as their descriptions.

CHAPTER 2. PRACTICES INVOLVING REVERSE-OSMOSIS

2.1. Water Purification is a Global Challenge

Household water "purification" continues to make a growing presence in everyday life. With the increased use of the wilderness and natural resources, there has also been an increase in the amount of bacteriological contamination of even the most remote water supplies. According to a 2007 World Health Organization (WHO) study, 1.1 billion people worldwide lack access to an improved drinking water supply. In addition, 88 percent of the 4 billion annual cases of diarrheal disease are attributed to unsafe water and inadequate sanitation and hygiene, and 1.8 million people die from diarrheal diseases each year. The WHO estimates that 94 percent of these diarrheal cases are preventable through modifications to the natural water supply and environment.

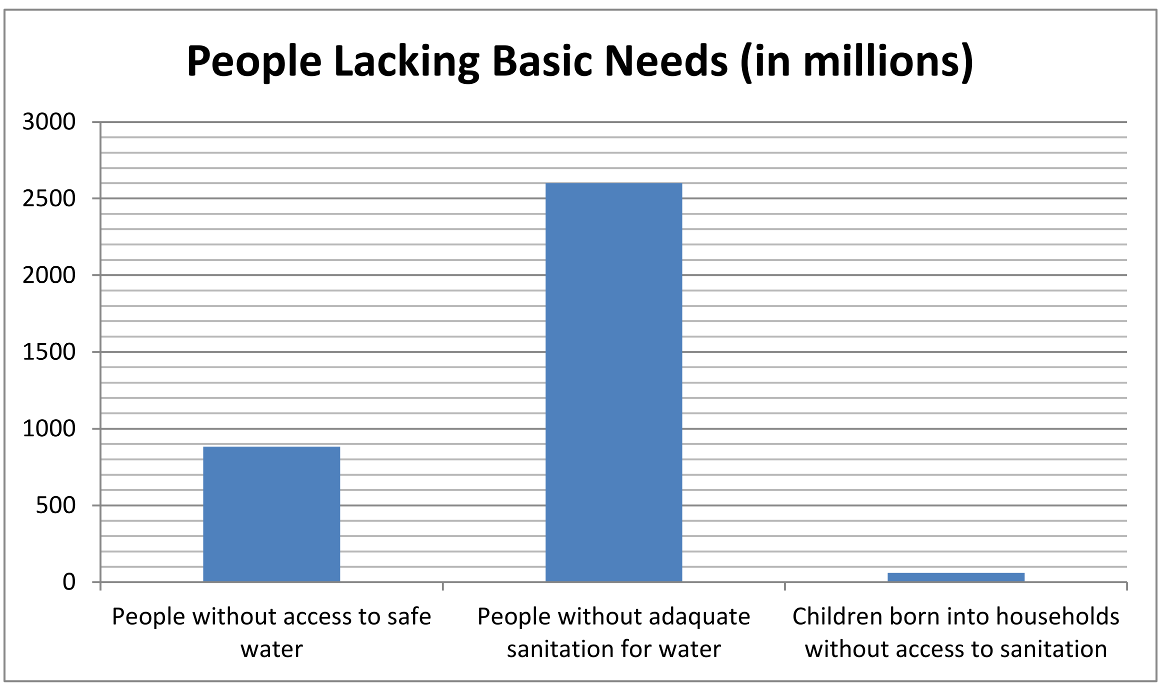

Figure 1: People Lacking Basic Water Needs

Many in the United States take water sanitation for granted, Figure 1 illustrates just how rampant the lack of necessary sanitation is throughout the rest of the world.

Biologically contaminated water is natural water which contains microorganisms such as Giardia, (a common microorganism that, if not killed, leads to intestinal disorders), bacteria, or viruses. The worst biological contaminations in water are from feces finding its way into the water. Millions of bacteria and viruses live in one gram of feces as illustrated in Figure 2. Parasites from fecal contamination are often found, by the thousand, in children living in areas with no water sanitation. Toxic water sources contain chemical contamination from pesticide runoffs, mine tailings, etc. Boiling, filtering, or chemically treating water can remove or kill microorganisms, but it cannot guarantee the removal of organic chemical toxins.

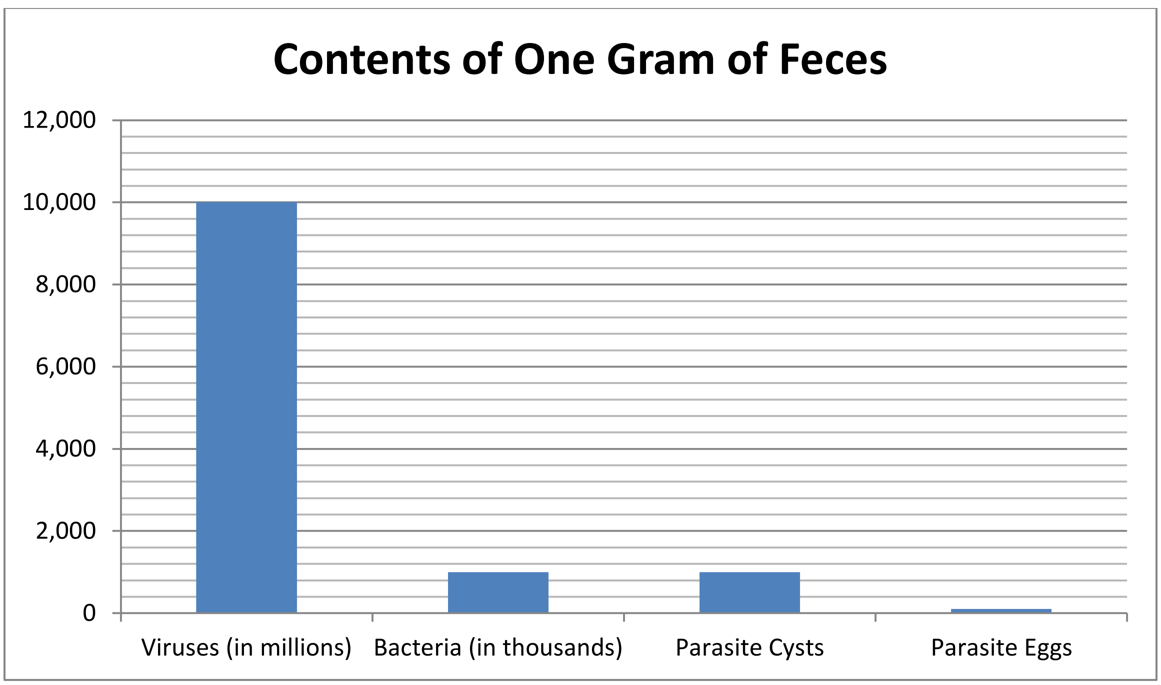

Figure 2: Contents of One Gram of Feces

In the field, boiling the water sample is the most certain way to kill all microorganisms. According to the Wilderness Medical Society, water temperatures above 70 °C kill all pathogens within 30 minutes and within 5-10 minutes above 85 °C. Therefore in the time it takes for the water to reach the boiling point (at sea level, 100 °C from 70 °C), essentially all of the biological contaminants will be killed, even at high altitude.

In most realistic cases, boiling your water supply is neither efficient nor possible. Especially combined with the processes of reverse osmosis, advances in filtration have made much more portable and effective means of water purification. Depending on the micron rating of the filter, smaller organisms (like viruses in larger thresholds) can pass through. Users should know what potential organisms or pathogens should be treated for. You don't want to go to an area where a virus like hepatitis A could be present in the water (a problem in some developing countries) with a filter that will handle only a larger organism like Giardia.

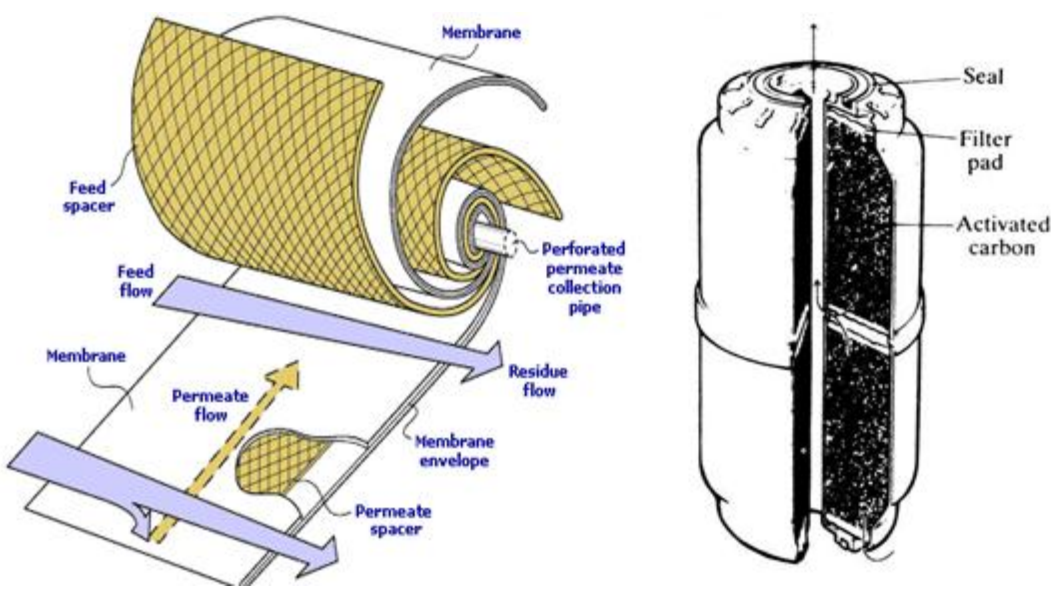

Figure 3: Comparison of Membrane and Carbon Filters

In general, there are two types of filters: membrane filters and depth filters which are illustrated in Figure 3. Membrane filters use thin sheets with precisely sized pores that prevent objects larger than the pore size from passing through. Reverse osmosis processes, although much more intricate, are built around the concept of membrane filtration capitalizing on the benefits of the spiral wound design. These filters are popular because they're relatively easy to clean, maintain, and reuse for extended periods of time. However, they do clog more quickly than depth filters, especially if the water is not pre-treated.

In comparison to membrane filters, depth filters use thick porous materials such as pure carbon configurations, as seen in Figure 3, or ceramics to trap particles as water flows through the material. This method is especially popular because the filters can be partially cleaned by backwashing. Specifically, Granular Activated Carbon filters can also remove a multitude of organic chemicals and heavy metals. On the downside, rough treatment or environmental conditions can crack the filter, rendering it useless, perhaps even allowing graphite crystals to enter the water sample. A common household example of depth filtration is the Brita faucet and pitcher technologies.

It's important to clarify that there's a difference between a water filter and a water purifier. Even the most advanced water filters cannot eliminate viruses because of their pore sizes. However, in order to make the distinction as a true water purifier, water must pass through both a filter and a disinfecting interface such as ultraviolet treatment. This will eliminate any smaller organisms, namely viruses, which have passed through the initial filter stage. Water quality is evaluated in three different grades, A, B, and C, as shown in Figure 4. Grade A water is the highest quality and Grade C Water is normal tap water.

	Grade A	Grade B	Grade C
Chlorides, ppm, max	0.1	1	35
Conductivity,µmho/cm, max	2.5	20	550
pH	6.0-8.0	N/A	N/A
Visual Clarity	No turbidity, oil, or sediment		

Figure 4: Water Grades

Grade A water is water used for deionized water, Grade B water is Reverse-Osmosis quality water, and Grade C water is standard tap water. Most water is purified for human consumption, but the general process may also be designed for a variety of other purposes, including, but not limited to the requirements of medical, pharmacology, chemical and industrial applications. Each of these applications has a given standard for the conditions of the water used, hence why purification methods are specifically engineered for their intended use. The greatest challenge to overcome in water purification is disinfection of the final product. Several methods exist, including chlorination and iodine, chloramines, ozone, ultraviolet, hydrogen peroxide, and solar treatments. Figure 4 lists the many requirements that must be met so that water can be used for specific functions. Grade A water is also known as Deionized water and can be used in steam generators, medical equipment, and nuclear reactors.

Control of the operation and process of distilling water is necessary so that the system responds as desired. Without control, the output will vary greatly with failure to adjust to effects from outside sources, and therefore the preferred outcome in ppm salt is unlikely. Currently, water is being distilled using 4 different methods: Flash-Type, Vertical Basket, Vapor-Compression, and Reverse-Osmosis. Each method has its advantages and disadvantages.

The use of reverse osmosis for the purification of water has been overlooked in the past compared to other desalination processes. However, there has been recent improvement of the process through the development of higher capacity and more efficient modules. The process of reverse osmosis could be dually used as a treatment for wastewater and seawater.

If two solutions of different solvent consistencies are separated by a semi-permeable membrane, the process of osmosis occurs when there is fluid transported until a thermodynamic equilibrium is achieved. When an external pressure overcomes the existing equilibrium, a pressure known as the osmotic pressure, the fluid flows through the membrane in the opposite direction completing the process of reverse osmosis [Ref. 2]. During the desalination of brackish and sea water the semi-permeable membrane is controlled to disallow contaminates such as brine into the fresh water. More importantly, the pressure applied to the fluid from the pump is controlled through the pump and motor used. By controlling these variables the desired product in ppm salt can be determined.

2.2. The Need for a Multi-Stage Process

The best method for purifying water utilizes a multistage process. No strategy standing alone has the capacity to fulfill the large water production capable in a combined process. The design used in this process combines the high capability potential of reverse-osmosis with the more advanced water processing capabilities of advanced purification filters as well as the chemical removal properties of carbon filters. Together damage to filters is reduced life expectancy increases, and the quality of the distillate greatly improves. Figure 5 illustrates the block diagram layout for the entire project. The paper's layout also follows this diagram to increase ease of understanding.

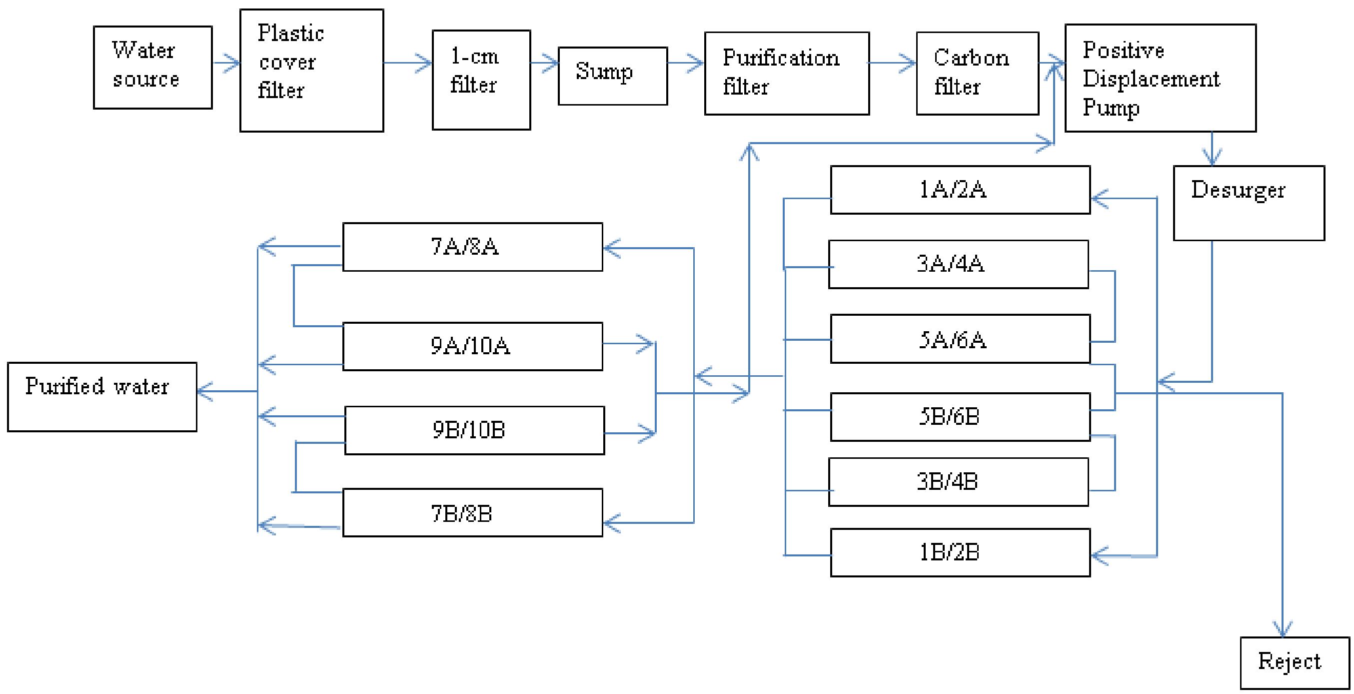

Figure 5: Block Diagram of Final Design Concept

2.3. Reverse-Osmosis

Reverse osmosis is a currently researched method of water distillation that takes up considerably less space than conventional means. Unlike other methods that require large amounts of heat, this method simply uses high pressure pumps which force water through a filter. In reverse-osmosis a fluid being driven against a membrane where the fluid is permitted to pass but the salts are retained. Reverse osmosis is most commonly used on Navy vessels, and is by far the most effective method for water distillation in this setting. The current reverse-osmosis pumps used by the United States Navy can produce a distillate that is 1 ppm, which is still useable for almost all shipboard systems with the exception of steam generators which require deionized water to operate.

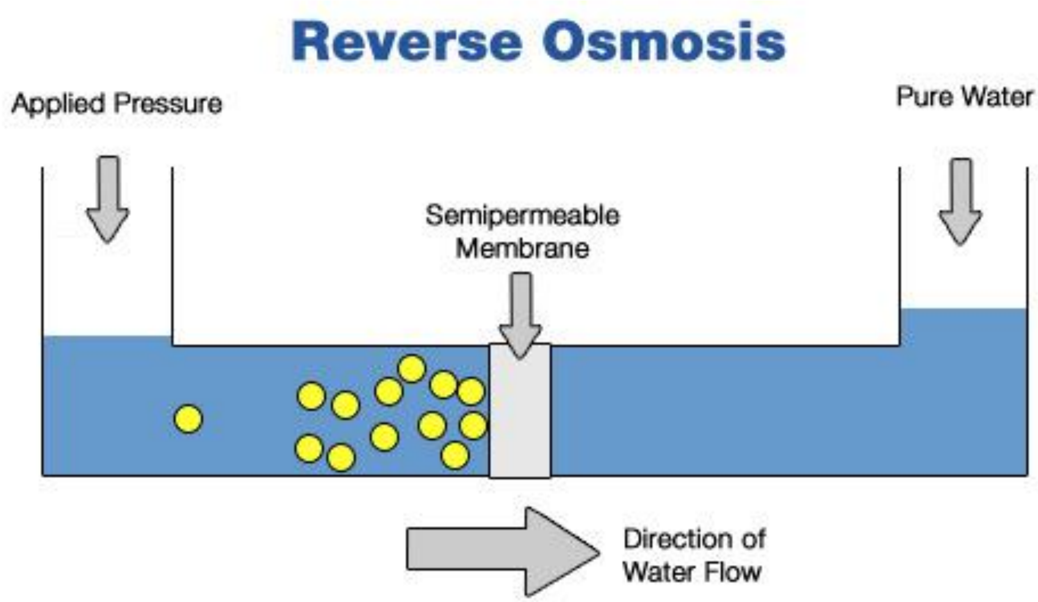

Figure 6: Simple Schematic of the Reverse-Osmosis Process

As pump designs improve and the membrane, used for filtration, is further researched the ability of reverse-osmosis pumps to fulfill the needs for water purification will be substantially increased. The basic concept behind Reverse-Osmosis, which completes most of the filtering in this design, is illustrated in Figure 6. The process of basic reverse-osmosis water distillation can be broken up into several parts; the pump, the motor, the membrane, and the salinity cells. Later additional phases including pre-processing and pump control will also be analyzed. Pre-processing is a vague term used to incorporate all filters put in place before the semi-permeable membranes. The jobs of the filters before the membrane range from removing solids to the removal of industrial grade chemicals commonly found in third world water sources as well as large commercial areas. All of the parts are integral in maintaining the quality of the distillate produced by the system and the prevention of the system's breakdown. A more detailed schematic can be found below in Figure 7. As the diagram indicates the process is a fairly simple process especially when compared to the other commonly used methods for distillation.

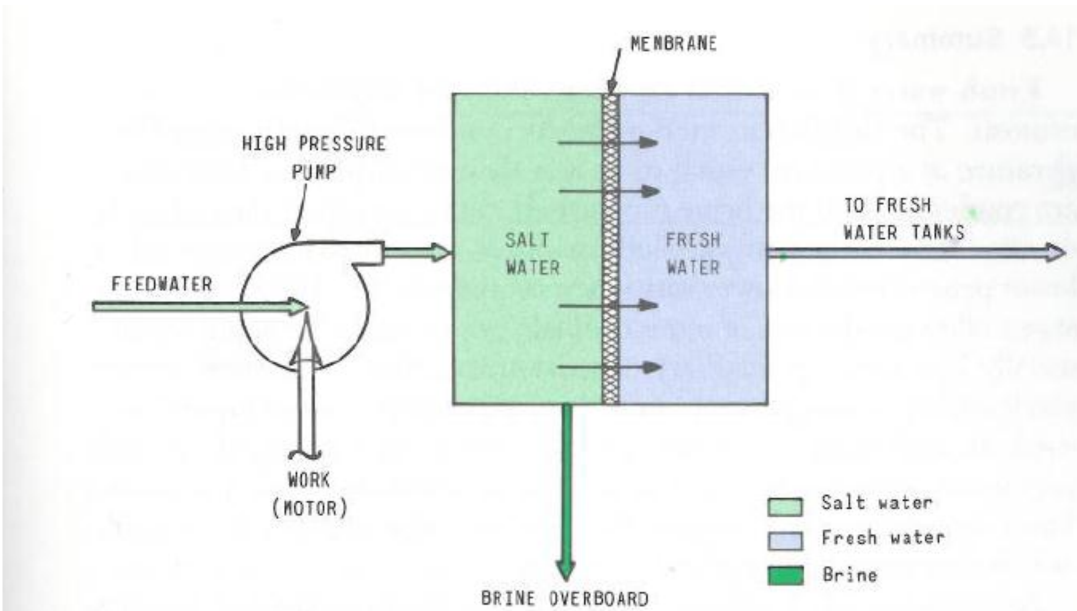

Figure 7: Schematic of Reverse-Osmosis Unit

2.4. Centrifugal Pumps

Reverse-osmosis requires high pressure, centrifugal pumps to force water through a membrane which separates the salt water into brine and distillate. The water pressure is determined by the type of water being processed. Higher pressures are used for the salt water due to the higher salinity of the water. Brackish water has between .5-30 parts per thousand (ppt) salt content, whereas saline water has between 30-50 ppt.

The normal standard for naval vessels is that the pumps operate at 74 psia for brackish water and 700-1000 psia for seawater. The design for this project requires a submersible pump operating between 30-40 psia used to remove water from wells, lakes, and other water sources and a higher power pump operating at 450 psia. The design is intended solely for freshwater or brackish water, not seawater, so 450 psia is used to increase the overall efficiency of the membranes which operate better at higher pressures due to increases in water flux.

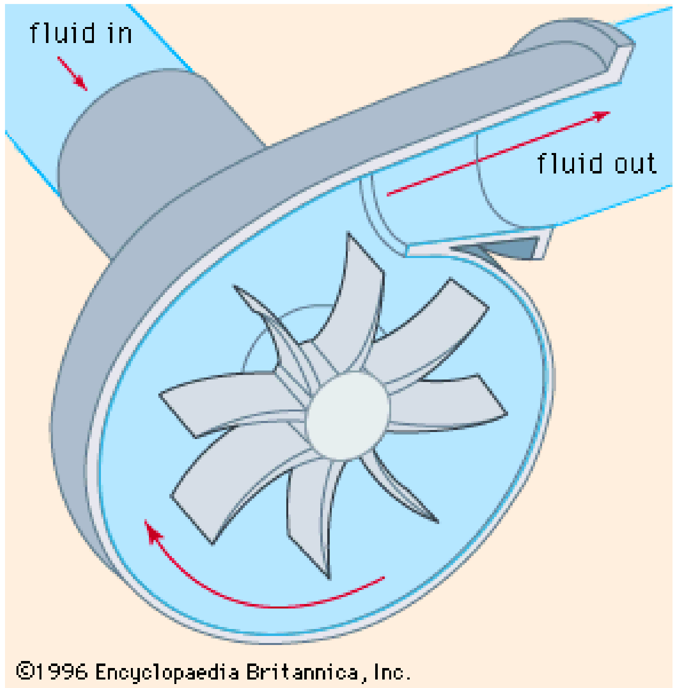

Figure 8: Centrifugal Pump Illustration

The simplest form of a centrifugal pump uses an impeller blade rotating inside an eccentric casing as illustrated in Figure 8. The centrifugal forces used by the pump, shown above, are generated by the high-speed rotation of the impeller blade. An impeller blade is a disc which has a series of curved vanes radially mounted on it. The fluid enters the pump at the center and the rotation of the impeller causes the vanes to thrust the liquid outward at extremely high velocities. When the high-velocity liquid leaves the impeller it enters the eccentric casing or volute. The volute takes the kinetic energy of the water and converts it into pressure by forcing the water diverging nozzles which slows down the water and increases pressure.

