Lab-Scale Zero Exchange Shrimp Aquaculture

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Abstract

Shrimp aquaculture is a global market that tends to negatively impact the environment due to excess nitrogen rich waste. The School of Natural Resources in coordination with the Department of Environmental Engineering at the University of Michigan are in need of over ten separate closed loop zero-exchange shrimp aquaculture systems to research survival and growth potential for dense shrimp populations. The focus is on biofilters, feed, and various environmental conditions. At the completion of the project there should be two customizable experimental lab setups prepared for the University of Michigan researchers to effectively conduct experiments.

Executive Summary

Faculty at the University of Michigan have started a project that involves building a re-circulating shrimp aquaculture experimental set-up with the purpose of testing system parameters and examining bio-organisms. The shrimp tanks must be self-sustaining while keeping the shrimp in optimal health. Feeding shrimp and balancing levels of salinity, oxygen, ammonia, and nitrogen is a necessity. Properties unique to our set-up include a backwash mechanism and a system monitoring device. Another challenge includes designing a flexible plumbing system.

After deliberation over different concept designs, as well as addressing a new customer request for two biofilter containers, an alpha design for the aquaculture system was developed. This system will use clear piping with ball valves and a dual backwash system utilizing air and water flow. The data acquisition system will continuously monitor individual systems and will constantly send email updates and alerts to users. This design was chosen because it addresses mobility, flexibility, monitoring, and self-cleaning. A CAD model of the design concept is shown in Fig. 17.

A prototype of the set-up has been completed and validation tests for the system are finished. The purpose of this report is to document the background, development, and analysis of the design. A number of recommendations are also included at the end of this report.

Introduction

Waste water released from shrimp farms can often devastate wildlife from the excess nutrient content (Sierra-Beltran et al. 2008). Zero exchange systems have been developed to eliminate the negative environmental impact of shrimp farms. Zero-exchange shrimp aquacultures need further understanding in terms of optimal feeding processes and most effective biofilters. The University of Michigan's School of Natural Resources and Department of Environmental Engineering is conducting research in this area, and multiple test beds are needed to conduct experiments.

A customizable lab design setup is needed for the experiments to be completed by University of Michigan lab researchers led by Professor Lutgarde Raskin, and Professor Jim Diana. Currently there exist multiple tubs that had previously been set up in an open loop interconnected aquaculture system for experimentation on fish. An entirely new lab setup has been requested that allows for over ten different closed loop zero-exchange aquaculture systems. The new systems need to be designed for optimum customizability to cover a range of different experimental setups. Automation of some of the systems and measurements is key so that some of the data can be recorded frequently and consistently so that the aquaculture system is properly maintained in the absence of the lab researchers. The features that were stressed by the current lab researchers were backwash, an automatic feeding system and a swappable filter system.

Project Requirements and Engineering Specifications

The objective for our design project is somewhat different from the norm in that there is no final consumer, but rather the end user in our case is the lab researchers. As a result the engineering specifications align very closely with the customer needs. It is our intention to make the equipment and use of the lab setup as user friendly as possible while allowing for optimal customization and flexibility.

Discussion with the sponsors and literature review led us to a list of specifications that meet the needs of the lab researchers. In Table 1 below, there is a list of the customer needs that have a number associated with them. This number is not representative of the importance of the customer need but is instead a designation for each need.

Customer Need	Numerical Designation
Shrimp Survival	1
Ease of Use	2
Experimental Customizability/Flexibility	3
Time Saving	4
Reliability	5
Safety	6
Closed Loop	7
Maintainability	8
Dual Backwash	9

Table 1: Areas of Customer Needs and Designations

Subsequently in Table 2, there are three separate categories for the specifications. There are customer specifications, primary specifications, and secondary specifications. The customer specifications were requests for certain system components that the sponsors voiced as critical. The primary objectives and specifications were experimental setup characteristics that our group deemed as critical for the survival of shrimp. Finally, our secondary specifications were chosen through research and were seen as additions that would improve the experimental setup. Relative importance within each category can be seen as insignificant. Each specification has a number(s) associated with it that indicates the numerical designation of the customer need it fulfills from Table 1.

Customer Specifications	Values	Description
Automated Feeding System(1,2,3,4,5)	> 0.45 kg Capacity	Multiple feedings/day. Necessary for experimental consistency
Biofilter Container (2,3,7)	0.041 m^3	Rubbermaid rectangular container for easy bulkhead installation
Air Pressure during Backwash (2,7,8,9)	2 atm	Necessary for proper biofilter agitation during backflow
Sampling Points (2,9)	4 locations	4 ball valves to sample and release water entering and exiting biofilter
Primary Specifications	Values	Description
Water Temperature(1)	23°C to 34°C	Consistent warm temperatures are necessary for shrimp survival
pH level (1,2,4,5)	6.5 to 8.0 pH	pH range for optimal shrimp growth
Salinity Concentration (1,2,3,4,5)	31g/L to 38g/L	Salinity tolerance range for shrimp survival
Dissolved Oxygen Concentration(1,5)	4mg/L to 9mg/L	Dissolved oxygen is necessary for shrimp survival
Water depth (1,5,6)	27 cm	Water depth determines temperature uniformity
Water Flow Rate(3,5,6)	162.6 gph	Flow rate necessary to remove TAN
Secondary Specification	Values	Description
Adjustable Rack(3,4)	30”x18”	Tank sized rack allows for component placement flexibility

Table 2: Categorization of Design Specifications (*Numbers following each specification correspond to fulfilled customer needs)

Information Sources

In order to create effective concept designs with original ideas, it was imperative to explore literature involving aquacultures. Also given the nature of our project, it was essential to find documents that show calculations of specifications such as water flow and biofilter size.

Shrimp aquacultures involve the growing of varying densities of shrimp within a confined area. A major problem with shrimp farming is the buildup of toxic concentration of nitrogen. Most farmers exchange the nitrogen filled water, in the process dumping the nutrient rich water into the wild. This causes large algal blooms to occur, devastating the local wildlife. Zero-exchange re-circulating shrimp aquacultures combat this by filtering nitrogen rich water instead of dumping it ("Saltwater Shrimp" 2008).

The shrimp re-circulating system is not entirely a closed loop system. Various nutrients go into the system, and water is leaving the system. To model the Zero-Exchange system, a control volume containing everything inside the shrimp container was used. Nutrients such as oxygen, light, and feed enter the control volume, and water in evaporation loss leaves. A diagram indicating the addition of nutrients is located in Appendix A.

Documentation of basic shrimp aquacultures is readily available and provided quantitative information concerning the parameters that affect shrimp growth and survival that will be needed when designing an aquaculture system. Salinity in most experiments was typically between 31g/L to 38g/L. Water temperatures for shrimp growing experiments ranged from 23ºC to 34ºC. Dissolved oxygen levels ranged from 4mg/L to 9mg/L. Dissolved oxygen levels lower than 2mg/L will stress and potentially kill shrimp. The acidity, or pH level, of the water tanks in the experiments ranged from 6.5 to 8.0 (Wasielesky Jr. et al. 2006; Timmons et al. 2002).

An important parameter of aquacultures is the concentration of ammonia and nitrogen in the system. This is commonly referred to as the total ammonia nitrogen or TAN. TAN is directly affected by the organism excretion and the amount of protein in the feed. As organisms consume feed, they release ammonia into the water and this raises the concentration of TAN. In an aquaculture system, the TAN level can be controlled by flowing water over bacteria growing on biofilters. These bacteria perform nitrification which is the oxidation of ammonia with oxygen into nitrite followed by the oxidation of these nitrites into nitrates. These nitrates are passive to the system and can actually be consumed by detritus feeders such as shrimp. The effectiveness and speed of nitrification is dependent on the biofilter design (Timmons et al., 2002).

Research into biofilter design was essential in engineering an effective closed loop aquaculture system. There is a codependency between biofilter efficiency, water flow rates, and ammonia production from feed that make the system difficult to optimize. The desired concentration level of TAN in a system is directly related to the tank volume and the amount of food consumed. To stay at or below the critical level of TAN, ammonia needs to be removed through the nitrification process that occurs from the bacteria on the biofilters. The shape, size, and material of the biofilters affect how well the bacteria work and this governs the optimal water flow rate for the system. The water flow must be slow enough to allow for the bacteria to work, but it must also be fast enough to recycle the water between the biofilter and the tank (Smith, Matt 2008). In this design project, it is also important to be able to accommodate as many types of biofilter media as possible. Different biofilter media feature considerably different surface area, ranging between 100 m^2/m^3 and 400 m^2/m^3, while also featuring different shapes (“Product Description” 2008). Due to the complications determining water flow and biofilter sizing, a computer spreadsheet was used and is shown later in engineering analysis (Losordo, Hobbs 2000).

Substantial research for re-circulating aquacultures with backwash was necessary to explore different techniques for backwashing. Backwashing is a method used to clean filter media without physically removing them from the biofilter container. This is usually accomplished through some form of agitation. In most backwashing systems, generally in water cleansing sand filters, external water is mixed with air and flushed using a flow rate of around 15 gallons per minute through the biofilters creating agitation that knocks off any attached biomass (Satterfield, Zach 2005).   This is important because excessive bio-mass can affect how well a bio-filter works and being able to test bio-filter productivity is one of our customer requirements. Certain flows for backwash require up to six times the flow rate of regular filtering (Satterfield, Zach 2005). This type of system is most effective when the input of the backwash is located at the bottom of the biofilter container to allow the air and water to rise through the filter media. The effectiveness of this particular method has a high dependence on water and air flow rates, which will be discussed later.

Another method explored for the backwashing system is to spin the water. We looked into canisters connected to a motor that would work similarly to putting water into a blender. The spinning motion of the canister would force the filter media to mix and collide causing enough agitation to clean the media. Also, small micro-bubbles are created from the spinning motion which also assists with cleaning. The biggest drawback with this method is that biofilters used in this system have to be floating, loose, and submerged. This is currently utilized in systems with bead filters and is commercially available with a company called Aquaculture Systems Technologies (“Bead Filter R&D” 2008). Currently, we are still exploring other methods to spin the water, particularly with propellers and mixers.

A more recent exploration of backwashing involved the use of ultrasonic waves. Ultrasonic cleaners already exist commercially and are typically used to clean and separate particulate matter from dentures, sewage pipes, and jewelry. So far, most of the products available are large and would be difficult to implement in our system, but we have started to see ultrasonic probes that could be used to cause enough agitation to clean the biofilters ("About Ultrasonic Cleaners and Cleaning Systems"). We know these vibrators can work, but one issue that could come up is that they might work too well. Ultrasonic waves would probably knock off bacteria from the biofilters, which in turn affect the filter effectiveness. Typical bio-filters take about ten days from start up to grow enough bacteria to properly clean a tank. If knocked off by ultrasonic vibrations, the bacteria will still be in the water when separated from the filters, but we do not know how it would affect the experiments. Literature in this area is still being explored.

Concept Generation

The concept generation stage of our project began with individual brainstorming. After brainstorming individually we met and discussed each other’s potential designs and the positive and negative aspects of each design. These meetings began with a broad perspective on how to accomplish the water circulation and the components desired to accomplish each of the needs specified by our sponsor. Some of the preliminary designs drawn up during this phase can be found as hand written sketches in Appendix B. The designs ranged from methods that stacked platforms to maximize the amount of shrimp that can be cultivated in a tank, to methods that used automated rack adjustment systems that utilized magnetic racks for positioning sensors. We tried not to limit the scope and range of our ideas but let them flow freely in earlier stages.

We found out more particulars about the components that were essential for any aquarium systems. The main components that are necessary for our project are the pump, the plumbing system, a feeder, sensor and data acquisition components, a biofilter, and an adjustable rack. We completed a functional decomposition of all the different components to determine equipment that was readily available, and components that would require construction. Equipment for the feeding system, sensor and data acquisition, piping, and the biofilter tank can all be found from off the shelf components, and are discussed in detail in the Appendix C.

After meeting productively with our sponsors and finding out what components could be store bought, it was determined that most of our design focus could be broken down into three different categories: plumbing system, backwash improvement methods, and data acquisition design. For each of these categories we brainstormed a number of concepts that fulfilled our required specifications.

Plumbing System

The first category that we approached was the plumbing system. Visits to different aquarium stores led to very unique and different concepts.

1. In the Canister Pump design, a simple pipe would bring the water through a canister filter before being pumped back into the shrimp tank (See Fig. 1). The filter media would be contained inside a cage, which would be taken out for backwashing. During backwashing, the cage containing the filters would be taken out, and flipped upside down. The pump in the canister filter would then pump a stream of water, which would be sprayed on the filter media.

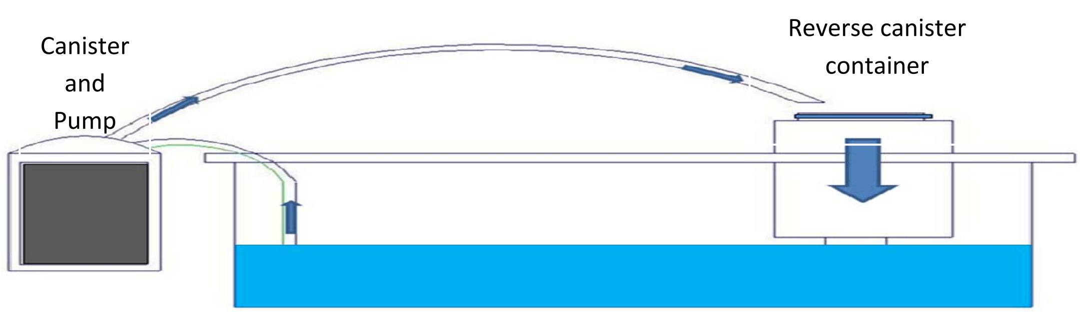


Figure 1: Canister Pump Design

2. A second design, the reverse dam, eliminates the need for piping to pump water through the filter (see Fig. 2). A pump, connected directly to a separate compartment, would pump water in. As the water filled the separate compartment, the water would be forced through the filters, and eventually go back into the shrimp tank. Valves could be placed in the appropriate area for sampling.

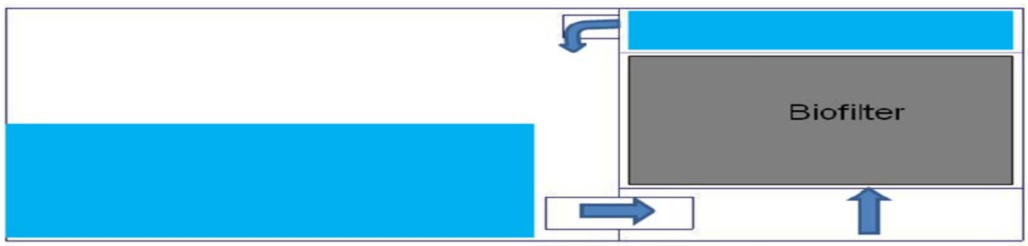


Figure 2: Reverse Dam

3. The last major layout for a piping system would involve the use of valves to re-route the water flow when a backwash was needed (See Fig.3). This layout uses the power of the water flow to backwash the filters.

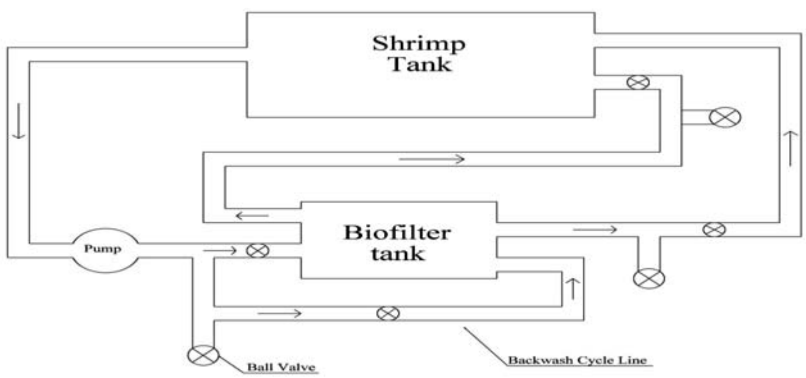


Figure 3: Reversible Flow Plumbing System

Backwash Improvement Methods

The backwash concepts involve using ultrasonic vibrations, mixing propellers, and just a powerful stream of water and air to clean out the biofilters during backwashing.

1. Ultrasonic cleansers use high frequency vibrations to stimulate dirt particles to fall off from their substrate. In our case, the ultrasonic cleansers would be turned on only when a backwash was necessary as seen in Fig. 4. The vibrations would then knock off the unwanted biomass from the biofilters. Finally, a directional water flow through the biofilters would drain the suspended biomass from the biofilter container ("About Ultrasonic Cleaners and Cleaning Systems").

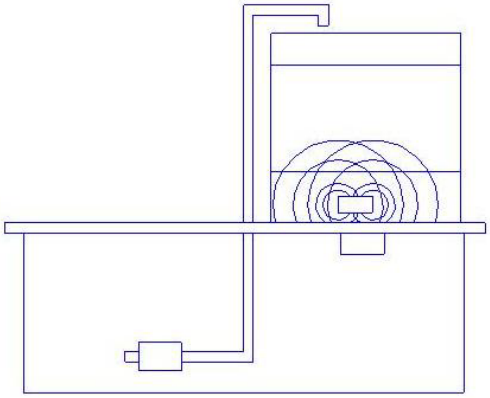


Figure 4: Ultrasonic Backwash creates vibrations to free biomass from biofilters

2. Lab mixers and agitators are commercially available for mixing chemicals. However, mixers work by stirring the liquid in a rapid fashion, and so they may be applied to backwashing the biofilters as shown in Fig. 5. Mixers in the biofilter container would be turned on during backwashing, to churn the water. This churning would knock off biomass from the filters into the water. A directional water flow would then rid the biofilter container of the suspended biomass particles.

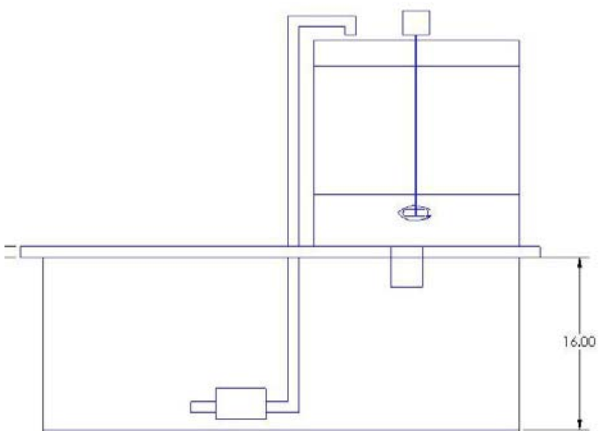


Figure 5: Mixer Backwash creates motion that agitates water in biofilter container

3. Alternatively, in our primary candidate, switching some valves would reverse the flow direction of the water. The flow rate of the pump would be increased by opening a ball valve. Additionally air bubbles would be added into the biofilter container to help knock off biomass particles. This schematic is depicted in Fig. 6 below.

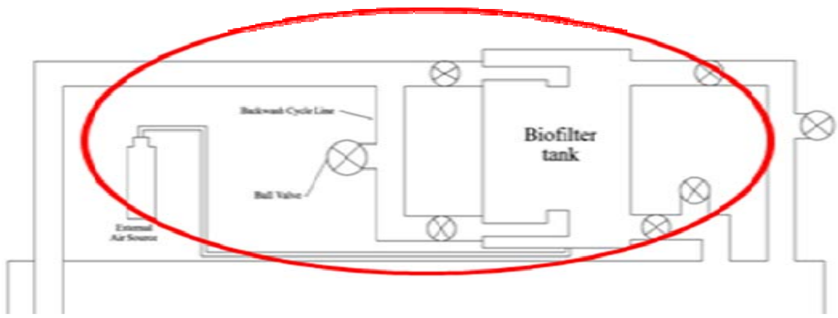


Figure 6: Reversible variable flow pump using backwash with air bubbling

Revised Plumbing System Concepts

After our initial brainstorming phase some critical changes were presented to us by our sponsors that had the greatest impact upon the plumbing concepts. A dual backwash system was requested so that each biofilter could be backwashed separately. There were two separate concepts proposed as a solution to this problem. There was a cascading system composed mostly of valves, and a unique system that involved physically moving filters but simplified the dual backwash cycles.

1. Cascading Dual Backwash Plumbing System-The normal flow operation occurs just as usual except there is a plumbing pipe connecting a top biofilter container to a bottom biofilter container. These containers are offset from one another to allow for easy removal of the biofilters. During backwash the ball valve in the pipe connection between the two containers can be shut off and the flow reversed where each container can be backwashed separately and the water leaves through a hole and pipe connection at the top of each container (See Fig. 7).

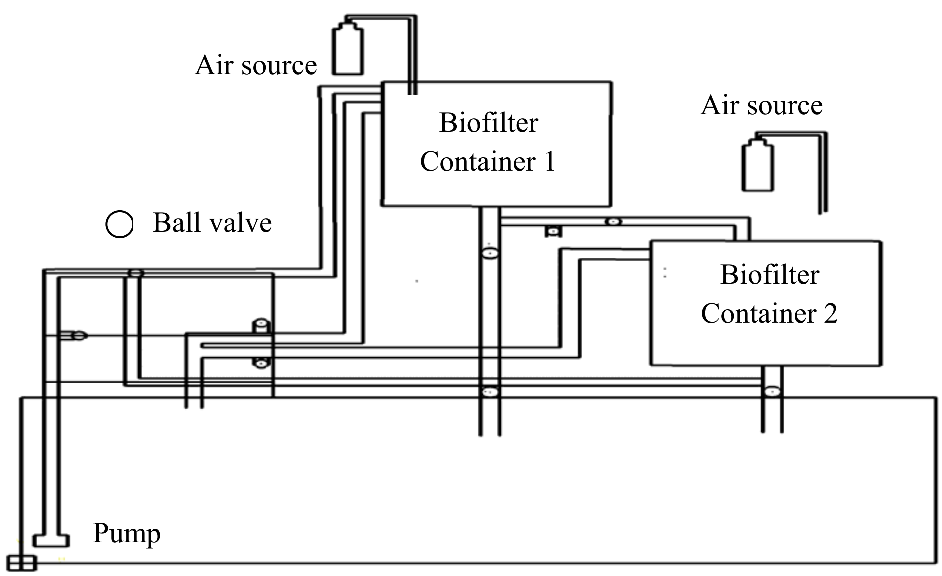


Figure 7: Valve dual back wash system

2. Basket Dual Backwash Plumbing System- There are two biofilter containers located at the same elevation and adjacent to one another. The containers consist of cages that hold the biofilters and can be easily removed. Only one biofilter container is used for normal flow and the two biofilter cages can be stacked on top of each other. During backwash, one cage is removed from the container and placed in the adjacent container. Backwash can then be carried out in the same manner as the cascading dual backwash plumbing system (See Fig. 8).

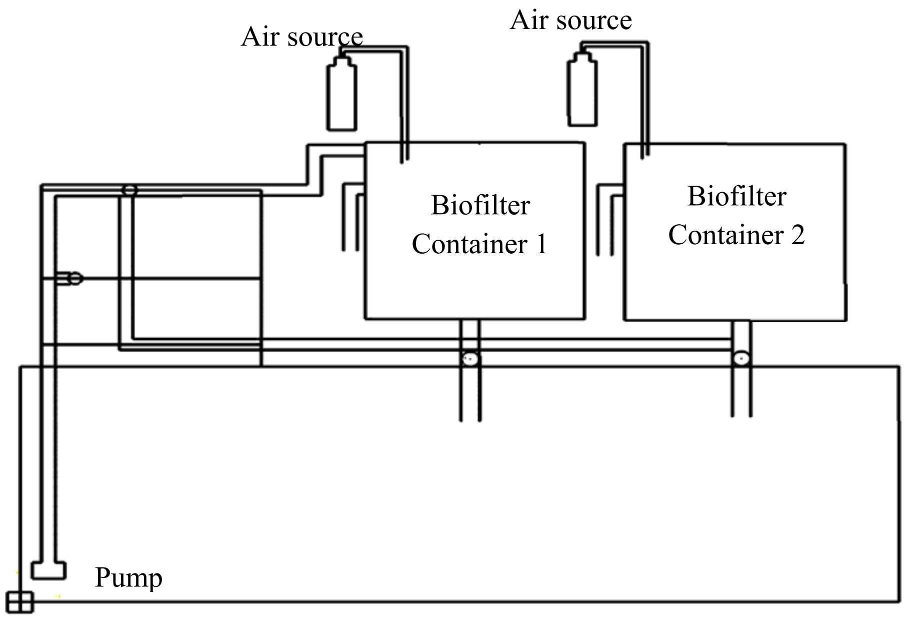


Figure 8: Dual Basket Backwash System

Data Acquisition Concepts

For the data acquisition system, the three concepts are a sampling pool with data loggers, a computer-based remote monitoring system using Remote Desktop, and a computer-based remote monitoring system using email notification through LabVIEW.

1. For the sampling pool with data logger, we used a sampling pool and then measured the water quality parameters using the sensors and data loggers. The sampling pool has tubes and a valve connected to each tank, and is equipped with one set of sensors for water quality measurements. If we wanted to measure the water quality parameters of a certain tank, we can open the corresponding valve so that the water inside that tank will flow into the sampling pool and then measured by the sensors. The sensors are connected to data loggers to record and display the measurements.

2. For the computer-based remote monitoring system using Remote desktop, the idea is to install one set of water quality sensors in each tank, and connect all the sensors to a data acquisition device, and then transfer the measurements to a computer. The measurements will be monitored and recorded by a computer code written in LabVIEW. If we want to know the values of the water quality parameters, we can find a computer with internet

access and use the Remote Desktop function provided by Microsoft to log into the lab computer used for data acquisition, and read the measurements from the LabVIEW code.

3. The computer-based remote monitoring system using email notification of LabVIEW is similar to the previous concept. The only difference is that we plan to use the email notification function in LabVIEW instead of the Remote desktop for remote monitoring. In the LabVIEW code, we can set the upper and lower limits for the parameters, so that if some parameters go beyond the limit, the code will send an email to us, telling us which parameters are abnormal, so that we can take measures to bring the parameters back to the normal range. There will also be daily status reports sent out to the researchers so they can monitor the conditions of the system while it is operating within acceptable ranges.

Schematics for concepts 1, 2, and 3 of the data acquisition setups can be found in Appendix D Fig. D3.

Concept Selection Process

Plumbing System

After the visits to the aquarium stores and a meeting with our sponsors we were able to modify our initial plumbing designs and narrowed our designs down to the two choices seen in Fig. 1, and Fig. 3. The schematic shown in Fig. 1 includes a canister component permanently connected to a pump that would allow for the installation of biofilters into the plumbing system in an extremely compact device. Some immediate concerns with this system were the limitations in flexibility. For example, the canister is a set size and if a larger size container were needed, this system would be rendered useless. Additionally, rigid PVC is not an option with this system but rather clear plastic tubing must be used. If components break in this system it is all dependent on a particular product. If this product at some point comes off the shelves in stores there is no alternative. Additionally backwashing with this system is highly constrained. A summary of factors leading to our final decision can be found in Table 3.

Concept Designs	**Specifications Met**	**Critical Sponsor Needs Met**	**Eliminating Factors**
1. Canister Filter	-4 sampling points	-Ease of Use -Maintainability -Backwash	-0.3m^3 biofilter container not feasible -Max flow rate under 325 gph -Lack of flexibility
2. Reverse Dam	-2 sampling points	-Reliability -Maintainability	-No Backwash capability
3. Reversible Flow	-Any size biofilter -4 sampling points	-Maintainability -Backwash	-Many components

Table 3: Characteristics of main concept designs for plumbing system

Ultimately the design chosen allows for maximum customization options, fulfills all the sponsors' requests and allows for the installation of many alternative systems in case of failure. The concept that best fit these criteria was the Reversible Flow pictured in Fig. 9.

