J_2MH Problem Statement

Aquaculture is a growing field that is already playing a key role in world food supplies. Many of the earth's residents depend on aquaculture for physical and financial sustenance. Some of the technical challenges facing semi-intensive aquaculture today are nutrient recycling/disposal, water consumption, aeration, and profitability of small scale farmers.

The environment which we are designing for is a tropical to subtropical climate in rural areas with no access to line-power electricity . We are assuming high levels of incoming solar radiation. The water bodies in this region are assumed to be unlined earthen ponds with algae.

The problem as we see it is to design an aeration system that can tackle low dissolved oxygen (DO) levels due to the respiration of fish and algae during the night. As a result of this higher densities of tilapia can be raised with less die off events. One side of the problem is to engineer a robust and intelligent aeration system to address fluctuating DO levels. The other side of the design is to provide an affordable product with a high NPV and low payback period. In order for the design to be scalable it must have simple operation, maintenance, and instructions for non-engineers. In summary the problem is to create a design that is financially viable, marketable, and increases aquaculture yields through intelligent aeration technology.

The oxygen delivery system for tilapia fish that we will be designing for will be based on the following conditions:

- A stocking rate of 4 tilapia/m3
- A maximum weight of 200 g per fish
- An average DO level of no less than 4 ppm in the pond
- Solar intensities characteristic of Ghana
- No access to electrical line-power
- A goal parts cost of less than 750 USD for full scale model
- Theft prone rural environment
- Awareness of safety, environmental, and regulatory laws
- Cultural sensitivity
- A healthy algal population (I.E. no algal blooms to consume all oxygen)
- Design to work within 15 degrees latitude of the equator
- Design for a 15m x 30m x 2m pond size

JMH2
Consultant Engineers

Final Design Report

BEE 469 TEAM 3

Technology Review and Design Selection

[redacted]

Table of Content

I. Executive Summary

Providing an adequate supply of oxygen for fish to increase productivity can be a limiting factor for small scale aquaculture farmers in the developing world. This report describes components of a solar powered diffuser aeration system and the process and reasoning by which J_2MH engineers came to a decision on choosing an aeration system and final design calculations.

The general process of design specification was to first analyze the different sub-technologies of components like the solar panel, pump, diffuser, and battery and to evaluate each of these categories based upon economic, technical, social, and environmental decision criteria. After completion of the J_2MH modeling software a higher level analysis was completed to optimize system design. This model was used to quickly see how changes in location, component sizing, and market value of fish affected the total investment and sustained fish health. Components were also judged based off of their ability to meet flow rate, power, pressure, and budget requirements. For pumps, the diaphragm technology scored highest on the decision matrix. Two BOYU ACQ 906 diaphragm and one BOYU ACQ 903 (combined 135 L/min) were chosen to meet budget and engineered requirements. Flexible membrane diffusers scored the highest on the decision matrix. Rubber epdm disc diffusers were chosen for their self cleaning ability and flow rate requirement compatibility. Deep cycle lead acid batteries(200-250 Ahr) were chosen for their affordable cost and variable power discharge regime. Solar panels (250-500W) were chosen for their power requirement compatibility in an off the grid environment. Based on input from Hillary Egna, J_2MH engineers designed for all components to be on a flotation device to decrease risk of theft and to keep wires and technology out of human traffic. Through the research process it was found that oxygen transfer efficiency of diffusers increases by 2.5 percent per foot of water depth. Because of this J_2MH's final design consists of diffusers that are buried one meter below the bottom of the pond encased in pvc. *J_2MH Consultant Engineers* final design consist of a float with panel, battery, pump, and tubing centrally located in the pond that leads to buried diffusers for increased efficiency with a total parts cost of 1470-1670 dollars.

II. Introduction

Aquaculture is an increasingly popular way of producing protein and providing physical and financial sustenance across the globe. According to the world health organization twenty percent of the world's population receives at least twenty percent of their dietary protein from fish, with some cultures relying on fish entirely [1]. Sustainable protein sources are increasingly important due to the growing human population. Recently humans have been counting on aquaculture as a source of food to overcome this dilemma. To increase the availability of sustainable protein sources and to continue to make small farmers profitable, efficient aquacultural farming is needed. Aquaculture is the farming of aquatic organisms such as fish, shellfish as well as marine plants. Aquacultural farming is not limited to marine but also to freshwater organisms. Production facilities can be housed anywhere from small ponds to the oceans [2].