Centrifugal pumps can either be single-stage, such as the example in Figure 8, or multistage. These pumps are either classified as single-suction or double-suction. The staging and suction rating of a centrifugal pump determines its capacity and operation. The rotating member of the pump, in the simplest case the impeller, is driven by a prime mover (a motor).

2.5. Motor

A prime mover is a source of work for the impeller in the centrifugal pump. These devices range from turbines, in large operations such as propellers, to AC motors, used in pumps throughout ships and other hydraulic systems. The motors, on US Naval vessels, operate off of the ships main electrical distribution or Ship's Service Distribution Systems (SSDS).

	Phase	Voltage	Frequency
US Navy	3	450 Volts	60 Hz
US residential	1	115 Volts	60 Hz

Figure 9: Electrical Ratings

Figure 9 shows the electrical ratings of both residential and military systems. The standard electrical plan on Naval Vessels operates on a 3-Phase, AC, 450 Volt, 60 Hz system. The system is also ungrounded so that it takes two faults to short a system as opposed to grounded systems which only require one fault. US residential power, which supplies the power for many commercial reverse-osmosis units, operates at 115 Volts, with 1 phase, 60 Hz, AC electricity. The increase in voltage allows the reverse-osmosis units used by Naval Vessels to have higher standards of filtration that seen in even the highest ranked Industrial system. The electrical needs of the Navy require that the electricity be three phase for maximum redundancy.

2.6. Membrane

The membrane, synthetic and semi permeable, blocks the passage of the salts, which are concentrated and removed as brine. Industrial reverse osmosis use spiral wound membranes mounted in high pressure containers. The membrane stack is two, very long semipermeable membranes, made of either polyamide or cellulose fiber, with a spacer mesh between them that is sealed along the two long edges. The membrane is then wound up in a spiral tube with another spacer to separate the outside of the stack. The spiral winding provides a very high surface area for transfer during the reverse-osmosis process. Between each membrane layer is a mesh separator that allows the distillate water to flow. Water is forced through one end of the spiral cylinder and out the opposing end. Backpressure forces the water through the membrane where it is collected in the space between the membranes. Distillate then flows around the spiral where it is collected in the center of the tube. For redundancy naval vessels use multistage units which also increases the purity of the distillate substantially compared to a single stage reverse-osmosis unit. The design of this project will also require multistage units to increase its efficiency.

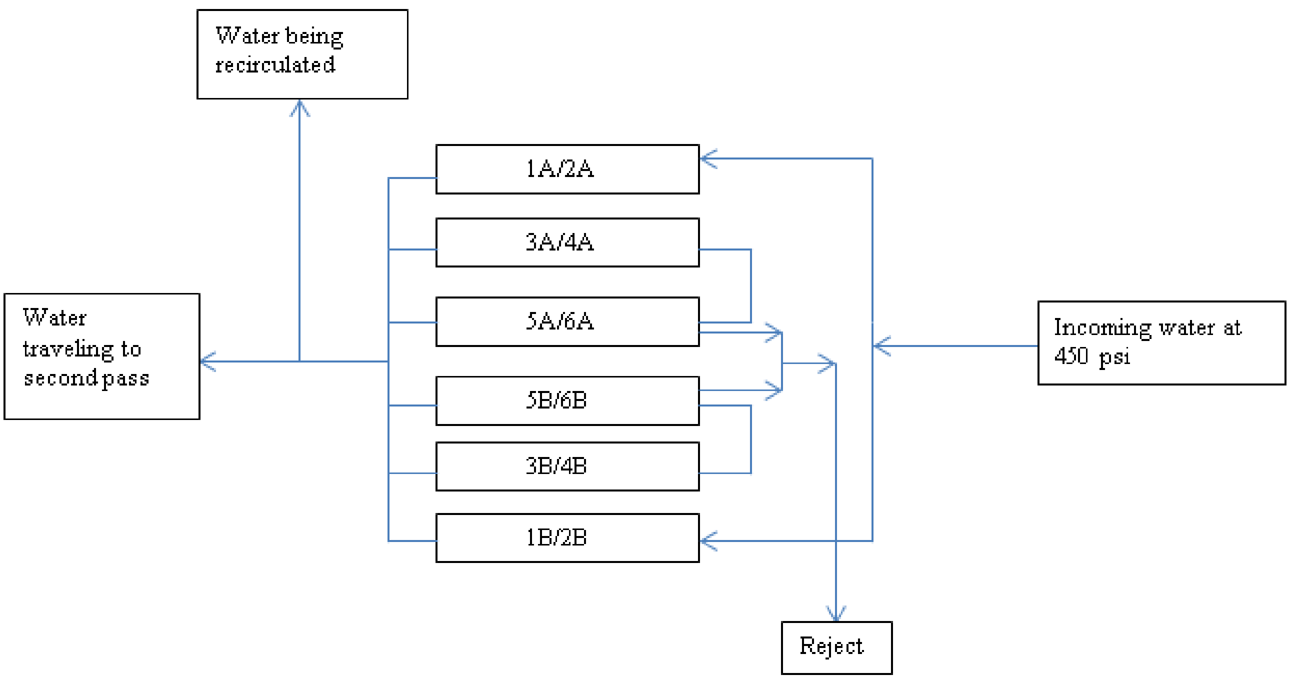

Figure 10: First-Pass Filtration

The design required for the purification system developed for this project embraces the idea of recirculation to dilute incoming water and the staging of membranes in parallel series. As observed in Figure 10 water can enter membranes 1A or 1B. The concentrate from the first membranes will then be passed to the second membranes and the concentrate from the second membranes will be passed on to the third membranes. Concentrate from the third membranes will then be rejected by the system. Some water will be recirculated back into the system to dilute the incoming water while the rest of the water will continue on to a second pass through several more membranes.

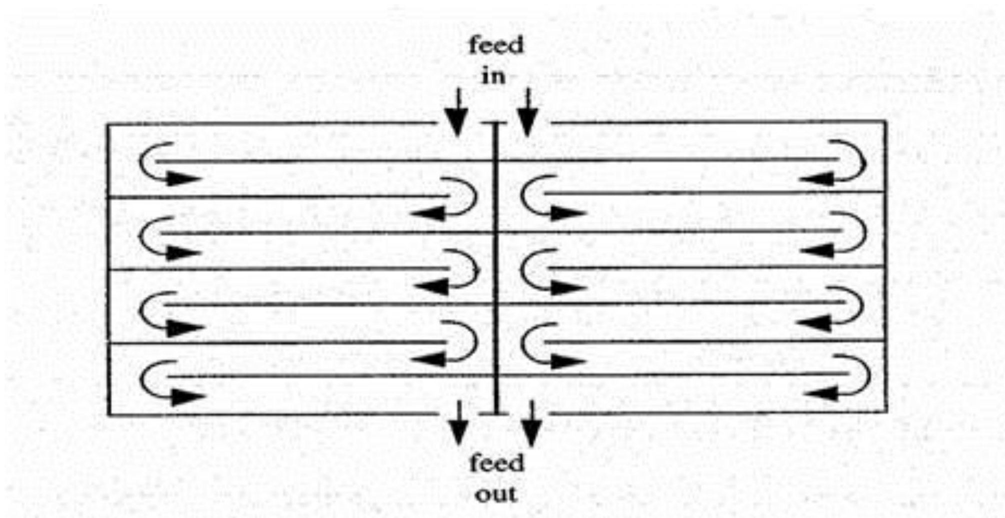

Figure 11: Feed Diagram

The purity of the distillate is determined by the type of salts in the solution as well as the reject ration of the membrane. Figure 11 depicts the feed flowing through the membrane, which can either lead to rejection or reverse-osmosis. A 95% reject ration means that 5% of the salt concentration leaks through the membrane. If a 35,000 ppm seawater sample is put through a membrane with a 5% reject ration the distillate produced will be 1750 ppm. Operating on a 99% reject ration would produce a distillate with 350 ppm. The current systems used on board naval vessels produce a distillate that is 1 ppm. 1 ppm is achieved by staging the membranes such that there are several passes and the membranes are staged in series and in parallel. 1 ppm distillate can be used in hotel services (cooking, cleaning, bathrooms, and drinking water) but not for boiler feed aboard vessels. The improved efficiency on naval vessels is a result of the filters being staged; reducing the salinity after the water is forced through each membrane. The first stage, or pass, is shown in Figure 10. The project's design calls for two passes, which will provide more than enough filtration for the quality of water expected to be used as feed and the desired filtration levels.

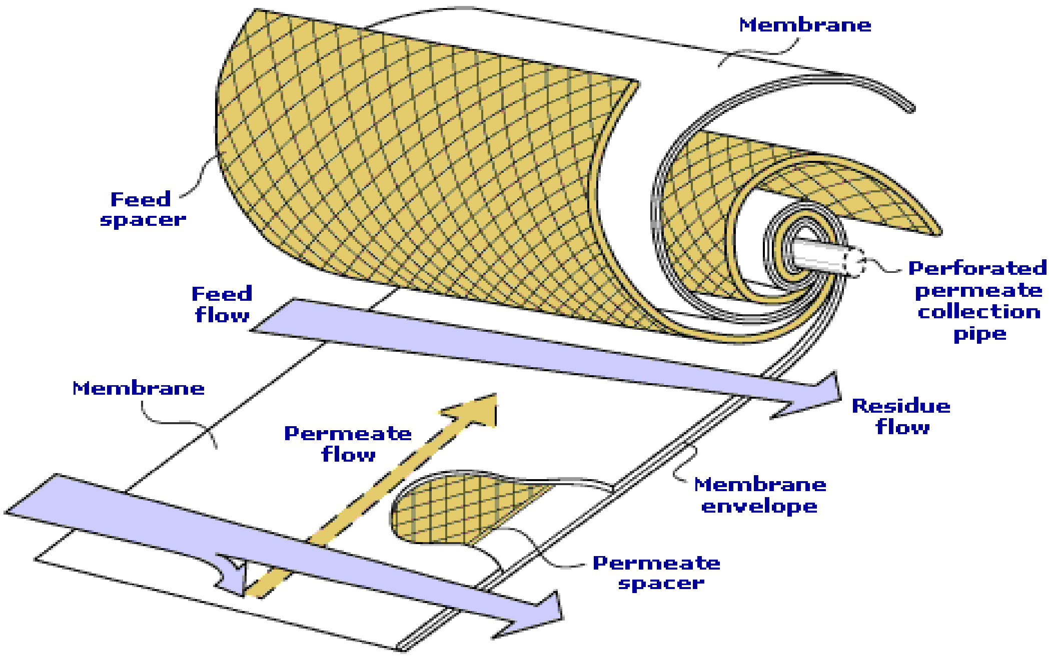

Figure 12: Spiral Wound Membrane Diagram

After leaving the pump at 700-1000 psi the water reaches the first pass membranes. These membranes require 700-1000 psi to overcome the osmotic pressure necessary to force the separation of freshwater from seawater. The resulting forces leave behind NaCl and compounds with calcium and sulfates. The membranes can be visualized as containing numerous tiny holes that allow water molecules to pass through. Figure 12 shows the breakdown of a membrane used in reverse-osmosis. The solids and remaining solution, or reject, flow past the membrane surface and are discharged. Water that passes through the membrane is known as permeate. Water production and quality are affected by inlet water temp, pressure and salt concentration. As operating pressure goes up, water flux, the amount of permeate per area of membrane surface, also increases in a direct relationship with pressure. Permeate salinity is highest immediately after feed pressure has exceeded osmotic pressure. The osmotic pressure of seawater is 350 psi. Rejected water from the first reverse-osmosis element is directed as feed to the second reverse-osmosis element. The process continues such that the concentrate from the second reverse-osmosis element is the feed to the third element, the concentrate from the third element is feed to the fourth and so on. Because the feed water to each successive reverse-osmosis element becomes increasingly concentrated it follows that the permeate drawn from each successive pressure vessel is also more concentrated. The majority of the first pass reverse-osmosis permeate is fed to the second pass reverse-osmosis pump and the rest is recirculated back into the feed water system.

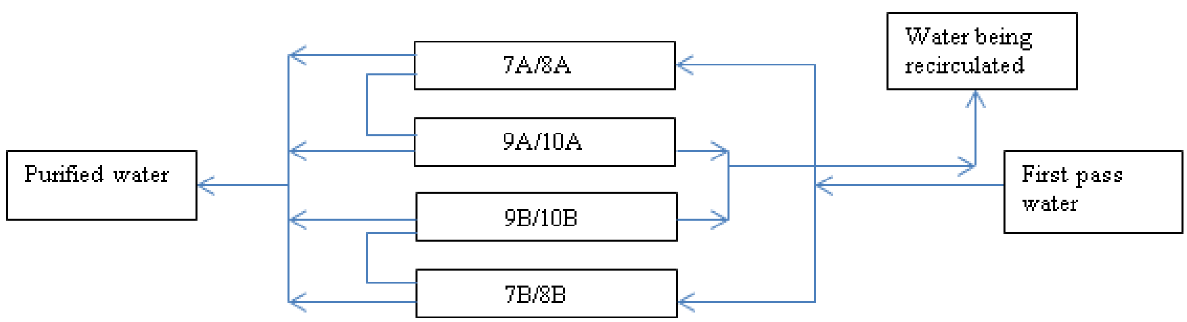

Figure 13: Second-Pass Filtration

The second pass membranes shown in Figure 13 are identical in design to those used in the first pass membranes. However they are staged differently with only two sets of membranes per side. The figure above shows water leaving the first pass membranes traveling immediately to the second pass membranes which are also staged in parallel-series. The majority of the water in the second pass is purified and becomes Grade B water.

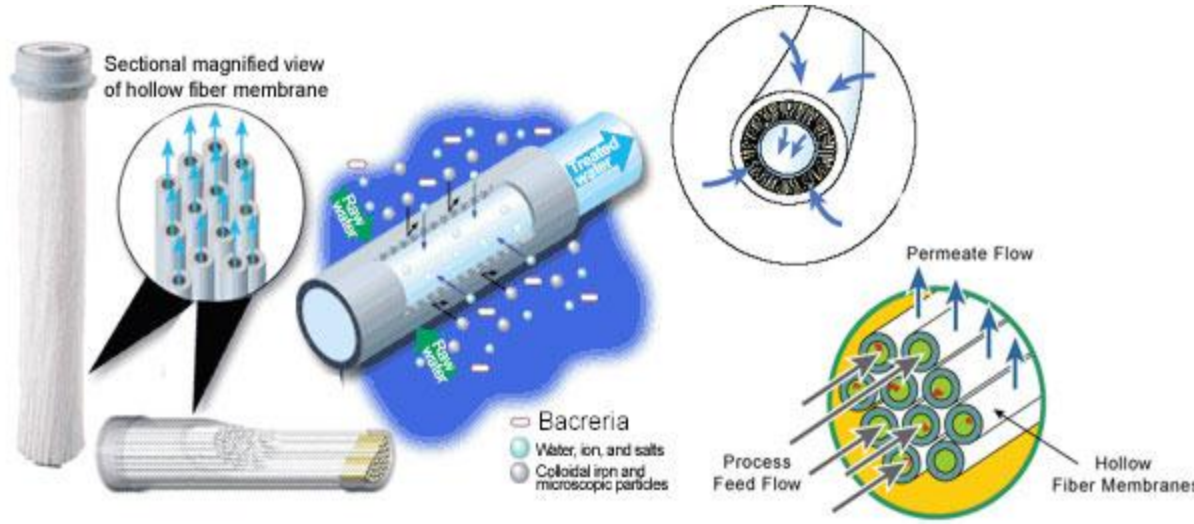

Figure 14: Diagram Depicting Effect on Bacteria

Proper maintenance is required to prevent the membranes from corroding and prevent the membrane from being clogged with salts and organic matter. Careful maintenance can also prevent bacteria build-up when, like in Figure 14, the membranes separate them from the water. When the system is processing dirty water (shallow water with high levels of sediment) the membrane needs to be cleaned often. Clogging of membranes and the appearance of dark-colored or clear, gelatinous deposits may indicate the existence of biological growth in the system. If this is the suspected cause of issues the system must be flushed and the membranes cleaned. The project's design uses several filters staged before and after the pumps to prevent as much biologics from entering the system as possible. The most common cause of biologic growth is stagnant water in pipes or tanks so water should not be stored in the tanks when the system is not in use.

2.7. Salinity Cells

The salinity of the distillate that is created by the reverse-osmosis unit is continuously measured by numerous salinity cells placed throughout the plant. These devices provide continuous remote monitoring of fresh water systems, allowing these devices to act as relays, sending information to a computer system that monitors the pressure of the system as a function of the salinity it produces. Salinity cells also act as an auto flow shutoff in the case of emergencies using solenoid valves. Figure 15 shows a typical salinity cell, which can be installed in pipes to monitor the salinity of the flow.

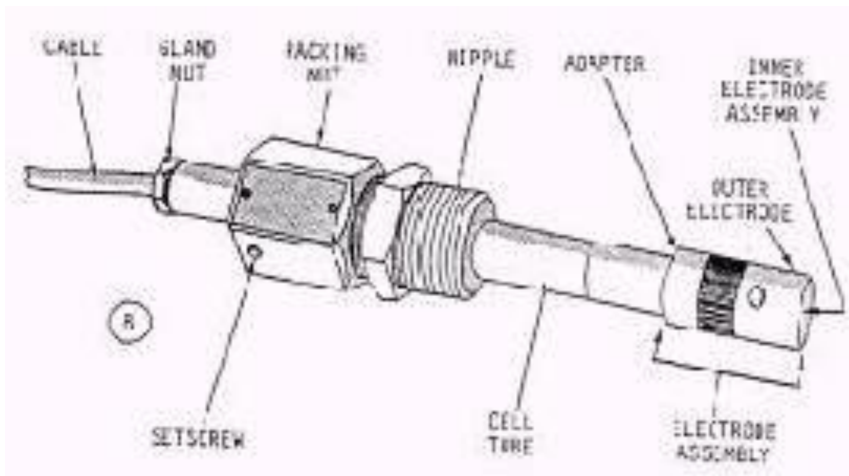

Figure 15: Salinity Cell

2.8. Advantages and Disadvantages of Reverse-Osmosis

The reverse-osmosis method for distillation has many advantages over the systems it replaces and supplements. The system is significantly lighter and has fewer parts which makes maintenance and repair work easier. However the system is not as adept at producing distillate as other methods. Reverse-osmosis produces a distillate that is 50 ppm salt whereas the other methods produce a distillate with salinity less than 1 ppm. The difference in salinity however, is not as important as it might seem. The water produced by reverse-osmosis is useable in all systems accept boiler feed systems, so the system is still able to provide most of the daily water needed in Naval systems. Reverse-osmosis is the most economic way of producing distillate as it uses electricity as opposed to heat. The electricity that is used is generated by turbine generators, thus are part of normal shipboard electrical distribution. Flash-type methods of distillation require the use of heat, which is often generated through the combustion of a fuel source. The process of reverse-osmosis is capable of producing more water per day than comparable flash type systems. Reverse-osmosis is the future of clean water production and furthering the research of the membranes used to filter the water will be integral in the development of a more sustainable and green Navy.

2.9. Flash-Type Distilling

Flash-type is one of the major types of marine distilling plants and depends upon differences in pressure and temperature to create vapor from sea water. Flash-type systems consist of either one or multiple stages with a flash chamber, a feed box, a vapor separator and a distiller condenser. The sea water passes through a series of heat exchangers that heat the water to vapor and then condense it. At the last stage of the process the feed that does not vaporize, brine, is removed by a pump and the distillate is discharged and stored in fresh water tanks.

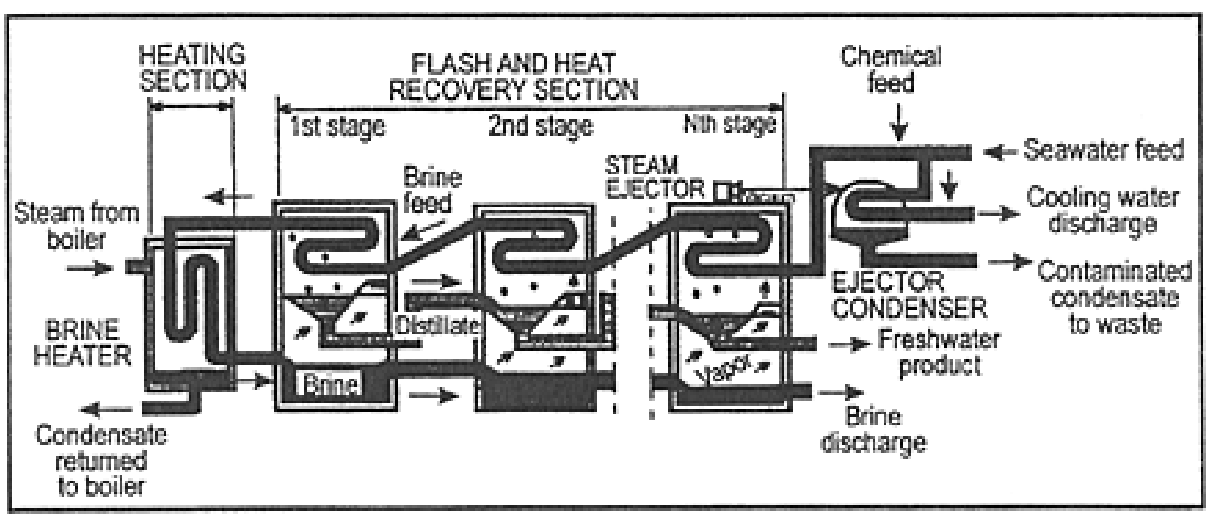

Figure 16: Flash Type Distillation

As shown in Figure 16 the flash boiling method uses steam from a boiler to superheat the water so that the salt is separated from the water.

2.10. Advantages and Disadvantages of Flash-Type Distillation

Flash-type distillation is the most effective method for removing salt and purifying water. The distillate produced by flash type distillation is <.065 ppm salt. The system is also able to produce up to 50,000 gallons per day. However, in order to attain distillate, with <.065 ppm salt, the system must use fuel to attain the temperatures required to superheat the water. The system is also very large, containing many mechanical parts, and is subject to labor intensive repairs.

2.11. Vertical-Basket Distilling

Vertical-basket units consist of an evaporator, a distiller condenser, a vapor feed heater, a distillate cooler, and air ejectors. Each unit is set up vertically in which the feed water is vaporized by low-pressure steam. The vapor generated by the boiling seawater passes through a cyclonic separator in which most of the entrained liquid particles are removed from the vapor by centrifugal force. After, the vapor passes through the second vapor separator, called the snail, where the remaining water droplets are separated from the vapor. The liquid particles from both of the separators drain downward and become part of the brine drains. This process is essentially repeated in which the vapor from the second effect shell is condensed and drained into a tank.

2.12. Advantages and Disadvantages of Vertical-Basket Distillation

Vertical-basket distillation requires a significantly smaller system that operates on low pressure steam, and has a capacity of about 10,000 gallons per day. However, the system still requires the expenditure of fuel, still labor intensive to repair, and 10,000 gallons per day is not enough water to operate all systems on a large-scale system, such as a marine vessel.

2.13. Vapor-Compression Distillation

Vapor-compression distilling units are commonly used as the primary means of producing fresh water on ships that don't use steam propulsion systems. The three main components in vapor-compression systems are the evaporator, the compressor, and the heat exchanger. Vapor-compression works by first creating water vapor from the sea water. The generated vapor is then passed through a mist separator to remove any entrained water droplets that may contain salts. The vapor condenses on the outside of the tubes, is collected and is pumped into a three steam heat exchanger. The brine is also pumped into the heat exchanger which cools the distillate and brine while heating the incoming feed water. The use of the three-way heat exchanger helps to minimize energy consumption by the system.

2.14. Advantages and Disadvantages of Vapor-Compression Distillation

A significant advantage of vapor-compression distillation is that the system does not require steam, so the expenditure of fuel is unnecessary. Not using fuel is a significant improvement, but the system has a very low capacity for producing water, only 4000 gallons per day. Thus the system is often used as an emergency back-up system.

Side by Side Analysis of Different Distillation Methods

Type Of Distillation	Maintenance	Power	Capacity	Efficiency
Reverse Osmosis	4	4	3	11
Flash Type Distillation	2	2	4	8
Vertical Basket Distillation	3	3	3	9
Vapor Compression Distillation	4	3	1	8

Figure 17: Comparison of Distillation

In order to gauge to most viable solution to filter the water, the three most important aspects to our project were compared on a scale of 1-5 in order to select the best solution. Maintenance was taken into account on how difficult the system was to repair and the complexity of its design. Power was based on a fuel consumption weight ratio, and capacity was based on how much water was filtered per unit time. After assigning numbers to these specifics, the efficiency was equated in order to show the most promising system. While all of the systems could achieve the desired result of the system, reverse osmosis showed the most promise in terms of our goals.

2.15. Valves

In engineering applications there are multiple valves used in controlling and containing fluid and gas flow. In this particular project research will be focused on fluid flow due to the requirements of a high output of pressure through the piping system. Due to valves having many different applications they can be made of a variety of materials ranging from steal to PVC and combinations thereof. There are two main types of valves used to help control fluid flow, they are stop valves and check valves. There are also several other valves that do not fall in this category that are relevant to engineering such as pressure control valves which, as there name states, control the pressure in the valves. Most valves consist of five or six parts depending on the valve type, starting with a stem, bonnet, body and some sort of closing mechanism. The stem moves up and down on a y-axis using threads by rotating the stem clock wise or counter clock wise. The bonnet provides a covering over the closing mechanism to help prevent outside elements getting into the valve or the material going through the valve. The closing mechanism can consist of many things depending on the valve type such as a gate, ball, or some kind of disk. Each valve type operates the closing mechanism differently. Some control the opening and closing through electrical means, pressure means, or mechanical means.