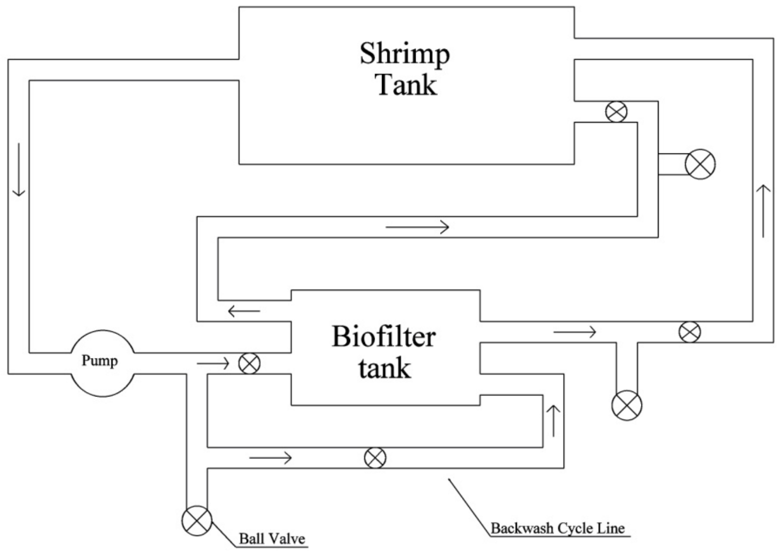


Figure 9: Second to last Iteration before Final Alpha Design

Backwash Improvement Methods

The decision for which backwash improvement method was simple because in the Reverse Flow concept, air is readily available in the lab already and ultrasound or a mixer would be costly. Additionally, these components can be added later to the system for increased backwashing potential if reverse flow and air are not sufficient. For a more detailed breakdown of the analysis reference Appendix D, Table D2.

Revised Plumbing System for Dual Backwash

In essence, the plumbing system revision was a second wave of brainstorming spawned from additional requests received from our sponsor. There were two different modification choices to the chosen reversible flow concept chosen above. Both options met the dual backwash requirement but the basket dual backwash plumbing system reduced the number of valves, amount of piping material, and height of head from pump to biofilter container. For the cascading dual backwash design the tubing would have had to extend to a height of roughly 6 ft. above the pump. Additionally, building a stable filter container support that extends 2 ft. above the top of the shrimp tank capable of supporting 10 gallons of water would have been challenging and more costly. See Appendix D, Table D3 for greater detail in analysis.

Data Acquisition System

The decision for the data acquisition system came down to convenience for the user and providing a desired level of information to the researchers. Table 4 below summarizes the factors leading to the final decision of using the email alert data acquisition system.

Concept Designs	**Specifications Met**	**Critical Sponsor Needs Met**	**Eliminating Factors**
1. Sampling pool with data logger	All sensor specs.	-Cost effective -Only one set of sensors needed -No need for programming -No need for computer -Simple setup	-Alignment of tubing and valves can be problematic. -No continuous measurement -Manual measurement and presence in lab required -High time cost and labor cost
2. Computer-based remote monitoring system using Remote desktop	All sensor specs	- Great convenience for parameter monitoring -No need for going to the lab regularly	-Frequently logging in and off is problematic when the code is running -Though no need to go to the lab, still need to check regularly to make sure that the water quality does not deteriorate.
3. Computer-based remote monitoring system using email notification from LabVIEW	All sensor specs	-Most responsive alert for abnormal parameters -No need for regular checking.	-Complexity in programming and testing.

Table 4: Characteristics of main concept designs for data acquisition system

Selected Concept Description

The final design for the aquaculture system is composed of a mix of the different ideas generated during the concept generation phase, and improvements made to these ideas through an iterative concept selection process. The main components to the design are the plumbing/backwash system, sensor system, and biofilter design.

Plumbing System Design

Rather than the pump being gravity fed and being positioned below the level of the tank, it was decided that it be best if the pump be fully submersed in the water eliminating the need to drill a hole in the side of the tank and having to deal with additional bulkheads with sealants. Water is pumped up a 4 ft. head and can be delivered to either the normal flow entrance to the biofilter container or the backwash entrance. Two Rubbermaid© containers made from high density poly ethylene with volumes of .041 m^3 that allow for easy access to the biofilters were chosen. The biofilter placement is above the shrimp tank because if the pump is shut off all the water will drain from the plumbing system. The routing of the water can be determined by ball valves placed in strategic locations. Before entering the biofilter tank there is a ball valve that can be used to obtain influent water samples. In the non-backwash cycle there is another ball valve open to the ambient to obtain effluent water samples.

For the back wash cycle the top basket containing biofilters must be removed and placed in the second biofilter container. Next, both the normal flow ball valves are to be closed and the backwash valves to be opened. The backwash valve should be opened to a greater extent to allow a greater potential water flow through for greater agitation. Both biofilter containers will fill at the same time. In addition to the water plumbing attachments to the biofilter there is a pressurized air plumbing tube that allows air to be turned on during the backwash phase. The air source can pump air through 5/8 in. I.D. tubing that can be placed in the biofilter containers from the top so the tube touches the bottom . Finally as the backwashed water leaves the biofilter containers there are final ball valves open to the ambient for the option of filtering the biomass purged from the biofilters. The design can be seen in Fig. 10 below.

One of the drawbacks of the proposed design is that even though the number of ball valves was reduced from alternative designs, it still has a complex valve system. In the current piping design there exist seven ball valves. This can lead to complications as to which valves need to be open during different processes (i.e. normal flow vs. backwash). To counter this issue the ball valves will be color coded according to process. Another drawback with this system is that with only one pump present there is no backup system if failure occurs.

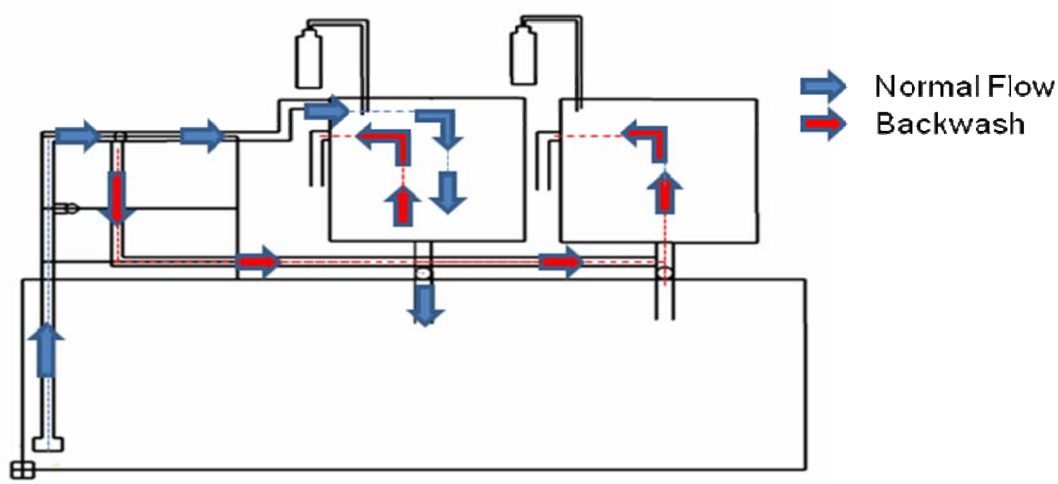


Figure 10: Current Aquaculture tank plumbing system

__Data Acquisition and Lab View Design__

We are planning to build a computer-based water quality monitoring system to consistently monitor and record the water quality parameters including the water temperature, pH value, ammonia level, dissolved oxygen level, and salinity in the tank so that we can effectively ensure that the water quality parameters are maintained at a certain level. In addition, it facilitates parameter analysis using the recorded data.

A schematic sketch of the data acquisition system setup is shown below in Fig. 11.

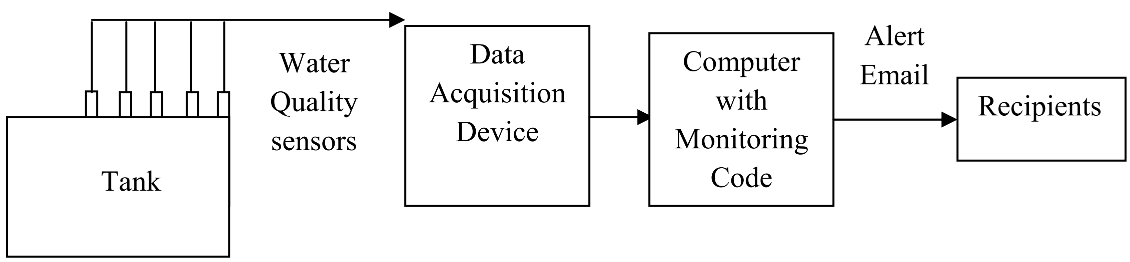


Figure 11: Schematic sketch of the data acquisition system setup

The diagram above shows the setup of one of the tanks. As shown in diagram, the water quality sensors are in the tank and are connected to the data acquisition device. The values measured by the sensors are transferred to the computer via the data acquisition device and then monitored and recorded by a code written in LabVIEW. Once any parameter goes beyond the limit, the LabVIEW code will send an alert email automatically to the recipients designated in the code, telling them which parameter is going out of the range, so that the recipients can take measures to make the water quality under control or to conduct the backwash at first time. The specs of the sensors and data acquisition device are listed in Appendix B. A sample LabVIEW code interface was shown below in Fig.12

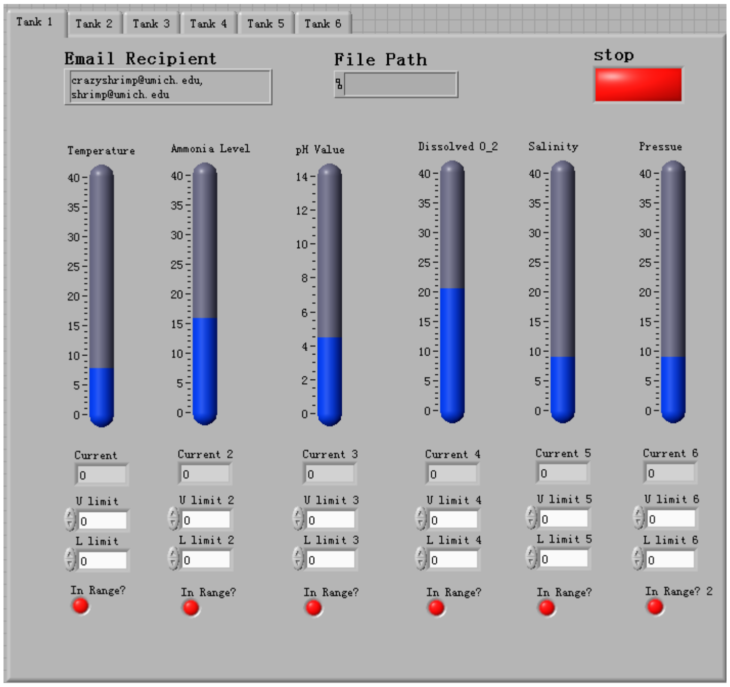


Figure 12: Interface of LabVIEW monitoring code

Engineering Design Parameter Analysis

Delving into concept design, the major engineering challenges involved sizing the biofilter, optimizing water flow, ensuring effective backwashing, selecting flexible plumbing, determining pressures, velocities, and piping diameters and simplifying data acquisition. Additionally stress analysis had to be completed for the support frame built to hold the biofilter containers.

Amount of Feed

The amount of food required for one test bed is obviously dependent on the number of shrimp in the system. Typically shrimp are fed 3% to 15% of their body mass a day ("Saltwater Shrimp."). The requested maximum mass density of the shrimp is 20 kg/m^3. If we set the water volume for the shrimp tank to 0.15 m^3, the total biomass for our system will be about 3 kg. The set water volume was chosen to be less than the container volume of 0.23 m^3 to account for a lower water depth. Using the projected biomass of 3 kg and assuming that the shrimp are fed 15% of their body mass a day, the shrimp will require at max capacity 0.45 kg of food a day (Losordo, Thomas 2000). To address this amount of food, it will be necessary to use automatic pond feeders with a large enough capacity of about 0.5kg to ensure that the shrimp can be fed for a week without refilling the feeder.

Biofilter and Water Flow

The bio-filter container must be large enough and the water flow fast enough to ensure that the total ammonia nitrogen (*TAN*) concentration levels are below 1 mg/L. TAN concentration levels are directly related to the protein content of the feed, the amount of feed, the bio-filter efficiency, and the water flow. Assuming that the food is 50% protein, the feeding rate is 0.45 kg/day, and the amount of TAN generated is about 9.2% of the protein consumed, then the total amount of TAN generated is about 0.03 kg/day. Assuming that the bio-filters work at 50% capacity, the .15 m^3 system would then require a flow rate of about 10 Liters per minute in order to stay below the desired level of 1 mg/L TAN. At this flow rate and at a nitrification rate of 0.45 g/TAN/m^2/day, the bio filter container will require at most .12 m^3 of volume space for bio-filter media. The lowest considered surface area for bio-filter media is a very conservative 100 m^2/m^3 (Losordo, Thomas 2000).

A computer spreadsheet was used to determine the specifics of the biofilters and water flow (Losordo, Hobbs 2000). The required inputs are listed below and the current values for our system are shown in parenthesis. The required inputs include tank volume (.15 m^2), desired biomass (max 20 kg/m^3), mass of food (15% of biomass), food protein percentage (50%), desired TAN (1 mg/L), estimated nitrification rate (0.45 TAN/m^2/day), and bio-filter media surface area (100 m^2/m^3). An example of this spreadsheet can be seen below in Table 5.

Tank Size and Biomass	**Values**	**Units**	**Calculation Formula**
Tank length	1.12	m	=44*0.0254
Tank width	0.51	m	=20*0.0254
Tank depth	0.41	m	=16*0.0254
Tank volume	0.23	m³	=B2*B3*B4
Tank water volume	0.15	m³	=40/264.172
Tank water depth	0.27	m	=B6/(B2*B3)
Maximum culture density	20	kg/m³	50
Shrimp biomass	3.03	kg	=F6*F8
Shrimp count	100		100
Shrimp weight	30.28	gm	=1000*B9/B10
Feed rate as % of body weight	15.00	%	3
Feed rate	0.45	kg/day	=B9*B12/100
TAN Mass Balance			
Feed protein content	50	%	100
Total ammonia nitrogen (TAN) production rate	0.01476	kg/day	=(0.065*F13*F16/100)
Percent TAN from feed	3.25	%	=F16/F13*100
Desired TAN in recirculating water	1.8	mg/L	1.8
Passive nitrification	10	%	10
TAN available after passive nitrification	0.01329	kg/day	=F17*(1-F20/100)
Passive denitrification	0	%	0
Maximum nitrate concentration desired	150	mg/L	150
New water required to maintain nitrate concentration	88.6	L/day	=((F21*10^6*(1-F22/100))/F23)
TAN available to biofilter	0.01329	kg/day	=F21
Biofilter efficiency	50	%	50
Flow rate to remove TAN to desired concentration	14763	L/day	=F25/(F26/100*(F19/10^6)
	10.25	L/min	=F27/1440
	2.71	gpm	=F28/3.785
Biofilter Sizing			

Estimated nitrification rate	0.45	g TAN/m²/day	0.45
Active nitrification surface area required rate	29.5	m²	=F25/(F32/1000)
Surface area of media	100	m²/m³	100
Total volume media	0.295	m³	=F33/F34
Media depth	1	m	1
Filter surface area	0.295	m²	=F35/F36
Diameter of biofilter	0.613	m	=2*sqrt(F37/3.1416)

Table 5: Spreadsheet of water flow and bio-filter sizing estimation

The water flow was determined with the assumption that all water is recycled and that no water is added or removed from the system. A method to determine water flow is shown below (Van Wyk 2008).

First, determine the amount of TAN produced (P_{tan}).

$$\text{TAN Produced } (P_{tan}) = \frac{\text{kg feed/feeding} * (\text{\% of protein in feed}) * 0.092 * 10^{6}\ \text{mg/kg}}{\text{time between feedings}}$$

The number 0.092 is an assumption for the fraction of protein nitrogen that is excreted as TAN from shrimp feed. Next, to calculate the amount of flow rate (Q_f) required to keep the TAN concentration below a desired value (C_{TAN}).

$$Q_f = P_{Tan} / (C_{TAN} * \text{efficiency of Bio-filter})$$

For our system, we found that that a regular water flow of 10 L/min will be required.

Backwash

Backwashing is a challenge because it requires some form of bio-filter agitation, whether in the form of flowing water or vibrations. For our system, it is really difficult to predict the efficiency of backwashing because the effectiveness of cleaning the filters is dependent on the bio-filter media. In some filtration systems, the difference between regular flow and backwash flow ranged from a 1:1 ratio to a 1:6 ratio ("Flow & Backwash Chart for Various Filter Media."). Since our experiment is meant to test different types of bio-filters, each individual experiment will have a different optimization for backwashing. The best solution for our purposes is simply to provide enough flexibility with the flow rates and the flow directions that each possible type of bio-filter media is accommodated. This has to include media of different size, shape, and geometries. The packing density and the floatability of the media must also be considered. Using the water flow of 10 L/min and taking choosing a conservative ratio of 1:6, we will require a pump that can go at a max speed of 60 L/min or about 15 gal/min.

Data Acquisition

The data acquisition system works as a feed-back control system. The difference between our system and typical feedback control system is that instead of having a controller and actuator, we have manual water treatments that act as the actuating mechanism. A block diagram describing the working mechanism of our system is shown in Fig. 13 below:

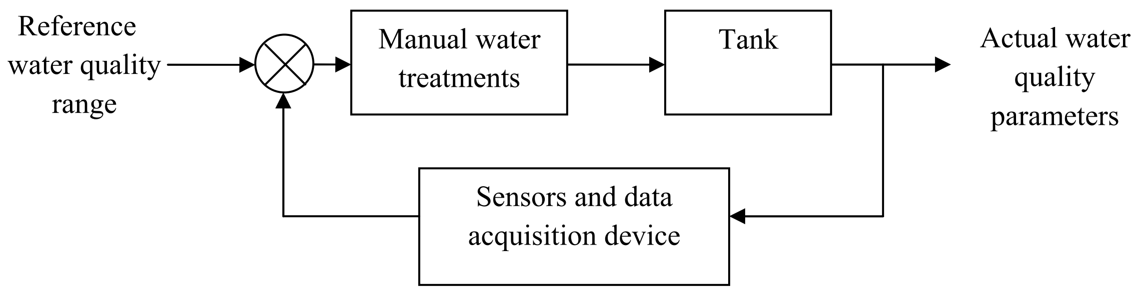


Figure 13: Block diagram of our data acquisition system

Since we will have at least 60 analog sensors in the data acquisition system, we purchased the National Instrument PCI-6225 data acquisition card, which has 80 analog inputs. Its physical sampling rate is 250 kS/s (kilo sample per second). Since the code we are working on is running in a while loop, the actual sampling rate will also be dependent on the rate of the while loop, which is determined by the speed of the computer and operation system we will use. For a typical CAEN desktop with Windows XP, the rate of the while loop is at most 50 HZ. It is enough for our application, as the water quality is not likely to change significantly in a one second time frame.

Regarding the connection mode between the sensors and the data acquisition card, we decided to use single-ended mode rather than differential mode because it will simplify the wiring significantly and save more terminals on the data acquisition card.

The resolution of the data acquisition card is 16-bit, which is capable of dividing the measurement range into 2^{16}=65536 sections and perceiving a change as small as the length of each section. For our application, all the sensor signals are weaker than 100 mV. Therefore, we will use the minimum measurement range of the data acquisition card: -200 mV to 200 mV, in which case the resolution is going to be 0.4V/65536 = 6.1 μV. The thermal couple has the weakest signal output, which is around 1 mV, and has a voltage/temperature ratio of approximately 40μV/ ℃. Thus the minimum temperature change we can measure is about 0.15 ℃, which is sufficient for the research.

Pressure and Velocity Fluid Dynamics Analysis

In order to verify that our design is functional, we did theoretical calculations of the fluid dynamics inside our system.

For simplicity, we made the following assumptions:

1. The system is overall steady-state
2. The fluid is inviscid, and the material of the tubing is plastic with smooth inner surface. Therefore, there is no major loss due to friction.
3. The fluid is incompressible

Based on these assumptions, the energy form of Bernoulli Equation is valid for our calculation:

$$\frac{p_{in}}{\gamma} + \frac{V_{in}^2}{2g} + z_1 = \frac{p_{out}}{\gamma} + \frac{V_{out}^2}{2g} + z_2 + h_{L,minor} - h_s \qquad \text{(Eq. 1)}$$

Where p is the pressure at the specific inlet or outlet, V is the flow velocity, z is the height with respect to the bottom of the tank, γ is the specific weight of the fluid, and g is the local gravitational acceleration. $h_{L,minor}$ is the minor head loss due to the components in the system, which equals to $\frac{K_L V^2}{2g}$, where loss coefficient K_L is determined by the components of the system. h_s is the shaft head representing the net power introduced by the pump, which equals to $\frac{\dot{W}_{pump}}{\dot{m}g} = \frac{\dot{W}_{pump}}{\rho AVg}$ ("A" stands for the cross sectional area of the tubing) The net power input of the pump $\dot{W}_{pump}$ is derived from its specifications below:

Height of head	1'	3'	5'
Flowrate@Head (Gph)	325	275	225

Table 6: Flow rate specifications of the pump

Using Bernoulli Equation:

$$\frac{p_{in}}{\gamma} + \frac{V_{in}^2}{2g} + z_1 = \frac{p_{out}}{\gamma} + \frac{V_{out}^2}{2g} + z_2 - \frac{\dot{W}_{pump}}{\rho AVg} \qquad \text{(Eq. 2)}$$

We derived that the net pump power input for a 1 ft. high head is 0.9 Watts, for a 3 ft. high one it is 1.98 Watts, and for a 5 ft. head it is 2.99 Watts. For our application, the height of the head is approximately 4 ft. Therefore, we used the average pump power input of 3 ft. and 5 ft. high head as the net pump power input, which is 2.49 Watts.

Therefore, the overall Bernoulli equation is:

$$\frac{p_{in}}{\gamma} + \frac{V_{in}^2}{2g} + z_1 = \frac{p_{out}}{\gamma} + \frac{V_{out}^2}{2g} + z_2 + \sum \frac{K_L V^2}{2g} - \frac{2.49\ \text{W}}{\rho AVg} \qquad \text{(Eq. 3)}$$

The plot of system when doing normal flow is shown below in Fig. 14:

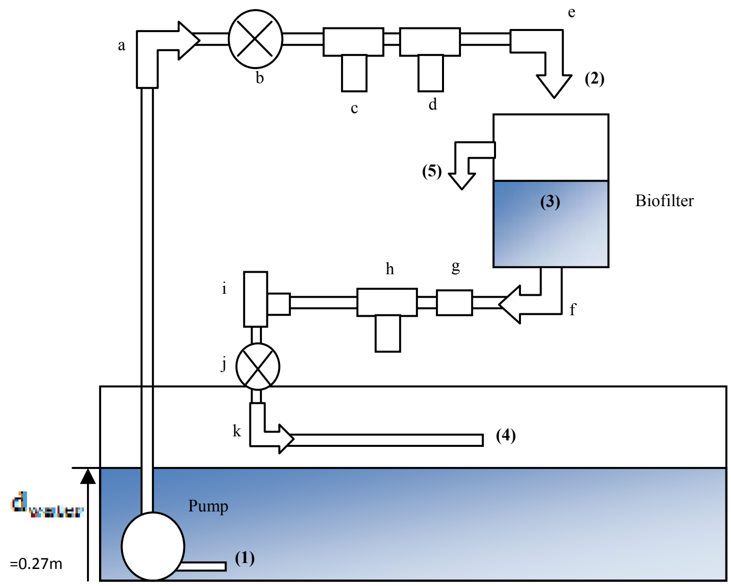


Figure 14: Schematic sketch of flow path during normal flow

We defined the inlet of the pump as point (1), the outlet of the tubing above the biofilter as point (2), the top surface of the fluid inside the biofilter as point (3), the outlet guiding water back to the tank as point (4), and the outlet on the biofilter for backwash as (5). The components in the system were labeled from “a” to “k”.

The conditions of each point are list below in Table.7:

	(1)	**(2)**	**(3)**	**(4)**
P (Pa)	$\rho g d_{water}$	0	0	0
V (m/s)	0	Unknown	0	Unknown
Z (m)	0	1.2	Unknown	0.46

Table 7: Conditions of point (1) to (4)

We first applied Eq. 3 on point (1) and (2). For the minor loss coefficient, the types of components were determined as Table 8 on the next page.

	a	**b**	**c**	**d**	**e**	**f**
Type	Elbow	Valve	Tee (line flow)	Tee (line flow)	Elbow	Elbow
	g	**h**	**i**	**J**	**k**	
Type	Elbow & tee (branch flow)	Tee (line flow)	Elbow	Valve	Elbow	

Table 8: Designation of components

As can been seen in Fig. 14 and Table 8, from point (1) to (2), there are two 90º elbows, two line flow tees, and a ball valve. We assumed that the ball valve is fully open. In this case, we found the loss coefficient K_L=1.05. For our calculation, we used ρ=1000 kg/m^3, and g=9.81 m/s^2. Using

Eq. 3 and the conditions given in Table 7, we derived the flow velocity at point (2) V_2=0.88 m/s.

Based on the assumption that the system is under steady-state, the flow rate Q of point (2) and (4) should be the same:

$$Q_2=Q_4 \quad \Rightarrow \quad A_2V_2=A_4V_4 \qquad \text{(Eq. 4)}$$

Given that the diameter of (2) is 0.019 m (3/4 inch), and the diameter of (4) is 0.0254 m (1 inch), the velocity at point (4) can be calculated: $V_4 = 0.495$ m/s. Then we applied Eq. 3 again on point (3) and (4). Using Table 8, we found K_L=3.15. Finally we found that the height of fluid surface with respect to the bottom of the tank z_3 has to be 0.51 m, which is lower than the bottom of the biofilter. It indicates that there will not be overflow from the biofilter tank, and there will not even be water staying in the biofilter tank, which is most ideal for nitrification.

For backwash, the schematic sketch of the flow inside the system is shown in Fig.15 on the next page.

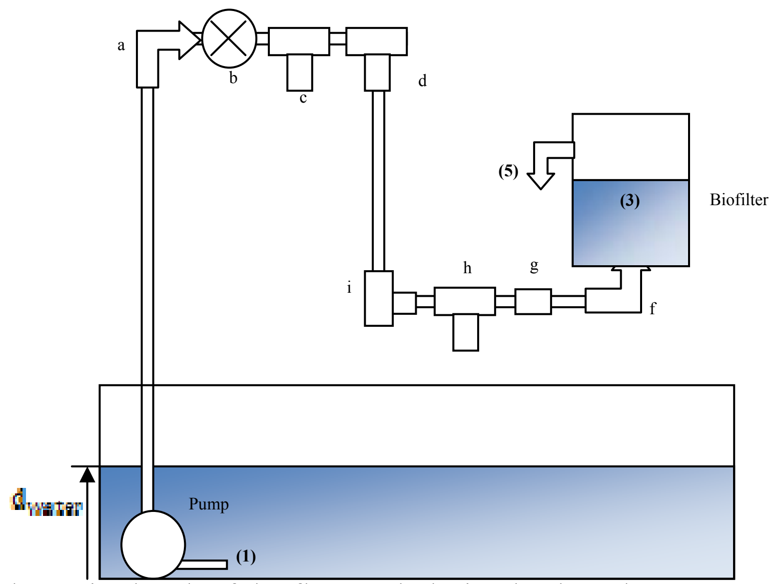


Figure 15: Schematic sketch of the flow path during backwash

The procedures of calculations are the same as for normal flow. We used Eq. 3 on points (1) and (5), and determined the flow velocity at point (5) to be 0.93 m/s under steady-state.