The aquaculture farming industry is a growing industry. According to WWF organization the aquacultural industry is the fastest growing food industry in the whole world, as it has been growing steady rate of 8-10% over the past 30 years. [3] The challenges facing the aquacultural industry presently are nutrient recycling, aeration, and profitability of small scale farmers. The profitability of small scale farmers is directly tied to their ability to keep fish healthy, minimize die off risk, and to increase stocking densities of fish. One of the main challenges facing this industry is the ability to provide enough oxygen to ponds. To reach final sale weight there is an optimum amount of oxygen that needed to be diffused to the pond at a constant rate, otherwise the fish will not grow to the targeted size due to growth stress and possibly mortality.

The senior undergraduate class in the Biological and Ecological Engineering department has been tasked with designing aeration systems for aquaculture farmers in the developing world. The major challenge of the design is providing a system that is user friendly, cost effective, and one that optimizes all the parts for maximum use of harvested solar energy. The environment designed for consists of earthen ponds located outside of city line power. The earthen ponds contain algae and tilapia. During the day the algae photosynthesize and provide oxygen to the pond and act as a food source for the fish. At night the algae and fish start consuming oxygen. This diurnal fluctuation is very dangerous for farmer’s crop due to the possibility of toxically low dissolved oxygen levels.

The design problem is to create a system that can provide aeration off the grid reliably and to still be economically feasible.The oxygen delivery system for tilapia fish that we will be designing for will be based on the following conditions:

- A variable stocking rate of 5-7 tilapia/m3 based upon resulting net present value(NPV)
- A maximum weight of 250 g per fish
- An average dissolved oxygen(DO) threshold of 4 ppm in the pond
- Solar intensities characteristic of Ghana
- No access to electrical line-power
- A goal parts cost of less than 750 USD for full scale model
- Theft prone rural environment
- Awareness of safety, environmental, and regulatory laws
- Cultural sensitivity
- A healthy algal population (I.E. no algal blooms to consume all oxygen)
- Design to work within 15 degrees latitude of the equator
- Design to work for a variable pond size based upon resulting net present value(NPV)

A more in depth summary of the problem statement by the *J$_2$MH* consultants specifically can be found in Appendix II. Through successful implementation of robust and economically feasible designs, local farmers will be able to increase productivity and/or decrease the risk of fish kills.

The major components of any aeration system consists of a power source, an air pump, a battery if storage is necessary, and an aeration device. This document is a summary of J$_2$MH Consulting Firm's research and the recommended engineered technologies and design for accomplishing the goals set forth in the problem statement.

Following the final design section , justification for technologies chosen will be provided from page 9 to page 31. The component selection section provides background on the function of each component and how the differing components compare to each other. The system selection section starting on page 32 provides the justification and narrative by which J$_2$MH came about sizing components in order to optimize the investment and ability to meet fish health needs.

III. Final Design

J$_2$MH Consulting Firm's final design consists of a centralized flotation system that contains a solar panel roof for rain deflection with battery, pump, and charge controller housed underneath it. The centralized flotation system primary purpose is to make theft less likely and to have the system self contained and out of the way of foot traffic for the farmers. Dr. Hillary Egna (director of AquaFish Innovation Lab) stressed the need for anti-theft capabilities and the desire for an out of sight out of mind system without wires running every which way from the shore. The design consists of a deep cycle lead acid battery, DC diaphragm pumps, and flexible membrane diffusers.

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Table 1 : Major Component Specifications of the J$_2$MH Design

2 BOYU ACQ 906 & 1 ACQ 903 Flow Rate (L/min)	Battery (Ahrs)	Pump Draw (W)	Solar Panel Power (W)	Rubber EPDM Diffuser Efficiency at 2 meter depth
135	250	185	250-500	15%

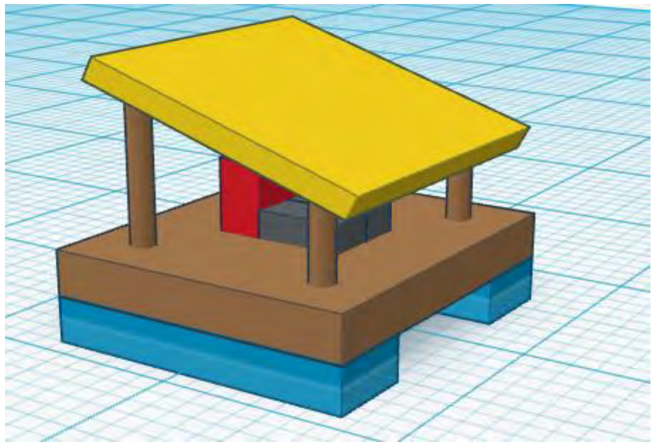

Figure 1 :Flotation system design

The final design consists of the same flotation device, but with lines running directly to submerged pvc pipes in the pond floor. Calculations for flotation buoyancy and critical tipping angle is in Appendix VIII. The figures below shows the proposed diffuser housing design.