Check valves, or non-return valves, are part of almost ever piping system simply because they can protect expensive parts from being damaged. Most piping systems use pumps or compressors to generate movement of the media throughout the piping. When rotating equipment stops, back flow occurs and has the potential to damage the rotating equipment. These valves can also check the pressure surges and prevent flooding. Check valves essentially allow flow only in one direction and act exclusively on reaction to the media flowing through the pipe. There are several types of check valves the ones most relevant to this project consist of Lift check valves, swing check valves, Disc check valves, Swing type wafer check valves, and Split dis check valves.

Lift check valves, such as illustrated in Figure 18 below are related to globe valves, a type of stop valve, due to its design and how it operates.

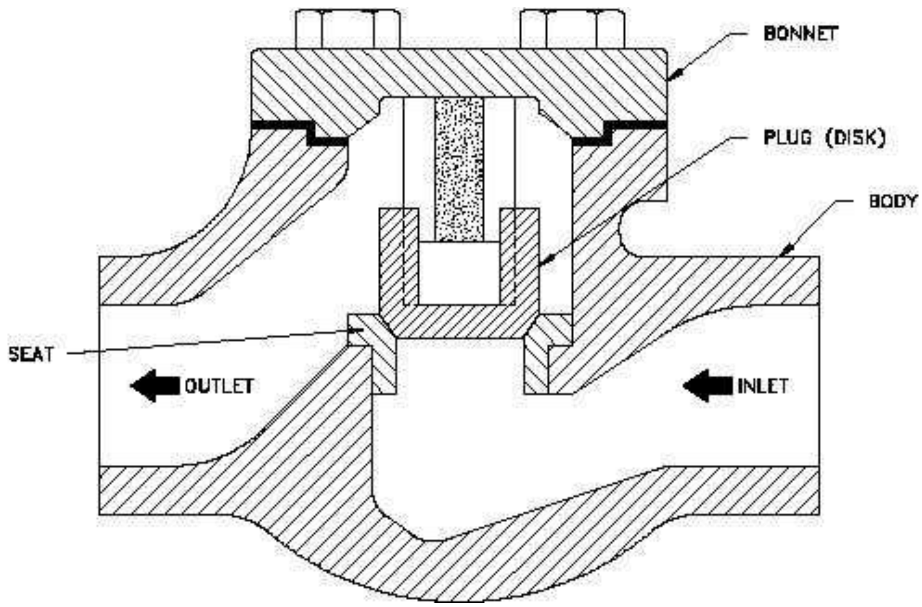

Figure 18: Lift Check Valve Diagram

The difference is that lift check valves disc is automatically operated by flow of material through the valve. Simplicity is this valves main advantage since it only has one moving part, the plug/disc. It also is a very reliable valve that requires little maintenance. Lift check valves limit the selves due to the valve only being able to be installed in horizontal piping.

Swing check valves (shown below in Figure 19) are a form of automated close/release valve that use a flap or disc the same diameter of the pipe. Media flows into the hinged disc forces the disc to swing up allowing the media to flow through the valve. Having reverse flow of back pressure will close the valve, if there is no flow through the valve the weight of the disc will close the valve shut. This valve produces a relatively high resistance flow to the media due to the disc, when in the open position, is fairly heavy. This also creates turbulence due to the disk floating on the media and “slapping” the media as it flows through the valve. Because of turbulence and high resistance flow, swing check valves normally have a larger pressure drop then other valves.

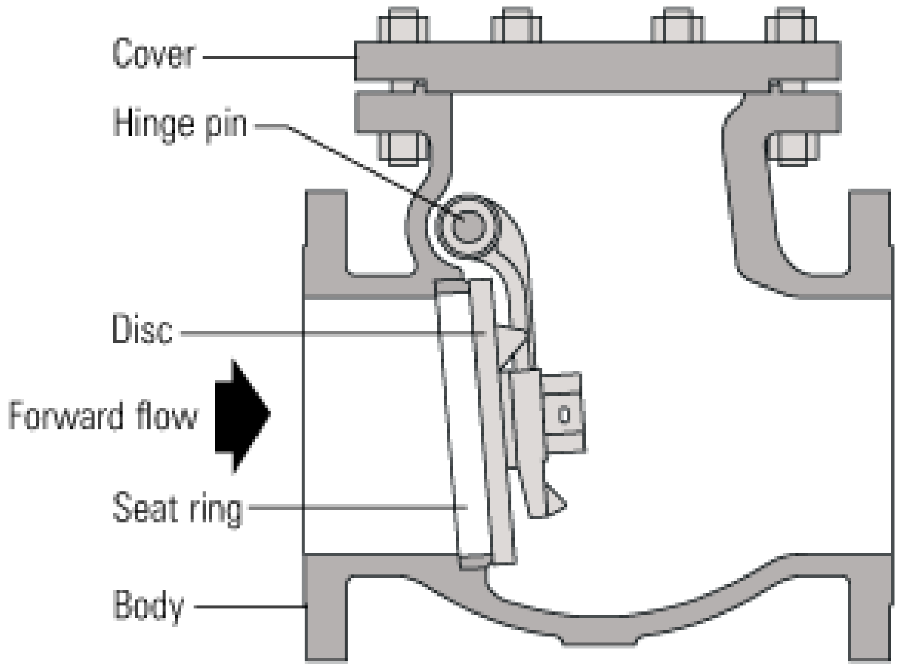

Figure 19: Swing Check Valve

Disc check valves (Figure 20) are made of a body, disc, spring, and retainer. The disc moves in a plane at right angles to the flow of the fluid, resisted by the spring that is held in place by the retainer. The body is designed to be used as an integral centering collar that aids installation in a pipe, this meaning the valve is essentially the size of the pipe. This valves works by the media force needing to be greater than the force on the spring. This forcing the disc open and off its seat. Once the force against the disc is less than that of the spring, the disc will return to its original position making back flow impossible.

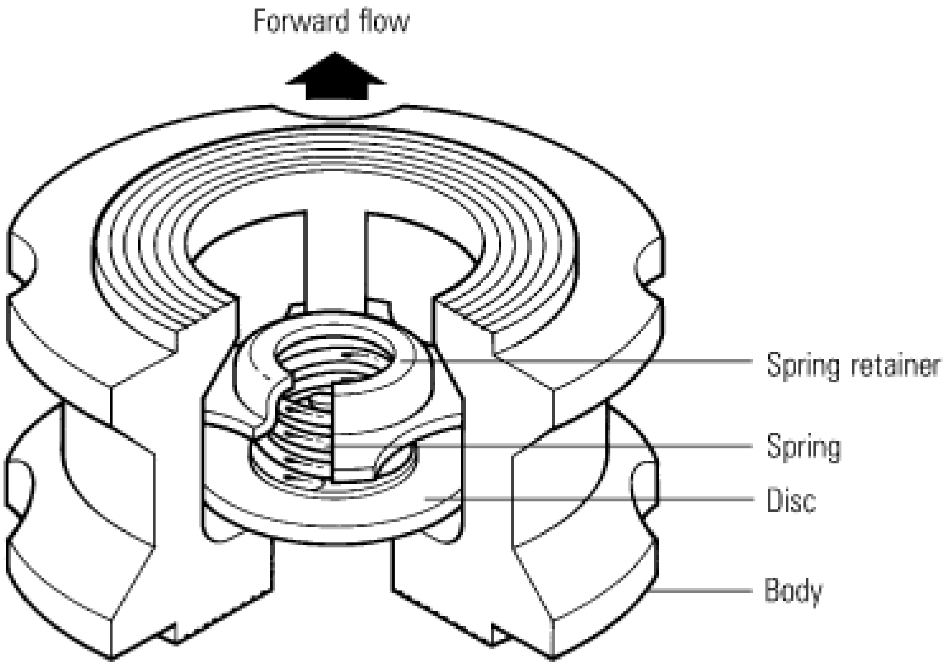

Figure 20: Disc Check Valve

Swing type wafer check valves are very similar to the standard swing check valve valves but instead of having the full-bodied arrangement the regular valve has, when the valve opens the flap is forced open into the top of the pipeline. Due to the design the flap must have a smaller diameter then that of the pipeline causing a relatively high pressure drop which is uncommonly high for swing type valves. This valve is usually used on larger pipelines due to the pressure drop caused by the disc floating on the fluid stream becoming more substantial on smaller pipelines. When used on larger pipelines this type of valve is also more cost efficient due to less material needed to make the valve but, as the valve gets larger, the flap becomes harder to open requiring a higher flow through the pipe. When the pressure increases in the pipeline, in order to open the valve, the chance of damaging the valve also increase due to if the flap possibly slamming shut and damaging the seal or causing water hammer from the slamming of the flap.

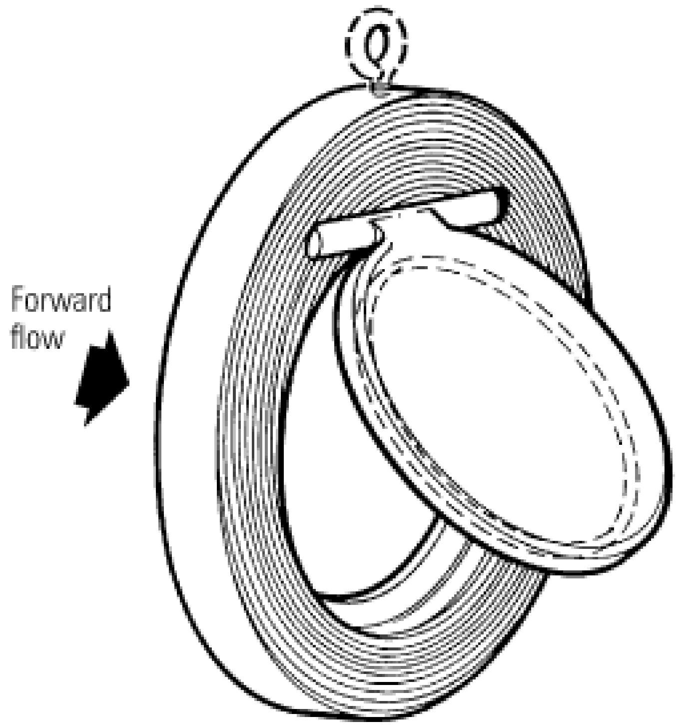

Figure 21: Swing-Type Wafer Check Valve

Split disc check valves (Figure 22) are intended and designed to provide the same functionality of a swing check valve but at the same time overcome the size and pressure drop limitations that swing check valves have. In split disc valves the flap is split down the middle and hinged so that the two disc plates will only swing in one direction. When flow of the media through the valve has stopped, the valve seals its self by to torsion springs, stopping back flow from occurring. External retainer springs allows the hinge in the disc plates to be mounted in the center of the valve. The advantages of a split disc check valve are that the design is not limited on size, the pressure drop across the valve is significantly lower than other valves, are able to function using lower pressures, and are able to be installed in any positions making it a very versatile valve.

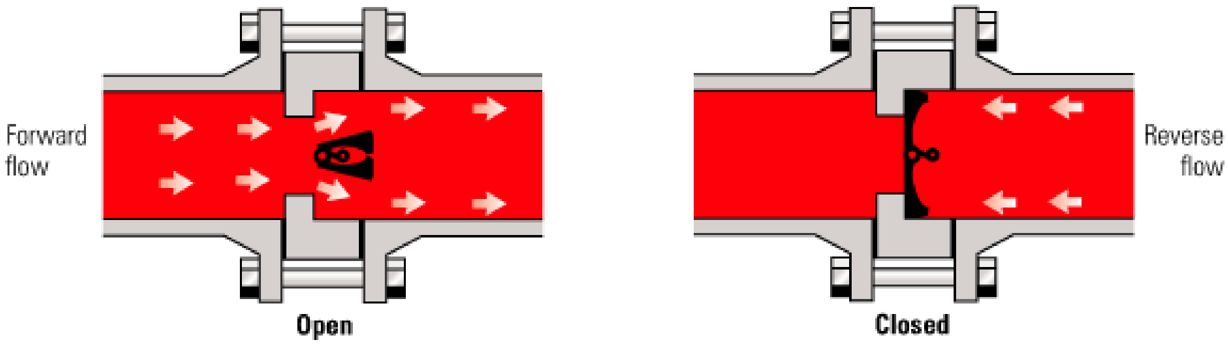

Figure 22: Split-Disc Check Valve

The second major category of valves is stop valves which are used to shut off or partially shut off fluid flow in pipes. There are essentially four categories of stop valves; globe, gate, butterfly, and ball. Although these are the main types of stop valves a fifth type does exist consisting of plug and needle valves. Though these do exist they are not readily used in engineering applications.

Globe valves (Figure 23) are the most common type of valve in existence. They are used in a many different applications such as oil and gas industry to control and transmit fluids, steam and condensate distribution, swimming pools, booster pump systems, and water treatment systems. This valve gets its name from its exterior shape. Although externally named, other valves look similar and an actual globe valve can be classified by its interior parts and assembly. Globe valves come in straight flow, angle flow, and cross flow valves. One of the valves biggest advantages is that it’s able to accurately control throttle through the valve efficiently. It also has exceptionally resilient qualities due to its disc and seat erosion being very high. Angle flow valves can also increase globe valves efficiency when used at a corner or elbow of pipes. This is due to the piping requiring less fittings or elbows to make the necessary turn. Angle globe valves due require flow on the inlet side of the valve to be at a right angle to the flow on the outlet side in order for the valve to work correctly. Although globe valves are resilient and well used they are not recommended when resistance to flow and pressure drop are unwanted. This is partially due to the design of the valve body changing the direction of the flow. This in turn can cause turbulence and pressure drop within the valve and the rest of the system.

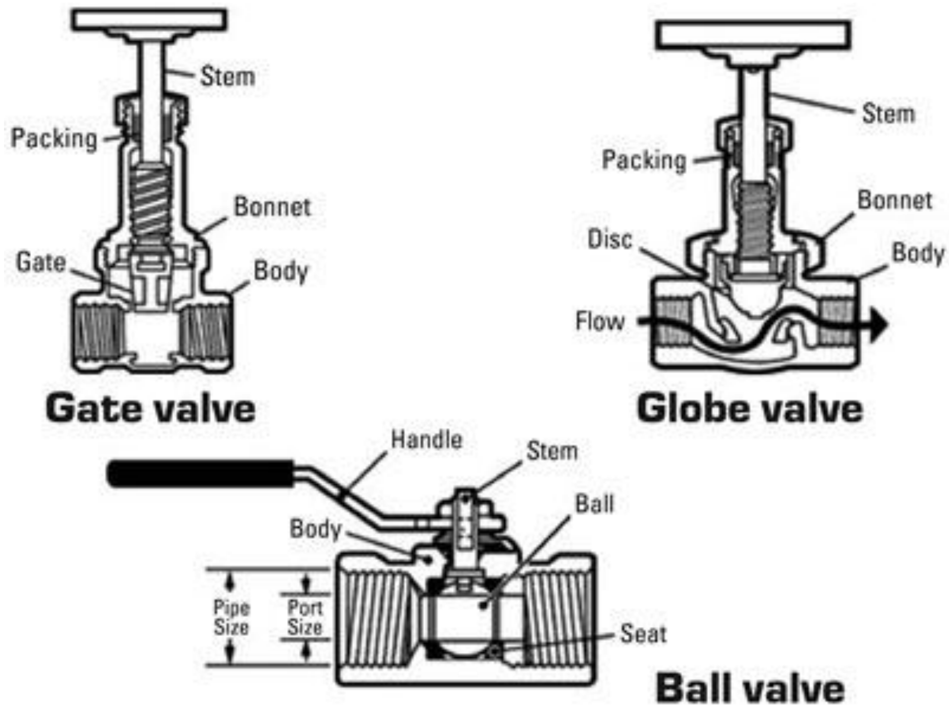

Figure 23: Globe, Gate, and Ball Valves

Gate valves (also illustrated in Figure 23) are used in products that require straight-line flow of fluid and minimum restriction of the fluid is required. This valve is simply named a gate valve due to the valve either stopping or allowing flow through the valve using the same motion as a gate. Using this type of valve allows the opening in the valve to be as large as the pipe its self by drawing the gate fully into the valve allowing more fluid flow, thus allowing only slight pressure drop. Although gate valves allow flow as large as the attached pipe, they are not suitable for controlling throttle threw the valve. This is partially due to the design of gate valves making it difficult to control the throttle and that flow of fluid slapping against a partially open gate can cause severe damage to the valve. Gate Valves can be classified into two different types, Risingstem or Non-Risingstem (Figure 24). Non-Risingstem has threads on the lower end of the stem into the gate. In this type, as the handle is turned/rotated the gate is lowered or raised on the threads while the stem remains vertical and not moving.

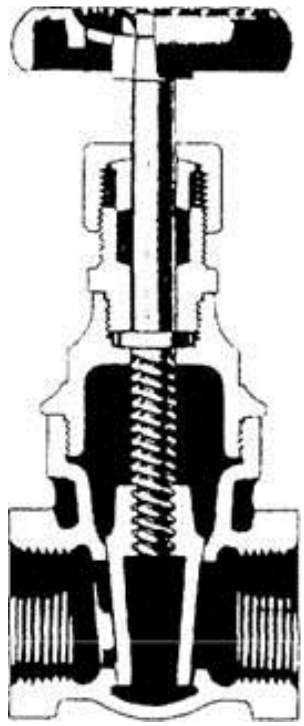

Figure 24: Gate Valve, Non-Risingstem

Risingstem (Figure 25) valves have the stem attached to the gate directly. This makes the gate itself rise and fall together with the stem as the valve is operated.

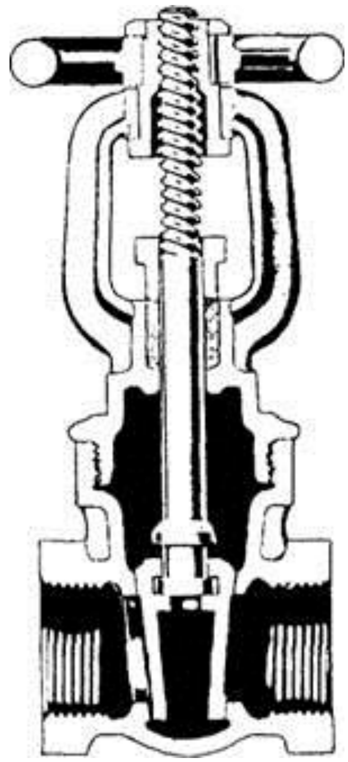

Figure 25: Gate Valve-Rising Stem

Butterfly valves (Figure 26) are very versatile valves when it comes to what kind of material can be run threw them, such as fresh water, salt water, oil, JP-5, or F-76. This is due to its resilient seat. In this specific type of valve, the seat becomes resilient due to it being under compression when it is mounted in the valve body. Once under compression, the seat creates a seal around the disk and both upper and lower points where the stem passes through the joint. This valve is considered to be very light weight, small, relatively quick acting, has positive shut off, can be used for throttling, and has easy maintenance care. Butterfly valves also require less torque to operate due to the seal being created after disc is closed.

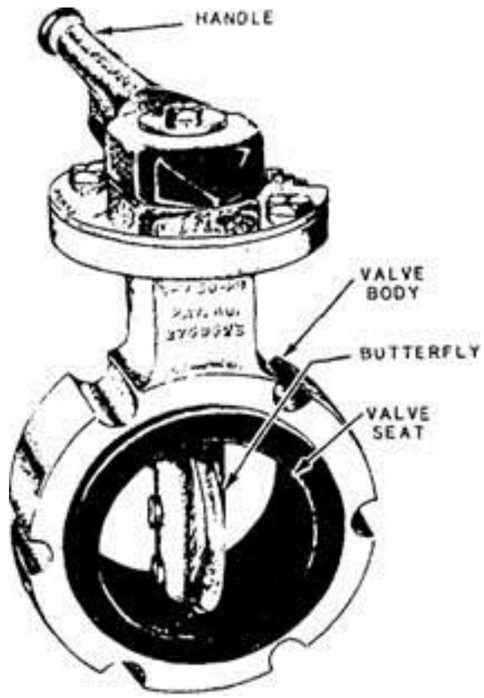

Figure 26: Butterfly Valve

Ball valves are another type of stop valve that instead of a disc in other valves, it uses a ball. This valves is quick acting due to it using gases to operate. Using gases to operate also allows a relativly small handle and force to close a fairly large valve.

Although some valves are designed to be automated, most can also be opened or closed by using a solenoid valve. A solenoid valve is a device that controls the liquid flow in the valve by using an electrical current that is run through a coil. Once the coil is energized, a magnetic field is created causing the closing/opening mechanism of the valve to activate. Depending on the valve type and palcement, this electric current could open or close a valve. Once the current is turned off the valve will return to its original state. Using a solenoid valve allows remote control to valves that would normally need to be manuely closed/opened or allowing programs to control these valves.

When using any type of valve in a pipeline system, the size of the valve and the pressure lossed through the valve are the two important calculations needed in desiging a working pipelining system. Using a valve that is two small can created more pressure loss through the valve and can cause damage to the valve it self. Pressure loss is an important figure to calculate in our project due to our filtration system needing a certain amount of pressure in order to properly clean the water. Fluid pressure is typically shown in a pressure loss chart for water (Figure 27).

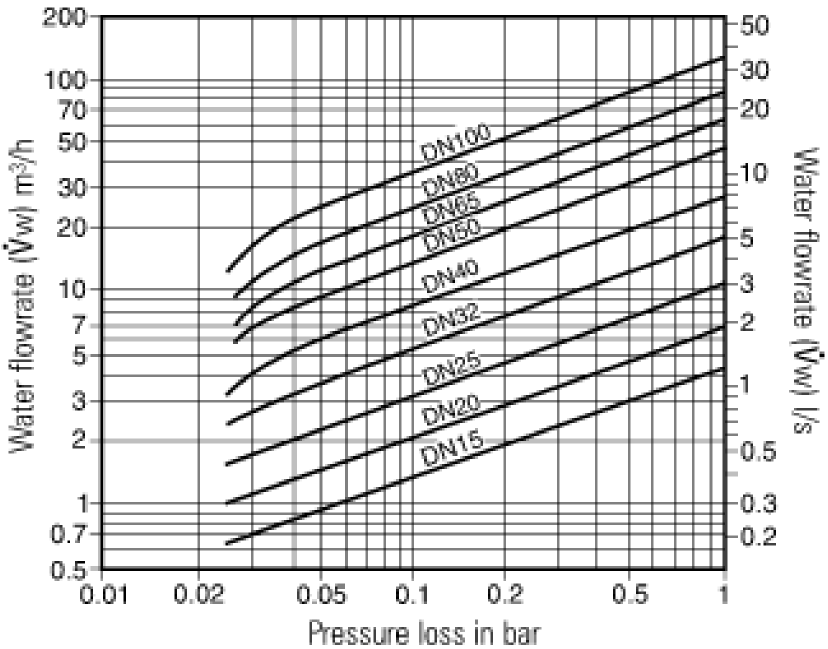

Figure 27: Water Pressure Loss

Figure 27 shows an example of what a typical pressure loss chart looks like for a specific check valve. Each valve type has its own chart showing the pressure losses according to the size of the valve. In order to find pressure drop over a valve the equivalent water volume flow rate (Figure 28) is first needed. In order to find this flow rate, the density of the media being used (ρ) and the volume flow rate of liquid (V’) are needed.

$$\dot{V}w = \sqrt{\frac{\rho}{1000}}\,\dot{V}$$

Figure 28: Water Volume Flow Rate Equation

After the equivalent volume flow rate is calculated, the pressure drop across the particular valve can been read off of a chart similar to the one provided in Figure 27.

Calculating the correct size of a valve requires the calculation of the flow coefficient and the allowable pressure drop in the valve. Using the equation in Figure 29, the flow coefficient (C_v) can be calculated by providing the values for ΔP, S.G. and Q.

$$C_v = \frac{Q}{\sqrt{\frac{\Delta P}{S.G.}}}$$

.

Figure 29: Flow Coefficient Equation

ΔP is the pressure drop in psi, S.G. is specific gravity, and Q is the flow in gpm. If needed, ΔP can be calculated by using the equation in Figure 30, where F_L^2 is equal to the recovery coefficient from C_v chart, r_c equaling critical pressure ratio from r_c chart, and P_v equaling vapor pressure. After acquiring the necessary values for ΔP, S.G. and Q, these numbers can then be plugged into the C_v equation. Essentially C_v is the numerical value of the number of US gallons of water that will flow through a valve in one minute with water at 60º F and a one psi differential pressure across the valve.

$$\Delta P_{allow} = F_L{}^2(P_1 - r_c P_V)$$

Figure 30: Equation for Pressure Drop Allowance

Figure 27 is the general equation used for the correct sizing of valves and follows Bernoulli's Principle that "if the pressure drop increases, the flow should also increase".