Tubing, and Frame Selection and Parameters

PVC polyurethane Tubing was chosen with an inner diameter of ¾" and 1". The wall thickness of the PVC is rated up to 100 psi. For the prototype the standard reinforced tubing was used but there is a large range of variations of polyurethane tubing available in manufacturing catalogues that could suit any changing needs of the researchers. When the remaining aquaculture systems are constructed it is recommended that corrosion protected PVC be purchased to prevent leaching. Additionally there is a large range of durometer values for the hardness and pressure values ranging up to 200 psi (McMaster-Carr Catalog 113), well beyond the needs of our system as evidenced above.

The PVC tubing used for the frame needs to only be able to support the sensors, and the angle iron frame needs to only support the elbows, ball valves and Ts. The force of these items applied to the supports is minimal considering. The PVC and A36 grade steel racks are overdesigned with regards to yielding.

Biofilter Container Support Stress Analysis

Each container can hold up to .041 m^3 of water which comes to 37.85 kg. This is a total of 75.7 kg of water that must be supported by two Spruce Pine wood 2x4s that extend across the width of the shrimp tank. Completing a beam bending analysis assuming the load of the two containers is evenly distributed across the entire width of the beam (a very close approximation of the actual situation) we can determine the maximum stress that occurs along the length of the beam. See Fig. 16 below for the free body diagram of the section. The load on each of the two beams is actually 37.85 kg and each half of the beam supports 14.38 kg. Using Eq. 5 and Eq. 6 below the maximum stress is calculated.

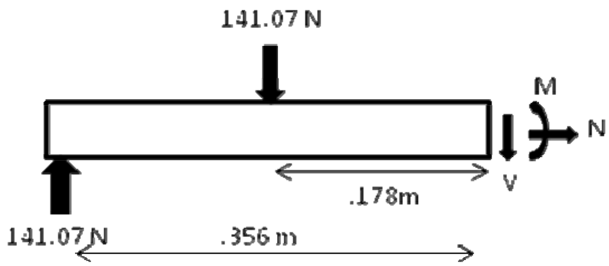


Figure 16: Free Body Diagram of Forces on Biofilter Container Support Beams

I=Moment of Inertia
b=Base of beam cross section
h=Height of beam cross section
σ_{max}=Maximum normal stress
S=Safety Factor
σ_y=Flexural Yield Stress

$$I = \frac{1}{12} b \cdot h^3 = \frac{1}{12} 0.089m \cdot (0.0381m)^3 \qquad \text{(Eq. 5)}$$

$$\sigma_{\max} = \frac{Mc}{I} = \frac{14.38kg \cdot 9.81 m/s^2 \cdot 0.178m \cdot 0.01905m}{4.097 \cdot 10^{-7} m^4} = 1.17 \text{ MPa} \qquad \text{(Eq. 6)}$$

$$S = \frac{\sigma_y}{\sigma_{\max}} = \frac{17.2MPa}{1.17MPa} \approx 15 \qquad \text{(Eq. 7)}$$

The Flexural yield stress was found using Matweb (Matweb, 2008) for North American Engelmann Spruce Wood. This type of wood had a lower yield stress than most other commonly available wood types. This ensured that a variety of different woods would be safe to use in our design.

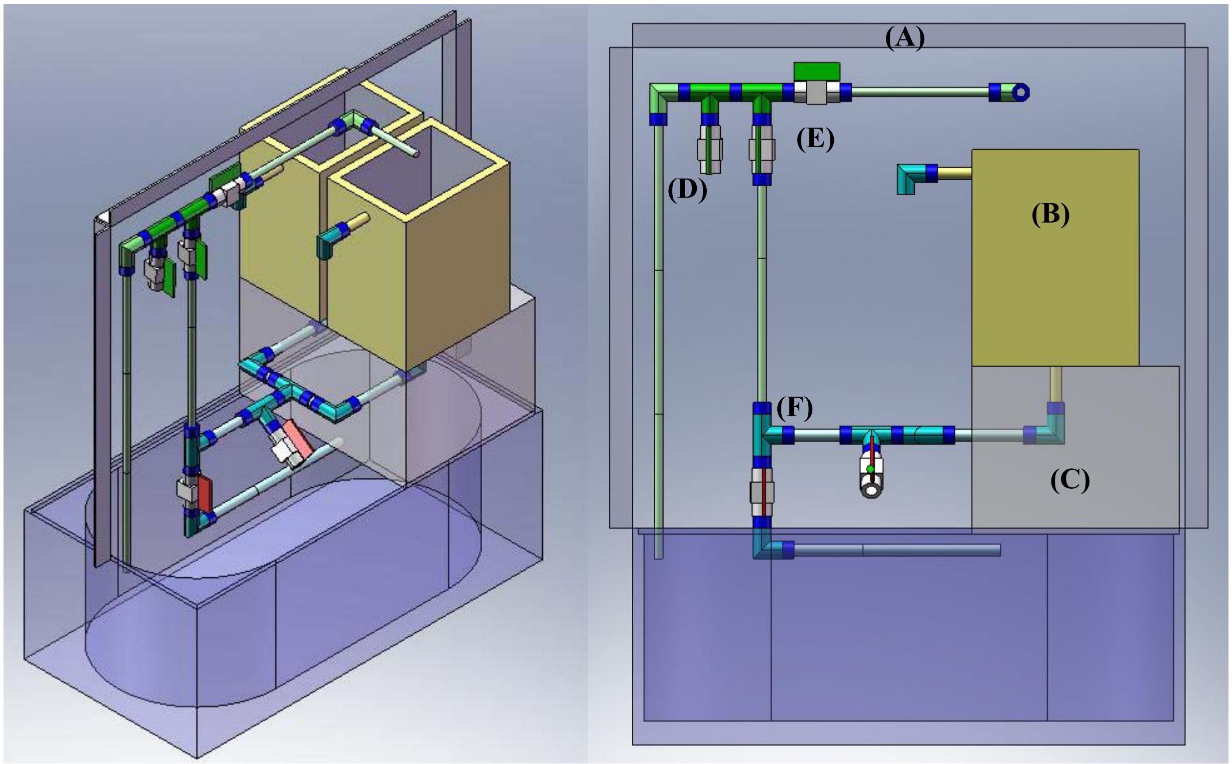
Final Design and Prototype Description

The prototype will be able to act as a functional zero-exchange aquaculture and will be used to validate whether or not our design meets expectations for a computer monitored research-level aquaculture. The functionality of the prototype is similar enough to the final design that the water flow through the piping system, sampling points, and backwash will be very similar to the final design, and will allow testing for biofilter and backwash effectiveness. The sensors and program used to monitor the prototype system will be identical to the ones used to monitor the final design system. This will give a direct comparison that will allow an accurate validation for the sensors. It should be noted that the conductivity sensor will be missing from the prototype due to cost, but will be featured in the final design.

Plumbing System

CAD models of the prototype are shown in Fig. 17a and 17b below. The following prototype description will walk through Fig 17, describing each part. A dimensioned drawing is shown in Fig. 18. Drawings for the components of the tank are shown in Appendix F and a Bill of Materials can be found in Appendix G.

The prototype will be built using 48”x24”x18” tanks with a maximum volume of 60 gallons provided by our sponsors. Vertical 45 in. angle-iron bars will be mounted to the center front and the center back of the tank, connected by a horizontal 54 in. angle-iron bar above the tank (**A**). For the dual biofilter tanks, the prototype will use two 14.5”x11”x18” plastic containers (**B**) that will be mounted 7.5 in. above the aquaculture tank using wooden 2”x4” pieces(**C**) made of spruce pine wood. The mount will be located on one far end of the tank. On the opposite end of the tank, a submersible water pump rated at 1230 Lph with an outlet of 0.75 in. diameter is connected to a vertical PVC 0.75 in. diameter pipe. This PVC pipe continues vertically for 40 in. supported by the vertical angle-iron bar and connects to a 0.75 in. diameter adaptor and elbow tube. All tubing connections will feature an adaptor, connector, or both. A sample point for the entering flow is built by connecting a ball valve to a T-section, both with diameters of 0.75 in. The sample point is connected to another T-section with two ball valves that will be used to direct the water between normal flow and backwash flow; all diameters are 0.75 in. (**D**). For normal flow (**E**), the 0.75 in. diameter piping will lead to the top of the biofilter container and water is evenly distributed over the biofilters by a PVC plate with holes symmetrically cut. The trickling flow will travel through two cages inside of the biofilter container that hold biofilter media. The outlet of the biofilter will be a 1 in. diameter tube that guides the water back into the tank. For backwash flow (**F**), the .75 in. diameter piping is adapted to a 1 in. diameter T-section that leads the water pass a sampling point, through two T-Sections and Elbows, and into the biofilters. The biofilters will fill with water and an air source will be used to agitate the water in order to clean the biofilters. Two solid PVC plates must be inserted in the top of the biofilter container before air agitation to prevent overflow and splashing. Backwashed water will flow out of the biofilter near the top of the container and back into the tank. Sensors for temperature, salinity, and pH will be mounted on a PVC frame rack (not shown on CAD drawing) that uses 1 in. and 1.25 in. diameter tubing located on top of the tank. The total amount of PVC used is about 76 in. of .75 in. diameter tubing and 138 in. of 1 in. diameter and and 48 in. of 1.25 in. tubing.



(a) (b)

Figure 17a, b: CAD models showing isometric (a) and side view (b) of prototype.

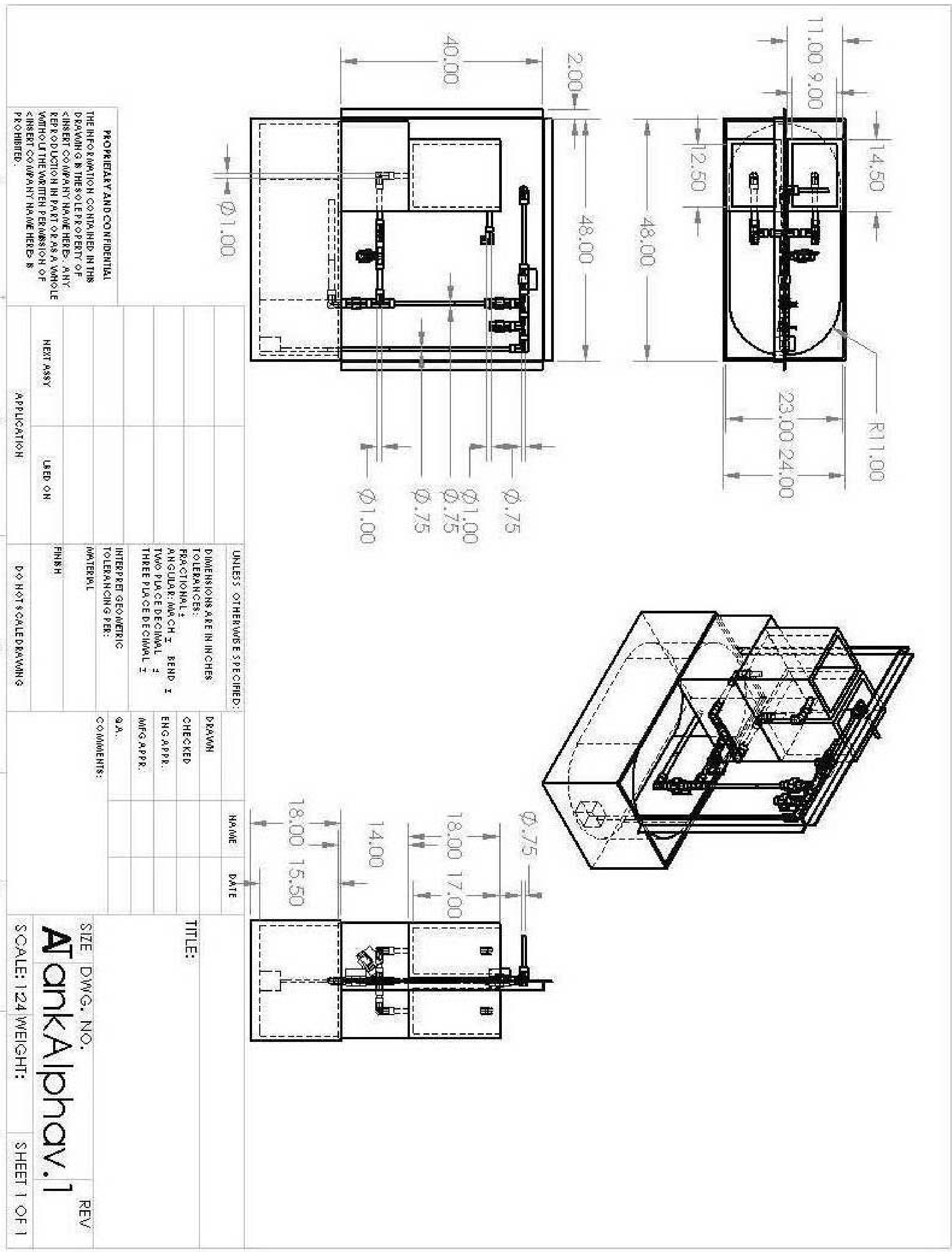
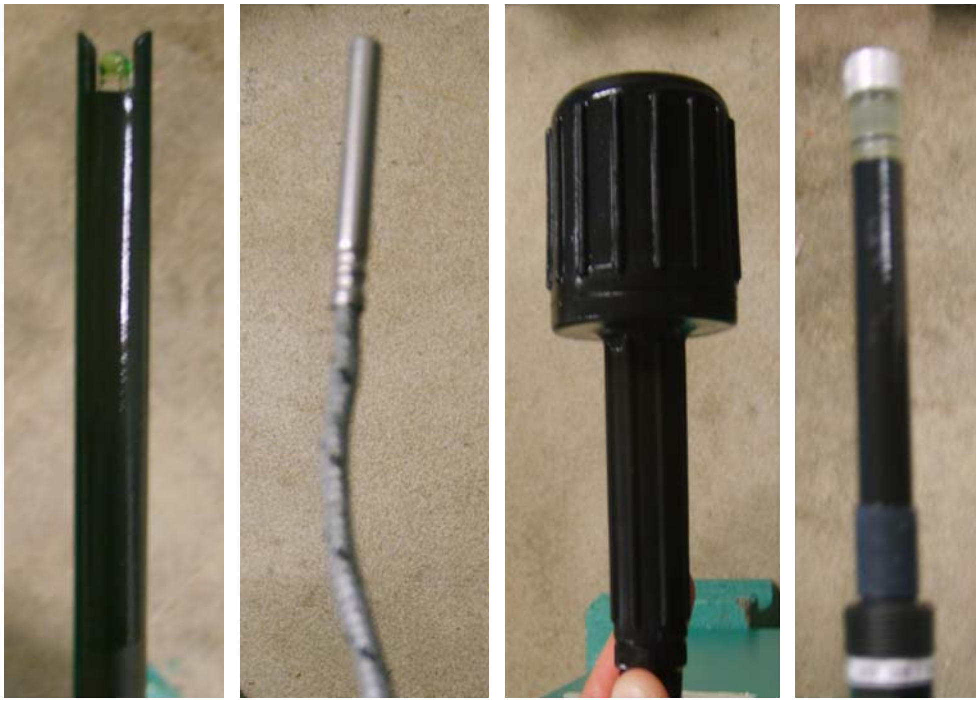


Figure 18: Dimensioned CAD drawing of the Alpha Design.

Data Acquisition Hardware Setup

As discussed in a previous section, we have four sensors for our water monitoring system, which are pH, temperature, dissolve oxygen, and ammonia sensors. The actual pictures of the sensors are shown below in Fig.19:



(a) (b) (c) (d)

Figure 19: Pictures of sensors: (a) pH; (b) Temperature (c) Dissolved Oxygen (d) Ammonia

These sensors were fixed on the sliding rack by using zip ties, and were then connected to a PCI-6225 data acquisition card via terminal blocks, as shown in Fig. 20 below. We used two different terminal blocks: BNC-2090A and SCC-68. BNC-2090A is used for sensors with BNC connectors (pH and ammonia), and SCC-68 is used for bare wire connection (temperature and dissolved oxygen).

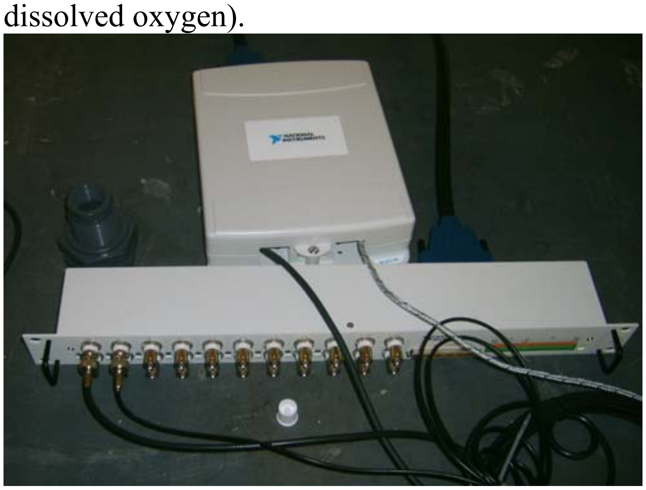


Figure 20: Terminal blocks of PCI-6225 data acquisition card with sensors connected

Data Acquisition Software Setup

The voltage outputs of the sensors were then transferred via the data acquisition card into the computer, and monitored by the LabVIEW code. The code converted the voltage readings into the actual measurement values using the conversion equations we derived from calibration. For detailed information, please refer to the Validation section. The interface of our final LabVIEW code was shown in Fig. 21:

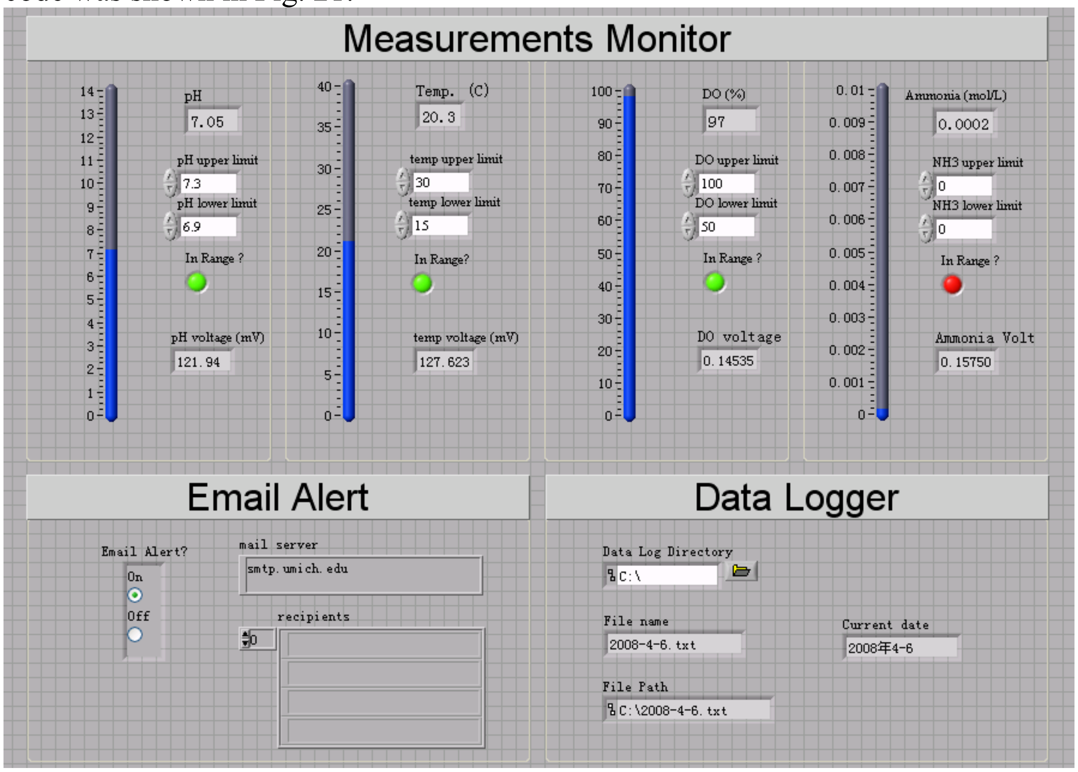


Figure 21: LabVIEW code interface

The interface was divided into three sections: measurements monitor, email alert, and data logger. Under the measurements monitor, there are both bar and numeric indicators showing the current measurement of each sensor. Upper and lower limits of each measurement can also be specified, so that when any of the measurements goes beyond the limit, the corresponding "In Range?" status indicator will turn red, and an alert email will be sent out. In the email alert section, we can turn on or off this function by clicking on the radio buttons on the left. An smtp server and recipients can be designated in the blanks on the right. In the data logger section, the path of data log files can be specified in the "Data log directory" blank. The current log file will be named as the current date, with an extension of .txt.

Fabrication Plan

The most logical fabrication plan is laid out in Table 9 below.

	Description	**Tools and Equipment Required**	**Materials Needed**
Step 1	Measure dimensions of the Aquarium to be used and the base of the biofilter containers	Tape Measure	N/A
Step 2	Biofilter Container Frame-Cut two pieces of the wood to be the distance of the width of the aquarium and cut 16 pieces that are the length of the biofilter container base plus 3". Finally nail two pieces into the base frame of the aquarium, and place the other pieces perpendicular to the base pieces in four stacks, four pieces high. Nail all of the pieces of wood together. Be sure that the pieces of wood are spaced adequately so there is enough room for the bulkhead and tubing to go through. See Fig. 22	Hacksaw or circular saw(power tool), nails, tape measure, pencil  **Fig. 22**: Cutting the biofilter container supports	6x - 7' 2X4 pieces of maple or oak (any type that is readily available allowing reasonable safety factor), nails
Step 3	PVC horizontal Rack - Measure the distance that the biofilter container frame occupies lengthwise along the tank and subtract the length from the length of the tank. Cut 2 pieces of the 1" diameter PVC tubing to match this length, cut two pieces of PVC piping to match the width of the aquariums. Next Cut three pieces of the 1-1/8" PVC piping to the width of the tank. Put 1-1/8" T's on the ends of each of these pieces. Place the T's on the long ends of the frame and attaches the frame fully together using the remaining elbows. Finally glue the elbows to the tubes. Cut four 3"x3" pieces of wood with thickness greater than 0.5". Nail these four squares into the aquarium wooden frame at the locations of the elbows. Finally place a screw right through the center of each elbow and into the wooden squares. This provides an offset so the T's can slide smoothly along the frame. See Figure 23.	Hacksaw, pencil, tape measure  **Fig 23**: Fabricating biofilter container supports	PVC glue, 1 1" diameter PVC piece 96" long, 1 1-1/8" diameter PVC piece 54" long, nails

Step 4	Angle Iron Vertical Frame - Cut two pieces of angle iron to be 57" long, and three pieces to be the length of the aquarium. Drill the two 57" pieces into the wooden aquarium frame with the base of the angle iron aligned with the base of the tank along the centerline of its width. Screw the horizontal pieces of angle iron onto the previously attached vertical pieces at the desired heights. See Fig. 24.	Power Hand Drill, Hacksaw  **Figure 24**: Fabricating plumbing support frame	8 2" Screws, Angle Iron
Step 5	Biofilter Container Holes-Using a power drill with a hole saw bit attached, drill holes at a height of 13.5” on the centerline of the shorter side of each container. Also drill a 2” diameter hole at the center of the bottom of both containers. Attach bulkheads to the hole locations	Power Drills (Machine Shop), 2” Diameter Hole Saw	N/A
Step 6	Zip tie the ball valves to the vertical frame at their appropriate locations	N/A	zip ties
Step 7	Cut the polyurethane tubing and attach all elbows, T's, ball valves starting from the pumping and ending at the biofilter container, then move from the bulkheads back to re-entry to the tank. Reference Fig. 18 for placement of ball valves and tubing.	Razor Cutter	3/4" I.D. polyurethane tubing, 1" I.D. polyurethane tubing, 2x 3/4" elbows, 7x 1" elbows, 2x 1" T's, 5x 3/4" T's, 11x 1"-1" male to barb adapters, 1x 1"-3/4" male to barb adapters, 5x 3/4" -3/4" male to barb adapters, 4 bulkheads, metal fasteners

Step 8	Cut three plexiglass covers for the biofilter containers for both distributing water evenly over the biofilters, and for deterring water from overflowing during backwash. Cut the pieces out to fit within the contours of the biofilter container. Cut a 1" diameter hole in the center of each plexiglass piece so that it can be removed by placing finger in hole. For one of the plates drill ½" holes symmetrically drilled around centerline see Fig. 25. Place weather stripping around outside edge of plate to seal plate.	 Fig. 25 Plexiglass plate with holes	Plexiglass plates, weather stripping
Step 9	Install the DAQ card into the computer, and then install drivers and LabVIEW with necessary modules	N/A	N/A
Step 10	Program sensor testing codes	N/A	N/A
Step 11	Connect sensors to the terminal blocks	wire cutter, screw driver	insulation tape
Step 12	Test and calibrate sensors to make sure that they all work well	Multimeter, liquid containers	Standardized buffer solutions
Step 13	Program the monitoring and alarming code, and then test and implement it with the sensors	N/A	N/A

Table 9: Fabrication Plan Steps

Problems Encountered

The following subsections will address some of the issues we encountered and the solutions to the problems

Internet Accessibility

Internet access is needed in order for the email alert function to work. Currently there is no ethernet port in the lab. There is wireless signal, but the quality of it is not satisfactory. We tested the wireless signal there using two laptops with different wireless adapters, and they gave different outcomes. One has consistent signal reception, while the other was disconnected frequently. Therefore, the reliability of signal reception will be dependent on the wireless adapter we use. We attempted to use a qualified wireless adapter for the desktop to see if it was workable with our applications but we found that without a constant IP address the application would not work. We integrated an on/off function so the email alert is a possibility in the future if internet access becomes possible. We designed a computer-based data logging and monitoring system without the email alert function so the data can still be stored and analyzed. The measurements will be continuously monitored and recorded. Once any measurement goes beyond the range, the code will show an alert notation on the code interface, and record the time it happened. It requires research staff to go to the lab and check the code on a regular time basis to ensure that the water quality is under normal level.

Leakage in Plumbing

The plumbing system design is composed of a network of different valves, elbows, Ts and bulkheads. We have found that although the diameters of the barbed elbows are labeled the same size, there is actually variation in tolerances between parts purchased in different hardware stores. For example, an elbow that was purchased from Ace hardware fits in the tubing entirely, while another elbow with the same specified dimensions from Stadium Hardware only fits up to the second barb. We also use metal clasps to better seal and tighten the polyurethane tubing to the connectors. With the differences in the fittings there were some leakage issues at a few connections but all the leaks were stopped using sealing tape and metal fasteners. It is also important to ensure that the threaded connections are fully tightened. In order to avoid these differences in standards we recommend that all the parts be bought from the same supplier. In this case we recommend McMaster-Carr.