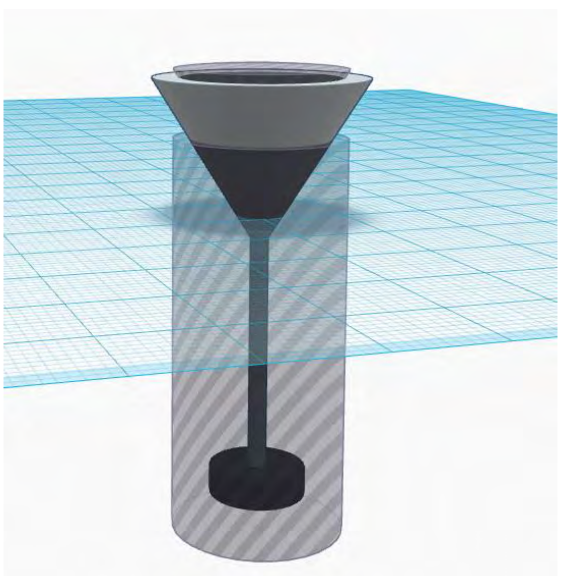

Figure 2: Proposed diffuser housing

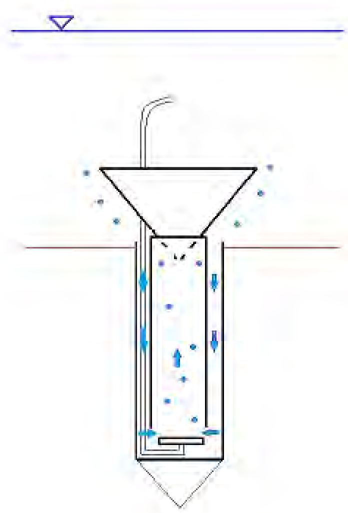

Figure 3: Proposed diffuser housing

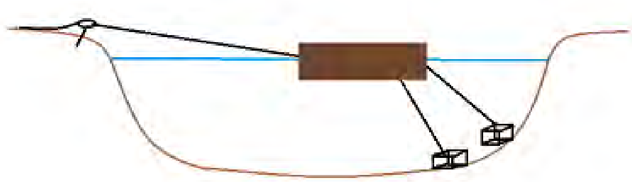

Figure 4: Anti Theft/Variable Water Level Design

Figure 4 is showing the final design of the aeration system and how the floating platform will be secured to the bottom of the pond by two cinder block and to the side of the pond with any anchor and lock.

The main function of the buried pvc diffuser housing is to increase oxygen transfer efficiency. With increasing depth comes increased time for the bubble to rise to the surface and transfer its gaseous contents. The cone at the top functions to spread the bubbles so they can aerate a higher surface area water column and in order to keep particles from settling into the bottom of the chamber. The disc diffuser is located at the bottom of the pvc pipe. The buried diffuser design increased oxygen transfer efficiency which helped lessen the total amount of air needed to be pumped into the pond. Justification of the J_2MH design choices and different alternative component technologies are analyzed discussed further into the report. The J_2MH system design offers aeration efficiency innovation through buried pvc housing and an optimized solar aeration system for increased economic value and sustained fish health.

IV. Component Selection

1. Matrix of Design Alternatives

A decision matrix was made to evaluate the technological alternatives based upon four categories. The major categories were economic, social, environmental and technical aspects of the system. The weighting for each of these are shown below.