2.15. Desurgers

When water is forced into a chamber or through a pipe at high velocity or high pressure, the presence of empty space within the pipe or chamber can cause turbulence in the water. Turbulence in the water can cause shaking, movement, or even constant vibrations during the operation of the water system. In the case of our reverse osmosis water purification system, we will have to overcome startup vibrations, and the possible vibrations caused by general flow driven turbulence. The major problem we will need to overcome during the operation of our system will be the water flow turbulence which can be detrimental to the life of our reverse osmosis system.

In our system, we would like to have laminar flow of water, which is smooth and constant. As is explained in Figure 31, turbulence of water is created by high pressure and high speed water flow.

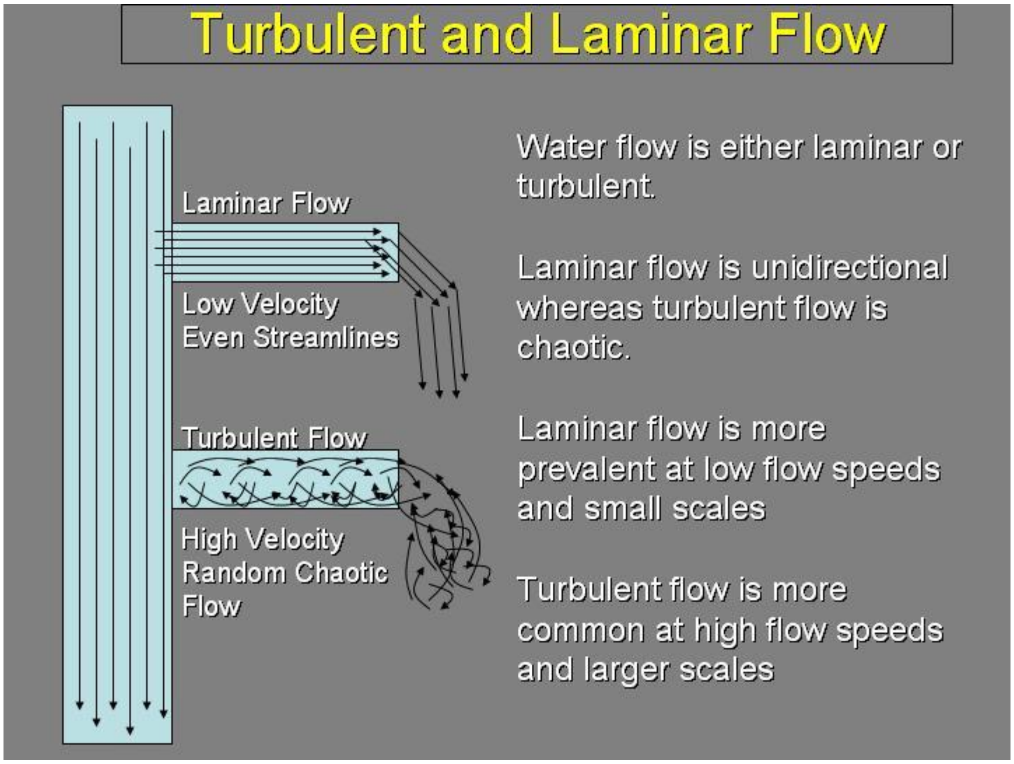

Figure 31: Turbulent and Laminar Flow

In a low pressure and low speed system, the water flow would remain mostly laminar, as the water would flow smoothly through the pipe or tube. This makes small, low pressure water systems ideal in quiet or delicate environments. “The smooth motion of laminar flow occurs because viscous forces cause parallel streamlines to stick to each other. In this situation the viscous forces of the fluid are dominant over inertial forces.” (“Adams”). In our system, which will not necessarily need to be quiet, and will be durable and in aggressive environments, higher water pressures and flow speeds will be present.

As our reverse-osmosis water purification system reaches its operating state, the water flow will become turbulent. “If the velocity of the fluid is increased inertial forces will increase, the sticky effect of viscosity will be dampened and the evenness of the laminar flow will progress into chaotic and turbulent flow.” (Robertson). As the water travels along a solid surface, the viscous forces transmit friction between the water flow and the wall of the pipe or tube. This friction causes the water along the boundary to exhibit zero velocity, where the water molecules in the middle of the diameter of the pipe are travelling at maximum velocity. This velocity gradient, as the water molecules bound past one another, causes a transfer of friction which at high velocities, such as those present in our water purification system, causes uneven flow of water molecules through the pipe. Displayed in Figure 32 below is an image of both laminar and turbulent flows.

Laminar velocity profiles in a rectangular duct — Turbulent flow in a rectangular duct

Figure 32: Laminar and Turbulent Flow in a Rectangular Duct

These images are still images captured using equipment from Armfield Limited. Armfield Limited, based in England, produces engineering teaching equipment to aid in class understanding through visual provisions. The Armfield Hydrogen Bubble Flow Visualization System is the particular model through which the above images were acquired. The Armfield Hydrogen Bubble Flow Visualization System "has been designed to allow viewing of the complex flow patterns associated with water flowing past solid objects or boundaries. A stream of small hydrogen bubbles accurately follows the water and clearly shows any changes in direction of the water as it flows around objects in its path." ("Armfield Engineering Teaching Equipment"). This method provides an easy way to visualize the flow of a liquid.

The percussion, or audibility of shock ("Water Hammer Desurgers from ShockGuard") resulting from the turbulence of the water through a pipe, is also known as "water hammer." This vibration and pulsation shown in Figure 33 is derived from a "series of pressure shocks created by a sudden change in flow velocity of a liquid travelling through a pipe." This condition should be eliminated because it potentially hazardous to the system, and the dry environment. Not only does water hammer result from the fast flow of water through a pipe, but the abrupt stopping of water flow through the closing of a valve in the water flow system.

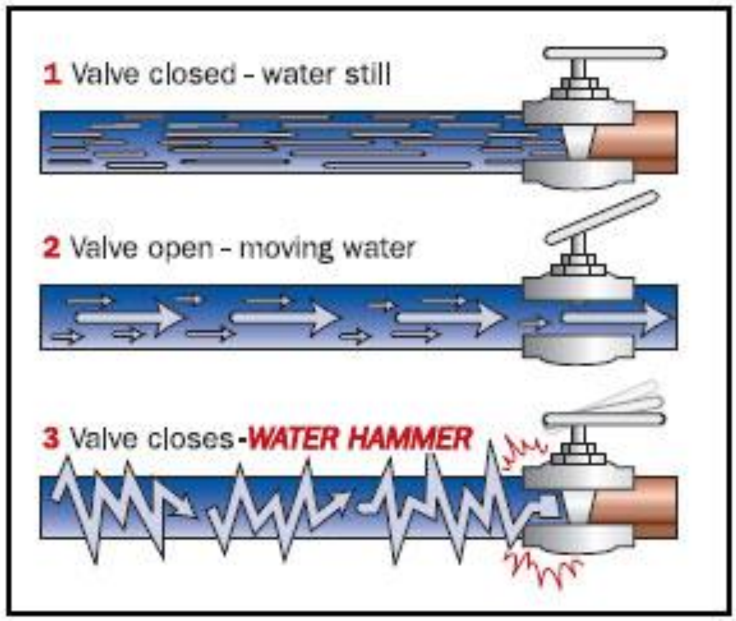

Figure 33: Valve-Induced Water Hammer

As the quickly moving water, at a high volume flow rate, suddenly hits a wall that is the closed valve, the inertia of the moving mass will cause a bump in the system that will result in shaking or vibrations. Water hammer is a common dilemma in household and other water flow systems, there are many possible, and simple, solutions to combat the noise and vibration. Some of these solutions to stop and prevent the condition can be replacing small piping with larger piping so that the water is not under high pressure. One can secure pipes so that they cannot shift during this water hammer effect, which can cause them to tighten or oscillate. Air chambers can be installed, such as the one illustrated in Figure 34 below. These help to eliminate the water hammer effect and conserve the flowing water's kinetic energy.

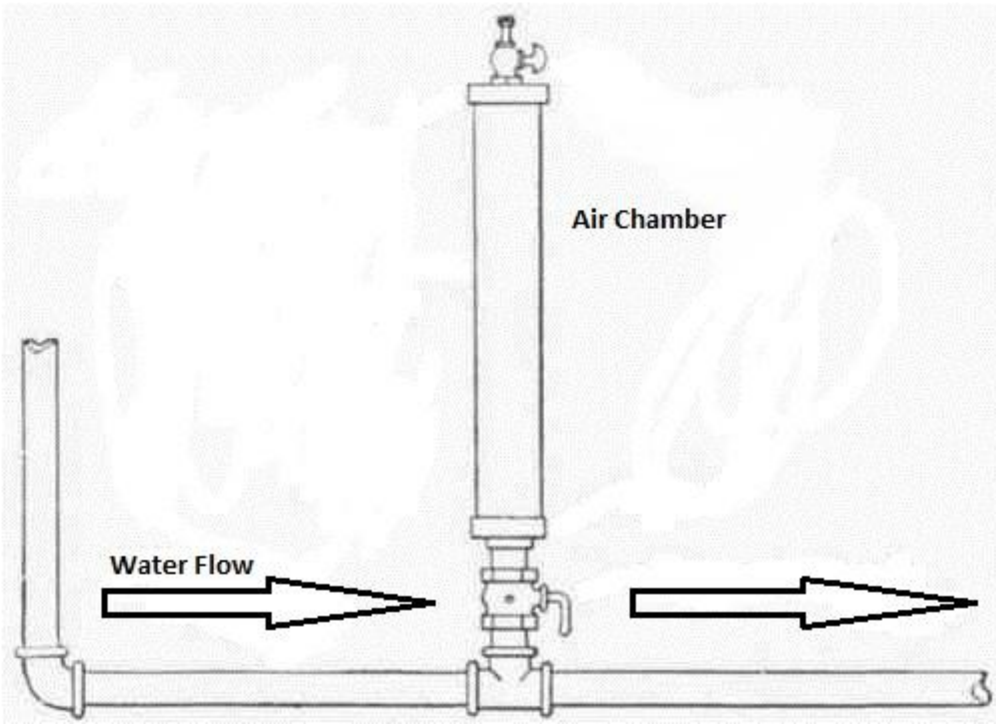

Figure 34: Air Chamber

The presence of the air “absorbs the force of the moving water by compressing within the chamber, acting like a shock absorber.” ("Natural Handy Man") Lengthening the transitions in pipe diameter can help in preventing the water hammer effect, as well, by increasing the amount of time the water flow. Another method, similar to the use of air chambers, is the implementation of pulsation dampener. A pulsation dampener, also known as a desurger, such as those shown in Figure 35 below ("Pulsation Dampeners"), incorporate a gas-loaded internal bladed and orifice for harsher shocks induced by the water hammer effect. ("How to Eliminate Water Hammer”).

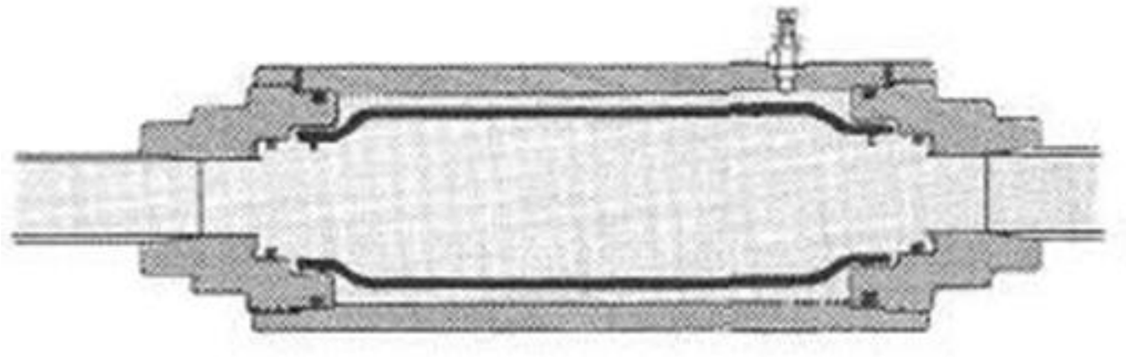

Figure 35: In-Line Pulsation Dampener

Looking at applications of reverse osmosis to purify water for drinking, cooking, bathing, and even for medical purposes, we are taking heavily from the Naval applications of reverse osmosis in ships and submarines. From these general designs, combined with our intended application of the reverse osmosis system, we can easily rule out the majority of the possible quick fixes to combat the water surge. Our overall intentions are to create a simple and portable reverse osmosis water purification system that can be simply scaled to operate one different levels of water necessity, from a small and hand-portable system to support small numbers of people, to large, assembled systems to aid in disaster relief. With simplicity and portability in mind, a somewhat uniform pipe size is optimum, so there are very few transitions in pipe diameter. In being mobile, the piping will be free to move at will, helpless to the orders of the flowing water, so securing the pipes would just be time consuming and, at times, not at all possible.

One major factor in causing the water hammer effect is high water pressure. For our reverse osmosis system to function properly, high pressure will be required, as reverse osmosis filters necessitate this. Operating at upwards of 400 psi, a large amount of water flow induced vibration can be present. Due to our application, we were able to conclude that the use of a pulsation dampener, or desurger, would be best. This decision is also supported by the success which the United States Navy has with the use of desurgers in the reverse osmosis water purification systems on board their ships and submersibles.

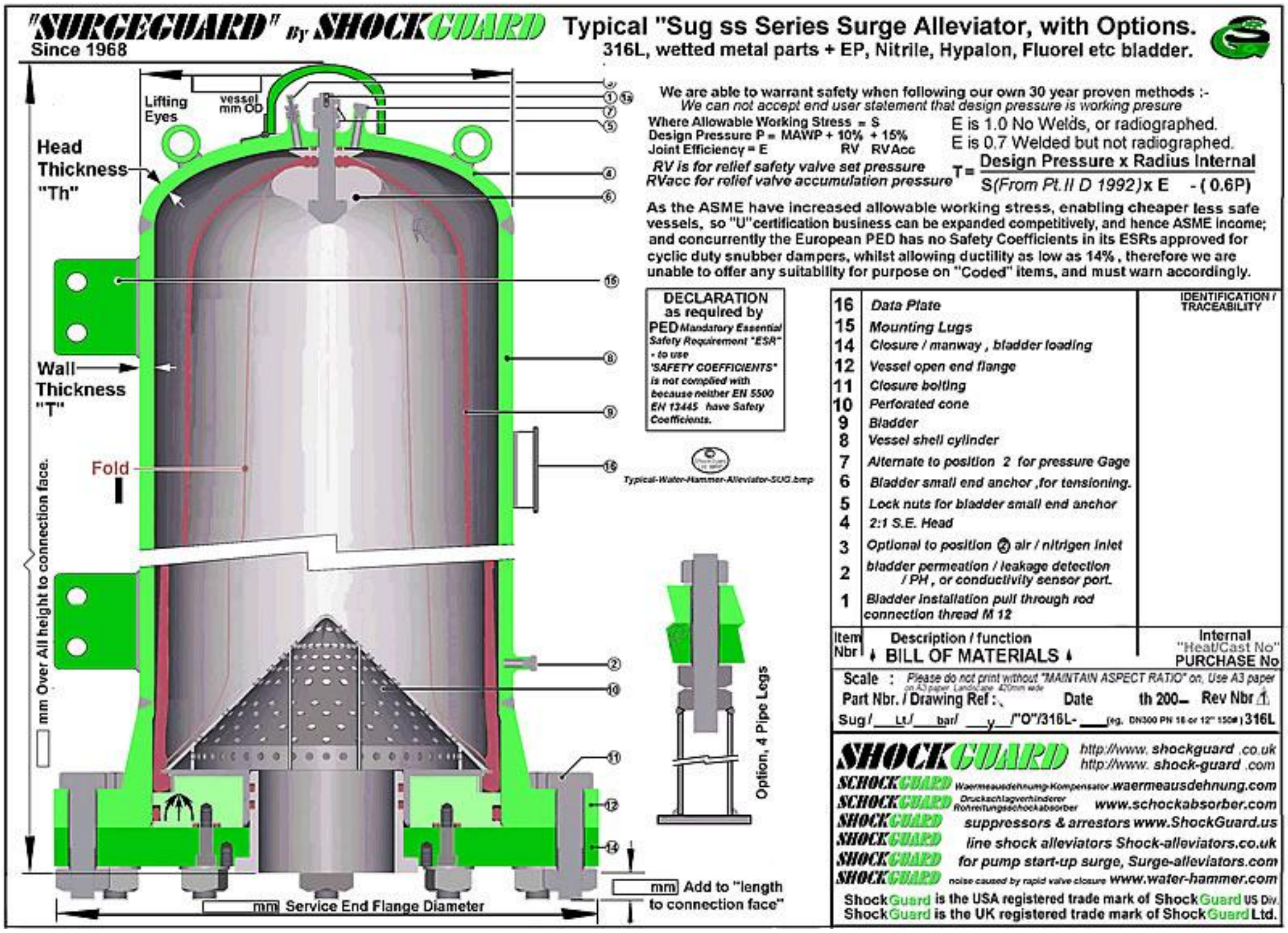

Figure 36: *SurgeGuard* by ShockGuard

Although water surge will be present the use of surge dampers will not be sufficient. Surge dampers reduce and prevent problems in pipe and pump systems. ("Water Hammer Desurgers from Shock Guard") The necessity for a pulsation dampener is evident. One company, ShockGuard, based out of North Carolina, sells desurgers. The product they sell, called the Water Hammer Desurger, seen above in Figure 36, has several desurger designs which may be required for different applications.

Their Water Hammer Desurgers dampen the surges in a flow so that they do not shake the pipe. Primarily, they are used when the speed of pump start up is so great that the level of pressure surge causes the pipes to vibrate. Water Hammer Desurgers are installed as close to the source of the surge as possible. The reason a Water Hammer Desurger is placed as near as attainable to the basis of a surge, is to reduce the weight of liquid that has to be made move before the softness of the desurger is felt." ("Water Hammer Desurgers from Shock Guard")" One manufacturer of reverse osmosis water purification systems, Parker Racor's nautical filtration branch, Village Marine Technology, produces both products for purifying water commercially and small scale, and entire systems which consist of all necessary parts to purify water. Some of these are displayed in Figure 37, below.

Figure 37: Village Marine Tech Products

Village Marine Technology has a distributor in New Bedford, MA. The distributor, Shuster Marine (www.shustermarine.com), will be able to provide us with top quality products, comparable to those used in operations by the United States Navy.

2.16. Purification Filters

Carbon possesses many unique and useful properties that allows it be used in numerous materials, such as carbon filters. It is a one of the most powerful absorbents in the field. Only one pound of carbon creates a surface area of 125 acres. With an exceptional weight to surface area ratio, it would be able to purify a large amount of substance, in our case water. Carbon filters is an effective way of treating and purifying water for producing a source of drinking for people.

Figure 38: Granular Activated Carbon

There are usually two types of carbon filters, granular activated carbon (GAC) shown above in Figure 38, or powdered block carbon. Both treatments can create acceptable drinking water. When comparing them, GAC uses relatively larger particle sizes of carbon but they have a smaller external surface area. Also, granulated activated carbon can adsorb more substances like mineral oil, BTEX, Poly aromatic hydrocarbons, odor, yeasts various fermentation products, and non-polar substances. They can also adsorb halogenated substances such as iodine, bromine, chlorine, and hydrogen.

Arsenic	Bacteria and Viruses	Bad Tastes & Odors	Chlorine	Fluoride	Hydrogen Sulfide	Heavy Metals	Nitrates	Radon	Sediment	Iron	VOC's
○	○	●	●	○	◐**	◐	○	●	◐to ●	○	●

●= Effectively Removes ◐ = Significantly Reduces ○ = Minimal or No Removal

Figure 39: Effectiveness of Contaminant Absorption in Carbon Filters

Figure 39 above demonstrates how effective carbon can adsorb some contaminants from the water stream. High levels of hydrogen sulfide will reduce filter significantly, so either manganese greensand or a KDF filter must be added to avoid corrosion.

Looking more in depth into the chemical process, the carbon removes the contaminants from the water using adsorption and catalytic reduction. Adsorption basically is when a substance diffuses into a liquid or solid to form a solution. The activity level of adsorption is taken from the concentration, temperature, and the polarity of the substance in the water. There are different types of carbon which means each has a unique adsorption property. When dealing with water treatment, the function of Freundlich is typically used to resolve any adsorption differences.

$$\frac{x}{m} = K_f C_e^{1/n}$$; where

$\frac{x}{m}$ = adsorbed substance per gram of active carbon

C_e = concentration difference

K_f, $1/n$ = specific constants

Catalytic reduction involves negatively-charged ions from the contaminant in the water attracting to the positively-charged ions in the activated carbon.

There are several factors one must take into account in order to maximize efficiency in carbon filtering. The type of impurities in the water can affect the efficiency, the higher the molecular weight and the lower the solubility it is, the better adsorption. Also, the pH of the waste stream contributes to the efficiency; acidic compounds tend to be adsorbed at lower pH levels.

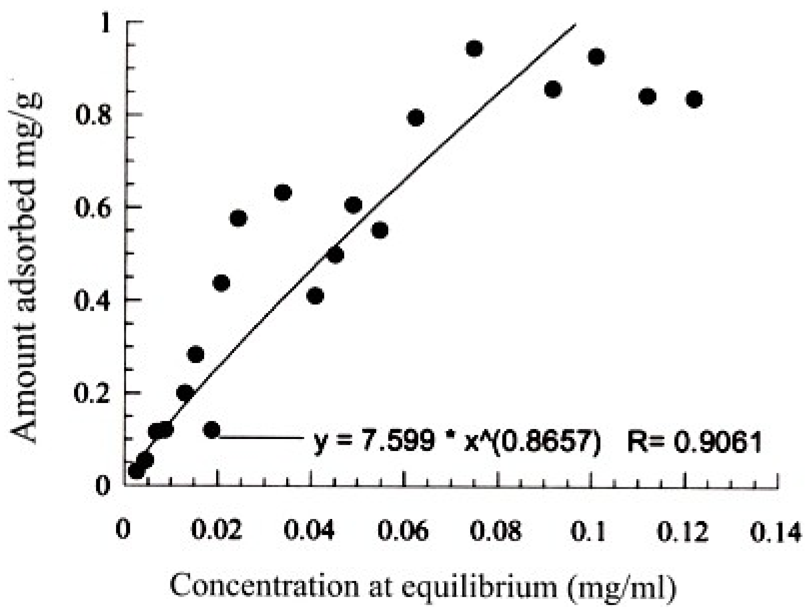

Figure 40: Graph Depicting Specific Adsorption Isotherm for Active Carbon

Figure 40 above depicts the relation between the concentration and the necessary quantity of carbon in order to show the specific adsorption isotherm for active carbon. Another way is to either increase the amount of carbon in the module or increase the amount of time the water spends flowing through the carbon. One can lower the flow rate of the water to increase time.

Figure 41: Activated Carbon Filters

Implementing these filters is primarily expensive at first, but the savings for the long run is worth it. Based on the prices from Alpha Water Systems Inc. , carbon filters designed for households can be priced anywhere from $700 to $825. Carbon filters that are as big as a ruler can have prices of as low as $8. Several examples are shown above in Figure 41. Activated carbon filters do not require much maintenance, but scheduled replacement is very important to ensure proper water treatment. Once bad tasting water starts coming out of the filter, it is obviously time to change the carbon filter as this can make a person very ill. Depending on the uses for the carbon filter, the activated carbon can only adsorb as much as it can hold, so life expectancy of the filter must be determined by an average of the amount of contaminants that travel through the filter per day.

These carbon filters would not be as effective if they weren't included in a multi stage filtration process. The image below depicts a Rhino water filtration system for houses sold by Aquasana. This particular and well-known model is certified by Underwriters Laboratories to

“NSF standard 42 with class 1 performance and has a 1,200,000 liter/3year capacity at 27 lpm” ("Raw Power Australia"). The exceptional standard this model possesses means that it has the capabilities to remove chlorine, odor, foul tastes, and sediment. The system has an overall height of 1145 mm and a base diameter of 230 mm. It comes in two packages, one weighing 25 kg and the other 2.5 kg. The installation typically takes a licensed plumber about 1-2 hours and the main filter is usually replaced once from 3 years. Once installed into a home, the flow of water goes through four stages of the filtration system.

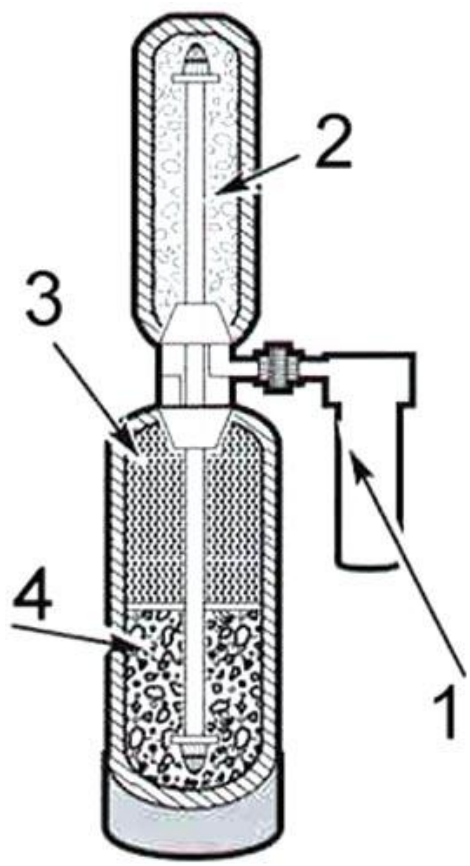

Figure 42: Rhino Whole of House Water Filtration System

The first stage consists of a sediment pre-filter able to filter down to 5 microns and doesn’t allow sediment to pass through the other stages of filtration. The reason for this particular filter is that it protects the main filter from clogging and decreasing efficiency of the whole system. The purpose of the second stage is to create another process of filtration made of granular fused zinc and copper. This type of active filtration produces “an active filtration method, possessing a characteristic known as redox potential, which can alter the molecular structure of chlorine and turning it into a harmless zinc chloride ("Raw Power Australia").” By this time, the water is now flowing towards the third stage, where the larger granule activated carbon is located. At this point, the water is flowing through the final stage of the water filtration system. This stage has smaller granule “coconut shell based” activated carbon, this form of carbon provides a larger surface area thus resulting more adsorption and higher efficiency in water treatment.