Validation Plan

The tests that were completed to validate the design were a water flow test, a test for backwash efficacy, water evaporation, and sensor calibration. The water flow through the filter is tested instead of the actual nitrogen converting capability of the filter itself because of time constraints. The filter takes at the minimum 10 days of water cycling through for the bacteria to accumulate. Testing the nitrogen content of the water would also require lab equipment and knowledge that we don’t have.

Water Flow

Testing the water flow helps determine how efficiently the filter will work, given the expected amount of shrimp to be grown in the tank. The water flow was determined by measuring the amount of time required for the pump to fill up a gallon jug placed in the filter. We found that the water flow rate was 757 Lph which is higher than the minimum specification value of 616 Lph and lower than the calculated value of 902 Lph.

Water Evaporation

A test to determine amount of water evaporation from the tank was performed to assist the researchers in knowing how often to add water to the tank. We found that water should be supplied at a rate of 2 L/day. We believe this value is erroneous and more testing needs to be completed. At the time of the test we found that there was a minor leak at the bottom where there is a tube placed in a hole. More tests should be completed after calking is placed around the tube and hole.

Backwash Efficacy

To ensure our backwash concept was effective we took biofilters from a system that has been running in the basement of the School of Natural Resources for some time. We rinsed the biofilters to remove any loose particles. We then placed the biofilters in our biofilter container and filled the container with water. We then inserted an air tube and covered the container. We let the backwash run for 5 minutes. Upon removal of the cover and the biofilters we found that there were many particles of biomass elevated in the water and even more biomass particles lying at the bottom of the container.

Calibration Validation

In order to make sure that the water quality sensors give correct readings, we conducted calibration on each sensor

The pH sensor was calibrated by using solutions with reference pH values of 4,7, and 10, as shown below in Fig.26:

Figure 26: Reference pH solution with values of 4, 7 and 10.

The correlation between the actual pH values and voltage readings were shown below in Fig. 27:

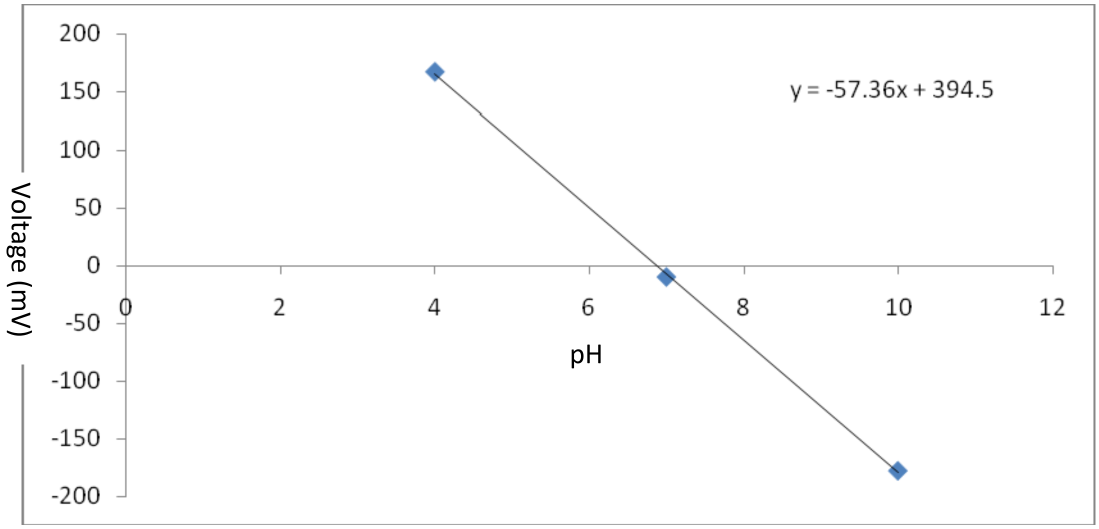


Figure 27: pH calibration curve

As shown by the curve, there is linear trend with a slope of –57.36 mV/decade, which is close to the theoretical slope of -58.16 mV/decade. The conversion equation was then derived as:

$$pH=-0.017V_{pH}(mV)+6.877 \qquad (Eq.8)$$

Temperature

The temperature sensor we used was a thermal couple, the voltage reading of which does not have a linear relation with the temperature in general, as shown in Fig.28:

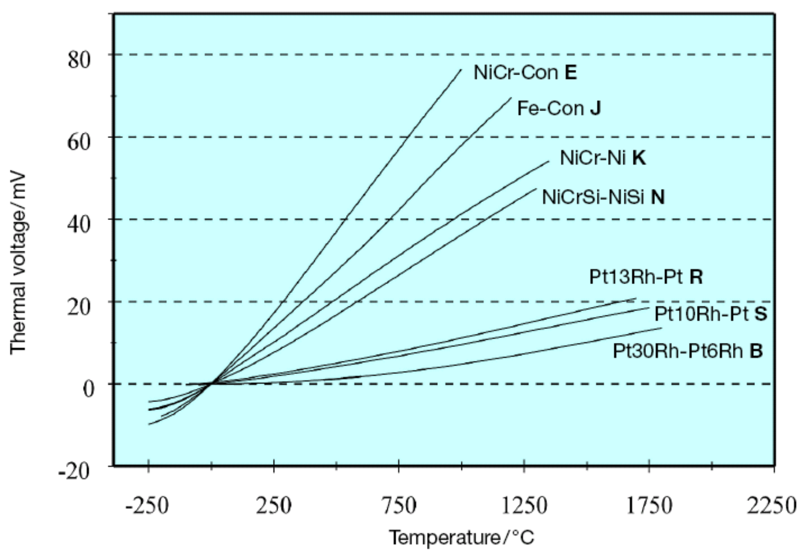


Figure 28: Characteristic curves of thermocouples (Jumo)

However, considering that our application is shrimp aquaculture, the temperature variation is small compared with the overall measurement range of the sensor. In this case, assuming a linear trend between the voltage and temperature is likely to be reasonable. To verify this assumption, we tested the sensor with ice water, room temperature, and boiling water, which have reference temperature of 0 ℃, 18 ℃, and 100 ℃ respectively. The calibration curve was shown below in Fig. 29:

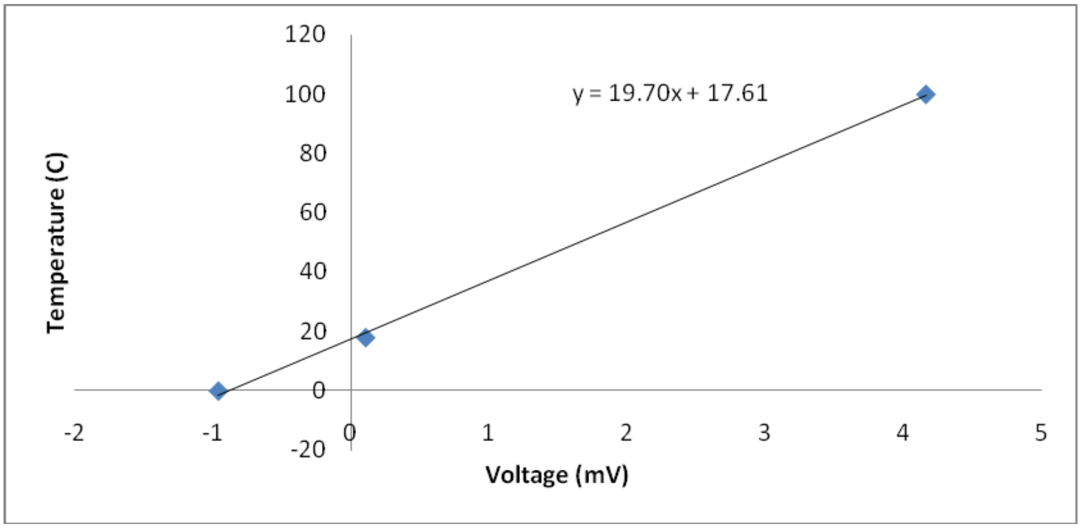


Figure 29: Temperature sensor calibration curve.

As shown in Fig. 29, the voltage and temperature show a linear correlation. Therefore, we concluded that within the range of our application, the linearity assumption is valid. The conversion equation of temperature sensor is:

$$\text{Temperature } (^{\circ}\text{C}) = 19.70\ V_{temp}(\text{mV}) + 17.61 \qquad \text{(Eq. 9)}$$

Dissolved Oxygen

For the dissolve oxygen sensor, we have two reference values: 100%, and 0%. The 100% was achieved by exposing the sensor in the air with the membrane moistened by a drop of water, since air is saturated with oxygen. The 0% was achieved by using zero dissolved oxygen solution we purchased, as shown in Fig. 30:

Figure 30: Zero dissolved oxygen solution.

We observed that the voltage output of the sensor in the zero dissolve oxygen solution is extremely close to 0, thus we assumed it to be 0. The voltage reading of the sensor in the air is

30.3 mV. Given that there is a linear trend between the voltage and dissolved oxygen level due to the nature of the sensor, the conversion equation of dissolved oxygen sensor is simply:

$$DO\ (\%) = V_{DO}\ (mV) \times 100\% / 30.3 \qquad (Eq.\ 10)$$

Ammonia

Due to the difficulty in getting reference solutions with known ammonia level, we used the calibration curve provided by the vendor of ammonia sensor as shown below in Fig. 31:

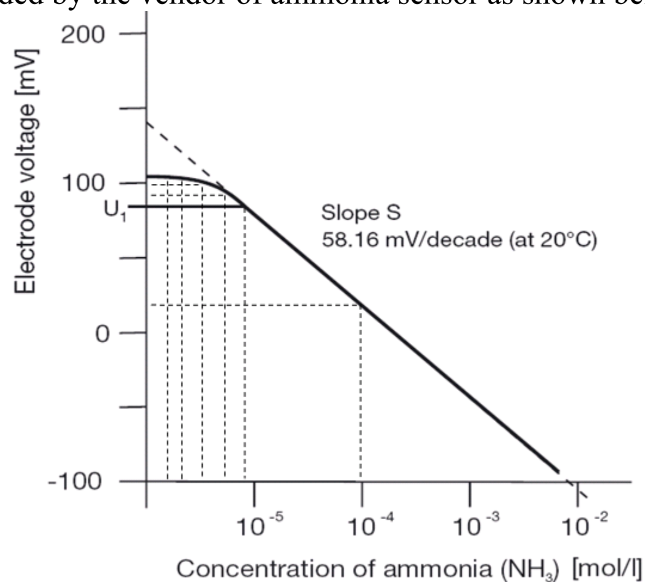


Figure 31: Calibration curve of the ammonia sensor (Jumo)

As can be seen in the figure, when the ammonia concentration is lower than 10^{-5} mol/L, the curve does not show a linear trend. In order to get the accurate correlation, rather than using a conversion equation, we used interpolation to find the ammonia concentration corresponding to the voltage reading. The look-up table we made for interpolation is shown below in Table 10:

Voltage(mV)	105	104	103	100	90	80	20	-100
Log_{10}(Ammonia)	-6.00	-5.80	-5.65	-5.40	-5.25	-5.10	-4.00	-2.00

Table 10: Look-up table for ammonia concentration interpolation

The only part of the design that cannot but should be validated is the effectiveness of the biofilter. This is key because without an effective enough biofilter, the aquaculture system cannot support a high number of shrimp without increasing toxic nitrogen levels in the water. Unfortunately, we may not have the time to test this part of the design before the Engineering Design Expo on April 10th. The biofilter requires at the bare minimum 10 days of the pump cycling water through the filters before enough bacteria grow on the filters. Also, shrimp will be needed to really see if the bacteria can cope with the waste produced. It is possible to only test the nitrogen filtering ability of the bacteria, but without the shrimp, there is a distinct difference between the test scenario and real usage.

Project Plan

We have mapped out a semester plan for the different milestones and steps that were accomplished for our project. These include periods for concept generation, component ordering, the subsequent Design Reviews following Design Review 1, system design, prototyping and the expo and final design. The tasks are divided among team members as indicated by the color coding. A Gantt chart of the project plan can be found in Appendix F.

Recommendations

The current design is a final design and prototype and there are a number of improvements that are recommended for the additional shrimp aquaculture systems the researchers plan to build. First, the biofilter containers currently used are made from high density polyethylene trash bins. Although they do serve their purpose, they lack customizability and visibility. It is recommended that these plastic bins are replaced by a container made from more customizable but also more expensive plastic, such as acrylic.

The biofilter containers require a lid during backwashing to prevent water from splashing out. Although the current flexoglass lid does work, we have already placed an order for a container that has a lid and can be purchased from United States Plastic Corp. This will make the transition from normal flow to backwash much simpler and the design will no longer require the flexible flexoglass and bungee cords.

The test-beds currently used have a 1-inch hole in the bottom used for draining and controlling the level of water in the tank. Although inserting a PVC pipe in these holes does prevent most of the leakage, it does not stop it completely. After about one week of testing, about one gallon of water leaked out underneath. It is recommended that these holes are properly sealed from leakage before using them in any closed-loop system.

The support system that props up the piping system is presently made from angle iron, which is susceptible to rust over time. It is recommended that the angle iron be replaced with a material that is more resistant to rust, such as PVC piping.

The water monitoring system requires reliable internet access in order for it to send out alert emails during emergencies. Currently, there is a wireless connection that is inconsistent and it is impossible to receive a permanent IP address. It is recommended that wired connection be made available to the lab so that the monitoring system can work at full potential.

Conclusions

A series of lab-scale shrimp re-circulating aquacultures was constructed so that researchers from the School of Natural Resources and Department of Environmental Engineering can conduct experiments on them involving different biofilters and different feeding schemes. For now, two test beds have been constructed for evaluations, with the possibility of eight more later. The final concept for the lab-scale shrimp re-circulating aquaculture involves multiple parts that were decided on through an iterative design process.

A re-circulating system was included in the design. With this system, multiple test scenarios can be run, including using a separate biofilter, separate bioflocs, and bioflocs within the shrimp tank. To clean the biofilter, the re-circulating system is able to backwash itself. If two different biofilter media are used inside the biofilter container, the design can backwash each type of media separately, and includes a method to sample backwashed biomass from each media type separately. An operator can flip a series of valves and reverse the flow of the water. This reversed water, combined with additional air bubbles, knocks off biomass stuck on the filters. There is an adjustable horizontal PVC rack present to mount sensors and a wooden support structure to hold the biofilter containers. A data acquisition system is currently in place to automatically collect data for pH, temperature, dissolved oxygen, and ammonia. There is also the capability to install additional sensors. Data is sent to a computer, where it will be stored and monitored by a program. Should any specified parameters fall outside set boundary limits, the program has the capability to send a notification to the researchers. Currently the email option is turned off because Ethernet internet is not available in the laboratory.

Engineering Analysis was completed on the various components of the design. The flow rates and biofilter sizes needed to run the re-circulating aquaculture were determined. Using calculations (Losordo, Hobbs 2000), inputs such as shrimp size and density were used to determine that a water flow of 616 L/hr and a biofilter size of 0.041 m^3 would be needed. It has been determined that the flow rate meets and exceeds the specification and is currently 757 Lph. Stress calculations were performed on the support structure holding up the biofilter tanks. It was determined that with one of the weaker woods available, the support structure had a safety factor of over 15. The performance of the sensors has also been validated using both sample reference solutions and calibration curves provided by the vendors. All of the customer requirements and specifications have been met.

The prototype testbed was designed with flexibility and customizability in mind. Though only two models of the prototype were built, additional testbeds can be made without the use of heavy machinery and machine shop. Most everything is ordered online through McMaster Carr and various vendors. Each component of the design is assembled by hand, or modified with drills and hacksaws before assembly. Another by-product of being able to order everything online is that the testbed is highly modular, and can be modified with relative ease. If a different water flow was desired, the piping can be modified relatively easily to accommodate. The goal was to allow repeatability and flexibility in construction for people with access to fewer tools. There are a few things that can be done to improve the design even more. These recommendations are included at the end of the paper on the previous page, and include things such as obtaining Ethernet internt access, sealing the shrimp tank better, and some more validation testing on the biofilters. We have set up the testbeds so that these recommendations can be accomplished easily, if given more time.

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Appendix A: Closed Loop Diagram

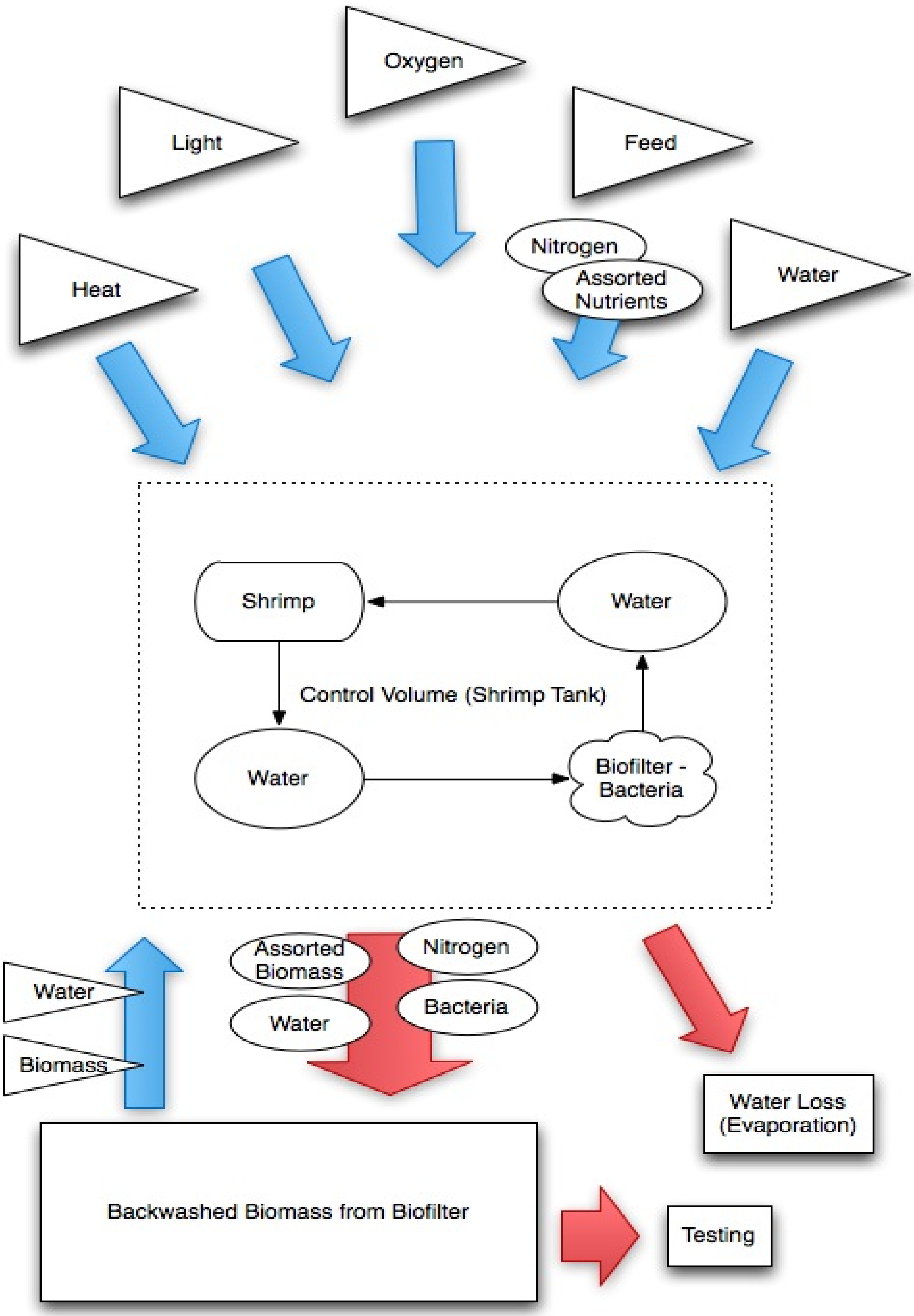


Figure A1: A control volume analysis of the nutrients entering and exiting the shrimp test bed.

Appendix B: Concept Generation Sketches

In our primary design, the plumbing system has a backwash system built in. By flipping a series of valves, the direction of water flow through the biofilter can be changed.

One of the original concepts that can be seen in Fig. B1 below on the right and B3 consisted of a biofilter container open to the ambient. However, having an open filter design allowed the possibility of overflow in the filter. Additionally, the loss of pressure in the system might require an additional pump to return water to the tank. Synchronizing the pumps to distribute water evenly would be difficult and it was determined that with an alternate design this barrier could be avoided. Also in Figure B1 was a concept where there are stackable platforms upon which multiple layers of shrimp can be cultivated. A challenge with this concept was even distribution of shrimp feed. If there was only one feeder at the top and feed could make it through the platforms shrimp on the bottom layer would receive more feed than shrimp in the other layers. A concept shown below shows a tower feeder in the corner where feed is distributed to each platform layer. Ultimately it was decided that this concept was impractical and it was best to stick with a single layer of shrimp in shallow water for each tank. Other concept designs such as a donut, raceway and trench design are shown in Fig. B2. These concepts all featured an internal biofilter and in the donut design, the ability to be stacked. The early design of reverse dam even played with the idea of a mixer cleaner.

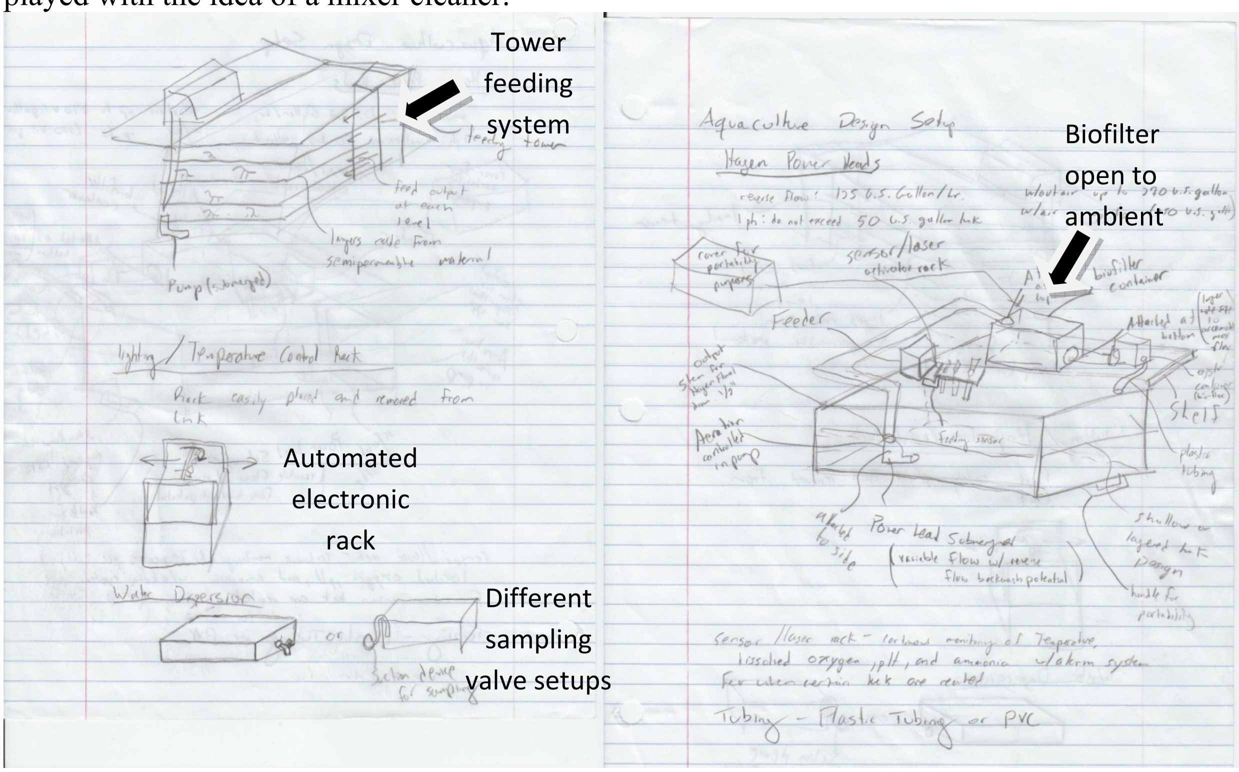


Figure B1: Shrimp platform, rack design and portable design concepts

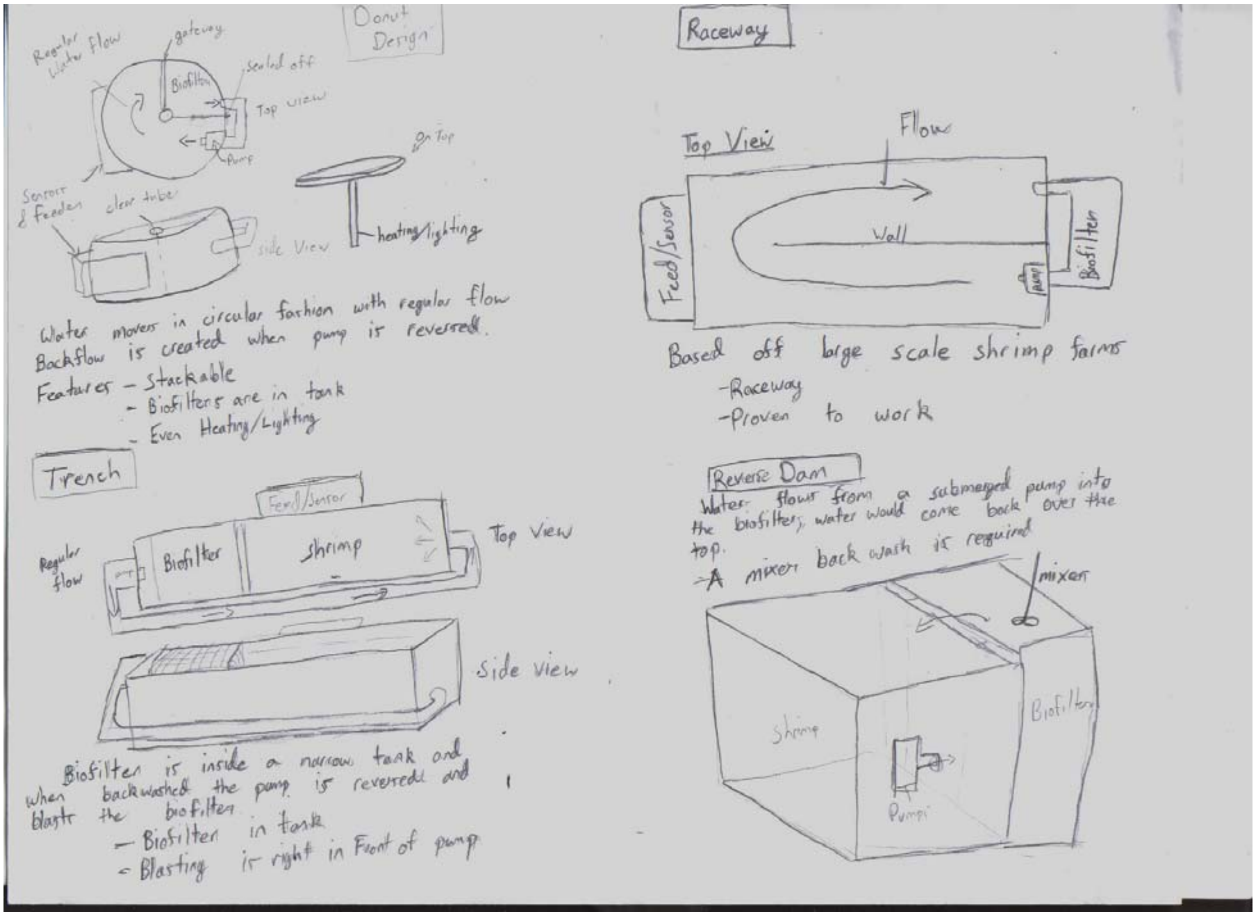


Figure B2: Other tank concept designs

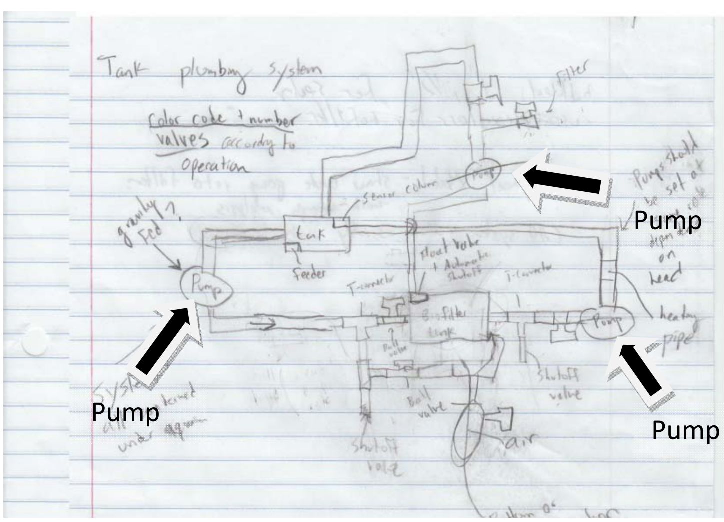


Figure B3: Biofilter open to ambient with 3 pumps required

After receiving new customer requirements we needed to make some modifications from the plumbing system designed initially. Some of the concepts that were review can be seen in Figs.