	Sub Category	Points
Economic (40 points total)		
	Operation/ Maintenance	10
	Lifetime	10
	Installation Costs	4
	Initial Capital Investment	15
	Salvage Value	1
Social (10 points total):		
	Theft	5
	Noise	2
	Trained Worker Availability	3
Technical (40 points total):		
	Efficiency of parts (metric varies)	10
	Battery Efficiency Unit	
	Diffuser Efficiency SOTE	
	Durability	10
	Reliabilty/Consistency	7
	Availabilty of Materials	4
	Simplicity/Repairability	9
Environmental (10 points total):		
	Oil Leakage	4
	Battery Flood Risk	4
	Greeness of Energy Production	2

Figure 5: Point values for corresponding evaluation criteria

Higher points symbolize a higher viability of the technology for our design. Economic was given a large percentage of the points because money matters, especially for small scale farmers. No matter what the NPV of our product, many small scale farmers will not be able to afford a large initial capital investment. Technical was also given high weight because if the design does not meet the deliverables of higher fish densities and decreased die off risk, it fails the objective. The specific scores of each technology can be found in appendix IV. The four categories of social, environmental, technical, and environmental factors are the basis by which the following technologies will be judged.

2. Survey of Component Technologies and Technological Constraints

2.1 Pump

2.1.1 Single Acting Pump:

Single acting pump uses one piston to pump air, with an inlet and an outlet to allow the air in and out. The force of pressure sends air out through the outlet. The inlet opens as the piston is moving up allowing air to get in. As the piston move down again the valve in the inlet closes preventing the air to escape, and the air will be forced to leave the pump through the outlet by force of pressure [4].

2.1.2 Double Acting Reciprocating:

Just like the single acting, double acting uses pistons to pump air. However double acting uses two pistons instead of one to pump air, and has an inlet and outlet on each side, so it can pump more air. Double acting reciprocating pumps, pump twice the amount of air in every crank cycle. These pumps are extremely large. Double acting reciprocating pumps can produce a lot of vibration, as they have been called earthmovers back in the day [4].

2.1.3 Diaphragm Reciprocating:

The diaphragm reciprocator shares the same working principle as the single acting reciprocating. However this pump uses a diaphragm that is connected to a piston. The movement of the diaphragm causes a difference in air pressure and moves the air into and out of pump [4].

2.1.4 Rotary Pumps:

Rotary pump is part of the positive displacement, and it can keep a constant flow of liquid in every revolution of the element part. Rotary pumps include the ears, lobes, rotary pistons, vanes, and screws. The popularity of this design is due to its high viscosity performance, compact design, and its ability to contain high differential pressure [5]. To move Fluids and these pumps uses the rotary movement of its parts to move it.

For instance the rotary screw pumps moves the liquid towards the discharge cavity by the rotary motion of the screw. Vanes are being used to pump air, but these pumps are usually big and too expensive for us to use. These pumps are mainly used in pumping lubricated liquid and fluids with high viscosity, and they are not of a good fit with our design.

2.1.5 Centrifugal Pumps:

This pump is from the dynamic family of pumps; they operate by developing a high velocity and converting the velocity to pressure. Centrifugal pumps use the centrifugal force to pump liquid and air. The centrifugal pump has an impeller at the heart of the system; the rotation of the impeller creates a centrifugal force the pushes the liquid/ air into the discharge tube. The rotation of the impeller creates a negative pressure at the center of the impeller, this negative pressure sucks in liquid/air into the centrifugal pump.

Of the options left, a Centrifugal pump is in our price range, but does not meet the pressure that the *J_2MH engineers* needed, and had a low flow rate of 1.32 CFM.

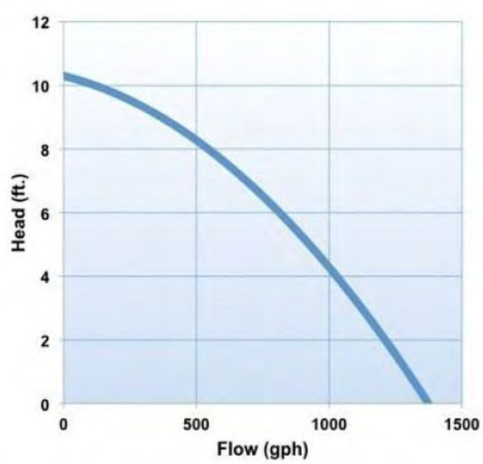

Figure 6: Centrifugal pump curve

A single piston pump was another alternative as well, however having a price range of 100 dollars made pump selection limited.