In order to design a prototype to our specifications, we looked into detail on the designs of other carbon filters. The first and larger one is the PMC 250-200C, shown below in Figure 43.

Figure 43: PMC 250-200C Filter

The inner diameter of this particular model is 1.18 in., the outer diameter is 2.52 in., and the height is 10 in. The PMC 250-200C weighs 200 g and the filter volume is an exceptional 38.27 cubic inches. The materials used for the end caps are silicon rubber or polyethylene while the material for the mesh pipe is polypropylene. The outside and inside nonwoven fabric materials are polypropylene and also polyethylene. When taking this model into consideration, the chart below (Figure 44) helped persuade us.

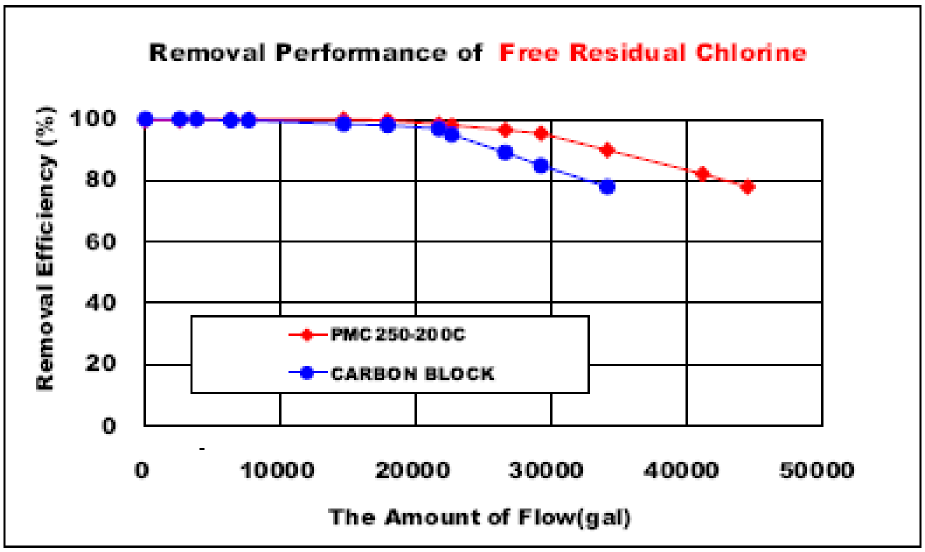

Figure 44: Removal Performance of the PMC250-200C vs. a Carbon Block

As one can see at around 15,000 gallons of water flowed through, the line graphs start to branch off. This separation of graphs demonstrates that the PMC250-200C retains its high performance for a longer period of time.

2.17. Hoses

Before materials and costs of the final hose can be considered, the team needed to analyze the restrictions of the part. The plan is to have two hoses on the product, one that receives the water from a source, and one that delivers it to the refugee. Since the final product is going to be a portable unit, the durability and weight are important factors to keep in mind.

The retrieving hose will have to prioritize durability and flexibility, if the water doesn't get to the pump or if there are leaks causing the pressure to drop, the unit loses its purpose. The second hose has to prioritize resistances to harmful bacteria and radiation. The water will be undrinkable if it is contaminated again after leaving the filter.

2.18. Delivery Hose

Assuming the unit is in a relatively safe place to give waters to refugees, the hose can focus more on bacterial and radiation safety than durability. Medical hoses often use silicone rubber to give medicine through drops into the bloodstream. Since medical practices often, if not always require the highest sanitation protection to prevent infection on the patient, we decided that this would be the best place to start our research. Silicone rubber has been used for many years ranging from intakes for engines, to food applications and all the way to medical purposes. One of the key elements that make this a good choice is its resistance to weather, heat and UV rays. Silicones properties also remain relatively constant from temperatures of -100^{o}C to 316^{o}C ("Dow Corning"). This will theoretically allow the hose to perform its tasks in most if not all parts of the world without having to worry about it melting of freezing the water.

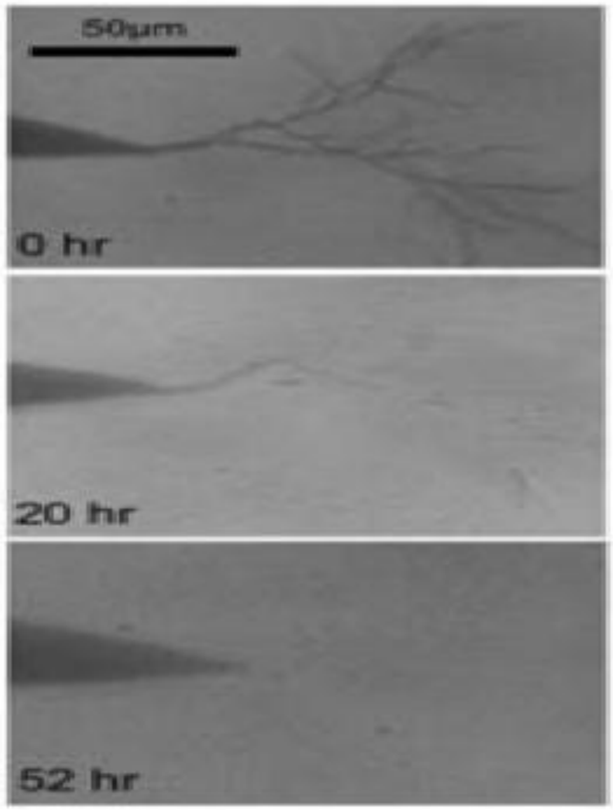

Figure 45: Silicon Self-Recovery

Another helpful benefit of Silicone rubber is its ability to “self-recover” which is depicted above in Figure 45. The following study and the figure below show’s a crack in silicone rubber repairing itself over a couple of days ("Toyohashi University of Technology"). This allows for the hose to stay in use for longer periods before being replaced, if any strains occur that could lead to a break, they would be repaired with time.

On top of previous benefits of silicone rubber hoses, the weight of it is very light (about 0.027lb per foot for a .2 inner diameter tube with a thickness of .11 inches). The size will be chosen later and modified due to practicality, but the weight is within practical use.

2.19. Receiving Hose

Water is a necessity of life, and is often scarce after disasters. Bringing safe drinking water is the most important role of the unit, however if no water can be obtained, or it is lost on the way, the unit becomes useless. The receiving hose will be one of the components placed through the disaster zone that has to be prepared for any kind of hazard, radiation, or temperature. The most important objective for this hose would be durability, it has to be able to bring water back and not get damaged (if the hose gets a hole in it water will be lost, and the drop in pressure could affect the unit. Safety is always important, but since people will not be drinking out of this hose directly, it isn't necessary to have a perfectly clean hose (most likely the water will undrinkable to begin with). Thermoplastic polyurethanes (TPU), often used in chemically hazard areas, are a class of polyurethane plastics. These plastics have a high resistance to oils, grease and abrasion; also there elasticity is high allowing for high flexibility ("Wikipedia"). Among these Thermoplastic polyurethanes, BASF creates hoses with their version called "Elastollan". This TPU is very similar to regular TPU's except with an increased elastic memory, hydrolytic stability and a higher range of hardness's ("BASF The Chemical Company"). Figure 46 depicts many of the materials considered for the project and their different strengths and weaknesses.

Physical Properties	Shore Hardness (A) ASTM D-2240	Shore Hardness (D) ASTM D-2240	Specific Gravity (g/cm3) ASTM D-792	Tensile Strength (psi, MPa) ASTM D-412	Tensile Stress @ 100% Elongation (psi, MPa) ASTM D-412	Elongation @ Break % ASTM D-412	Tear Strength (lb/in, N/mm) ASTM D-624, Die C	Taber Abrasion /mg loss 1000g & H18 Wheel mg ASTM D-1044
C59D		56	1.23	7600, 52	2400, 17	480	1100, 190	45
C60A	63		1.14	3300, 23	370, 2.6	870	300, 51	
C70A	71		1.15	4400, 30	450, 3.1	790	370, 65	
C75A	75		1.17	6100, 42	600, 4.1	770	440, 77	50
C78A	80		1.18	5300, 37	750, 5	690	500, 85	25
C85A	85		1.19	5650, 39	950, 6.6	620	575, 95	25
C90A	90	41	1.21	6000, 41	1450, 10	550	720, 120	25
C95A	95	46	1.21	5800, 40	1900, 13	480	830, 140	35
C98A		52 [1]	1.22 [2]	7252, 50 [3]	2176, 15 [3]	550 [3]	742, 130 [4]	

TEST METHOD
[1] DIN 53505
[2] DIN EN ISO 1183-1-A
[3] DIN 53504-S2
[4] DIN ISO 34-1Bb

Figure 46: Material Properties

There best product for our unit would be there C series C90A. The C series in general provides; oil/solvent resistance, Weather (UV) resistance, Abrasion resistance, and resistance to high temperatures. In addition the C series retains a relatively low weight and has a large tensile strength and stress, with a decent elongation before breaking as seen in Figure 46 ("BASF The Chemical Company").

These properties will allow the hose to be laid over relatively rough obstacles and allow for some error if something falls on it or it gets pulled and stretched. As with the delivery hose, after the final design is picked, the length of the hose will be determined.

2.20. Sump Pumps

In order for our reverse osmosis system to work pumps must be implemented in order to force water through the pipe system. And eventually through the membranes and filters used.

Although there are many different types of pumps in the engineering world a sump pump specifically will be needed in this project due to its ability to be submerged in water and pump water through our system.

Typically a sump pump is used in house hold applications such as removing water from a basement or pumping water up from a well. Sump pumps are also used in pumping oil and gases from the earth's inners or used in marine applications to drain bilges of water. In this project these pumps will be utilized by positioning them in unclean water containers in three potential categories, small, medium, and large. The small category will be approximately back pack size and the pump will be in a plastic bag of water containing about a gallon of unclean water. The medium category being able to fit in the back of a pickup truck will be in a plastic container being around 100 gallons of unclean water. The large system will be able to purify water for disaster relief and has unlimited potential. The potential system categories will be discussed in later chapters. These pumps will be submerged in these basins and will pump water into and through our system. The sump pump is very important for our design to work. The pump is one of the only power and flow supplies for the system to work. Without the sump working, there is no water flow through the pipe system, there for the system does not clean water. Sump pumps are available in a range of sizes and have different power outputs which make it ideal for our project

Sump pumps usually work by them sitting in a hole with some sort of gravel base that's about two feet deep and 18 inches wide. In our project the pump will be in plastic tubs as explained above. Although this is different than its original application, the pump is doing the same job and should work the same way. Once the pump is in the hole and water fills the hole, the pump turns on and pumps water out of the hole into a desired area. The pipe running from the sump pump has a check valve (chapter) that keeps water from returning back down to the hole. A typical sump pump uses a centrifugal pump (Figure 47) to move water through the system. When the pump is turned on it spins an impeller. The impeller uses centrifugal force to force water towards the sides of the pipe, creating a low-pressure area at its center. Water continuously tries to fill the emptiness, but the impellers spinning action forces the water up and through the pipe. Most sump pumps can turn on automatically through a float activator arm or a pressure sensor. Pressure sensors work in this type of application because water applies more pressure than air which causes the pump to activate. The float activator works by a buoyant ball is placed on top of the water that is attached to an arm from the pump. As the water level changes, the arm is raised up or down. At a certain set height of the arm, the pump will activate.

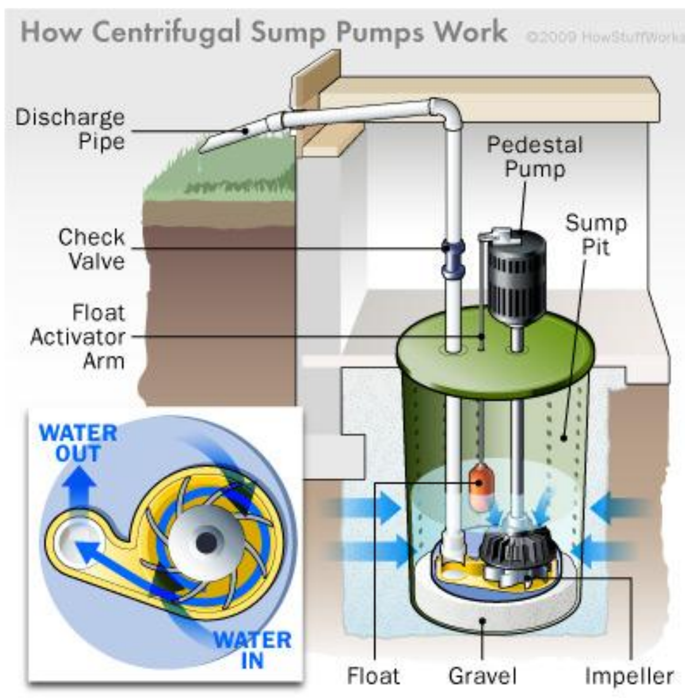

Figure 47: Diagram of a Centrifugal Sump Pump

There are two primary designs of sump pumps that would work with the group's project design. The first design is a submersible pump (Figure 48), which is just what it sounds it sounds like; the pump sits in the water. It is able to sit in the water due to its encasing of a water proof shell. The pump itself is located at the bottom of the enclosure and forces water up to the outlet pipe at the top.

The second type is a pedestal pump (such as the example shown in Figure 47). The pump in this design sits out of the water due to it resting on top of a pedestal. An inlet pipe extends down into the bottom of the pit in order to draw water out. Due to the motor and pump being out of the water, pedestal pump is usually louder, but in turn are less expensive.

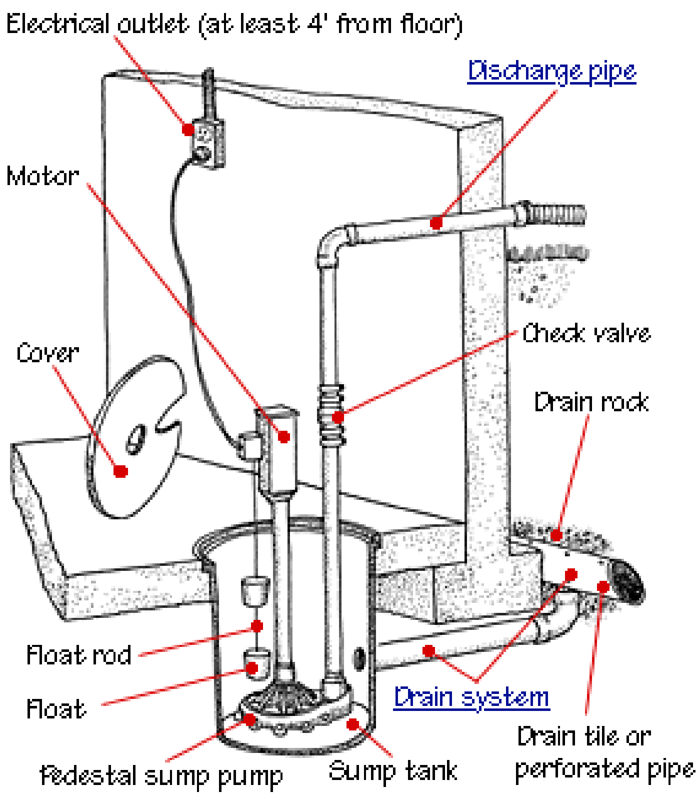

Figure 48: Submersible Sump Pump

The final design of the project requires a pump to be completely submerged in water. The pump also needs to vary in size and output. The smallest pump design would resemble Figure 48 and have similar specifications, while the larger ones will look like Figure 49.

Figure 49: Micro-DC Solar Pump

This particular mini pump requires 12 volt power and can work with voltages ranging from 4.5-24V. It can roughly generate 6 L/min at 6VDC, and 7 L/min at 24VDC with dimensions of 34mm x 36mm x 39 mm to 100mm x 84mm x64. Allowing this pump to be solar operated will supply the pump with its own power supply, decreasing the pumps limitations. Small pumps like this can also be designed to hook up to a car outlet. These specifications allows the pump satisfy our pump need for the small category of our design.

Figure 50: Submersible Titanium Sump Pump

The medium pumps would look similar to Figure 50 with this particular pump having dimensions of 9.625 inch Width and Length and a Height of 15.25 inches and a total weight of 17 lbs. These large pumps would have around ½ horsepower and being capable of pumping 4740 GPH (gallons per hour) which comes out to 113,760 gallons a day which fits the criteria of what the projects medium design would need to have an output of. Most of the medium size pumps are also corrosive resistant due to it being designed for salt water use. Having the pumps be corrosive resistant will increase the life of the pump in non-brackish waters and help make maintenance easier.

The large pumps are capable of producing 72000 GPH or 1,728,000 GPD, which is more than enough flow for our project. Figure 5 shows an example of a large pump that would work for the project. Weighing in at 600 lbs. gives it a significant weight disadvantage but what is good about this particular pump design is that it can run from 0-5 hp generating as much of as little water flow as needed. It is also programmable and its engine runs at 91.7% efficiency which both these specs can allow for energy savings.

Figure 51: Programmable Sump Pump

2.21. How These Efforts will Relate to the Index of Human Sustainability

Established by the MIRAD Laboratory, the vital index of human stability is a list of necessary life lines for the ongoing survival of the human race. "All MIRAD products and their engineering, technological and computational thinking encompass and interpret the vital index of human sustainability." (MIRAD) This mission statement establishes goals that each project group under the head of MIRAD must wholly, or partially, reach with the advancement of their project. The vital index of human sustainability is composed of the following: energy, education, health, food, safety, sanitation, social awareness & informatics, self-actualization, water, and governance/management/business/entrepreneurship. Our major qualifying project of water purification through reverse osmosis reaches each of these indices to some extent, achieving exposure on different levels.

Energy

To some extent, every MIRAD project either effects or requires energy to function or reach completion. In the process of water purification through reverse osmosis, the system requires energy to take the water in, to push the water through the system, and, especially, to force the water through the reverse osmosis membranes. This energy must come from someplace, and the major sources which the energy is likely to originate are electricity and fuel. By cutting down on the amount of energy required to run our system, we limit the amount of resources required to achieve this energy. The goal of our project is to minimize the need for additional resources for our reverse osmosis system to function.

Education

The education which comes from the major qualifying project, which is required for graduation for all WPI students, encompasses different areas of enlightenment. For members of

the group responsible for water purification through reverse osmosis, exposure to the different needs for purified water was an eye opening experience. Not all of the situations which purified water is required involve third world countries and poverty, but there are many environments which may be overlooked for their obviousness. One of these examples is in naval vessels, such as warships or submarines. Storage of potable water on these vessels would require a lot of space and add a large quantity of mass, so use of reverse osmosis systems saves in space and weight.
The vast number of people affected by the need for clean water ranges from undernourished, war-torn countries throughout the world, and victims of natural disasters. It can be easily understood that these people need clean water for drinking and eating, but the doctors and aids in the regions require clean water to treat patients, as well. The project experience provides an educational experience for all team members, as well as other groups working under the MIRAD heading along with us.

Health

Hearing stories of tourists in Mexico suffering from "Montezuma's Revenge," a bowel irritation resulting from drinking local water, one can understand that contaminated water can lead to sicknesses, both short and long term. Countries with few resources and victims of natural disasters such as hurricane Katrina have limited access to clean and safe drinking water. This can lead to spread of sickness and disease. By providing simple and accessible water purification with our reverse osmosis system, we can cut down on the sickness and death caused by insufficient water sources.

Food

When one considers water purification, food may not be the first item that comes to mind. On many levels of food production, though, clean water is necessary. When one cooks food with contaminated water, boiling the water may not be able to remove all contaminants. This can cause sickness on small or large scale. Livestock or animals intended for consumption may, also, incur sickness by ingestion of contaminated water, transferring this on to humans ingesting the byproducts of the resourced animals, whether meat or milk.

Safety

The safety of all human beings is a primary importance for human kind. Clean water for the use of all people is a necessity for the health of all. The water purification through reverse osmosis allows for production of de-ionized water. De-ionized water (DI water) is used in hospitals and aid centers to wash and in surgeries. The ability to produce the DI water for the doctors and aids to use will allow for cleaner, safer surgeries, eliminating the water as one possible source of infection.

Sanitation

Considering the use of water by doctors, washing ones hands in contaminated water can be counterproductive. The safety of patients is reliant upon the sanitation present in the surgery environment, from the surfaces, to the hands and tools which may be required to enter a wound or incision. Production of de-ionized water through the process of reverse osmosis improves the level of sanitation available to anyone with access to our reverse osmosis system.

Social Awareness & Informatics

The subject of clean water is something that many people may take for granted after growing up in places where potable water is just the turn of a handle away. Studying the applications and environments for water purification through reverse osmosis opens the doors to the broad scale of how many people are in need of clean water, and how many different environments and situations lead to this need. Our interaction with computers and technology provides a way for us to access research based information and discover methods for improving current systems to achieve the goal of our master qualifying project.

Self-Actualization

In an effort to reach our final goal of the master qualifying project, we are able to learn more about ourselves, as individuals. Spending the better part of a year studying the need for clean water, we are exposed to the negative effects that contaminated water can have on people, individual and in groups. The development of a water purification system is based on an understanding of need, and the completion of the project brings to an end one more stage in our growth as students at WPI and human beings.

Water

The most blatant connection of our project to the vital index of human sustainability is in its production of clean water. Water purification through reverse osmosis allows filtration of water at different rates, based upon the scale of the reverse osmosis system being utilized. Despite the fact that over seventy percent of the Earth's surface is covered by water, the amount of that water that is actually readily drinkable is quite small, on a scale of less than one percent. By increasing the accessibility of reverse osmosis water purification, we are also increasing the accessibility of safe drinking water to the inhabitants of the Earth.

Governance/Management/Business/Entrepreneurship

Over the course of the last eight months, the master qualifying project has required assertion and delegation on the part of all group members. Leadership roles have emerged and been filled based on personalities and personal relation to the subject. The group function, although a total group effort, runs like a business on a very small scale working to achieve a goal and produce a final product.

Our understanding that reverse osmosis systems are currently in use for water purification purposes, the group needed to be innovative and revolutionary. By accomplishing this, the final product of the master qualifying project will have the potential to be marketable as something more accessible and better than what is currently available to the masses. Establishing the project of water purification through reverse osmosis as a viable option for those in need of clean water, or those who intend to produce clean, safe water, we reach our goal, and produce a successful product.

CHAPTER 3. RESULTS AND DISCUSSION

3.1 Methods Used

The system was modeled theoretically by utilizing examples provided in Chapters 12 and 14 of the textbook. Once the problem was sufficiently understood, the examples in the textbook were modified to fit the conditions of the project's unique constraints. The equations were solved using a combination of MathCAD 15 and WolframAlpha. MathCAD 15, the computational software available to WPI students was used to solve most of the equations as well as check units. WolframAlpha was used solely to solve for the Darcy Friction Factor and provide the graphs which indicate the intersection point. The evolution of the solutions to the theoretical model is presented in detail in the Results and Discussion section that follows.

MathCAD was used to better understand the system. First the known values were entered and assigned a variable. All of the calculations in this project were done in English units due to the availability of data being mainly in those units.