B4, B5, and B6 below. Figure B6 was adapted to be the cascading system in the very early discussions because of problems with accessing the biofilters in the bottom container.

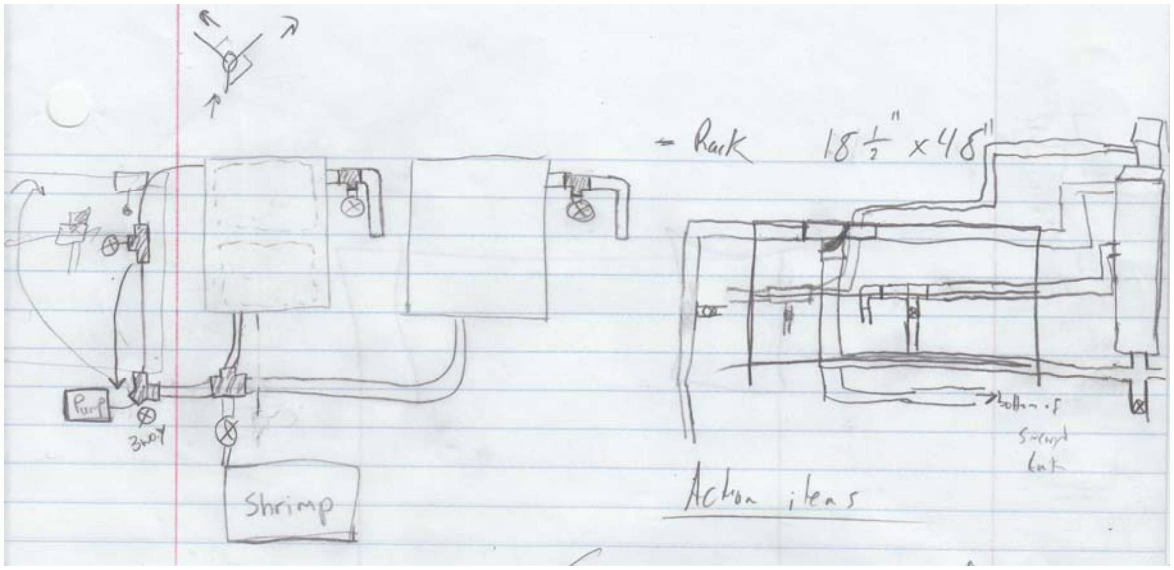


Fig B4: Initial Concept Sketch for Basket Dual Backwash System

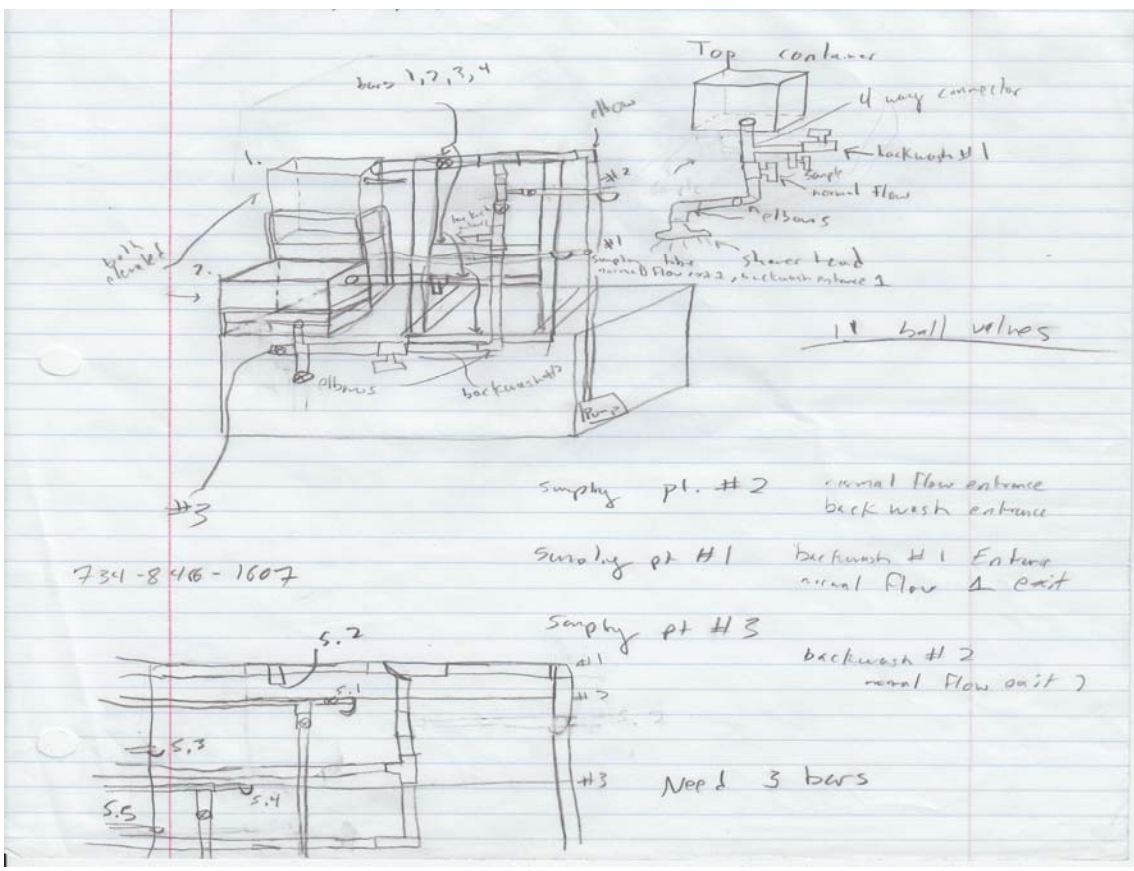


Fig. B5: Concept Drawings for the Cascading Dual Bucket System and Vertical Rack Setup

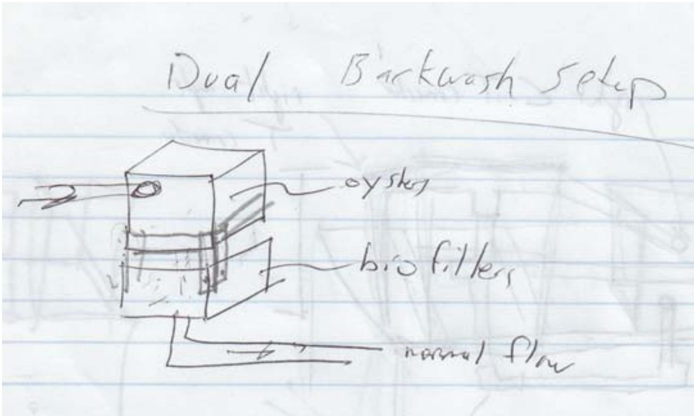


Figure B6: Problematic Initial Dual Bucket Setup

The adjustable rack was a solution engineered to provide a flexible benchtop for the aquaculture. Made of t-slotted aluminum extrusions, it will be rearrange-able with simple tools. The sensors for monitoring water quality will be hung or mounted to the rack, and the rungs of the rack will be slide-able, allowing quick and convenient repositioning of sensors. Any other equipment such as pumps or aeration devices will be able to be placed on top of the rack, thereby saving space in the laboratory. In several of the designs, the biofilters are placed on top of the rack. The adjustable rack is something that is common to all of our concepts, as it is a component that increases the flexibility of the overall design. It also does not obstruct or deter other components of the design.

The original concept for an adjustable rack involved having some sort of motorized arm to sweep the sensors connected to it back and forth. The heaters to keep the water temperature would also be attached to the motorized arm. Fig. C5 shows how something like this would be accomplished.

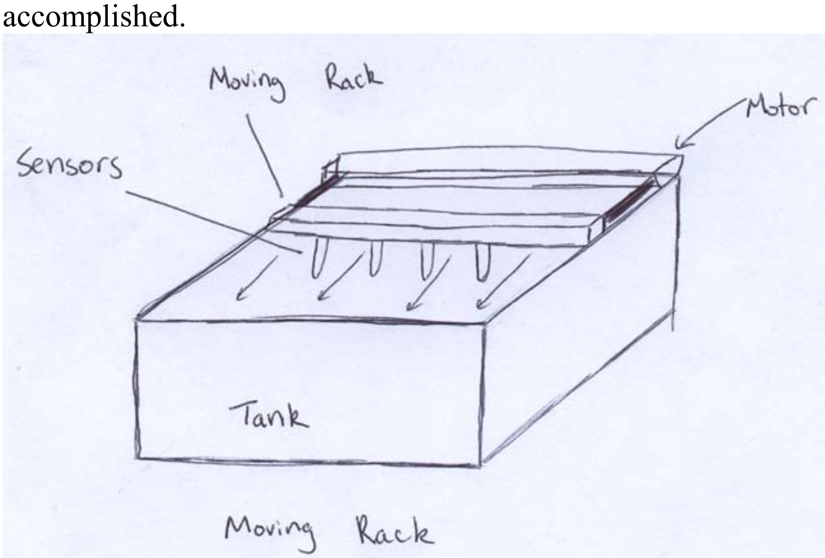
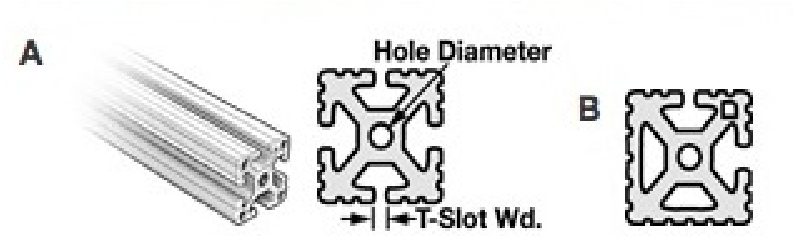


Figure B7: Initial concept sketches of adjustable rack

The current concept is to use T-slotted extruded aluminum oriented as shown in the CAD model in Fig. C6. Using T-bolts, a series of aluminum extrusions would be connected in a way that would still allow them to slide past one another.



www.mcmasters.com

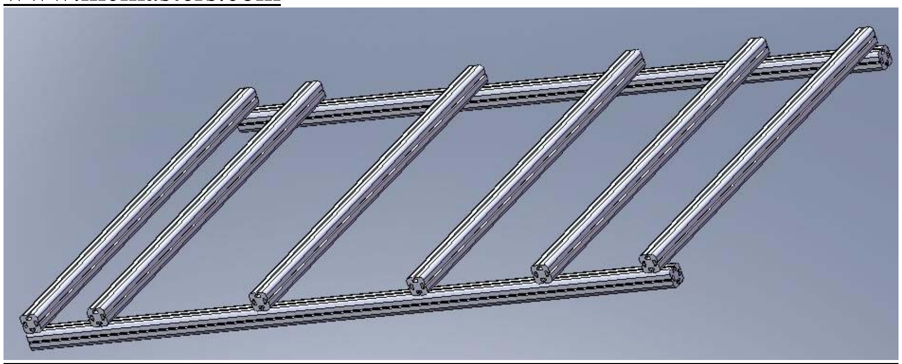


Figure B8: Rack Design Concept

Appendix C: Functional Decomposition

Shrimp Feeder

It was determined that to feed the shrimp, a commercial aquarium feeder could be bought, instead of designing and manufacturing our own. Many different types of feeders were found online, and most had the ability to automatically feed multiple times a day, for multiple days without refilling the feed. Feeders can be attached to tanks, and so we deemed the feeder to be a component that was separate from the rest of the design. Additionally, feeders included automatic timers. This solved one of our major design goals, which was to negate the need for someone to manually feed the shrimp several times a day. Some Possible feeders can be seen in Fig. C1

http://www.petmountain.com/shop/standard/feeders/508691/aquachef-aquarium-fish-feeder.jpg
http://spoiled-pups.com/images/ergo/images/2000pfm.jpg
Figure C1: Commercially Available Feeders

Pumps

Different pumps were examined from online sources and a local store (Aqua-Tec Engineers). Through talking with the salespeople at Aqua-Tec, it was determined that a ball bearing or oil driven pump would be a more flexible choice for us, compared with a magnetic drive pump. A non-magnetic drive pump would allow the use of a ball valve to control flow rates without overheating the pump. The lifetime of a non-magnetic drive pump was also reasonable; the Little Giant PEM 030 pump had an expected life time of 7-10 years (Mckenna, 2008). This number would of course vary depending on pump load, and the use of salt water.

The choice of a pump also depended on the flow rate that was required. From Monisha Brown's estimates, a flow rate of about 160 gph would be needed for normal operation. However, during backwash, a higher flow rate would be desirable, so a pump was chosen that could pump much more than the normal flow rate would dictate. Currently the most likely pump for our design is produced by Little Giant, has a max flow rate of 325 gph with a 2 ft. head. See Fig. C2.

http://www.lgpc.com/Aquarium/index.aspx?TypeID=5
Figure C2: Commercially Available Pumps

Piping

The best choice of piping for our aquarium setup is either flexible or rigid PVC. Both of these types of piping have their advantages and disadvantages. Flexible piping would be easier to rearrange, attach, and disconnect. Additionally, the clear varieties are more readily available and cheaper. Flexible PVC can have threads for connections, though threaded ends would have to be cemented on. Also, a biomass buildup in the tubing could be identified very easily which was a concern from our sponsor. On the other hand, inflexible PVC is more durable and can sustain higher pressures from within (McMaster-Carr Catalog 113). Ultimately, our choice of piping needs to mate with the type of pump selected.

Biofilter Media

The biofilter media comes in a variety of different geometries, sizes, and materials. The media efficiency affects the water quality by determining the amount of water cleaning bacteria, which is codependent on water flow rates (Losordo, Thomas). Our biofiilter container design must have great flexibility and needs to account for variable biofilter media.

Biofilter Container

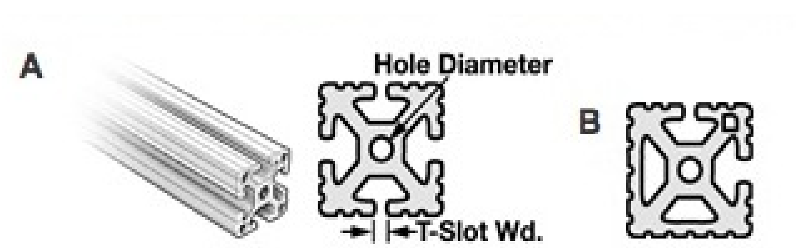
A large biofilter container is needed that can be sealed water tight, is easy to open to change biofilters, and must be large enough to hold bio-filter media. Effective water flow through the container must be ensured, and the maximum overall volume of the bio filter media is $0.3m^3$. The two top current choices for the biofilter containers are shown in Fig. C3.

http://www.usplastic.com/catalog/product.asp?catalog%5Fname=USPlastic&category%5Fname=20329&product%5Fid=16317
http://images.athleticstuff.com/f/726/16199/4h/www.athleticstuff.com/astuff/assets/product_images/CoolersandWaterBottles/5gatorade.jpg

Figure C3: Two possible sealable biofilter containers

Adjustable Rack

The large and adjustable rack must be strong and versatile enough to the weight of the plumbing system, backwash components, sensors, and biofilter container. A previous concept was to use T-slotted extruded aluminum oriented as shown in the CAD model in Fig. C4.



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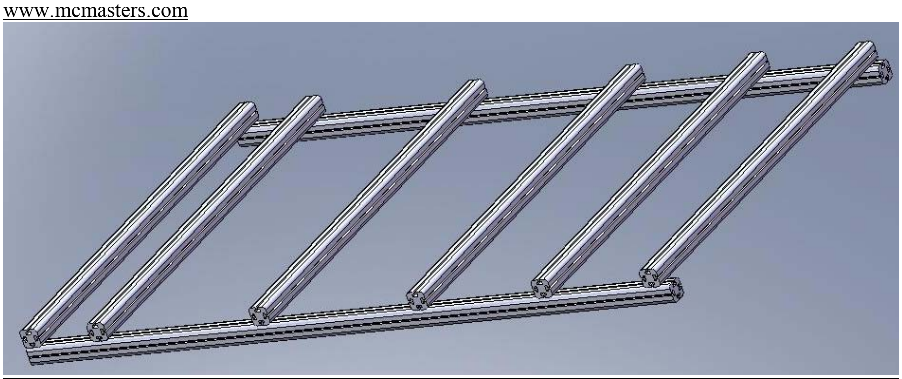

Figure C4. Rack Design Concept

Sensors

All the sensors necessary for the experiments to be carried out can be found commercially. All of the sensors are compatible with the data acquisition card to be used and can also be used in LabVIEW. The sensors to be used will measure pH, salinity, ammonia, dissolved oxygen, temperature, water level, and water pressure. Electrical components with manufacturer and specification are shown in Table C1 below.

Sensor	Manufacturer	Specifications
Ammonia	JUMO	**Range:** 0.01 - 20,000 ppm **Type:** Sealed, electrolyte-filled **Active membrane:** Glass **Reference membrane:** gas-permeable PTFE (Teflon) **Reference:** Double junction Ag/AgCl **Range:** 6 to 12 pH **Temp Range:** 0..50 °C **Accuracy:** +/- 2% **Connection:** Threaded Cap; Optional Cable with BNC **Dimensions:** 120mm (length), 12mm (dia)
Temp.	JUMO	**Type:** 2-Wire or 3-wire Pt100 Single Element **Case:** .25" x variable length, 6mm x 50mm or 6mm x 100mm, 316 Stainless Steel **Range:** -50 to +260 °C, -58 to +500 °C **Lead Wire:** 2500 mm (8.2'), metal braiding, stripped leads **Class:** B, alpha 0.00385/C
pH	JUMO	**Type:**Sealed,Gel-filled, Black-line, pH **Diaphragm:** Glass silk **Reference:** Single junction Ag/AgCl **Range:** 0 to 14 pH **Temp Range:** 0..60 °C **Connection:** 2m fixed cable with BNC connector (See image below) **Dimensions:** 120mm (length), 12mm (dia) **Typical Applications:** For Handheld Meters, Drinking water applications, much more
Salinity	Venier	**Range of Salinity Sensor:** 0 to 50 ppt **Accuracy:** ±1% of full-scale reading **Response time:** 98% of full-scale reading in 5 seconds. **Temp. compensation:** from 5 to 35°C **Temp. range** (can be placed in): 0 to 80°C **Cell constant**: 10 cm^{-1} **Description**: dip type, epoxy body, parallel platinum electrodes **Dimensions:** 12 mm OD and 150 mm length **Calibration Values:** Slope: 16.3 ppt/V

		Intercept: 0
Dissolved Oxygen	Cole-Parmer	**Immersion depth (mm)** 210 mm **Diameter** 12 mm **Temp compensation** none **Temp range** 32 to 140°F (0 to 60°C) **Stability** better than ±2% of reading per week **Response** 98% in 60 seconds **Sterilization temperature** 266°F (130°C) **Max pressure** 2.4 bar (35 psi) **Cable connection** threaded detachable lead **Probe** polarographic
Data Acquisition Device	**Manufacturer**	**Specifications**
PCI-6225	National Instrument	**General** **Form Factor** PCI **DAQ Product Family** M Series **Analog Input** **Number of Channels** 80 SE/40 DI **Sample Rate** 250 kS/s **Resolution** 16 bits **Maximum Voltage Range** -10..10 V

		Analog Output	
		Number of Channels	2
		Update Rate	833 kS/s
		Resolution	16 bits
		Maximum Voltage Range	-10..10 V
		Digital I/O	
		Number of Channels	24 DIO
		Timing	Hardware
		Maximum Clock Rate	1 MHz
		Logic Levels	TTL
		Maximum Input Range	0..5 V
		Maximum Output Range	0..5 V
		Supports Pattern I/O?	Yes
		Counter/Timers	
		Number of Counter/Timers	2
		Resolution	32 bits
		Maximum Source Frequency	80 MHz
		Minimum Input Pulse Width	12.5 ns
		Logic Levels	TTL
		Maximum Range	0..5 V
		Timebase Stability	50 ppm

Table C1: Electronic components manufacturer and specification.

Appendix D: Concept Selection Process

Figure D1 displays a visual schematic of the elimination process of the main plumbing designs.

Concept #1- The advantage of this design is simple backwashing. A person would simply take the filters out and leave it upside down to be sprayed with a hose. This design is also easy to create, and easy to replace. However, this design does not allow for a flexible flow rate. Flexible flow rates would normally be achieved by using a variable pump, or by using a ball valve.

Concept #2- The lack of piping in this design would mean less cleaning involved. A major problem reported by the sponsors is the need to clean and de-clog the system from growing bacteria and biomass. As it stands, the reverse dam has no way to backwash without some modifications.

Concept #3 –There is a larger number of plumbing components with this but there is also much more flexibility as a result. Any size biofilter can be integrated, any pump can be integrated, and there are four sampling points. With so many plumbing components preventing leaks in plumbing connections would be a greater challenge.

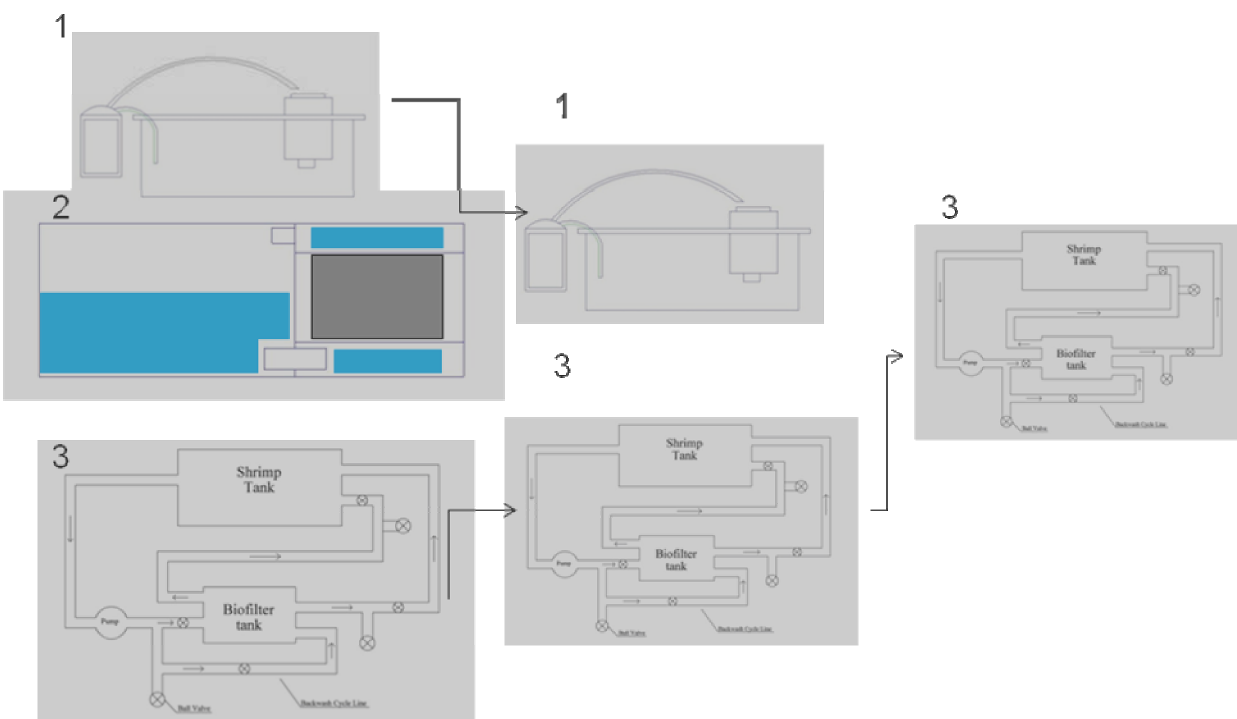

Figure D1: Design Breakdown bracket of Plumbing System

The second concept was eliminated upon receiving request that a backwash system be installed. This is one of the biggest drawbacks of the design as discussed in Table 1 below. Additionally there was no simple method of external flow rate adjustment since all the components would be built into the tank. The first and third concepts required much more discussion. Both of these designs would be effective designs but ultimately the lack of flexibility eliminated the canister pump design. There is too much reliance on a single component sold at Petco. We felt the canister design was much more compact and elegant but the biofilter size limitations and the challenges presented in trying to accomplish an effective backwash were too great to continue with the design.

The third concept of reverse flow involved a somewhat complex valve system to redirect flows according to the desired operations. Initially this design had the biofilter located below the tank with water falling to the pump and then pushed through the filter and back up to the tank. The tank was also originally open to the ambient and included a float valve to control the water level. We realized that the location of the biofilter below the tank would create too many issues with having to worry about biofilter container overflow and overflow when changing the biofilters. After some further thought we determined it would be better to place the plumbing components above the tank and the biofilter container sealed so that if the pump were shut off, the water would flow down through the piping and back into the main tank. The overflow issue was therefore resolved. The main obstacles were then removed and we determined the third concept would best meet the design specifications and customer needs.

Concept #	Pros	Cons
1. Canister Pump Design	• Compact filter design • Elegant design and simple construction • Simple backwashing operation • Amount of plumbing components reduced • Ability to monitor pressure differences	• Small filter container • Limited selection for motor power • Flexible tubing is only option • Backwash operation is limited to changing direction of filter • Setup dependent on single pump design
2. Reverse Dam	• Reduced piping, needs less maintenance • Saves space	• No way to reverse flow without additional piping • No backwash option
3. Reversible Flow	• Great flexibility and modification capability • Backwash versatility • Simple pressure detection across biofilter	• Excess pipe material used • Requires many ball valves • Large pump motor stresses and resistance • Complicated Valve system • Components external to tank

Table D1: Plumbing System discussion of Pros and Cons

The selection of the backwash improvement methods ultimately came down to efficacy and cost. The second concept shown below was eliminated quickly due to concerns regarding the intensity of the cleaning process. The concern is that the vibrations may be too strong and the design be too effective at removing biomass. If too much biomass is removed from the filters the cleaning system will not function properly. The ultrasonic concept still may be able to be incorporated into the current design but more research needs to be completed.