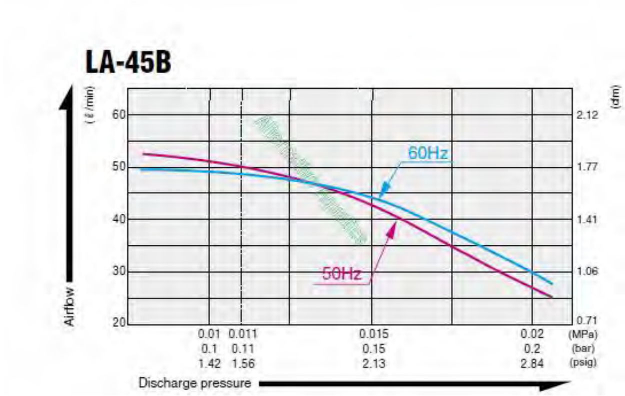

Figure 7: Linear Piston Pump curve.

As figure 5 shows, to pump air at 2.84 PSI the air flow provided is only 26 l/min, when we need a flow rate of 62 L/min. The Pump we have picked is the best fit because it met all the technical requirements. As the graph below shows the ACQ 906 will meet our pressure requirement of greater than 0.025 Mpa. When using two of these pumps the flow rate requirement of 200 L/min.

Модель	Уровень шума	Размер сепаратора	Вес	Размер
ACQ903	50dB(A)	6x10	2Kg	220x110x140
ACQ903A	50dB(A)	8x10	2Kg	220x110x140
ACQ906	60dB(A)	10x10	3Kg	250x120x160
ACQ908	60dB(A)	12x10	4.5Kg	235x140x170

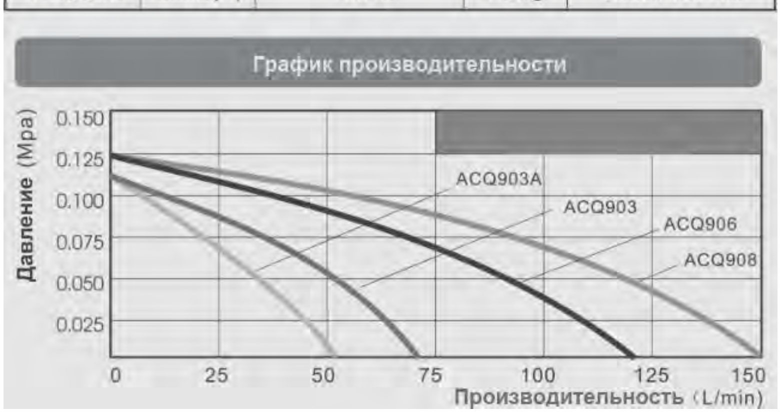

Figure 8: Diaphragm pump curve

2.2 Tubing

Air tubing is very important for the design because it is through the air tubing that the pressurised air goes from the pump to the diffuser. This makes it one of the critical components, and gives it the highest likelihood of being damaged. This is due to the fact that the air tubing will be stretched over the ground and through the water which gives it the possible of being tampered by animals chewing on it or brokened by human traffic stepping on it and breaking it. With the designed float this risk would be minimized.

2.2.1 Reinforced Clear Vinyl Tubing

This a very popular choice for air tubing. This type of tubing is upgrade from the standard clear vinyl tubing that one thinks of when first thinking of air tubing for fish. The reinforced part comes from synthetic fibers woven into Polyvinyl chloride, this means it can take larger pressures and is more resistant to cutting from animals.
This works for the design since we need a air hose that is resistant to cutting by animals the downfall is that it reinforced tubing is over engineered for the pressure requirements we need [6].

2.2.2 PVC Rigid pipe

PVC pipe is a rigid pipe made from solidified Polyvinyl chloride. The fact of PVC pipe is that it is rigid so it can be buried and also the since it is rigid it is more resistant to tampering from animals. thouh durability of PVC can degrade with solar exposure unless buried or painted.

Figure 9: PVC pipe [7]

2.2.3 Black vinyl Tubing

Black Vinyl Tubing is very similar to the clear vinyl tubing in its technical aspects such as pressure rating which is a max pressure of 40 psi for ¼ inch tubing [6].

Figure 10: Air tubing [8]

2.2.4 Air Tubing Conclusion

In conclusion the air tubing choices to choose from in this report all have their strong points. This means that the final choice of piping for J_2MH's design will have to be done with discussion and further calculations. There is a possibility of using multiple types depending on where in the system the tubing is needed.

2.3 Battery

Batteries are very important to the design because they are what will store the solar energy produced by the solar panels during the day and release the energy for use by the pump during the early morning hours. The different types of batteries that are being considered are deep-cycle flooded lead acid, deep-cycle valve regulated lead acid, lithium-ion, and nickel-cadmium batteries.