$T_w := 32$ °F Inlet Temp of Water

$\rho := 62.42$ $\frac{lb}{ft^3}$ Density

$g := 32.17$ $\frac{ft}{s^2}$ Gravity

$V := 24000$ gallons Required Output $\Delta t := 8$ hr

$V' := \frac{V}{8} \cdot \frac{1 \cdot 1}{60 \cdot 60}$ $\frac{\frac{ft}{gallons}}{second}$ $V' = 0.833$ $\frac{gal}{s}$ $V'_2 := .1114$ $\frac{ft^3}{s}$ (1)

$m' := \rho \cdot V'_2 = 6.954$ $\frac{lbm}{s}$ Mass flow rate (2)

$D := \frac{1}{2}\ ft$

$cost := .085$ $/kWh (3)

$\varepsilon := .00001$

Using Stainless Steel Tubing in the pipes. Data taken from table 14-1 pg 546

$D := \frac{6}{12} = 0.5$ **ft**

$P_{atm} := 14.7$ psi

$P_2 := 800$ psi

$z_2 := 15$ feet Distance Traveled by Water

$z_1 := 0$ feet

Using Table A-15E pg. 1055 the dynamic viscosity of water at 32 degrees Farenheit is

1.204x10^-3 (in units of lbm/ft*s). The Pr is 13.5

$\mu := 1.20410^{-3}$ $\frac{\text{lbm}}{\text{ft}\cdot\text{s}}$ Dynamic Viscosity

$L := 3$ **ft**

After adjusting the known values so that the units of the variables matched the equations the problem could be solved using equations available in Chapters 12 and 14 of the Thermal-Fluid Sciences book used for the class.

$$D_h := 4\cdot\frac{\left(\frac{D^2}{4}\right)}{\pi\cdot D} = 0.159 \qquad (4)$$

Hydraulic Diameter in ft

$$v_2 := \frac{m'}{\rho\cdot\left(\pi\frac{D^2}{4}\right)} \qquad v_2 = 0.567 \ \frac{\text{ft}}{\text{s}} \qquad (5)$$

$$Re := 4\cdot\frac{m'}{\pi\cdot D\cdot\mu} = 1.471\times 10^4 \qquad (6)$$

After determining velocity and Hydraulic Diameter the Reynold's Number for the system was determined. This number would determine the next series of equations to be used. The Reynold's number in this case is 14710 which indicate turbulent flow through the pipes, so the equations in the following sections utilize the equations adjusted for turbulent flow through pipes. The next major equation which needs to be solved for is the Colebrook's Equation for determining the Darcy Frictional Factor. To do so the dimensionless hydrodynamic entry length must be determined as well as the relative roughness of the stainless steel pipes. These equations are used to model the flow of the fluid in its vertical section after traveling through the pump and the increase in pressure due to the pump.

$$\frac{L_{h\_turbulent}}{D} := \left(1.359\,Re^{\frac{1}{4}}\right) \quad \text{Dimensionless Number} \quad (7)$$

Relative Roughness Equations

The dimensionless hydrodynamic entry length is 14.966 Diameters

$$1.359\,Re^{\frac{1}{4}} = 14.966$$

$$\frac{\varepsilon}{D} = 3 \times 10^{-5}$$

$$L_{h\_turbulent} := 14.966D = 7.483 \quad (8)$$

$$\frac{1}{\sqrt{f}} := -2 \cdot \log\left[\frac{\left(\frac{\varepsilon}{D}\right)}{3.7} + \left(\frac{2.51}{Re \cdot \sqrt{f}}\right)\right] \quad (9)$$

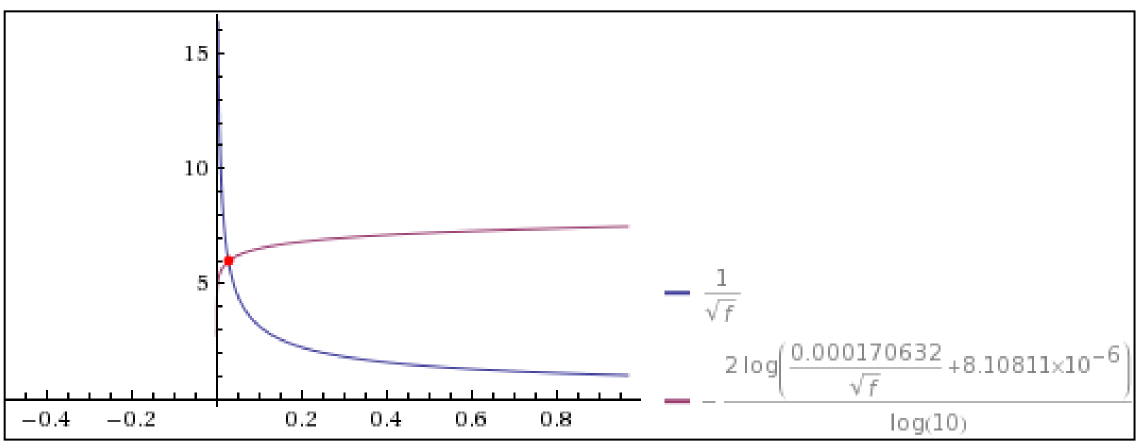

Figure 52 Darcy Friction Factor

The computational program WolframAlpha used the intersection of the two equations to determine f (Darcy Frictional Factor). This value was determined to be 0.0279999 for the values used in the project. The Darcy Frictional Factor is then inputted into the equation for head loss and pressure drop. These equations are used to determine the power required to overcome the friction losses due to the pipes.

$$h_L := f\cdot\left(\frac{L}{D}\right)\cdot\frac{{v_2}^2}{2\cdot g} = 8.405\times 10^{-4} \quad \textbf{ft} \qquad (10)$$

$$\Delta P := f\cdot\left(\frac{L}{D}\right)\cdot\frac{\left[\frac{(\rho\cdot v_2)^2}{2}\right]}{32.2} = 3.272\ \frac{lbf}{ft^2} \qquad (11)$$

The pressure drop between in the vertical section, after the pump and right before the membrane is .022722 psi. The head loss is approximately .010 inches.

$$\Delta W' := \frac{(V'_2\cdot\Delta P)}{.737} = 0.495\ W \qquad (12)$$

The power necessary to overcome the losses due to friction throughout the pipe's length is an additional .5 Watts. In the next series of equations the power required to move the water from the inlet through the pump is calculated.

$$W' := \left[m' \left[g \cdot (z_2 - z_1) + \frac{(v_2 - v_1)}{2} + \frac{(P_2 - P_{atm})}{\rho} \right] \right] = 3.445 \times 10^3 \quad \frac{Btu}{hr} \qquad (13)$$

The amount of power required to transport the water 15 feet vertically and force it through the pump at 800 psi is calculated to be 3445 Btu/hr. 3445 Btu/hr is equivalent to 1010 Watts or 1.01 kW. The total power required to overcome friction losses and transport the water vertically 15 ft is 1010.5 W.

$W'_{si} := 1.01 \quad kW$ kWh

$Energyconsumption := W'_{si} \cdot \Delta t \quad kWh$

$Energyconsumption = 8.08$ kWh   (14)

Energy consumption is 8.08 kWh

$Cost := Energyconsumption \cdot cost = 0.687$

Using the total power required to run the system it is possible to determine the total energy consumption required to create 24000 gallons of water. Using .085$/kWh as the base price for electricity the total cost of producing the 24000 gallons of fresh water is estimated at being $0.69. Even greater efficiency could be attained by using nozzles throughout the system to accelerate water. The data illustrates the effectiveness of the system at utilizing electricity and shows our designs potential.

CHAPTER 4. CONCLUDING REMARKS AND RECOMMENDATIONS

The solution to the problem of producing clean water is a multistage reverse-osmosis system. A single reverse-osmosis unit is capable of producing 12,000 GPD. Due to the small size of the system, multiple reverse-osmosis units can be utilized in many different instances and applications in today's society. In particular these units can be especially utilized in many naval vessels and throughout civilian water processing plants. Another significant feature of the reverse osmosis unit, related to size, is that the process has very few moving parts and requires significantly less maintenance than most other water treatment systems. When it does require maintenance, the system requires a significantly lower amount of man hours. The advantage of lower maintenance helps lower the cost and training to maintain the equipment making the unit much more desirable for businesses.

When comparing the size to output in gallons per day between reverse-osmosis units and flash boiling systems, the reverse-osmosis units are superior. The reverse osmosis systems also do not require the combustion of a fuel to produce energy, as they run on electricity which helps reduce emissions. The process uses the incompressibility of water to force the water through very fine membranes, which forces the separation of feed water into distillate and brine. Using the flow velocity, created by the pump, to accomplish the separation which also reduces the heat produced by the system. Flash boiling systems require an operation temperature of over 200 degrees Fahrenheit. Due to the operating temperature, as well as condensation process, the systems require substantial cooling in order to the system to operate correctly, thus expending even more energy in order to operate the system. For its size, energy consumption, and output, reverse-osmosis is the most successful method of distilling water.

This project addresses the issue of water distillation via reverse-osmosis in a theoretical manner. The next steps toward a solution are constructing a model, designing an experiment and performing the experiment. These would incorporate all the necessary parameters to fully define the conditions that would occur in a real-life situation. With this solution, clean and distilled water could be provided in a size, energy and cost efficient way.

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APPENDIX A

Design Specifications

Desurger

Designing our sample reverse osmosis system for this project required separate design of each individual piece of the system so as to combine them all into our reverse osmosis unit. In designing the desurger for our sample reverse osmosis system, we needed to take into account the overall size and purified water output we intend to achieve. The size of the total package will be relatively small in comparison to the possible size and output of our reverse osmosis water purification unit. With our packaging intentions, we established that the special volume to be occupied by the desurger would have to be less than one half cubic foot, or 864 cubic inches. Within this space, we needed to incorporate all the necessary aspects of a successful desurger design.

When looking upon our intended desurger design, which follows the mold of the simple inclusion perpendicular to the water flow, we inspected such as the figure below from a design from ShockGuard ("Shock-Silencers.com") based on their Surgeguard model.

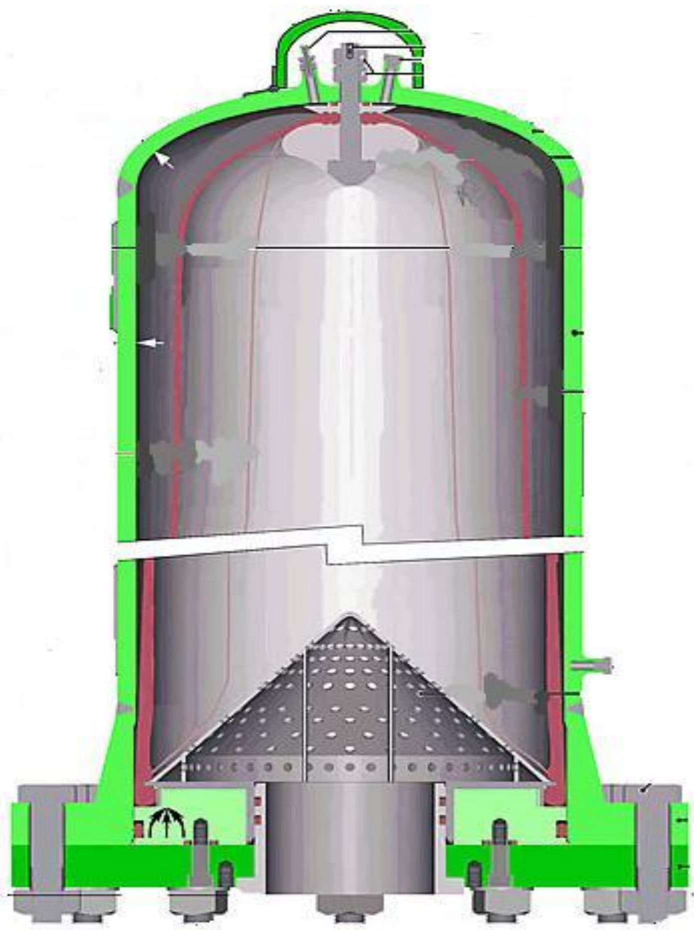

Figure 53: Perpendicular Desurger

This design incorporates the flush mounting to a section of t-pipe with the use of several bolts to promote a secure and strong connection in the event of high pressures. In an attempt to assure that there will be no worries of water leaking between the desurger and the pipe, we decided upon the use of a gasket as insurance. In our model, the gasket was made larger, or thicker, as a matter of exaggerating the presence of the gasket, as is shown in the figure below.

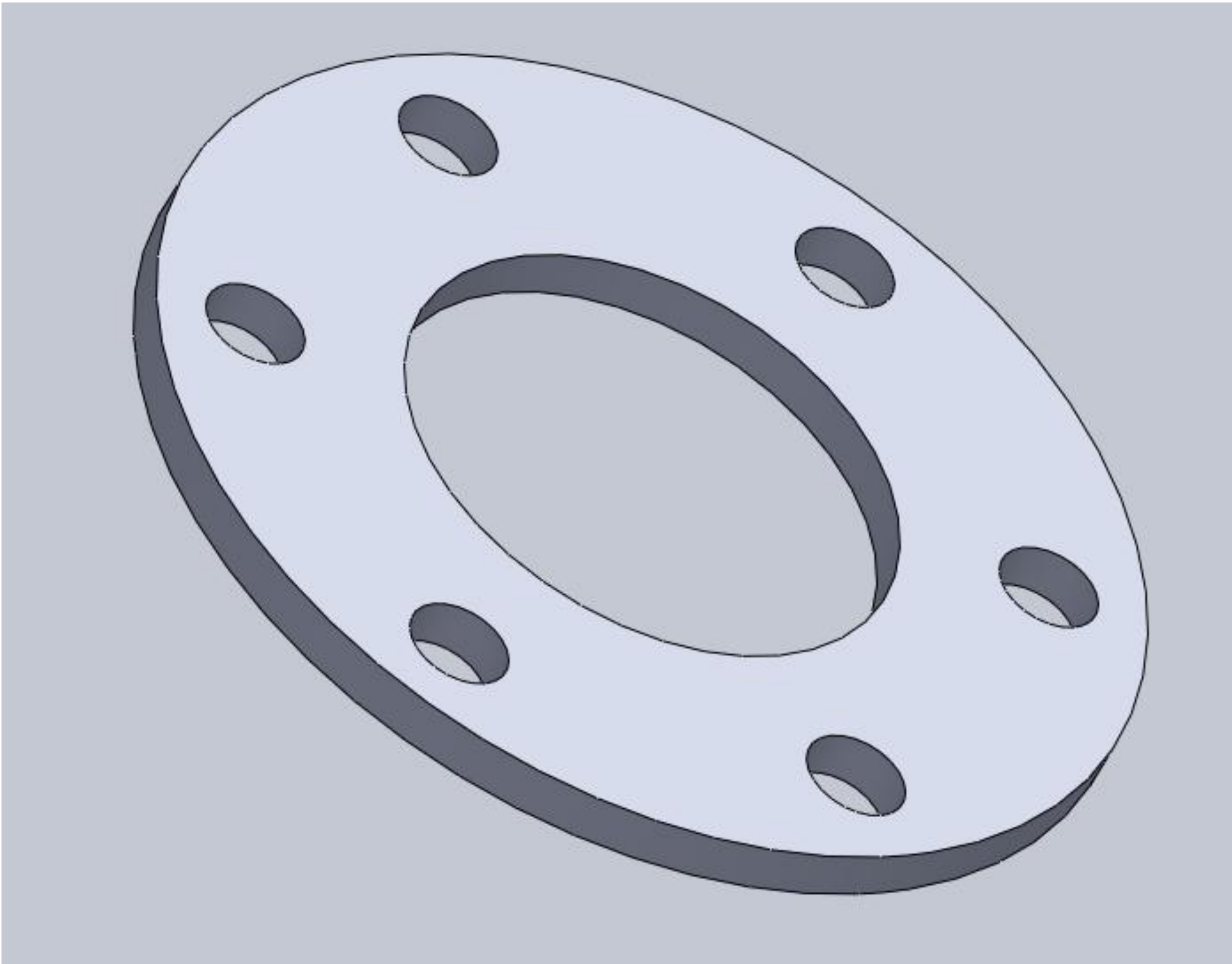

Figure 54: Desurger Gasket Model

The simplistic design of the desurger is intended to convey the intent of our design in a straightforward fashion. Minor design details were excluded in an effort to simplify the Solidworks model and decrease the design time.

Our intentions for the reverse osmosis water purification system are to create an efficient and effective package with a modular design to improve the ease with which one can make fixes to the system or replace filters. In an effort to apply this idea to the individual components of the reverse osmosis unit, we constructed the desurger out of two pieces. These two pieces consist of the body which houses the water bladder (Figure 55: Desurger Body Model) and the top piece of the desurger (Figure 56: Desurger Top Model) which will allow for easy access to the internals of the desurger.

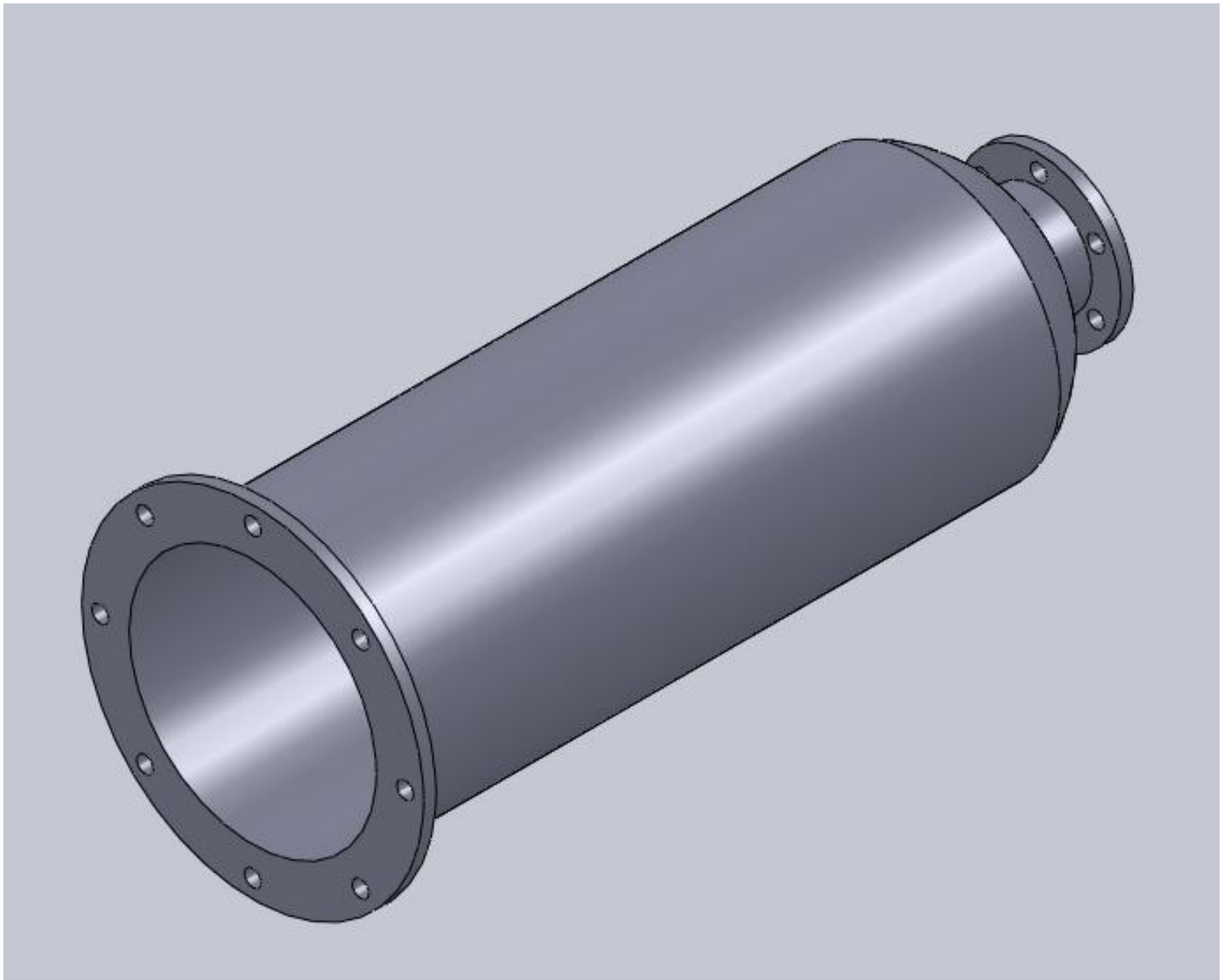

Figure 55: Desurger Body Model

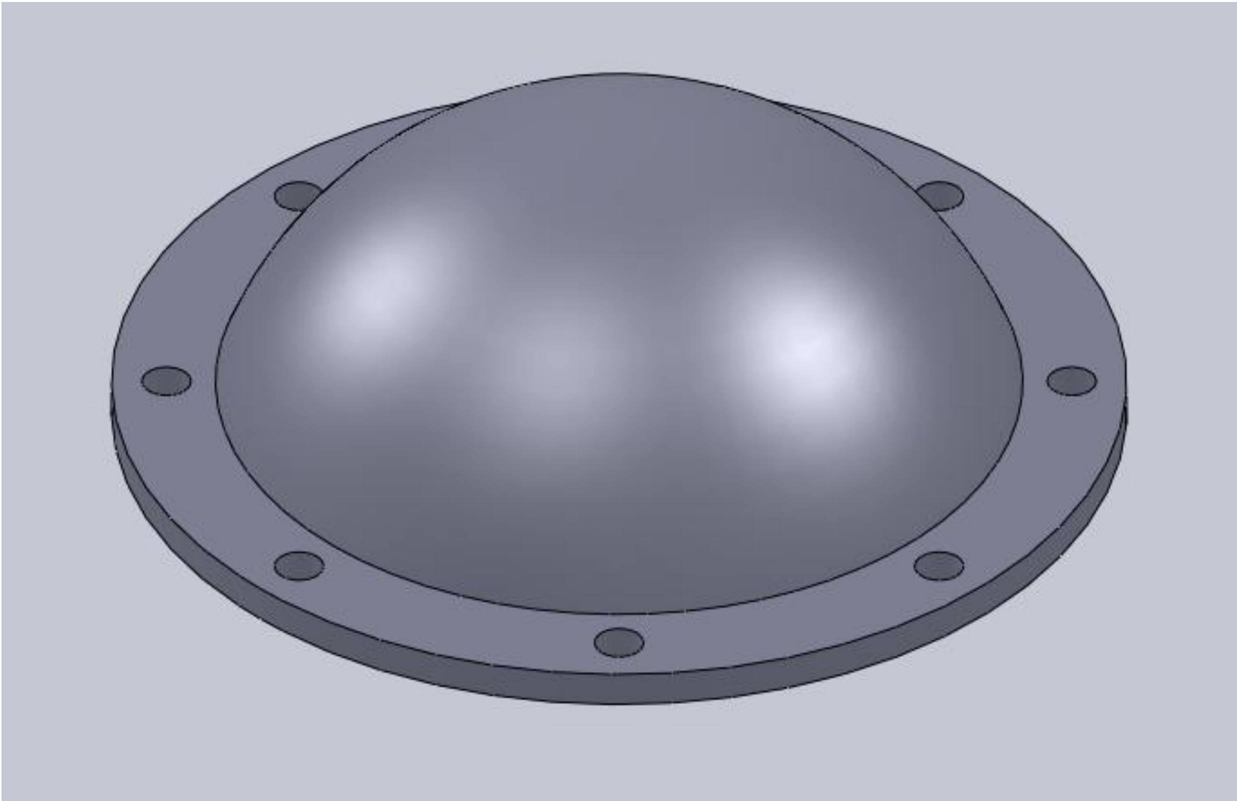

Figure 56: Desurger Top Model

To keep the entire desurger assembly within the necessary volume we decided upon an outer diameter for the desurger body of 3.3 inches so that the flange, on both the body and the top, necessary to bolt the top of the desurger to the body will not have a diameter which will be too large so as to interfere with any other components of the reverse osmosis water purification system or interfere with access to any of these components. This allows for a wall thickness of fifteen hundredths of an inch, which will allow for sufficient strength of the desurger to prevent and rupture from internal pressure. The height of the main body was limited to eight inches to maintain a compact size and still allow for a large enough internal volume for the bladder to sufficiently smooth the water flow. The bottom portion of the desurger body, as well as the top of the desurger, has a curved surface with radius of about one and three-quarter inches. These dimensions allow for sufficient internal volume while maintaining a compact desurger unit for our reverse osmosis water purification system.

Bolting the top to the base, we employed the same method as is used in connecting the desurger to the pipe by placing a gasket between the body of the desurger and the top. As demonstrated with the lower gasket, this gasket is also enlarged for emphasis on its presence.

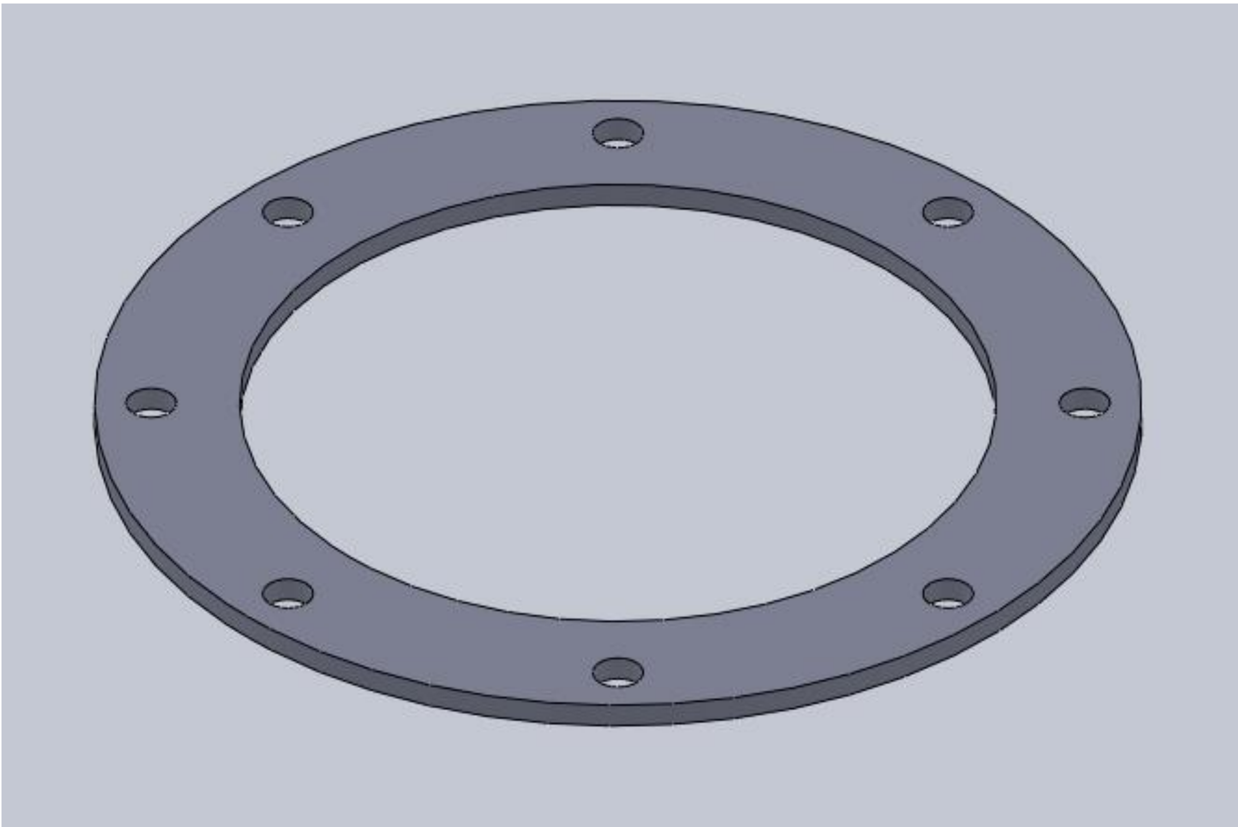

Figure 57: Top Gasket Model

In a manner of simplification of the design of our desurger, we have neglected to include only the flexible bladder which fits within the body of the desurger which is the important factor in the success of our desurger, and will prevent water seepage into our gas contained within the body of the desurger. Combining the different pieces of our desurger, we have a model of our desurger assembly, as is displayed in the figure below.