The main factor in choosing the third concept over the second was cost. To accomplish the third concept all that is needed is air which is already provided in the lab and a parallel piping setup. The lab mixer concept on the other hand requires the installation of a blender like component that costs up to $200. Concept three was ultimately chosen because if it can perform the backwash effectively at a lower cost it would be best for our sponsor. Further description of the pros and cons and a schematic of the selection process are shown in Fig. D2 and Table D2.

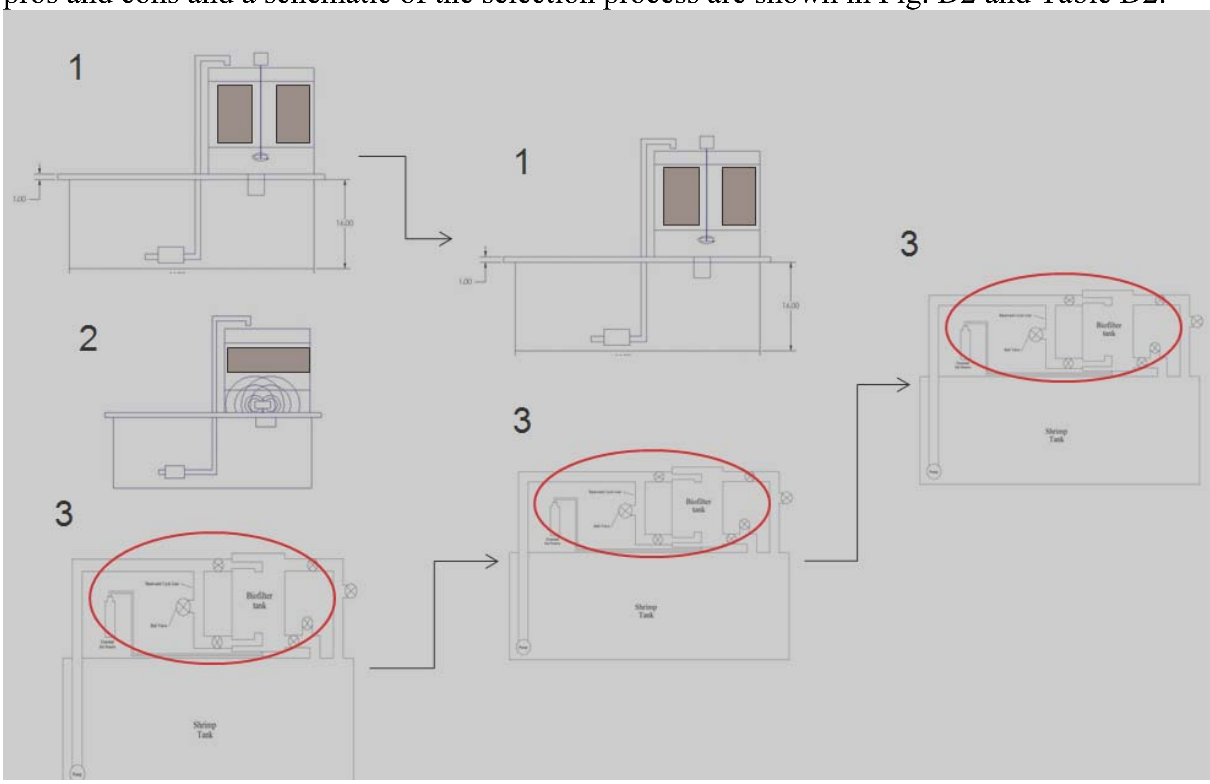

Figure D2: Design Breakdown bracket of Backwash Improvement Methods

Concept #	Pros	Cons
1. Lab Mixer	• More churning of water to agitate particles • Less piping needed	• Expensive ($200) • More mechanical components
2. Ulrasonic Backwash	• Effective at removing biomass • Hits all areas of filter	• May kill the bacteria on the filters (too effective) • Expensive

3. Reversible and variable flow	• Low cost • Great pressure and reverse flow potential • Reduced evaporation	• Many components • Biofilter container needs to be sealed

Table D2: Backwash Improvement Method discussion of Pros and Cons

The decision for the basket dual backwash plumbing system was a matter of fewer components, and materials, reduced complexity, more similar backwash environments, and a more stable support structure. A more compact design allows for greater space availability, and a more comfortable lab environment. Both systems are very similar, and the plumbing system outside of the backwashing remains largely unchanged. Table D3 below illustrates the factors that led to the final decision.

Concept #	Pros	Cons
1. Cascading Dual Backwash Plumbing System	• No physical contact with the biofilters necessary • Entirely controlled with valves • Simple sampling between two fileters during normal operation	• One biofilter container must be elevated over 2 ft. above tank • More expensive and bulky support system system • Additional materials and complicated valve system
4. Basket Dual Backwash Plumbing System	• Few valve components with simple backwash process • Equally elevated containers allow for similar water potentials to each	• Must physically move biofilters

Table D3: Dual Backwash

Finally, the final design chosen for the data acquisition system came down to reliability, ease of use, and convenience. The first concept is too work intensive for the lab researchers requiring a more consistent and constant presence in the lab. There are also the issues of cross contamination if using a single tub for the measurements of all the different tanks. It came down to the second and third concept, but the third concept was chosen because it automatically informs the researcher of issues, and allows them to receive daily updates on the status of the aquacultures. See Fig. D3 and Table D3 for more information.

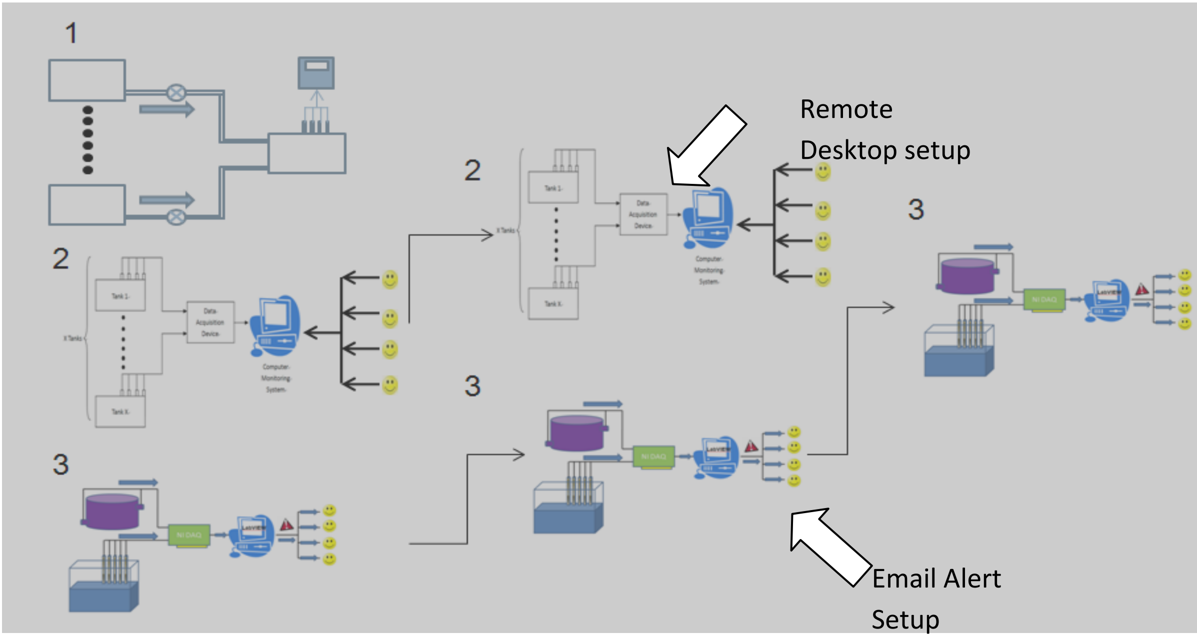

Figure D3: Design Breakdown bracket of Data acquisition System

Concept #	Pros	Cons
1. Sampling pool with data logger	• Low Hardware Cost • Easy Setup	• High time and labor cost • Discontinuous monitoring • Low Customizability • Cross contamination
2. Computer-based remote monitoring system using Remote desktop	• Timing saving	• Only allows one user to log in at a time • Frequently log in and off can be problematic • Still need regular check • High hardware cost
3. Computer-based remote monitoring system using email notification from LabVIEW	• No need for regular check	• Complexity in synchronizing the LabVIEW code and email server • High hardware cost

Table D4: Data Acquisition System discussion of Pros and Cons

The non-motorized rack designed using t-slotted extrusions was selected to be our adjustable rack. Looking at the feasibility and economics of this project, it was decided that making a motorized arm that swung back and forth over the water would be too time-consuming for the benefits that came with it.

Concept #	Pros	Cons
1 – Motorized Rack	• Sensors sample the entire tank. Avoids local sampling error • Feed is spread over entire tank. • Tank is heated evenly	• Potentially costly. A motor is needed • Design and construction needed • The need to hold filter container complicates design
2 – non-Motorized Rack	• Sensors can be repositioned, albeit manually.	• Not automatic • Can hold filter container natively