2.3.1 Lead acid Batteries:

Lead acid batteries have been around for over 100 years and are one of the dominant batteries on the market. They are made up of a cathode and anode within an acid solution to hold the electrical charge typically H_2SO_4 there are several different types of lead acid batteries. The ones that will be covered in this report are the flood lead acid and sealed/valve regulated lead acid (VRLA).

2.3.1.1 Differences between Flood Lead Acid and Valve regulated lead acid

Flood lead acid batteries and valve regulated lead acid batteries have very similar design aspects but flood lead acid have a few more design criteria than Valve Regulated Lead Acid. The requirements for flood lead acid batteries are one an upright orientation to prevent electrolyte leakage, two they require ventilated environment to diffuse gases created during cycling and lastly they require routine maintenance of electrolyte [9]. Lead acid batteries will work due to them being readily available and the ability to work with solar power.

2.3.2 Lithium-ion Batteries:

Lithium-ion Batteries are a fairly new technology and become widely accepted in the 1990's. The basic concept of the battery is that lithium ions travel back and forth between the anode and cathode in electrolytes made of lithium polymer. Lithium-ion batteries will work for the design due to their ability to be discharged a larger portion of the energy in the battery while retaining service-life. Lithium-ion will not work due to high fragility and price of the batteries.

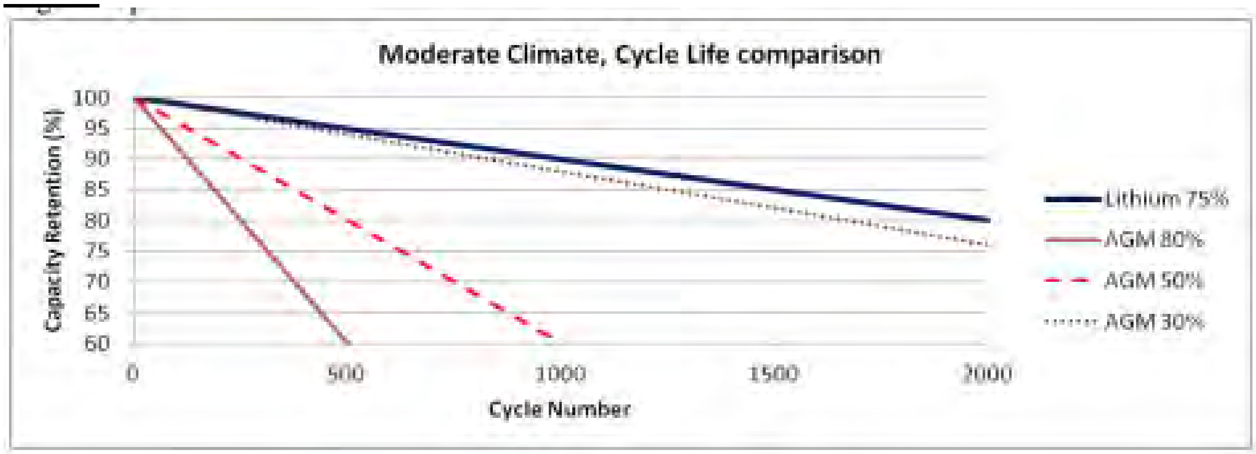

Figure 11:Comparing battery life with energy discharge. [9]

2.4 Diffuser

This section is an intensive look at available diffuser aeration technology and gives a qualitative and quantitative analysis to differentiate which technology could meet our project goals. J_2MH's focus has been on diffusers because of the intense power and capital cost needs of surface aerators like paddle wheels and fountains. Air diffusers have a low upfront cost when compared with paddle wheel aerators [10] and are compatible with solar systems because they can aerate with less horsepower needs [11]. The basic principle behind all diffusers is pushing a gas through a membrane to divide that gas into small bubbles that travel up the water column while exchanging the gas with the water. The main diffusers covered in this section are the glass bonded silica, aluminum oxide, EPDM/rubber membrane, and diffuser tubing. These were evaluated based on volume output, bubble size, cost, maintenance requirements, and longevity.

Gasses that are commonly diffused are pure oxygen, air, and ozone. One application of diffuser aeration is in municipal wastewater treatment to increase bacterial degradation of nutrients in an aerobic environment or to pump ozone into the drinking water to disinfect it as a final treatment. This technology is also used in aquaculture to meet the demand of respirating fish, bacteria, and algae.