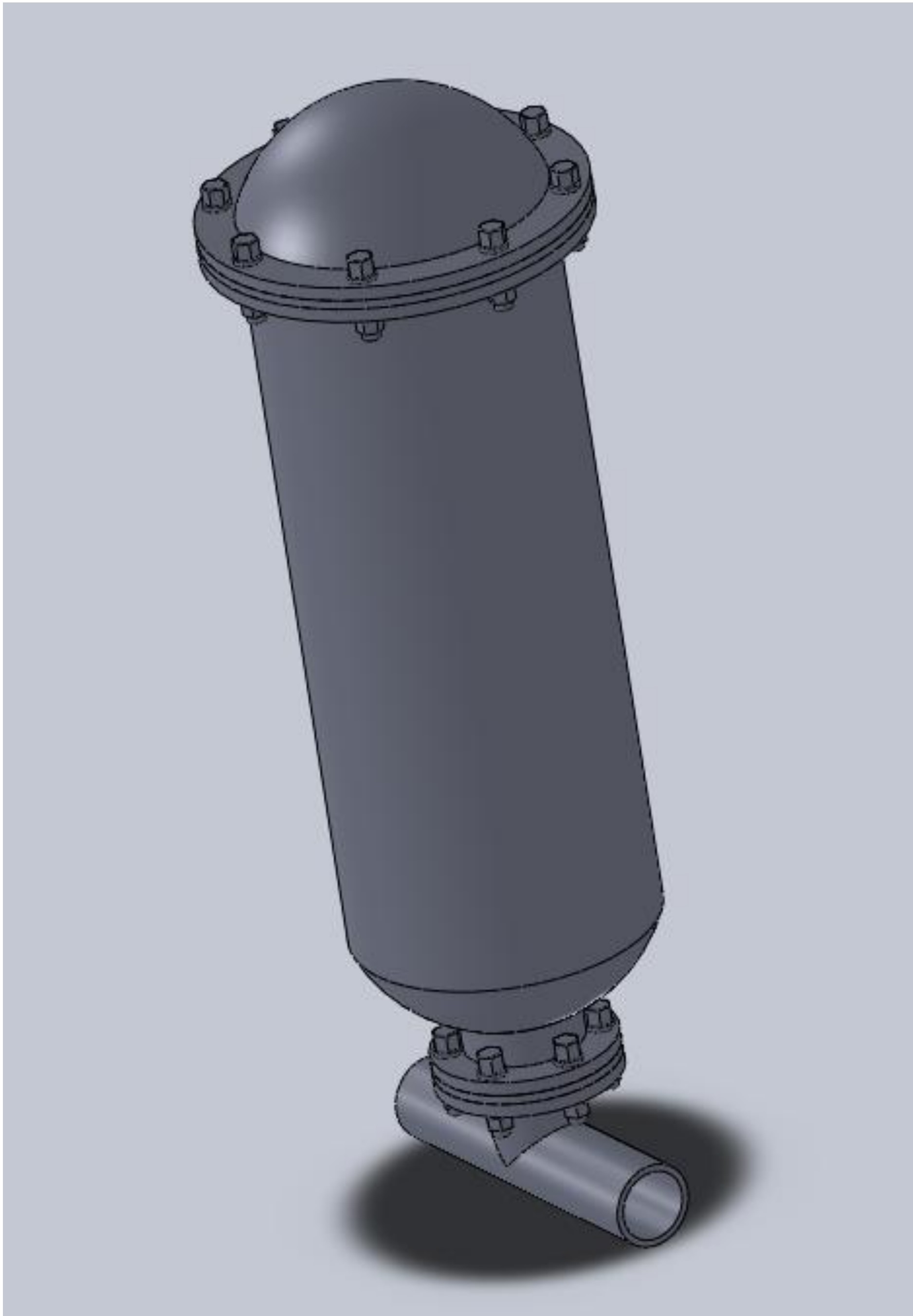

Figure 58: Desurger Assembly

The only addition not aforementioned which appears in the model of the desurger assembly is the section of piping which is the necessary t-pipe which has a flange to allow for securely bolting the desurger to the section of pipe. The desurger model we have designed is a very accessible, yet robust, design capable of fulfilling our requirements for this portion of our reverse osmosis water purification system.

Sump Pump Design Description

In order for our system to operate, there needs to be a flow of water. The main source of power to the system is the sump pump. If the pump failed to pull water consistently through the system, the water would not be cleaned. As specified earlier we looked at three sizes of pumps to use: small, medium and large. The small pump can output roughly 1.5-1.8 gallons per minute depending on the power source, the medium can output 79 Gallons per minute, and the large can output 1200 Gallons per minute. Since our pump was going to be in unclean water and more than likely fully submerged, the motor had to be placed inside the sump and fully sealed to insure that it would not be damaged by water. As a basis, commercial pumps such as Little Giant© were studied in order to get an idea on how our pump should be made (see figure below).

Figure 59: Sump

As mentioned earlier, the pump will be submerged in unclean water that can have bacteria or chemicals in it, therefore materials had to be studied to insure that the pump would not deteriorate under these conditions. HDPE (high density polyethylene) is used as sewer piping is rated from pH 1.5 to pH 14, it is easily wielded, rigid and has good abrasion resistance

"(HDPE) Sheeting". This material could be used for the main body of the sump or just the outside to provide it with the resistance required for the task.

In order to prevent the sump from getting clogged and to save the filters from large debris, a series of grates were placed at the water intake.

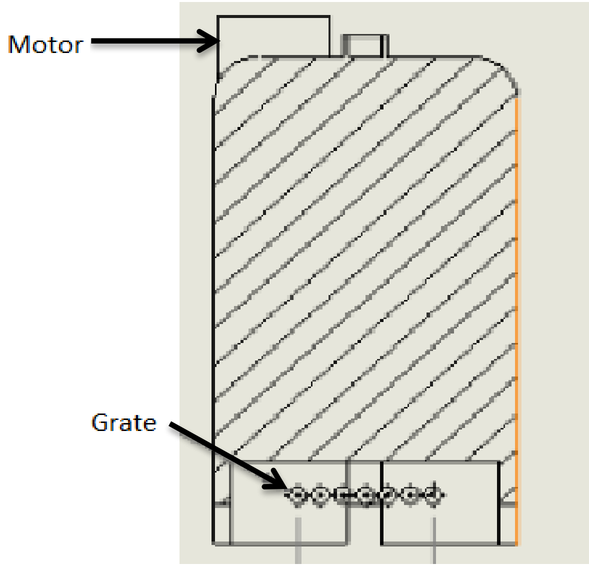

Figure 60: Sump Cross Section

The motor of the sump is located in an isolated spot near the top of the pump for easy access in case something goes wrong. The sump is also fitted with an attachable hose so that it can be quickly taken off or swapped for a different size. Also if the pump gets damaged, another one can be attached to allow the system to continue to function while the part is being fixed. Also the grates on the bottom are detachable so that different sizes can be used to match the requirements of the system.

Carbon Filter

When designing the carbon filter for our reverse osmosis system, weight, size, and cost are the main elements that must be focused on. The carbon filter must be lightweight, which means the material must be a durable, light plastic. The compact size will contribute to the lightweight characteristics of the filter and the overall system. To make this project possible, the cost of this system must be reasonable, so the smaller the filter, the less material that is being used. This must happen while at the same time produce equal or greater efficiency.

Figure 61: Similar Activated Carbon Filter Design

The above image depicts a rough idea of a similar activated carbon filter. The modified carbon filter will also possess three stages, one to gather larger debris, another for finer debris, and the final one for tiny harmful particles down to the micron. Instead of the flow of water come from the side, the one used for the system will come through the top side section of the device while exiting through the adjacent side of the piece. More detailed description of each part of the specially designed filter will be discussed below.

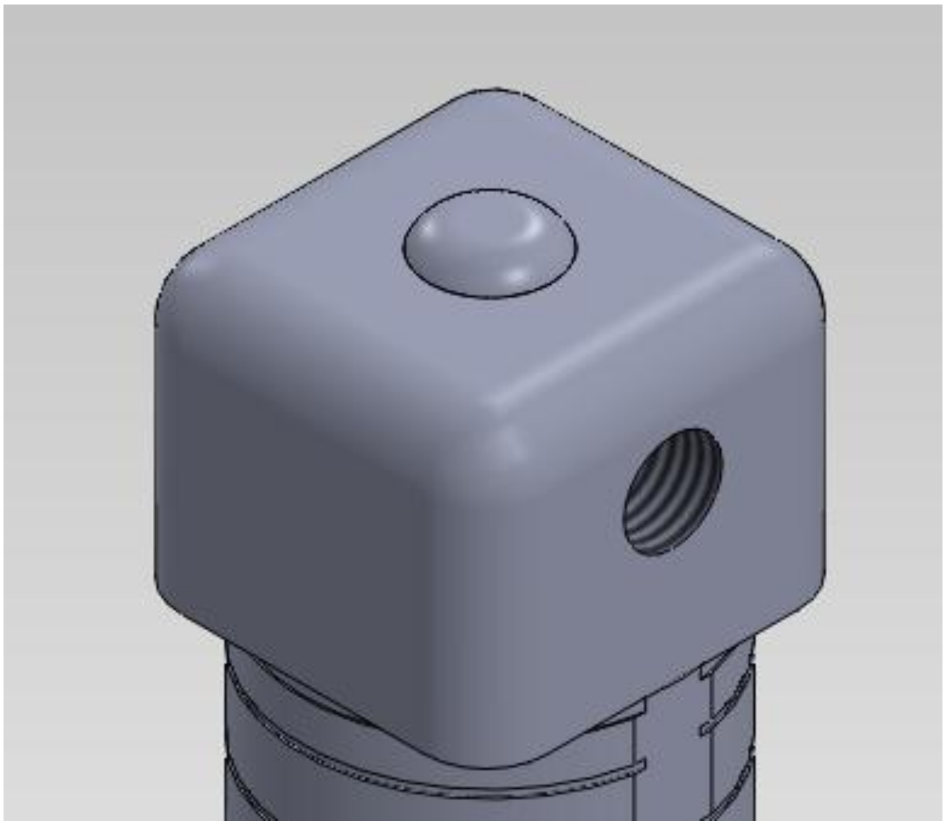

Figure 62: Inlet and Outlet of Carbon Filter

The image above shows the entrance of the carbon filter. This location is where the pipe from the reverse osmosis system would connect and start the carbon filtration process. The cap screw on top allows for easy accessibility to the filters inside the device. The filters must be changed regularly, so it is important to have a simple process to remove and apply the cover of the carbon filter. The cubic shape with the chamfered corners allows a more stable support for any kind of piping that will connect on either ends of the cover. On the opposite side of the filter top is the outlet of the filtration process and where an exit pipe meets.

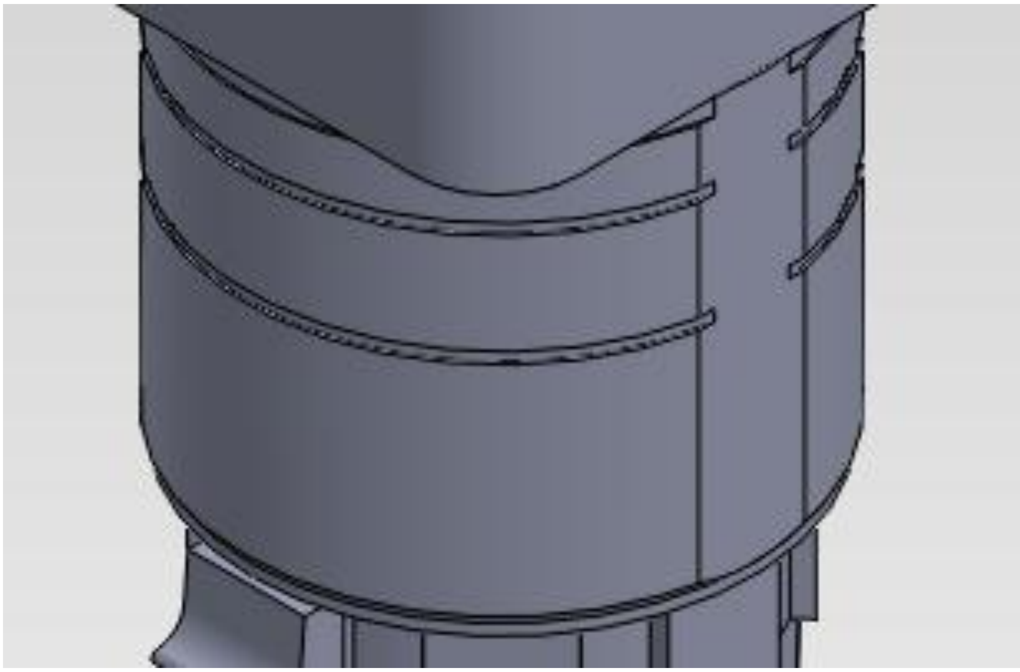

Figure 63: Primary and Secondary Filter

The midsection of the filter assembly contains the primary filters. These filters have larger opening patterns compared to the other filters. The purpose of these filters is to collect the larger debris such as rocks, garbage, or any similar sized objects. It is very important to avoid any clustering throughout the process, especially in the activated carbon filters. As a result, the initial stages of the filtering must be successfully achieved to stay clear of inefficiency and catastrophic failure.

Afterwards, the flow of water will travel through smaller filters to gather any particles that the initial filters did not pick up. The main goal of the secondary filters is to prepare the water to filter through the activated carbon filter, which means there must not be any large debris that can cause blockage in the next step of the filtration process.

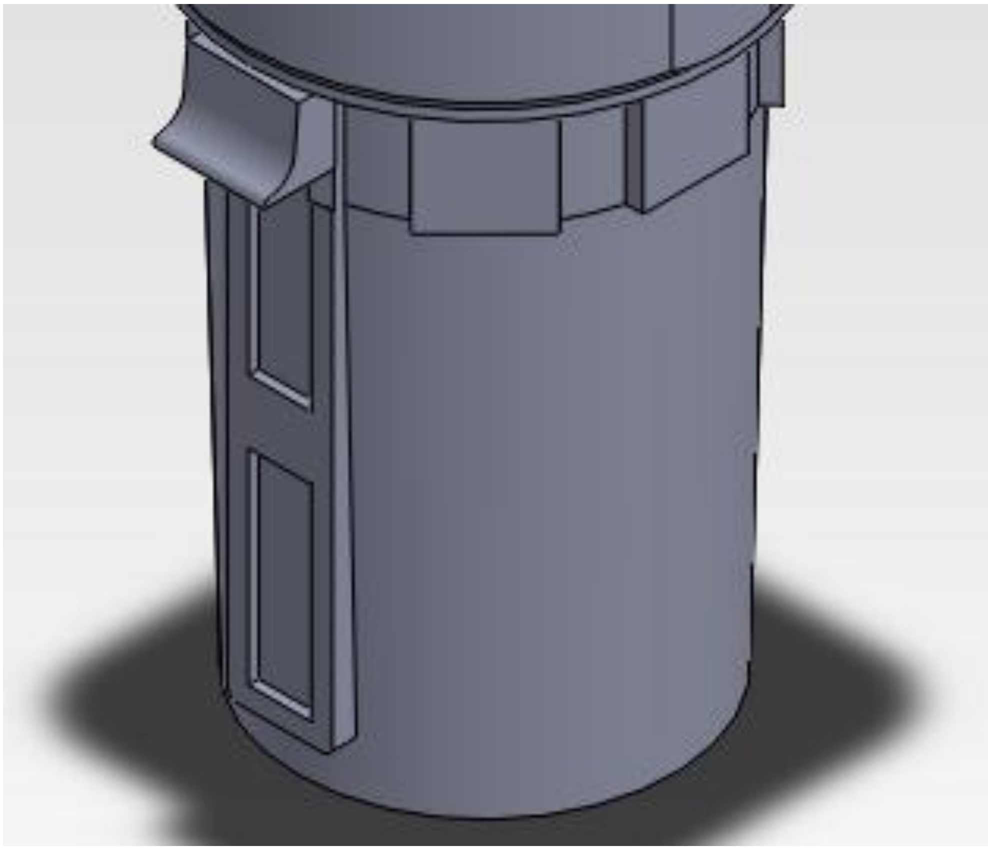

Figure 64: Activated Carbon Filter

The bottom part of the filter assembly consists of the activated carbon filters. These fine particles, ranging from 20 microns to 0.5 microns, gather any impurities from the flow of water. The advantage of having the granulated activated carbon is that it covers a larger surface area and adsorbs smaller contaminants measured single-digit microns. Another advantage of having this filter is that it attracts a wide range of harmful chemicals and contaminants. Also, activated carbon adds more variety of attractiveness due to its slight electro-positive charge added to it. The tab attached to the container allows access to the activated carbon for maintenance.

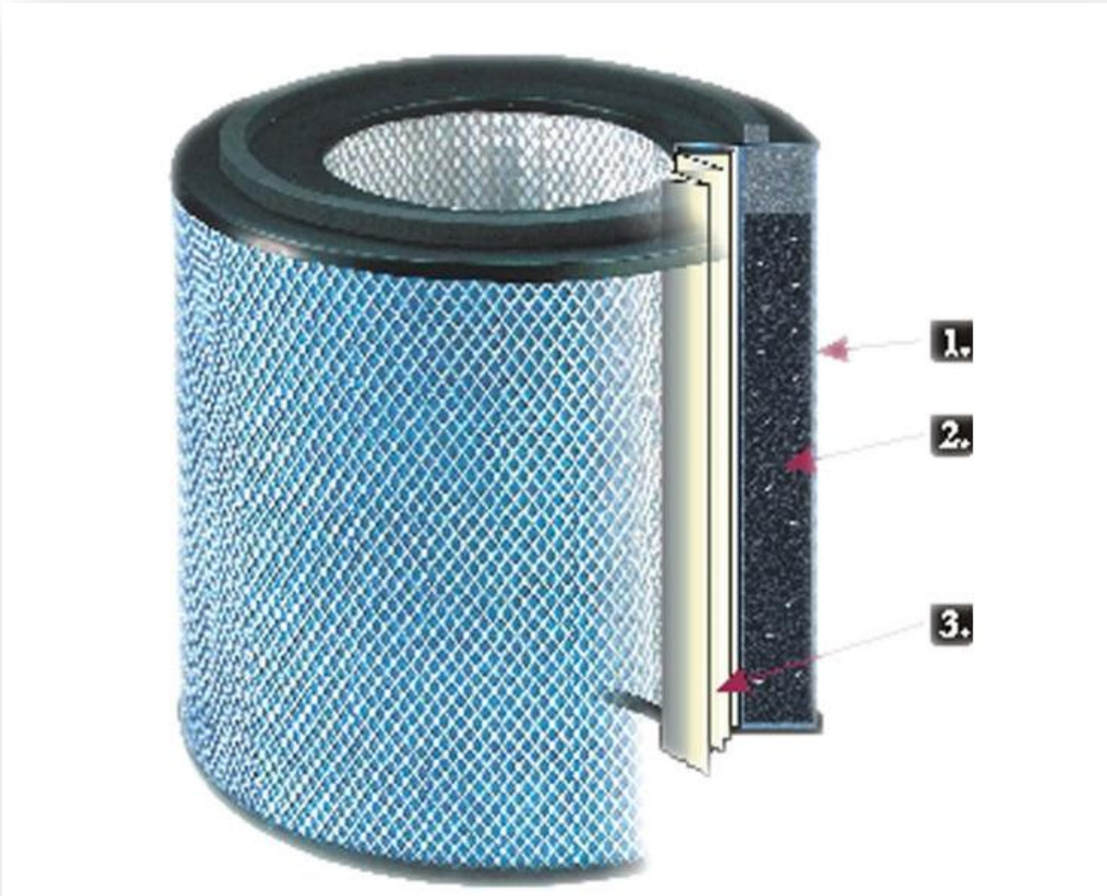

Figure 65: Orientation of the Actual Filters Inside of the Housing

The locations of the filters will be positioned as the way shown of the above image. As mentioned before, the filters will oriented from top to bottom rather than from side to side. This change was made to accommodate the reverse osmosis system prototype and its various stages of filtration. That outer blue filter, labeled as 1, will serve as the first stage of gathering the larger debris due to the size of the gaps within the patterns of the filter. As previously described, the purpose of the yellow secondary filter, labeled as 2, is to collect the smaller contaminants and eliminate blockage for the next and final stage. The activated carbon filter, labeled as 2, will use its adsorption characteristics to filter any remaining harmful particles in the water.

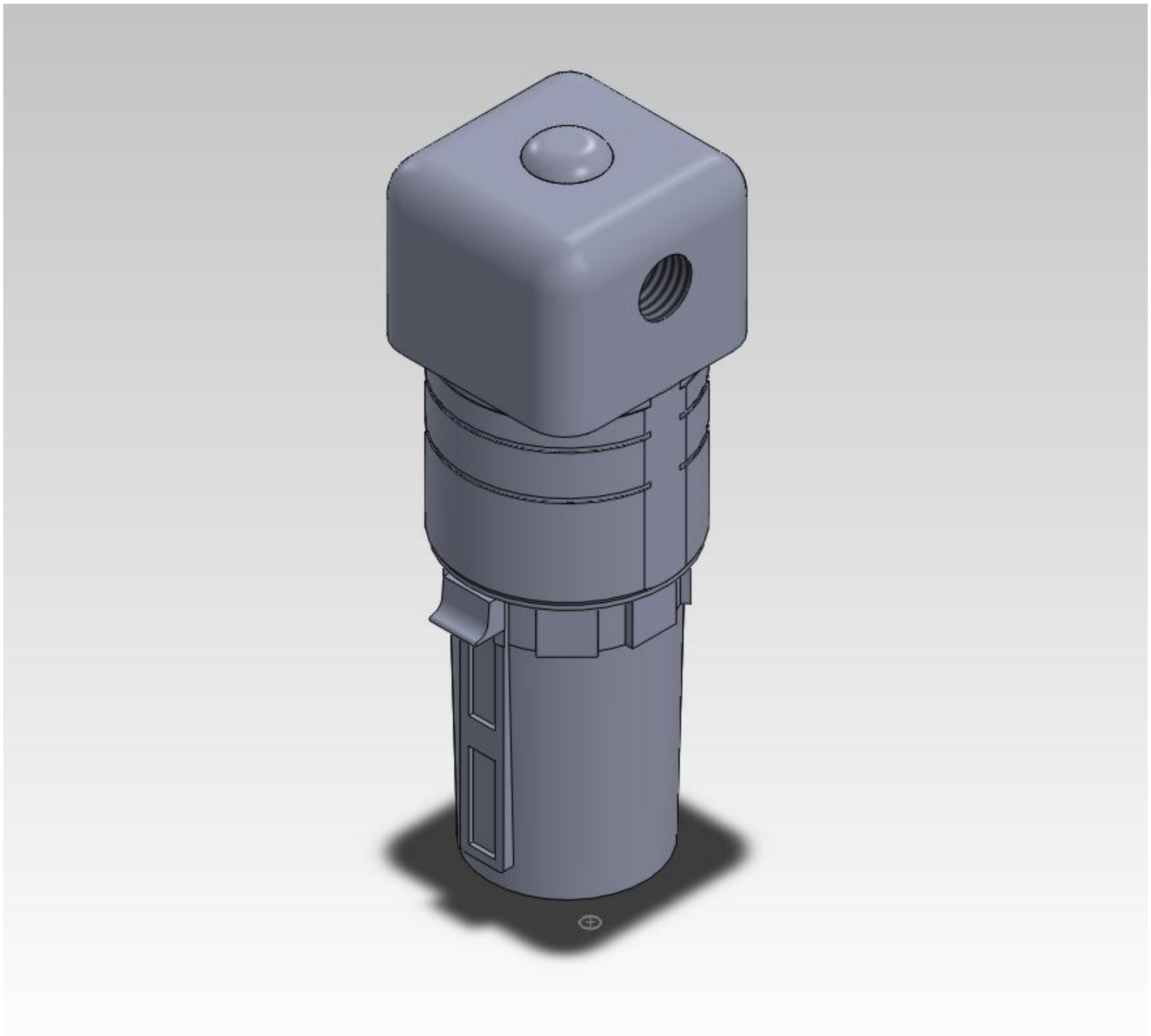

Figure 66:Overall Activated Carbon Filter Assembly

The overall assembly of this activated carbon ensures clean drinking down to the micron. Having individual parts for this filtration assembly makes it user friendly, while maximizing maintenance capabilities and minimizing failure to the whole process Independence of each process will provide more room for improvements within the device. This design will guarantee maximum efficiency while following our constraints of weight, size, and cost. Keeping this theme to not just the carbon filter, but throughout the reverse osmosis system will assist in producing the cleaner water greatly needed for our planet.