Table D5: Rack selection with Pros and Cons

Appendix E: LabVIEW Block Diagram

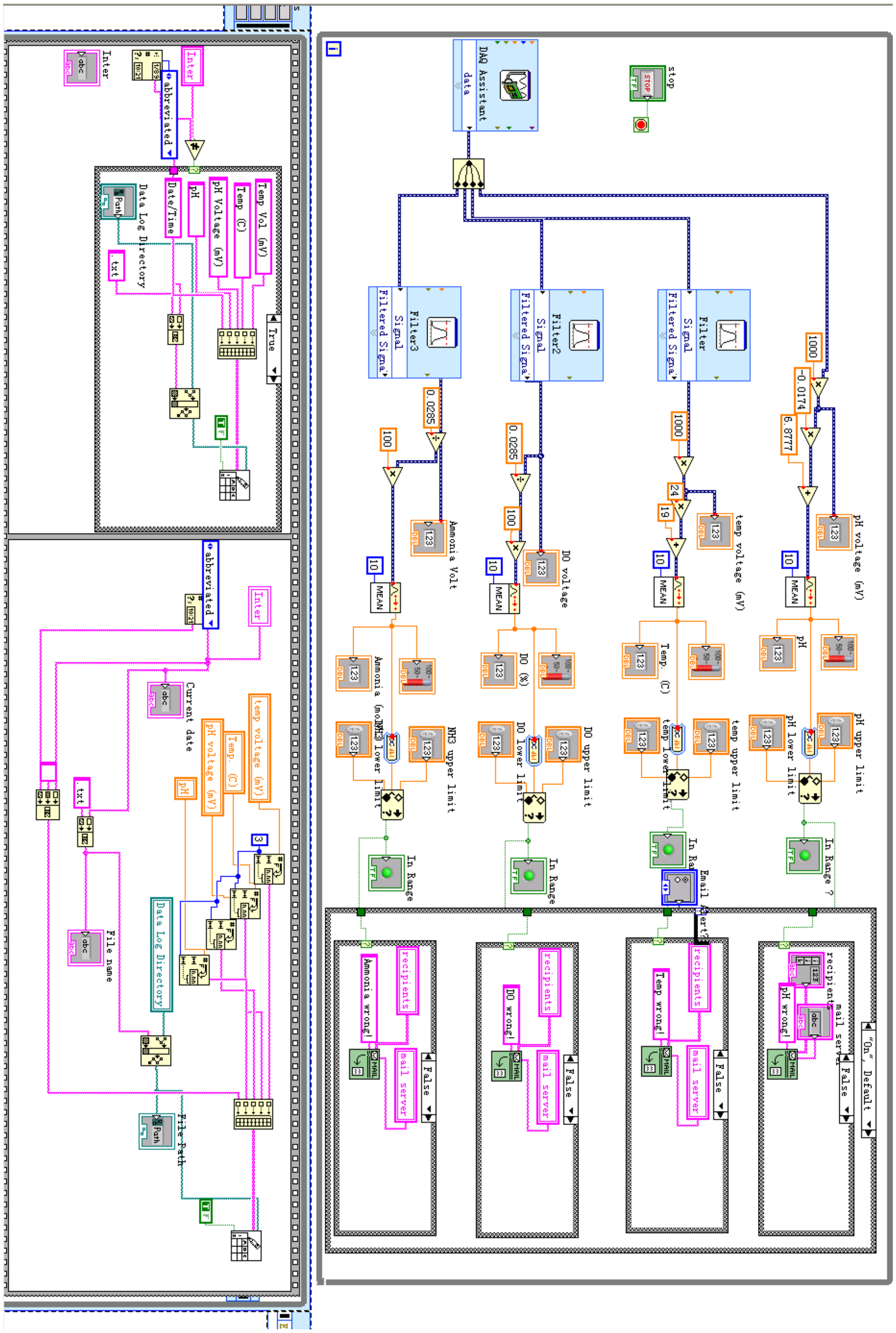

Figure E1: Labview Block Diagram

Appendix F: Engineering Drawings

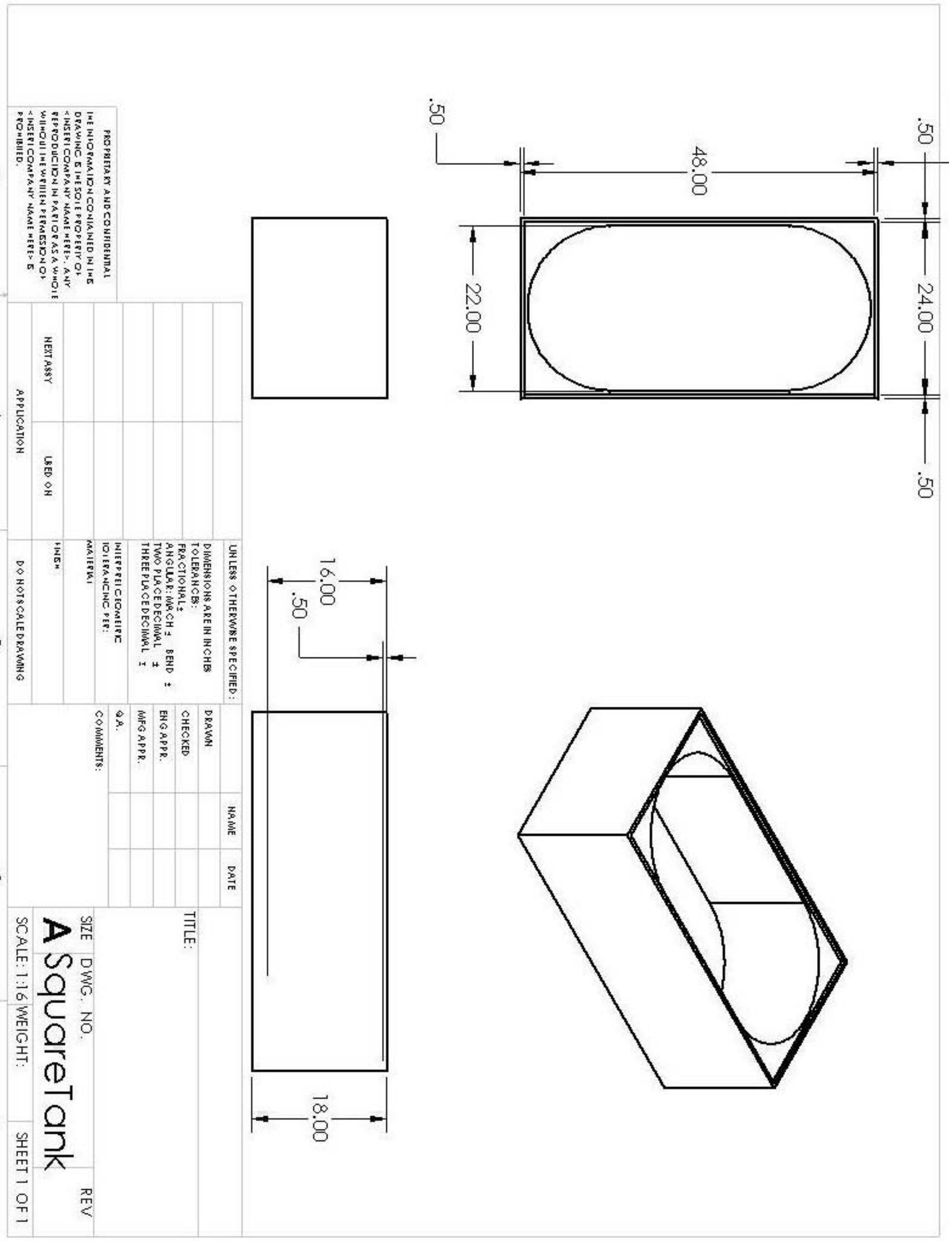

Figure F1: Aquarium dimensioned sketch

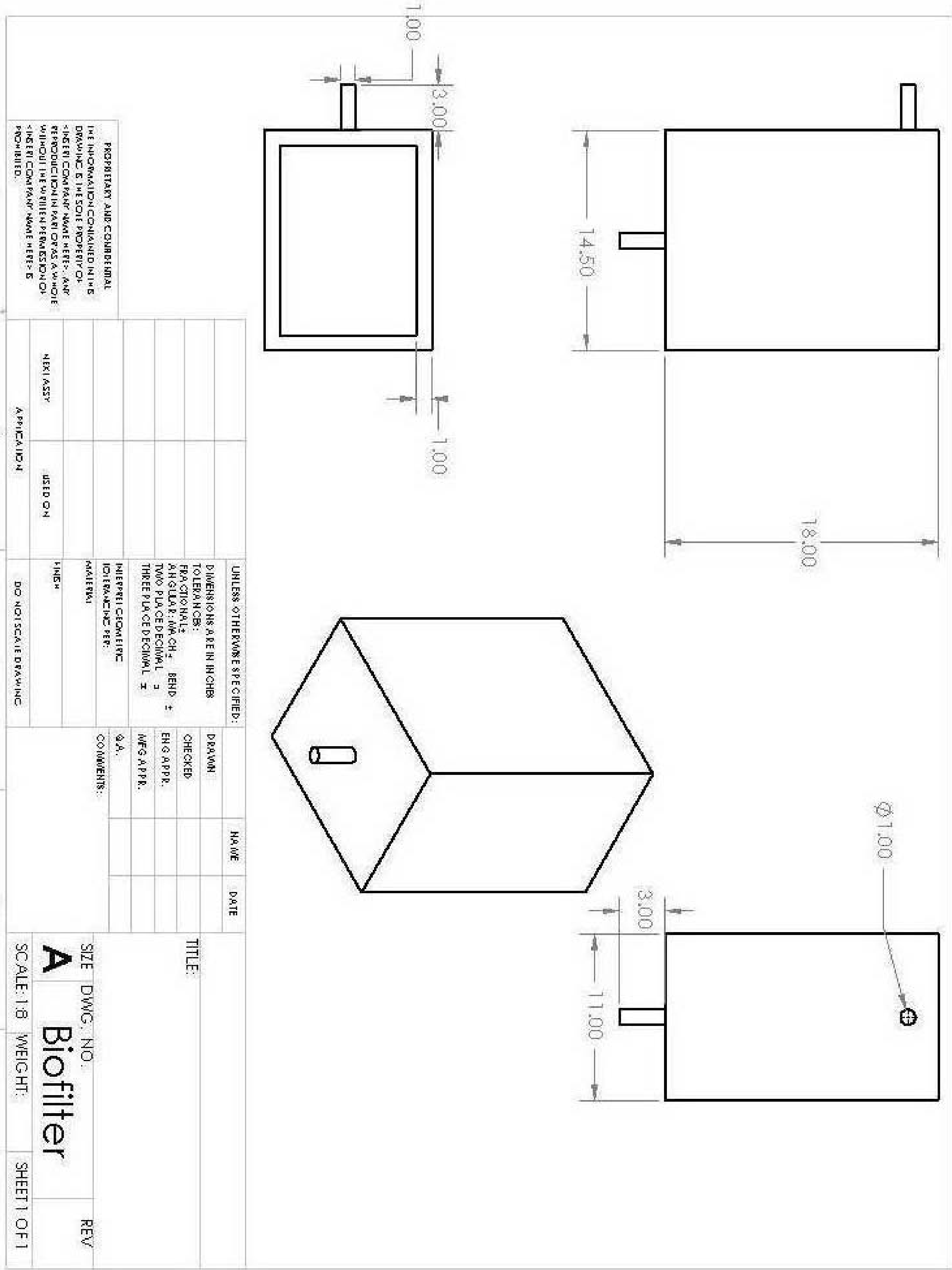

Figure F2: Biofilter Dimensioned Drawing

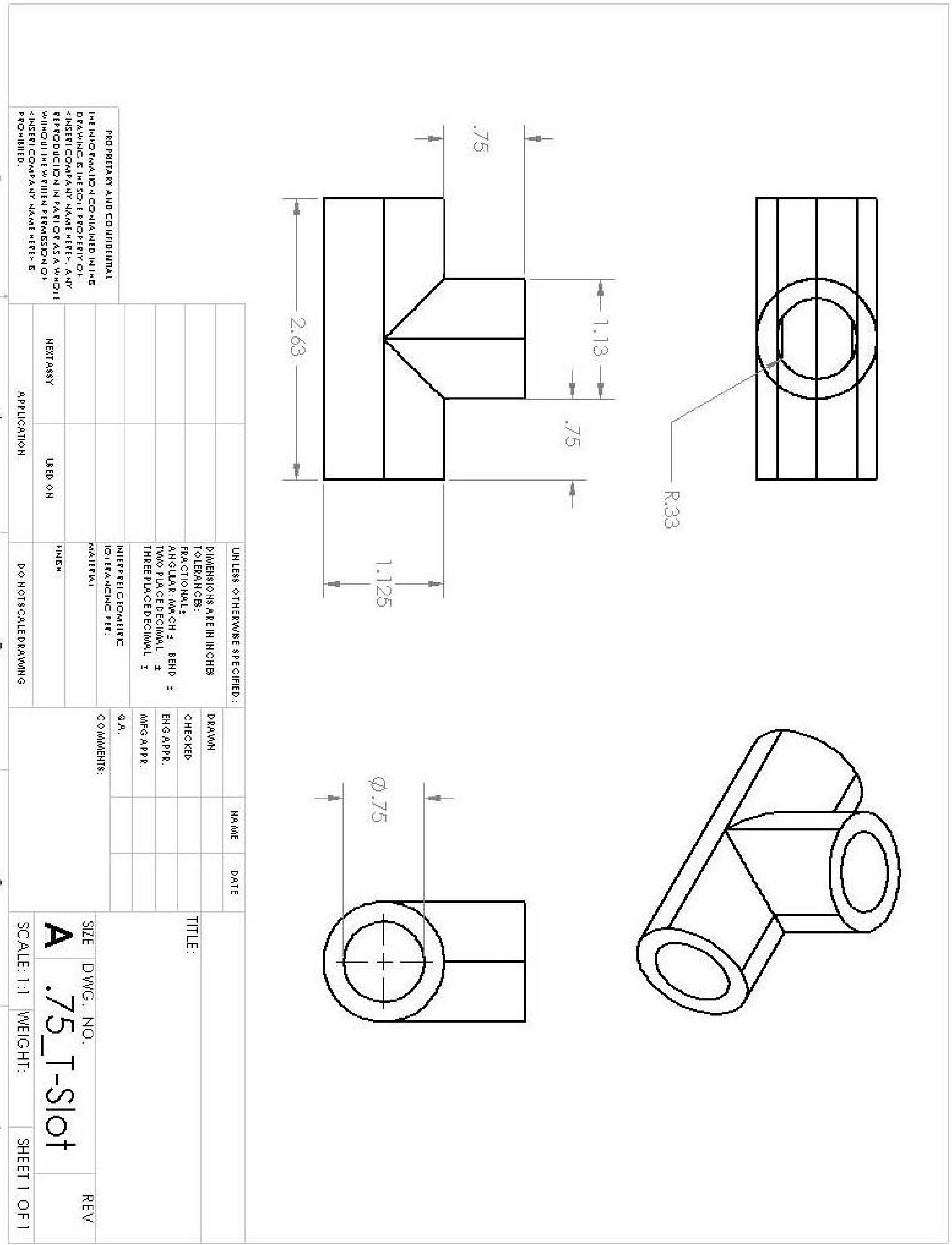

Figure F3: 3/4” T Dimensioned Sketch

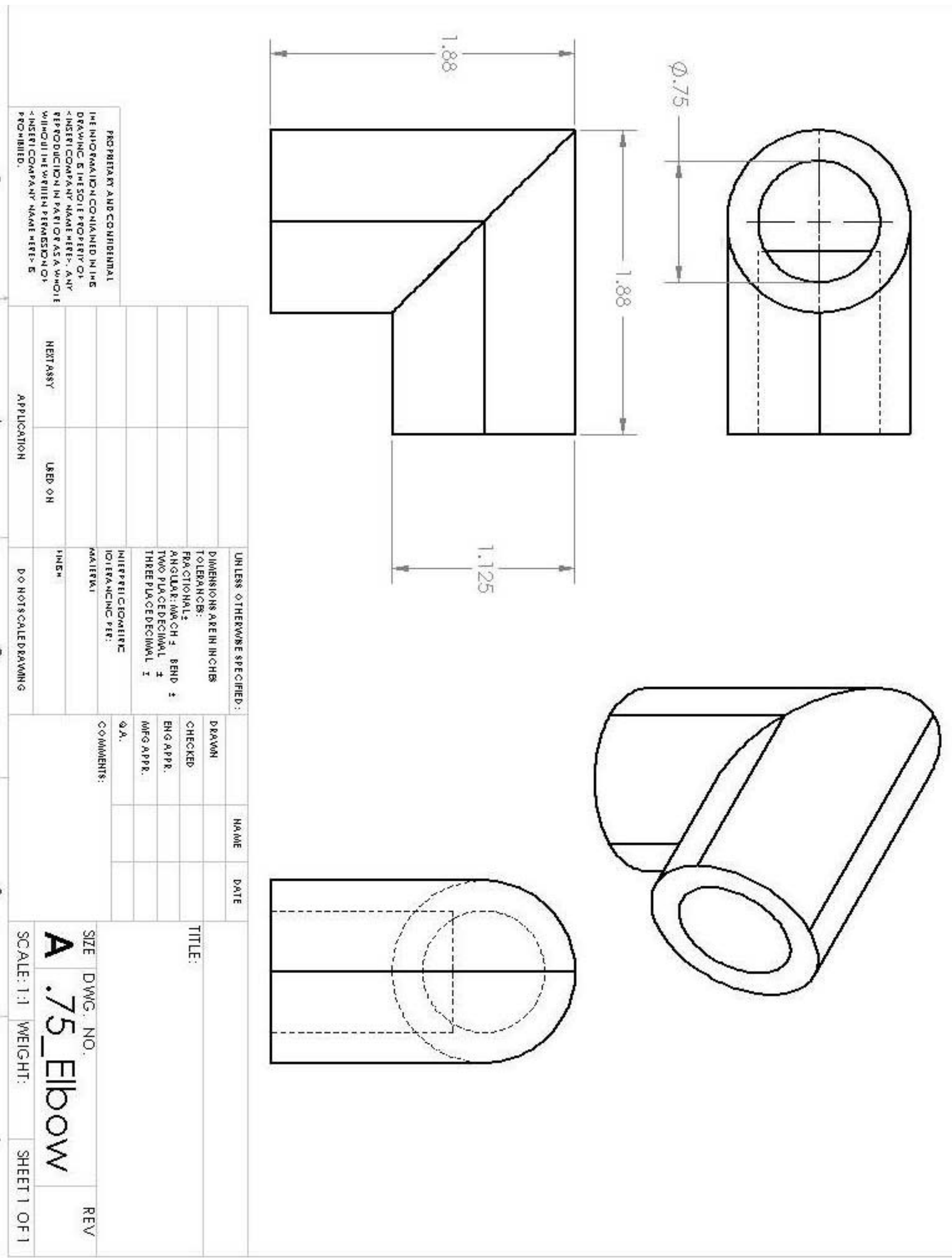

Figure F4: 3/4" Elbow Dimensioned Sketch

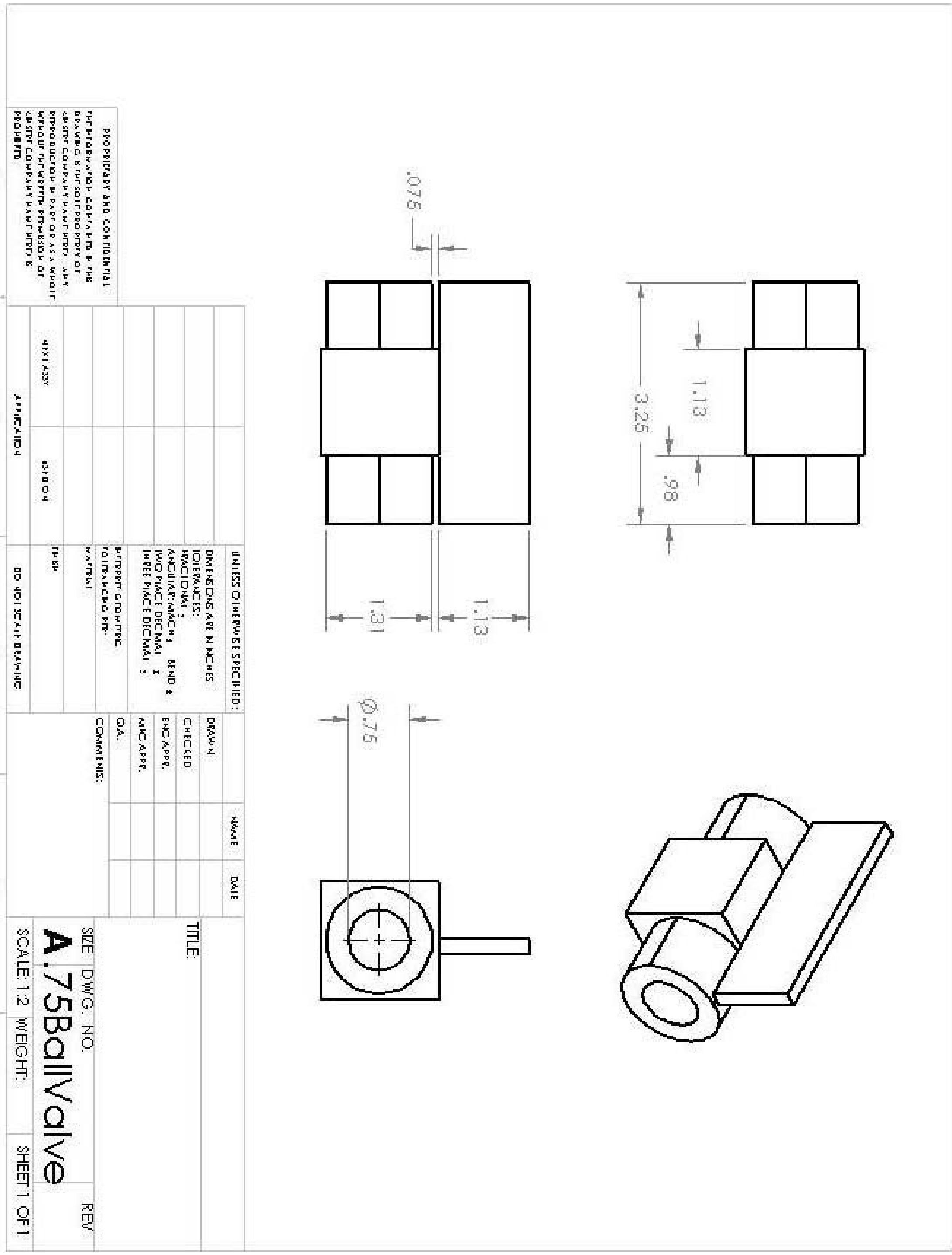

Figure F5: 3/4” Ball Valve Dimensioned Sketch

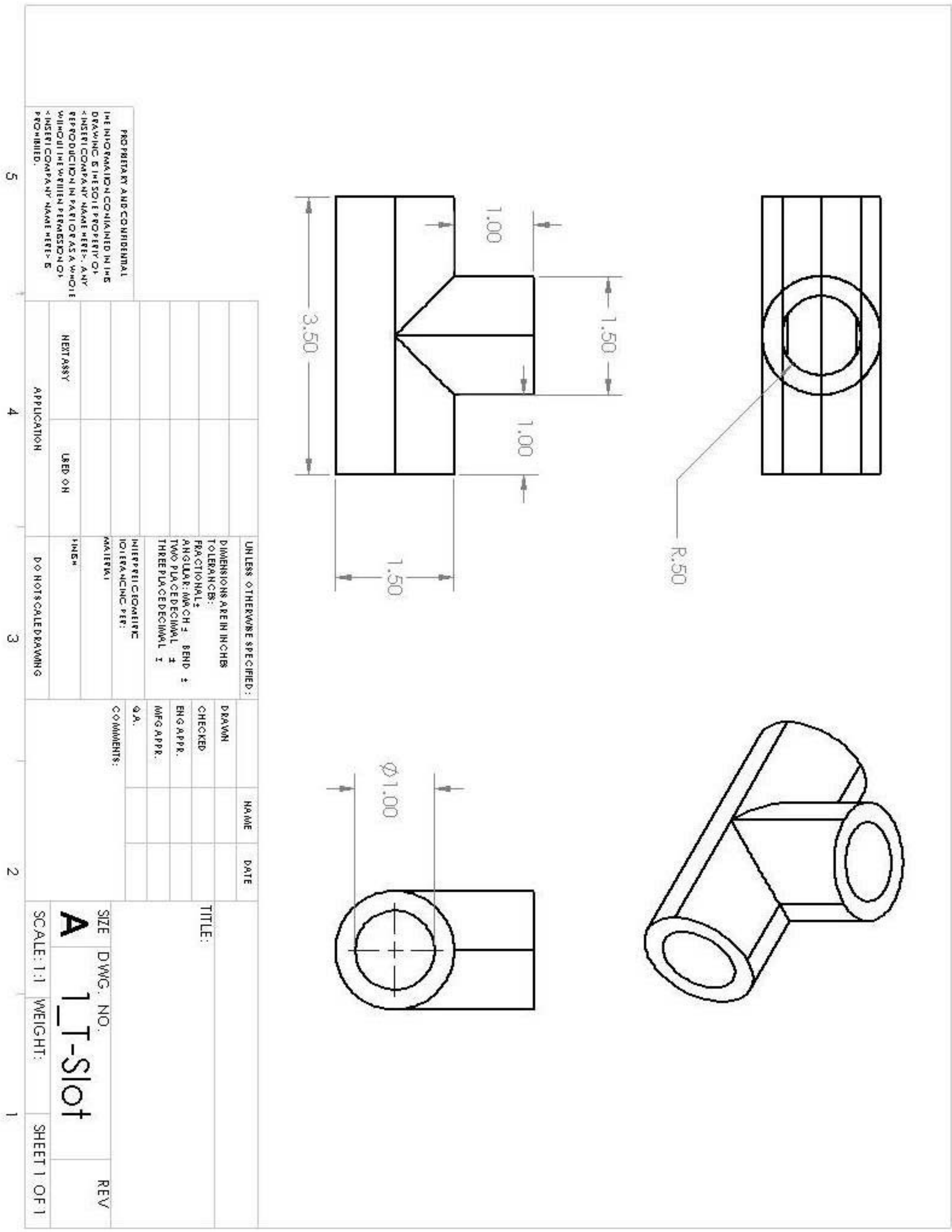

Figure F6: 1” T Joint Dimensioned Sketch

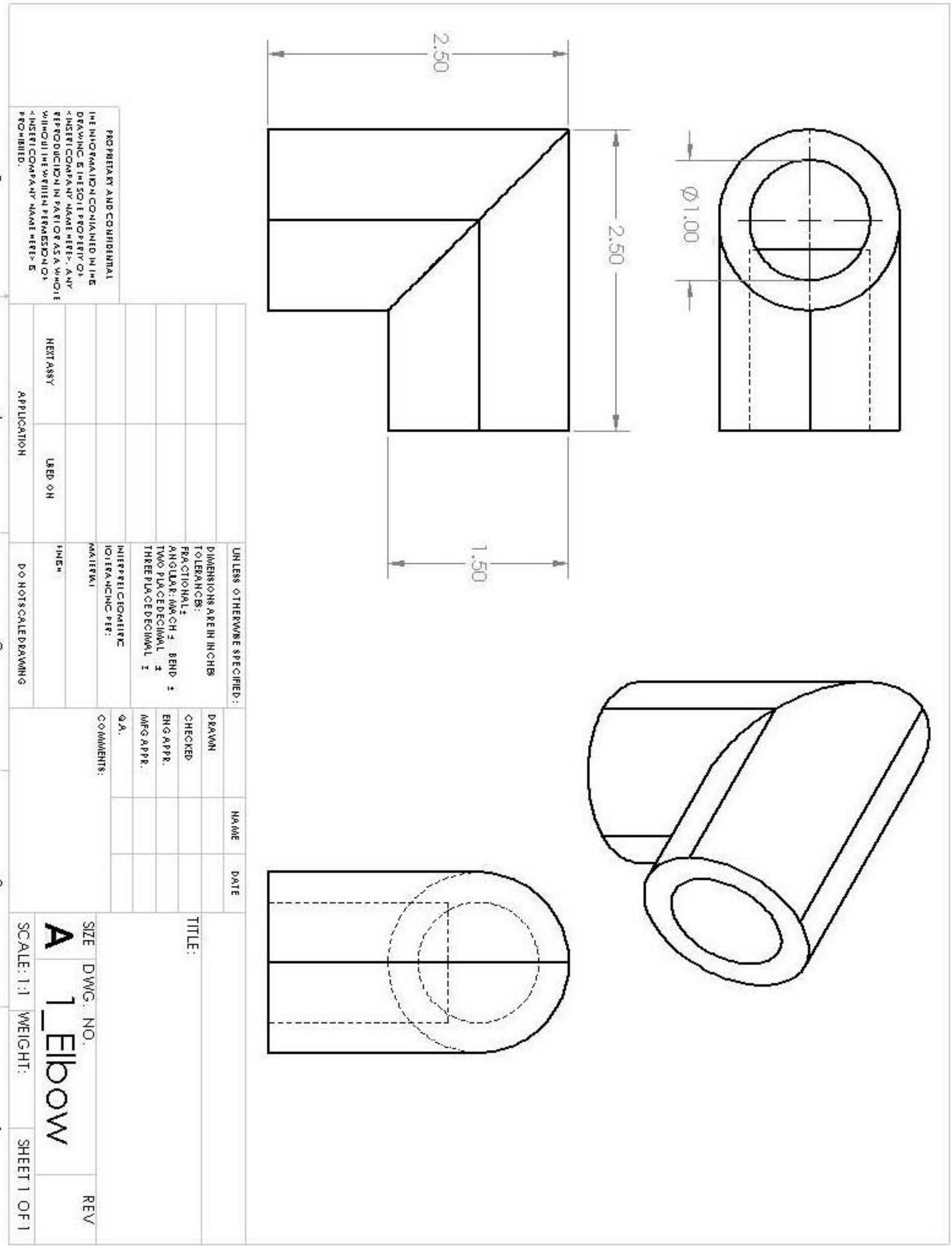

Figure F7: 1” Elbow Joint Dimensioned Sketch

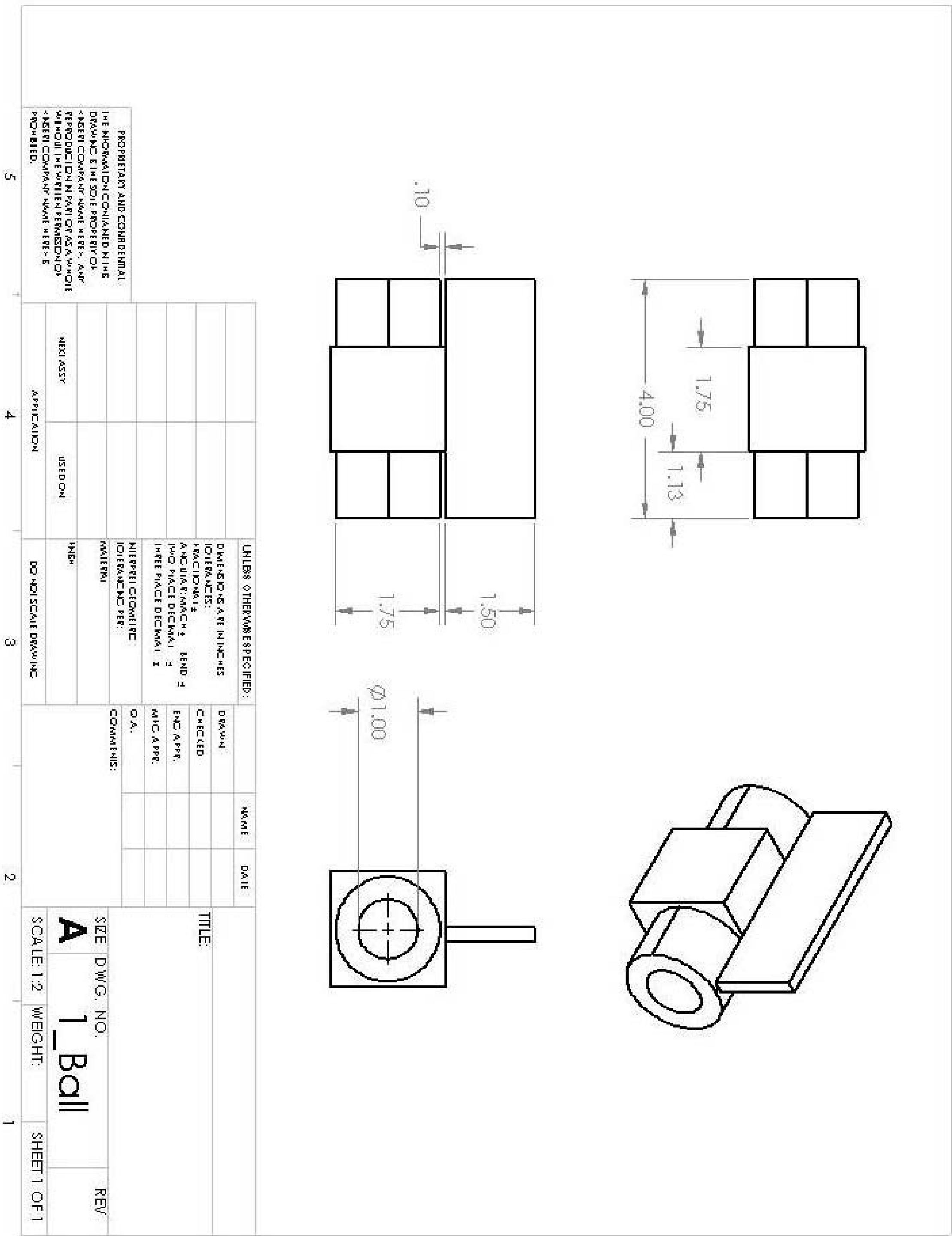

Figure F8: 1” Ball Valve Dimensioned Sketch

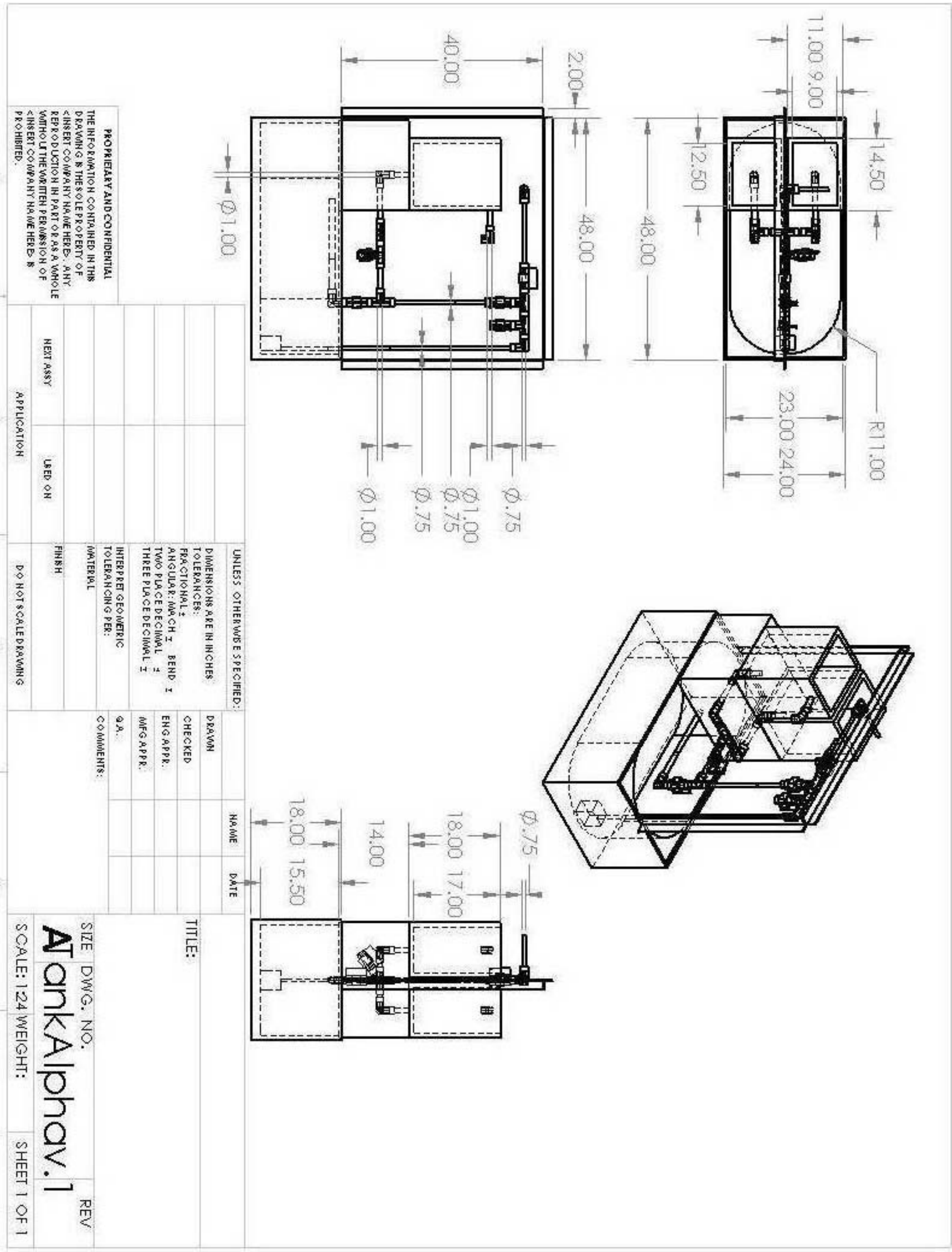

Figure F9: Alpha Design Dimensioned Sketch

Appendix G: Bill of Materials

Part # (McMaster Carr Catalog #)	Part Name	Qty	Material	Size	Manuf. Process	Function
	2x4 Wood	6	Spruce	7'	Handheld Power Saw	Mounts Biofilter
	Aquaculture Tank	1	Plastic	48"x24"x18"		Houses Experiment
	Biofilter Tank	2	Plastic	14.5"x11"x18"	Drill - up to 2" bits	Houses Biofilter Media
5463K615	T-Section	2	PVC	.75" diameter		Used for Piping system and Sampling points
5463K287	T-Sections	3	PVC	1" diameter		Used for Piping system and Sampling points
5463K604	Pipe Elbows	2	PVC	.75" diameter		Used for Piping system
5463K277	Pipe Elbows	7	PVC	1" diameter		Used for Piping system
4876K12	Ball Valves	3	PVC	.75" diameter		Used for Piping system and redirecting flow
4876K13	Ball Valves	4	PVC	1" diameter		Used for Piping system and redirecting flow
5195T82	Piping	N/A	Polyureth	76" piping of .75" diameter		Used for Piping system and Adjustible Rack
5195T84	Piping	N/A	Polyureth	140" piping of 1" diameter		Used for Piping system and Adjustible Rack
	Piping	N/A	PVC	48" piping of 1" diameter		Adjustible Rack
	Piping	N/A	PVC	48" piping of 1.25" diameter		Adjustible Rack
8968K26	Angle Iron	N/A	Iron	144"		Supports Piping system
5463K265	Pipe Adapters	5	PVC	.75" diameter		Connects Threaded with Polyurethane Piping
5463K481	Pipe Adapters	11	PVC	1" diameter		Connects Threaded with Polyurethane Piping
5372K136	Step down Adapter	1	PVC	1" to .75" diameter		Connects Threaded with Polyurethane Piping for backwash
	Pipe Connectors	5	PVC	,75" diameter		Connects PVC Sections
	Pipe Connectors	6	PVC	1" diameter		Connects PVC Sections
36895K123	BulkHead	2	PVC	1" Pipe Size		Connects Biofilter with Rubber Piping
36895K122	BulkHead	2	PVC	0.75" Pipe Size		Connects Biofilter with Rubber Piping
54195K18	Metal Fasteners	30	Stainless Steel			Secures piping connections

Figure G1: Bill of Materials

APPENDIX H: GANTT CHART

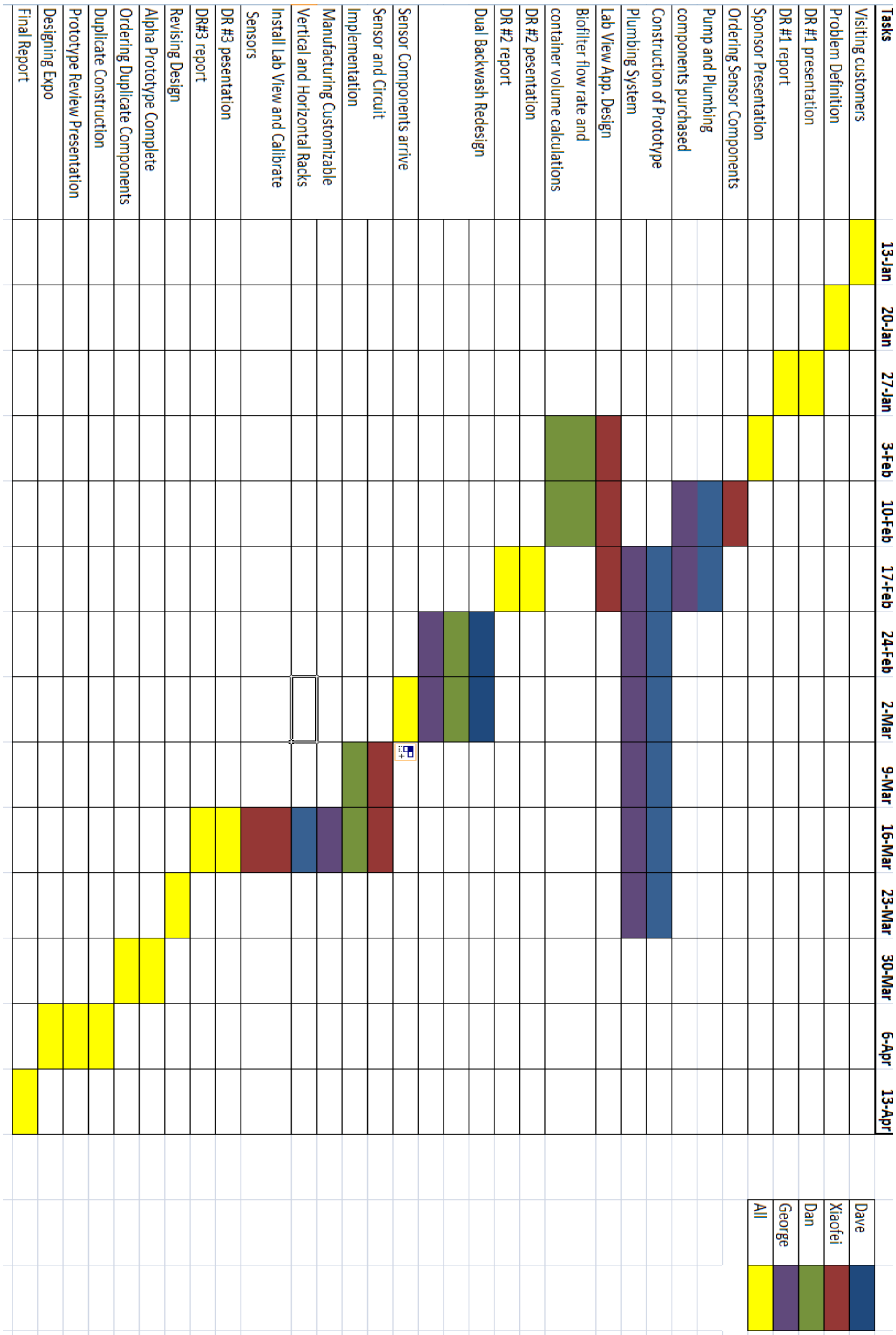

Figure H1: Project Gantt Chart

Appendix I: Additional Assignments

Materials Selection

The biofilter tank and biofilter support structure were selected for materials analysis. Materials analysis was performed using the Cambridge Engineering Selector. For each component, the important functions were determined, and from that the required characteristics were used to narrow the selection of materials.

The biofilter tank was used to contain the biofilters, which would filter out the water. The tank would have to be in contact with salt water constantly, as well as hold a maximum load of water during the backwashing cycle. This maximum load would be approximately 150 pounds of water, as the biofilter tank would be almost filled with water when backwashing. For the strength constraint, the bottom of the tank was simulated to be a thin walled pipe. We reasoned that bottom of the tank will be supported, and so the main mode of failing should be from the sides of the tank ripping. Using the formula below, the stress on the walls of the tank was calculated.

$$Stress = \frac{P * radius}{2 * thickness} \qquad \text{Eq.1I}$$

Longitudinal Stress on the sides of a pressurized cylinder

The stress on the tank was calculated from the pressure at the bottom of the filled biofilter tank, as that is the region of the tank experiencing the most pressure, and therefore the most stress. The radius was used as 7 inches, which is half the length of the biofilter tank. The calculated maximum stresses on the walls of the biofilter tank were found to be 0.193 MPa. These numbers were reasonably conservative, though a large safety factor would have to be used, as an unconventional method of approximating the biofilter tank as a thin walled tube was used.

In the Cambridge Engineering Selector (CES) software, two main constraints were used for the materials selection: yield strength and cost. Because this was a relatively un-intensive component, cost was used to really narrow the field of possible materials. The yield strength was placed between 0.28 ksi (10x 0.193 MPa) and 100 ksi. The range of materials strength was relatively high, so as not to exclude cheaper materials that were stronger. Even after placing the cost requirement at $1 USD, a large number of materials were left. These materials were grouped under five main categories: woods, stones, plastics, rubbers, and metals. Metals were discounted for being prone to corrosion. Both metals and stones were discounted for being too heavy as well. Rubbers were excluded for being too elastic. Though the yield strength is high, the yield strength represents the point at which elastic deformation stops; rubbers could deform significantly before actually yielding, and this was not desirable. With those three materials excluded, the decision was down to either woods or plastics. Both categories had a very large number of specific materials that could fulfill the task, so the decision would be made about which was cheaper and more convenient to obtain.