Diffuser performance over the long run is directly related to fouling, basin geometry, placement of diffuser, operator expertise, and the quality of the preventative operations and maintenance program. There are two types of fouling. Type I includes particles from the air clogging the diffuser while type II involves a biofilm taking root on the diffuser surface [12]. When you look at differing prices of air diffusers there are a few common characteristics that drive the resale price. These factors include durability/lifespan, frequency of servicing, oxygen transfer efficiency, energy requirements, bubble size, compatibility with ozone and pure oxygen, and parts/materials cost. As bubble size decreases you get higher surface area and oxygen transfer efficiency, but you lose the mixing effects of larger bubbles. The major aeration diffusers on the market are glass bonded silica ceramics, rubber tubing, BioWeave, EPDM/rubber, and aluminum oxide diffusers. BioWeave was initially researched, but a Pentair representative said that the material would quickly degrade within an earthen pond. A brief overview of each of these diffusers except BioWeave is given in the following sections with elaborations on their corresponding technological constraints.

2.4.1 Glass Bonded Silica:

The glass bonded silica diffuser stone is one of the most ubiquitous diffusers on the market. The modern diffuser is machined from a solid block of glass bonded silica and produces a medium/fine bubble. This type of diffuser is categorized as a subsurface aeration system [11] and is usually suspended right above the bottom surface of the body of water.
One of the drawbacks of ceramic stone diffuser is that they are apt to clogging/fouling from bacterial growth. For most soft water applications the diffusers only has to be cleaned once a year. For cleaning regimes one can either soak the ceramics in a acid bath, pump them with anhydrous HCL, or scrub them carefully with a brush [13][14]. The stones are quite fragile and should be handled with care [15]. The glass bonded silica diffuser has an air resistance of less than 0.25 psi which helps save on start up power needs and saves on energy consumption throughout its lifetime. The dust and particles collected from the air that are pumped downward primarily pass through the diffuser due to the pore size being large enough for air particles to pass (30 microns). This reduces the need for air filters on the pump housing. One rectangular diffuser of 1.5 x 6 in can provide up to 0.5 cubic feet of air per minute [10]. This type of diffuser stone can either be manufactured as a cylinder, rectangular cuboid, disk, or plate.

Glass Bonded Silica	

Figure 12: Glass bonded silica diffusers

2.4.2 Rubber/EPDM Membrane:

EPDM stands for ethylene propylene diene monomer and is a type of rubber. This material is most common in the roofing and wastewater sectors. The membrane can be found in many modern wastewater facilities across the country. The technology's major advantage is the ease of cleaning and resistance to fouling. The rubber membranes can be cleaned by increasing the pressure to all to slough off the biofilm or to divert all pressure to one diffuser. Another cleaning method is to simply pull it out of the water and rub the biofilm off with your hand [16]. The technology consists of a sheet of rubber that has hundreds of pores cut into it. When pressure/airflow is applied the membrane pores expand and release the air. This is advantageous because while the membrane sits idle it is much harder for biofilms to form on smooth rubber surfaces when compared with porous ceramics. The bubbles are slightly larger than the standard ceramic airstones [1]. According to a pentair representative rubber membrane diffusers are still compatible with air despite the catalog saying they are best used with pure oxygen. The EPDM membranes have a minimum pressure requirement of 0.5-0.6 psi [17]. The biggest technological constraint is the pressure requirement. In order to use these diffusers a higher back pressure is needed when compared with ceramic diffusers.

Rubber/EPDM Membrane	

Figure 13: Rubber/EPDM Membrane

<u>2.4.3 Aluminum Oxide:</u>

Aluminum oxide air stones are an alternative to the glass bonded silica air stones. They are in the same category of ceramics as glass bonded silica but are inherently more strong and resistant to breakage. The aluminum oxide ceramic is made of the same material that grinding stones are. Users do not have to worry about breaking the diffuser in half due to its strength [18]. One website claims that aluminum oxide diffusers have 3x times the lifespan of the glass bonded silica [19].The aluminum oxide can be cleaned with muriatic acid. If preferable the material can resist high heat so the burning of algae or bacteria for cleaning purposes is also an option. Caution should be taken to ensure no excess heat touches the plastic connectors.The resistance to air is 0.25 psi so the product is compatible with low pressure blowers [19]. The product also has anti-corrosive properties [20].