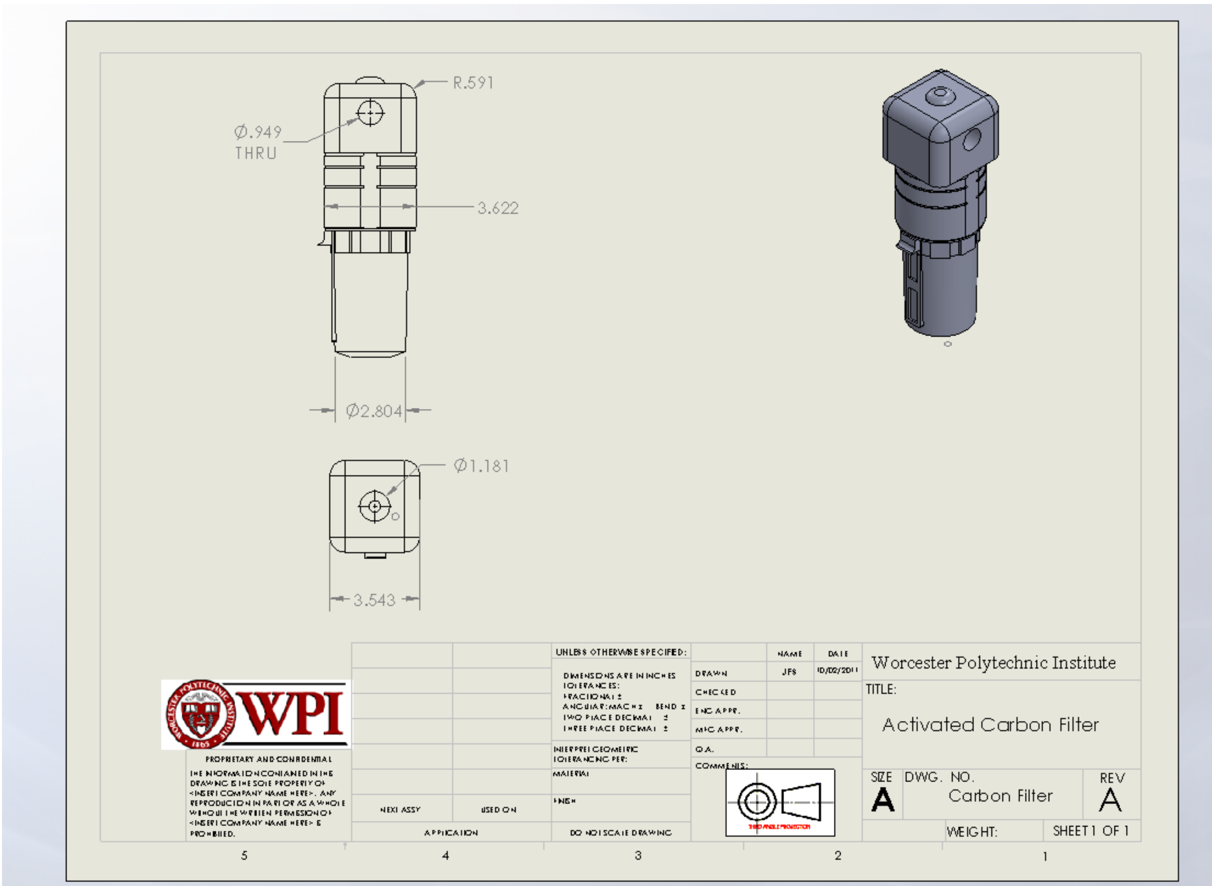

Figure 67: A-Sized Drawing of Activated Carbon Filter

In order to increase efficiency of the filter, the characteristics of activated carbon must be maximized and taken advantage of. When the molecular weight of carbon increases, the adsorption capabilities would also increase. The pore structure of the carbon must be large enough to allow most contaminants to travel within. As a result, a mixture of low and high molecular weight molecules would be the most effective way of filtering any sized contaminants.

Another factor that must be taken into consideration is the pH level. The lower the pH level, the less soluble and higher chance of adsorption the organics will be. A common trend carbon filter manufacturers use is to increase the size of the carbon bed by twenty percent for every pH unit about the neutral. Also, if the contaminant concentration is greater, then there will be more capacity for adsorption. The contact time with the carbon must be increased, thus the design of the filter with 90 degree bends for water flow. Decreasing the flow rate for this part of the reverse osmosis process will also improve contact time. The extra seconds sacrificed will prove to be effective in order to produce cleaner water.

Other Designs:

The many other 3D concepts initialized throughout the project were designed specifically to ensure the validity of the project. The pumps and motors were all designed specifically to meet requirements for the pipe diameter and power requirements all of which are responsible for achieving the necessary production which makes reverse-osmosis an integral part of all future investments in the water industry. 3D objects not explained in detail include: the pipes, the pump, and storage tanks.

The 3D objects are not explained in such avid detail as the three previous objects due to the necessity that the remainder of the parts of the design were as adaptable as possible to achieve the team's goal of designing a product which could be scaled to fit the need of any situation and any water demand. Pipes are exchangeable for hoses, pumps simply need to have their inlet and outlet diameters varied, and the motors need increased size in order to successfully meet the teams goal of designing a scalable, affordable system which could be brought to a disaster area in any country, in the most remote area, and still be easily operated by a group of volunteer workers.

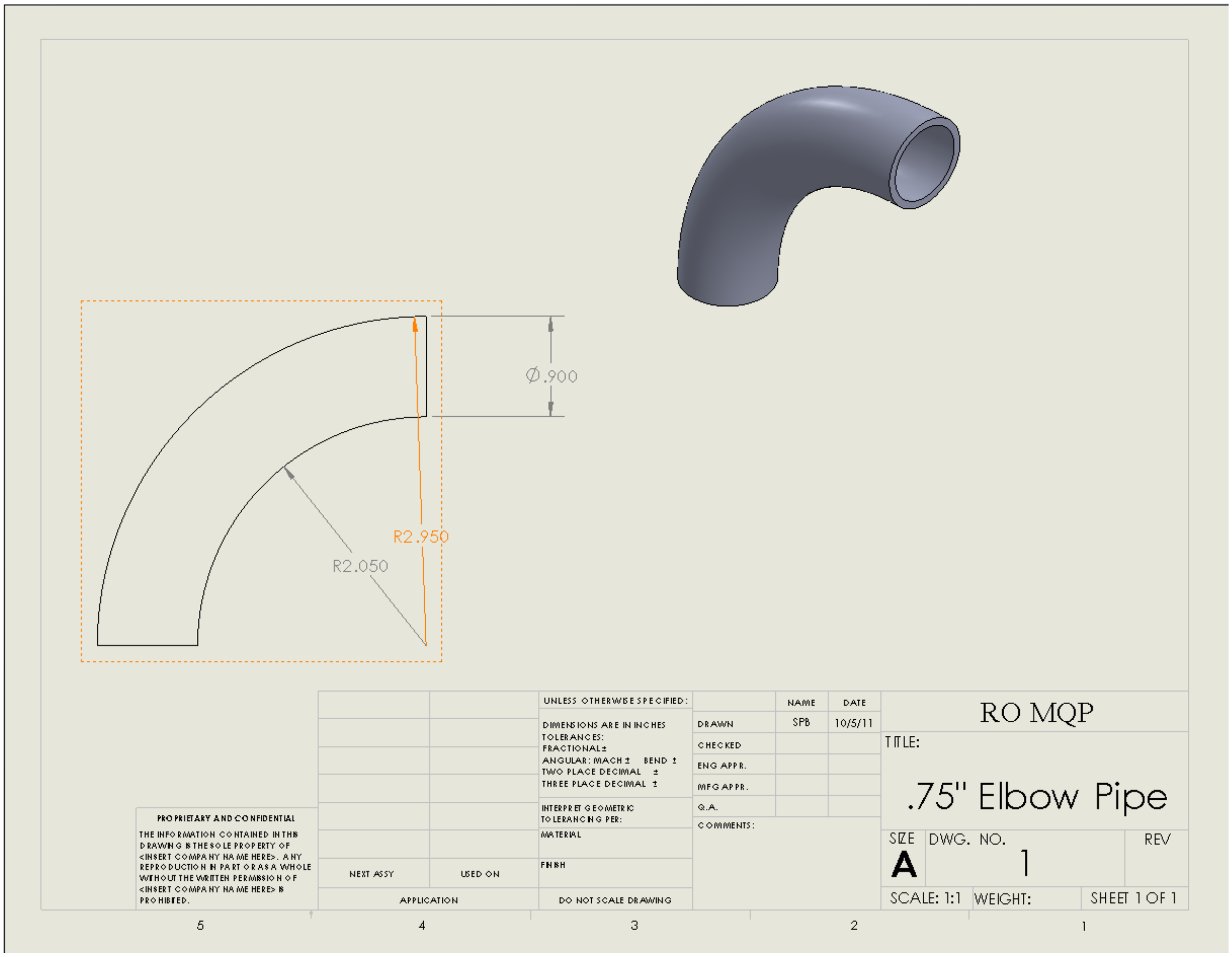

Figure 68: .75" Elbow Pipe

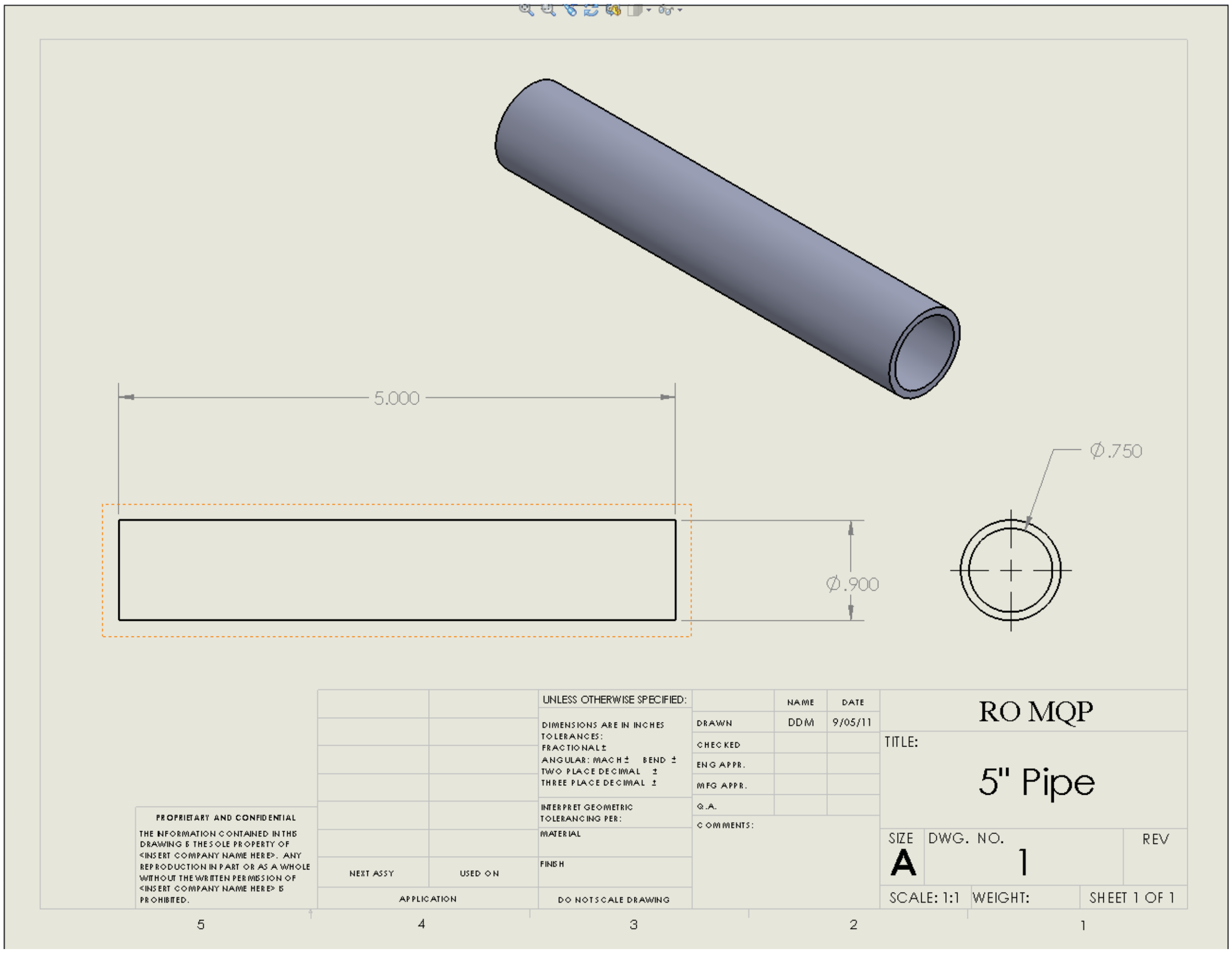

Figure 69: 5" Pipe Section

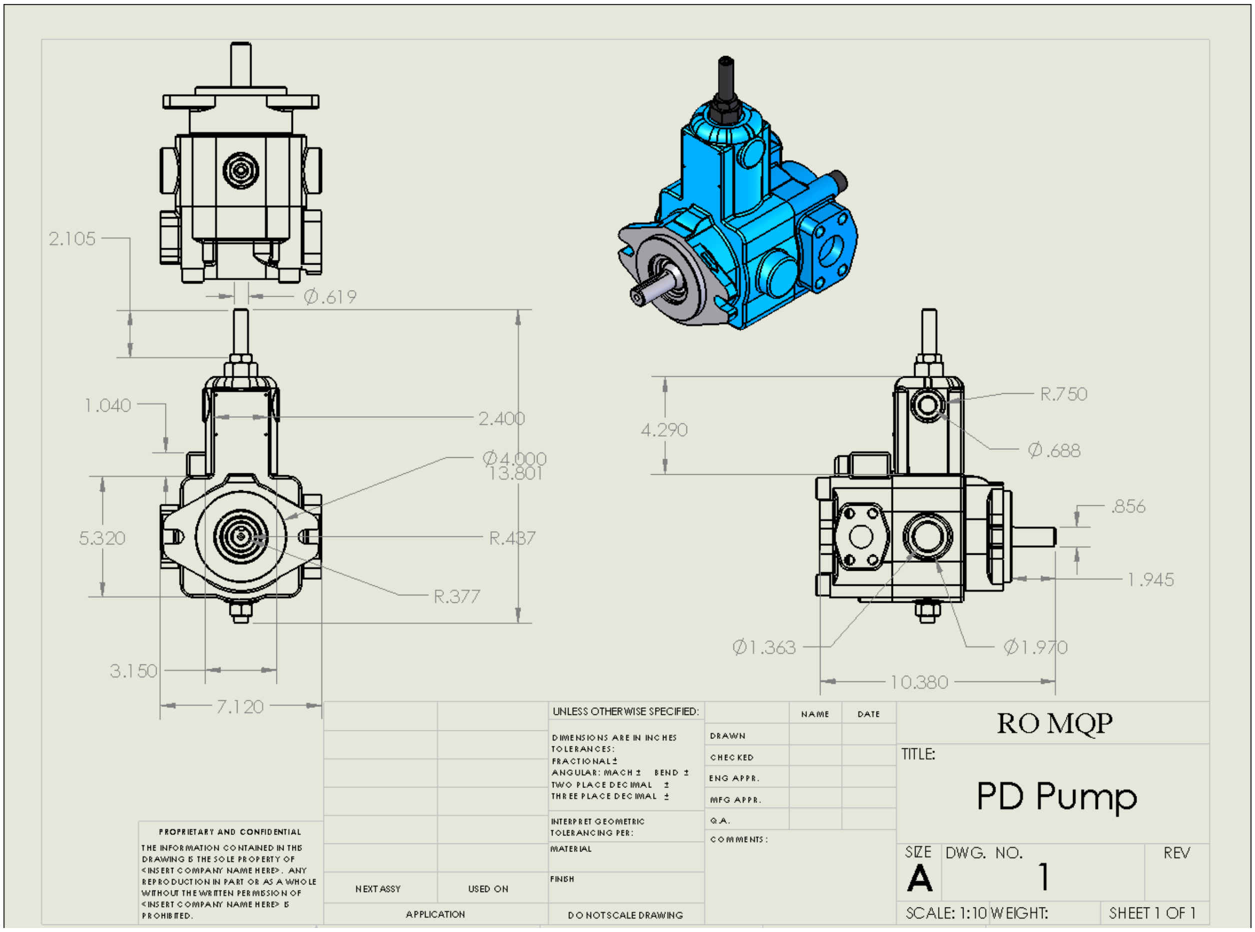

Figure 70: PD Pump

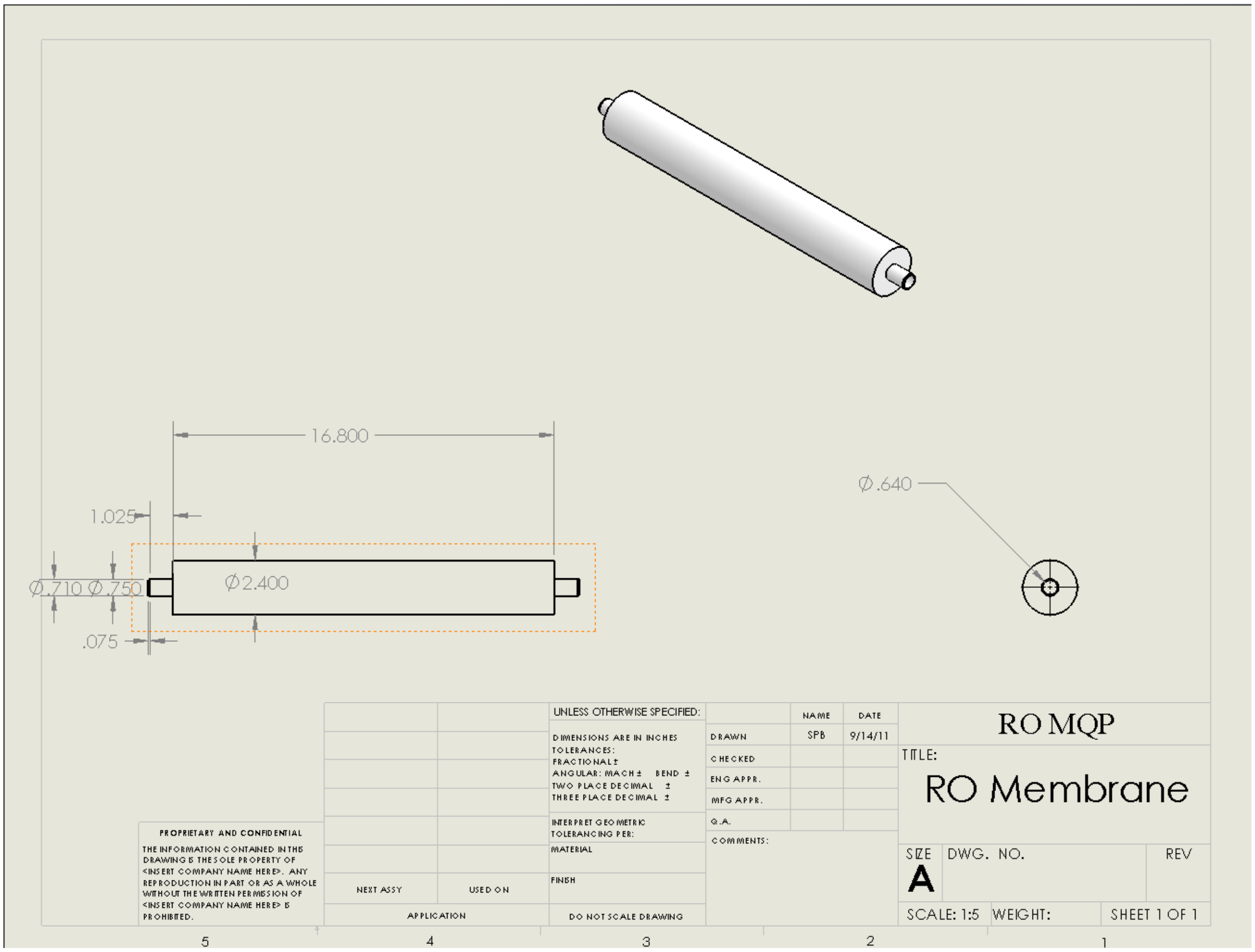

Figure 71: RO Membrane

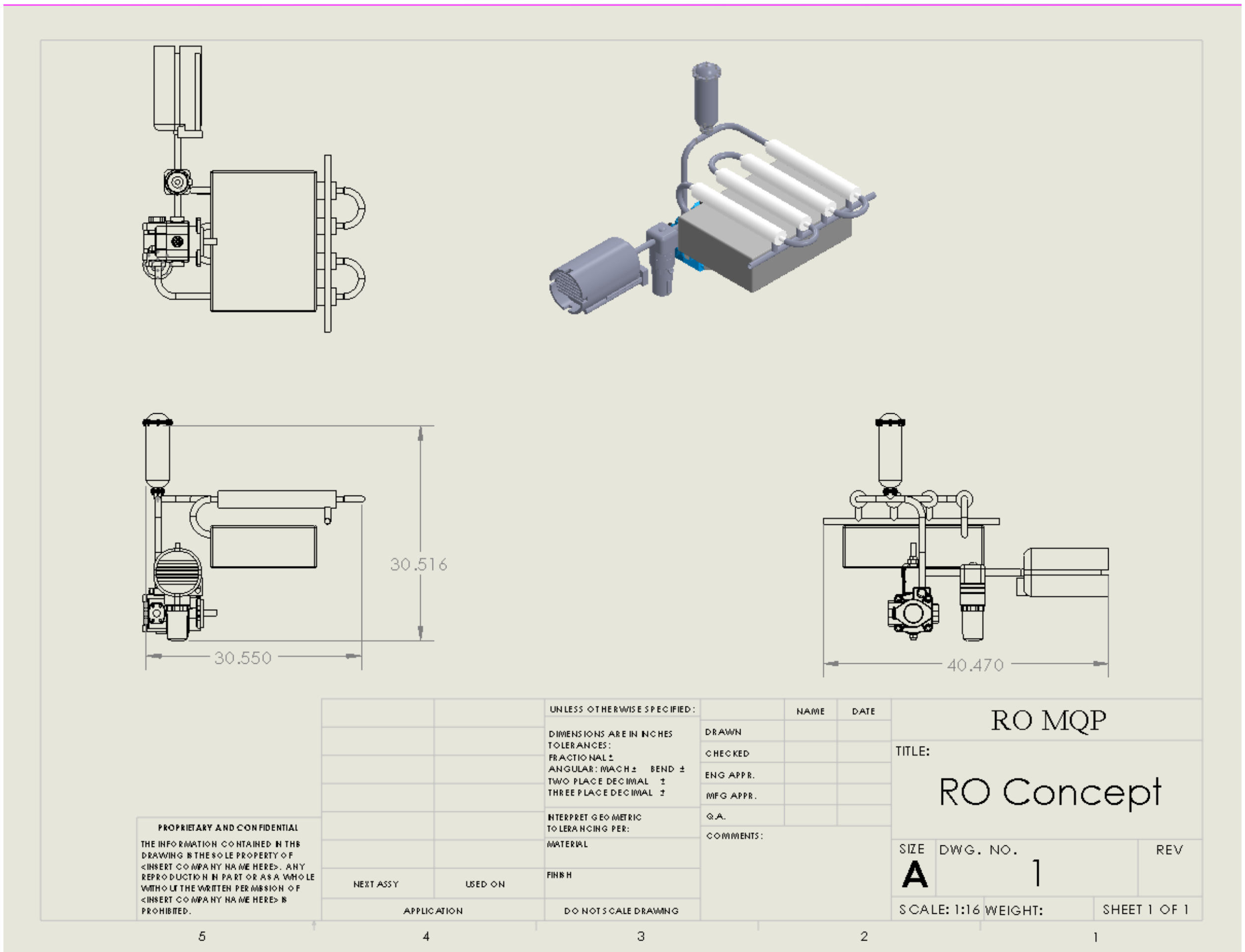

Figure 72: RO Concept Assembly

The Final RO Concept Assembly shows a conceptual drawing in which the size has been limited to 2.5’ x 2.5’ x 3.33’ which was the target size for the concept.