Not many water proof wood containers are made, so naturally, an easy to find plastic container was the solution. There is an enormous variety of plastic containers in the market, because plastics are relatively durable, lightweight, and cheap to produce. An easy solution for us would be to go to the local super market, and pick out a large plastic container. We ended up buying a

36L high density polyethylene (HDPE) trash can from ACE Hardware. For future tanks, a more durable container can be found on industrial plastic producers such as US Plastics.

The biofilter supports were already selected and validated before the materials design was complete, though the CES software can still be used to justify the materials used. The biofilter supports will experience a stress of 1.17 MPa, as shown from the Engineering Design Parameter Analysis section of this paper. The stress was calculated using beam bending equations. In the CES software, cost and yield strength were used again to select materials. Again, the biofilter supports did not have to support a very large amount of stress, so cost and convenience determined the materials used. The CES software narrowed the various materials included woods, stones, plastics, rubbers, and metals. Stones and metals were discarded for reasons of corrosion, and weight. Rubbers were discarded because of their elasticity and lower Young's Modulus. This time, wood was selected as the support materials because wood is easier to obtain as a structural material. It is also much cheaper to produce than plastics. There is a lumber yard in the downtown area, so researchers that want to build additional shrimp aquaculture can easily obtain wood. Also, wood is sold very commonly as 2x4 planks, whereas plastics are not. The exact grade of wood that was selected was "stud grade", which is made of a type of spruce. In total, the cost of the wood for the biofilter support structure was under $10 USD.

Design for Assembly

The profiles of the components we assembled for our final prototype are listed below in Table I1.

Components	**Total number**	**α**	**β**	**α+β**	**Thickness**	**Size**
Support for Sliding rack	4	90	180	270	>2 mm	>15 mm
Sliding rack	1	180	180	360	>2 mm	>15 mm
Wood support for biofilter	24	180	180	360	>2 mm	>15 mm
Frame	4	90	180	270	<2 mm	>15 mm
Pump	1	0	360	360	>2 mm	>15 mm
tubing	15	0	180	180	>2 mm	>15 mm
Corner	12	180	180	360	>2 mm	>15 mm
Adapter	12	0	360	360	>2 mm	>15 mm
T-valve	4	180	180	360	>2 mm	>15 mm
Ball Valve	5	180	0	180	>2 mm	>15 mm
Biofilter Fixture	8	360	360	720	<2 mm	>15 mm
Biofilter	2	180	360	540	>2 mm	>15 mm

Bulk Heads	4	0	360	360	>2 mm	>15 mm
Feeder	1	360	360	720	>2 mm	>15 mm

Table I1: Profiles of components for original design

The corresponding DFA worksheet is:

Part	Total number	Handling Code	Handling Time (sec)	Insersion Code	Insertion Time （sec)	Operating Time (sec)
Support for rack	4	0	1.13	38	6	28.52
Sliding rack	1	90	2	38	6	8
Wood support for biofilter	24	0	1.13	38	6	171.12
Frame	4	80	4.1	38	6	40.4
Pump	1	0	1.13	1	2.5	3.63
Tubing	15	0	1.13	1	2.5	54.45
Corner	12	10	1.5	1	2.5	48
Adapter	12	10	1.5	0	1.5	36
T-valve	4	10	1.5	0	1.5	12
Ball Valve	5	0	1.13	0	1.5	13.15
Biofilter Fixture	8	3	1.69	38	6	61.52
Biofilter	2	80	4.1	30	2	12.2
Bulk Heads	4	10	1.5	30	2	14
Feeder	1	83	5.6	38	6	11.6

Table I2: DFA worksheet for original design

As was determined by the DFA, the total assembly time is 514.59 sec, and the theoretical minimum number of parts required is 97, which lead to an assembly efficiency of 56.55%. Combining components will make the assembly easier. However, for most components of our design, combination of components will make the fabrication much more difficult. The only possible assembly improvement for our design is that instead of assembling 24 pieces of wood as the biofilter support, we use two big chucks of wood. The DFA worksheet for redesign is shown below in Table I3:

Part	Total number	Handling Code	Handling Time	Insersion Code	Insersion Time	Operating Time
Support for Sliding rack	4	0	1.13	38	6	28.52
Sliding rack	1	90	2	38	6	8
Wood support for biofilter	**2**	**80**	**4.1**	**38**	**6**	**20.2**
Frame	4	80	4.1	38	6	40.4
Pump	1	0	1.13	1	2.5	3.63
Tubing	15	0	1.13	1	2.5	54.45
Corner	12	10	1.5	1	2.5	48
Adapter	12	10	1.5	0	1.5	36
T-valve	4	10	1.5	0	1.5	12
Ball Valve	5	0	1.13	0	1.5	13.15
Biofilter Fixture	8	3	1.69	38	6	61.52
Biofilter	2	80	4.1	30	2	12.2
Bulk Heads	4	10	1.5	30	2	14
Feeder	1	83	5.6	38	6	11.6

Table I3: DFA worksheet for redesign

The total assembly time of our redesigned model is 363.67 sec, and the theoretical minimum number of parts required is 75. The assembly efficiency is 61.87%, which is increased by 5.3% compared with our original design.

Design for Environmental Sustainability

The materials used for the biofilter tank (HDPE) and biofilter support (American Engelmann Spruce Wood) were analyzed and compared to find their impact on the environment. After finding the closest materials available with the program SimaPro, data comparing total mass of air emissions, water emissions, raw materials, and solid waste was inputted into a graph shown in Fig I1. It can be seen that using HDPE has a greater amount of emissions than using Sprucewood. All values are based on EcoIndicator 99 (EI99) damage classification.

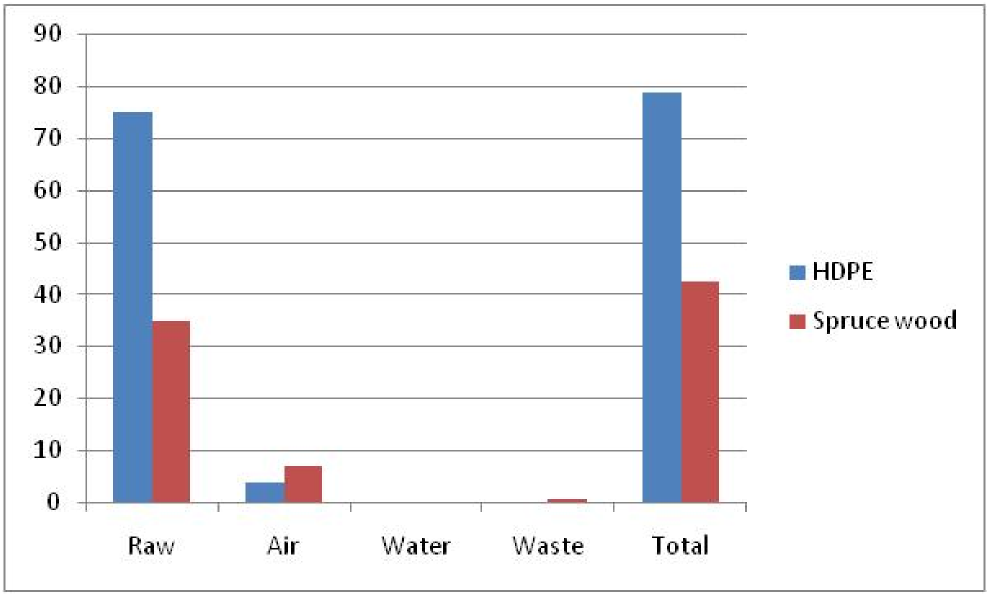

Figure I1: Total Emissions

A graph comparing the two materials in their relative impacts in disaggregated damage categories can be seen in Fig. I2. In this comparison, it can be seen that using spruce wood has a greater impact on six of the nine categories than using HDPE.

A comparison of the two materials using a normalized score in Human Health, Eco-Toxicity, and Resource Categories can be found in Fig. I3. According to this comparison, using spruce wood has a much larger impact on ecosystem quality, but using HDPE has a larger impact on human health. The effect of the two materials on Resources seems to be minimal.

Finally, a comparison of the two materials using single score comparisons “points” can be found in Fig I4. Again, this shows that spruce wood has a much greater impact on ecosystem quality, but HDPE has a greater impact on human health.

The result of these comparisons should not be surprising. Using any form of wood should have a substantial effect on the eco-system quality due to deforestation and creating plastics requires the use of numerous chemicals that have a negative effect on human health. Eco-toxicity seems to be the most important value based on EI99 point values, and this can be seen when comparing the relative weight given to each of the meta-categories in the single score comparisons shown in Fig I1. This could be due to the fact that eco-toxicity affects numerous irreplaceable resources such as eco-diversity and has an indirect effect on resources and human health. The other two meta-categories are more isolated and therefore less important.

Spruce wood has a higher EI99 “point value,” but would most likely have a lesser environmental impact when the entire life cycle of the whole product is considered. The HDPE plastic containers can be reused or recycled after the product is finished, but eventually the containers would need to be either broken down or melted down. This would require high temperatures and could release numerous chemicals that affect the environment negatively. When spruce wood is thrown away, it is easily decomposed.

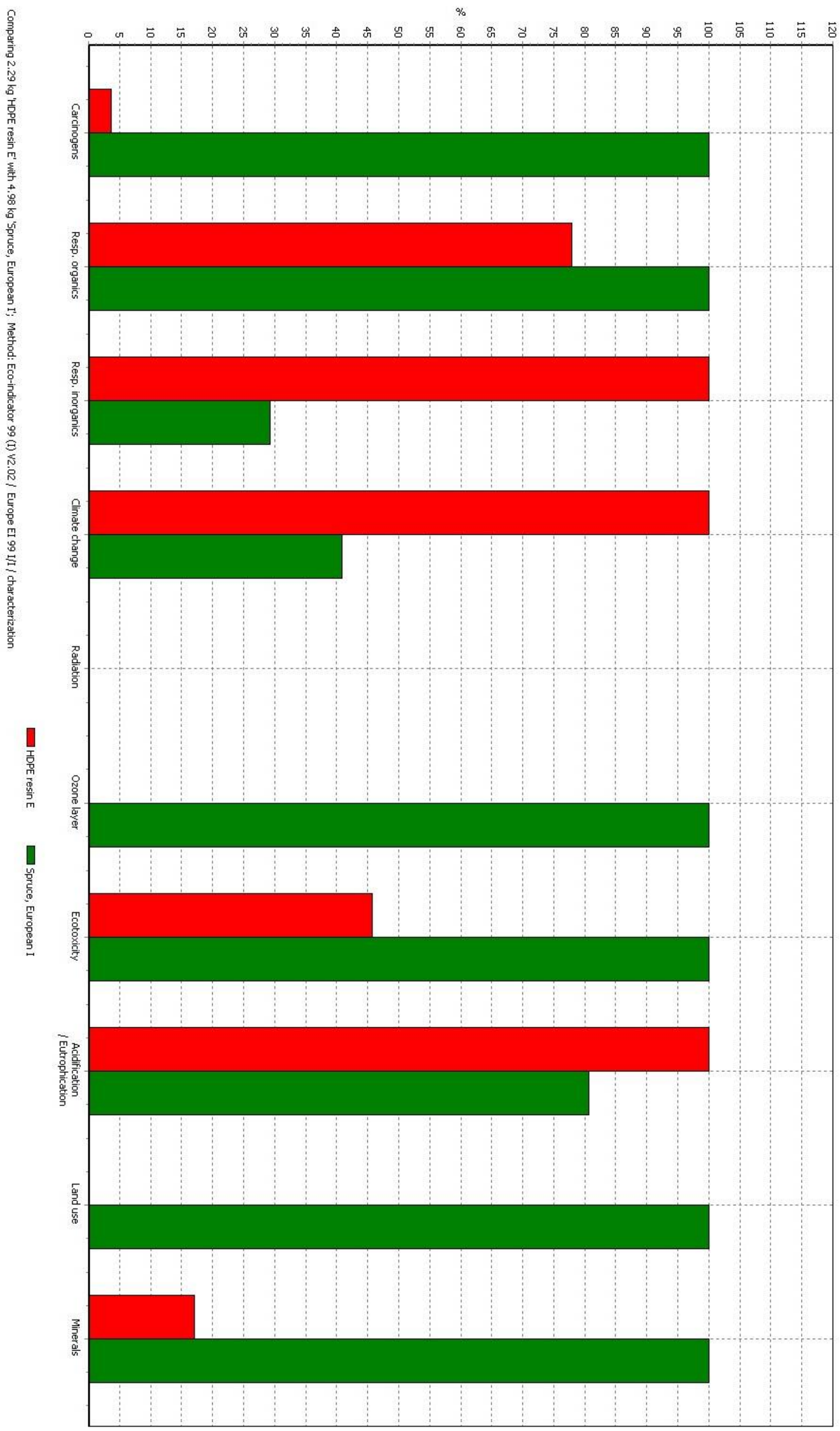

Figure I2: Relative Impacts in Disaggregated Damage Categories

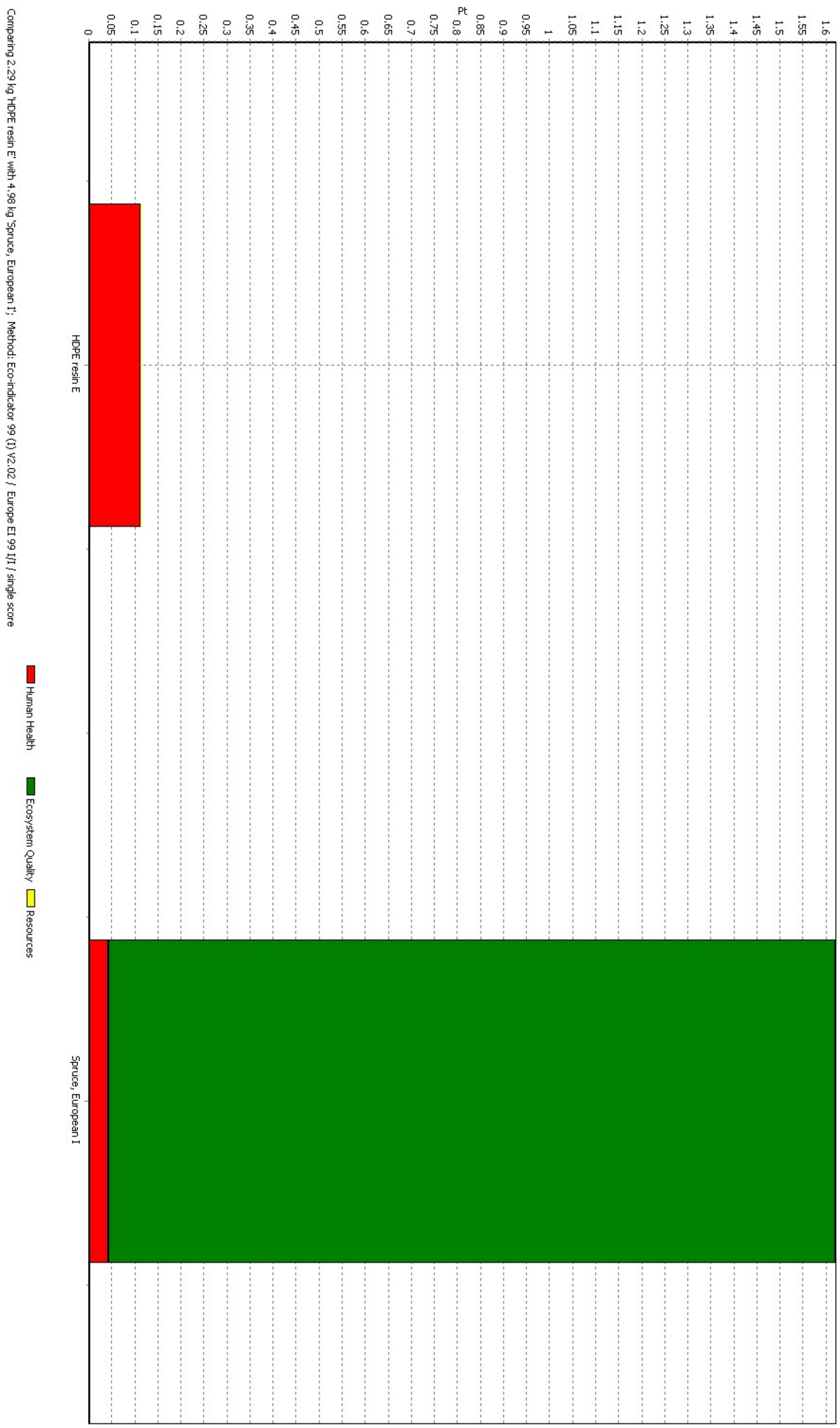

Figure I3: Normalized Score in Human Health, Eco-Toxicity, and Resource Categories

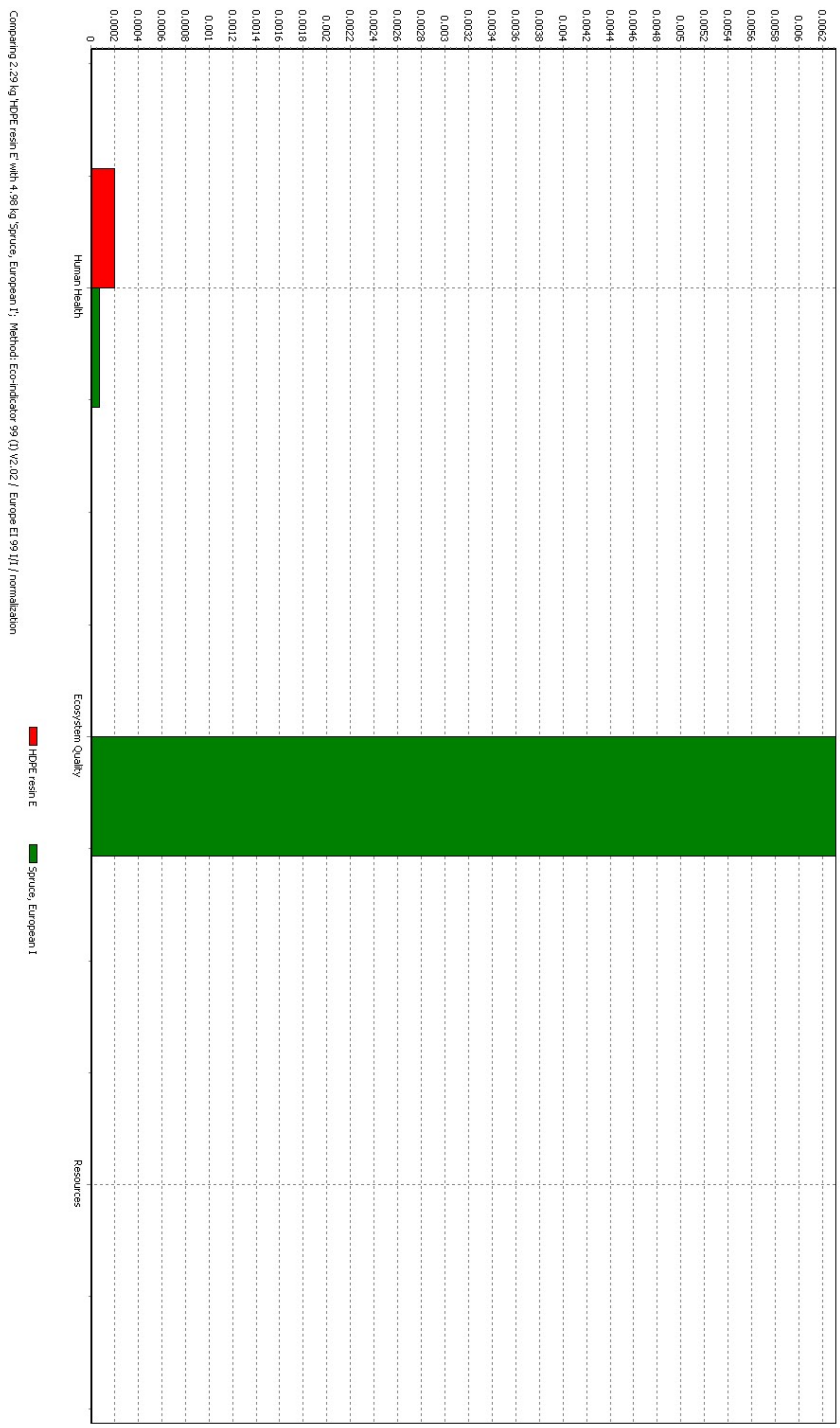

Figure I4: Single Score Comparison in Points.

Design for Safety

For our design the only people at risk are the researchers of the shrimp aquaculture system. The room where the experiments are to be conducted is isolated in the School of Natural Resources and researchers will be the only people who have access to the room. Most of the risk associated with the system relates to the construction and the maintenance of the system. There is very little risk to others in the School of Natural Resources building associated with the normal operation of the systems. The DesignSafe Assessment can be seen in Fig. I5 below.

None of the risks reported in the DesignSafe analysis output were really unexpected. The risk levels were all low to moderate in dealing with ergonomics, sharp tools and equipment, and high pressures and temperatures. All of these risk levels can all be minimized through using proper lab techniques and procedures. The most dangerous portion of our design deals with the fact that there is electrical equipment located near water. The risk level here was assessed as high but could be reduced to moderate given the insulation of the wires is maintained, and water is kept within the system.

Risk Assessment is different from FMEA in that it focuses on what the users do, tasks that must be performed with the design, and the hazards that exist. FMEA on the other hand is solely designed to identify failure mechanisms in a system or a result and determine actions that would eliminate the chances of occurrence of the failure. A design might meet all the criteria in FMEA but if used in certain environments, or used improperly could pose a great risk to individuals using the product.

With respect to safety, zero risk does not exist and acceptable risk is considered to be risk that remains after all protective measures have been taken. With respect to function, the objective is for there to be zero risk through analysis of all the possible modes of failure. The distinction between acceptable risk and zero risk shows up in our design because there is a level of acceptable risk associated with using electrical components near water. The sensors and pump are all electrical components that are placed directly in water. The risks associated with using this equipment can be greatly reduced if the wiring insulation is periodically inspected, and when using electrical sockets and components there be no stagnant water present external to the system. As long as all researchers are trained and aware of all the potential dangers and countermeasures any risk is minimal. According to our failure analysis, with our calculated safety factors, there should be no chance of component failure if the system is used as specified.

Shrimp Aquaculture 3/23/2008

designsafe Report

Application:	Shrimp Aquaculture	Analyst Name(s):	George Ni, Dan Nguyen, David Stile, Xiaofei Sun
Description:		Company:	Team 25
Product Identifier:		Facility Location:	SNRE
Assessment Type:	Detailed		
Limits:			
Sources:			

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

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : cutting / severing Sharp metal tighteners are used	Slight Remote Possible	Moderate	Wear gloves while tightening screws, clip sharp protruding edge	Minimal Remote Unlikely	Low	
All Users All Tasks	mechanical : stabbing / puncture Razors used for cutting tubing	Minimal Occasional Unlikely	Low	Wear gloves while cutting, use sharp new blade (no rust), use proper cutting technique	Minimal Occasional Unlikely	Low	
All Users All Tasks	mechanical : fatigue Vinyl Tubing Fatigue from stretching onto barbs	Minimal Occasional Unlikely	Low	Replace tubing periodically	Minimal Occasional Negligible	Low	
All Users All Tasks	electrical / electronic : water / wet locations Large volume of water located on floor and around electronics	Serious Occasional Possible	High	Ensure proper wiring insulation	Slight Occasional Possible	Moderate	
All Users All Tasks	slips / trips / falls : slip Lots of water movement and splashing potential	Slight Occasional Possible	Moderate	Cover biofilter during backwash operation	Slight Occasional Unlikely	Moderate	
All Users All Tasks	ergonomics / human factors : posture Valves located slightly below chest level	Minimal Occasional Unlikely	Low	No possible solution, design already created to accomodate ergonomics as much as possible			
All Users All Tasks	fire and explosions : hot surfaces Pump could get hot over time	Minimal Remote Unlikely	Low	Ensure interior components are properly maintained and oiled. Do not run with ball valve closed to for extended period of time	Minimal Remote Negligible	Low	
All Users All Tasks	fluid / pressure : high pressure air High pressure air lines used for backwash	Minimal Remote Unlikely	Low	Ensure piping system is rated to proper pressure levels	Minimal Remote Unlikely	Low	

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Figure I5: DesignSafe Report

Manufacturing Process Selection

If our prototype were to be reproduced for researchers all over the world to use, we would expect the number of orders to be on the scale of 10^3 to 10^4 units. A set of 10 units can be configured and used in a number of different experiments simultaneously, and would be enough for all the aquaculture researchers in a large sized University. This assumption is based on the requests made by the shrimp aquaculture group at the University of Michigan. Assuming approximately one large university per state in the US will be conducting aquaculture studies, and each university requiring 10 units, 500 units will be needed. Using a conservative estimate of the US providing a third of the aquaculture research in the world, we will require 1500 units.

The Cambridge Engineering Selector(CES) was used to select manufacturing processes to produce 10^3 units of the shrimp aquaculture. For the Biofilter support structure, a circular saw process was selected. This process was chosen for its low tooling costs and medium equipment costs. The CES software noted a medium labor cost for this process, but because the cuts required to produce the biofilter structure are very repetitive and simple, the labor cost can be reduced through automation. The circular saw is economical when producing from 1-10^7 units. An alternative process to the circular saw would be the bandsaw. The bandsaw process has similar costs to the circular saw, though it is only economical for producing from 1-10^4 units. Selecting a proper manufacturing process for the polyethylene biofilter tank was more difficult. Most of the shaping processes required a high set up cost on the order of 10^4 to 10^5 US Dollars, and required a high output (10^5 to 10^7) to be economical. Therefore, the most economical way to produce biofilter tanks would be to purchase polyethylene tanks from another company, and then modify them to fit our purposes. The company would use some type of hot molding process to make the containers, such as compression molding, blow molding, or injection molding. This is essentially what was done for the prototype construction. Drilling or hole-sawing would be used to modify the containers.

Different materials and production processes would have to be selected in order for our prototype to be scaled to an industrial scale. Manufacturing processes are not well suited to producing shrimp aquacultures, because we are attempting to build entire farms. Certain components could be produced using manufacturing process, but the main parts of the aquaculture, the shrimp tank and the biofilter tank, would best be produced out of some type of concrete. A terraced arrangement could reduce the need for a biofilter support structure, thus reducing the need for certain components. Both biofilter tank and shrimp tank could be laid in the ground, with the biofilter tank higher up than the shrimp tank. The soil would be dug out using earth moving machinery, and the tank created out of poured concrete. Analysis would have to be performed on the tank size and structure, to determine the amount of load on the concrete. This would also depend on the size of the shrimp aquaculture desired. A specific concrete type could then be selected using the CES. The piping between the biofilter tank and the shrimp would be laid into the ground using industrial sized plumbing, like those used for water distribution in cities. Concrete or plastic plumbing would be best suited, because the fluid running through them would be highly corrosive salt water. Some components of the shrimp aquaculture would have to be altered, because of the size issues. For example, anchoring the sensors to the bottom of the tank, and attaching a buoy would be a simple alternative to have sensors mounted on an adjustable around the tank. Backwashing the biofilter tank could be better accomplished using mixing devices within the tank, as opposed to using a multiple large air sources.

The production processes for reproducing the prototype shrimp aquaculture depend on whether a large number of units or a large unit is desired. To produce a large number of units for research, low production manufacturing processes can be used. To produce a large unit, not only do the manufacturing processes change, but the aquaculture design changes also.