Alumina Oxide	

Figure 14: Alumina Oxide diffuser

2.4.4 Rubber Tubing:

Diffuser tubing is just as it sounds and consists of a flexible tube that is porous in nature. This design allows for easy mobility and can help aerate non-traditionally shaped ponds. The most common types of tubing are rubber/polymer, paper, and bioweave tubing. The rubber tubing is often weighted so that it sinks to the bottom of the tank. Pentair tubing outputs 3 mm diameter bubbles. It can be perforated on only one side or release bubbles from the whole surface. Some of these tubes are equipped with antimicrobial properties. Some rubber tubing requires higher psi. Bioweave tubing is constructed with woven polyester fiber material and is claimed to last for "years" [10]. A Pentair representative said that the components would not be a fit for our project because they would rapidly biodegrade. There is also disposable paper tubing that is often used in shrimp aquaculture. Although this product is cheap it requires routine purchasing and lower lifetimes.
The major drawback of all tubing technology is the maintenance inconveniences. In a pond with high biological activity fouling is inevitable. The sweetwater stones the and aluminum oxide are the only diffusers that can use a acid bath. For this case scrubbing of the tube would be the most effective cleaning measure [11]. Overall the fouling and intensive cleaning regimes coupled with high pressure requirements make this diffusion method not do-able.

Rubber Tubing	

Figure 15: Rubber Tubing

2.5 Solar Panel

A solar panel is made by combining the effects of multiple solar cells. Each solar cell takes radiant solar light, excites electrons within, and converts that energy into electrical current. The two main groupings of solar panels on the market right now are crystalline and thin film technology.

The grouping of crystalline includes both monocrystalline and polycrystalline. Monocrystalline solar cells have slightly higher solar conversion efficiency (20% versus 15%) than polycrystalline, but for all intensive purposes the two are interchangeable. Monocrystalline solar panels are slightly more expensive as well due to the purity of the silicon and the waste of some silicon during the manufacturing process. Polycrystalline silicon wafers are poured into a square mold after heating versus a four sided cutting process of the crystal. Of the silicon based solar cells on the market, roughly ninety five percent of them are comprised of crystalline silicon [21].

The other solar cell grouping on the market is thin film technology. In 2011 thin film solar cells represented five percent of all the cells on the market. The technology is expected to jump from 7-13% solar conversion efficiency to 16% efficiency. The manufacturing of this technology is basically thin layers of semi-conducting materials layered on top of eachother. Thin film solar cells lend themselves towards mass production and are more flexible which allows them to be placed in unique ways [21]. Due to mono and polycrystalline panels being similar in efficiencies, the emphasis on which to use is less of a technology consideration, as much as it is a watts per dollar consideration. The main logic on panel selection is what panel can provide the energy needed for aeration at the lowest price.

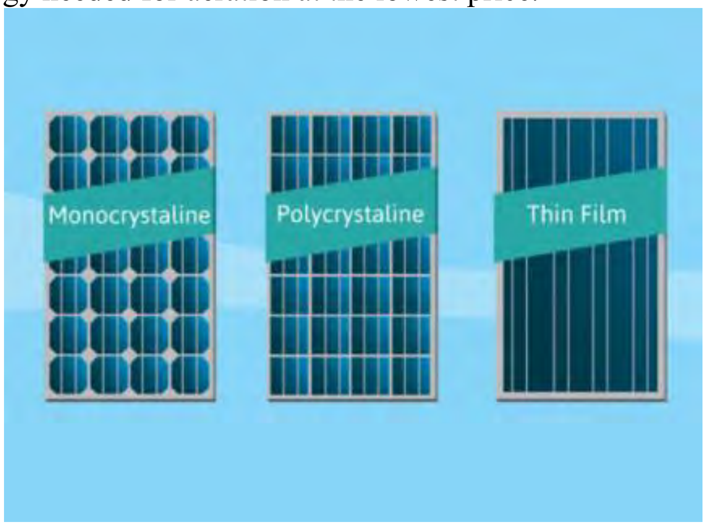

Figure 16: Various solar cell technologies [1]

2.6 Charge Controller and Arduino

Charge controllers are essential to taking in the energy harvested by the solar panel and optimizing what current and voltage to use to get the most amount of power to the battery and pump. Most charge controllers are basic in their function of turning on and off at a set time and turning off at set thresholds of battery. Resiliency to days of low solar insolation is very important for the system design because the fish may be unable to handle repeated days of low dissolved oxygen
Arduinos are microcontrollers that will help the J_2MH system to store and analyze data from testing, determine where power goes, and to control the on off switches for various parts of the design. Another key process for the arduino will be to make the design intelligent enough to perform well under a variety of situations. The logic chart presented below represents what programs the arduino will be expected to follow.

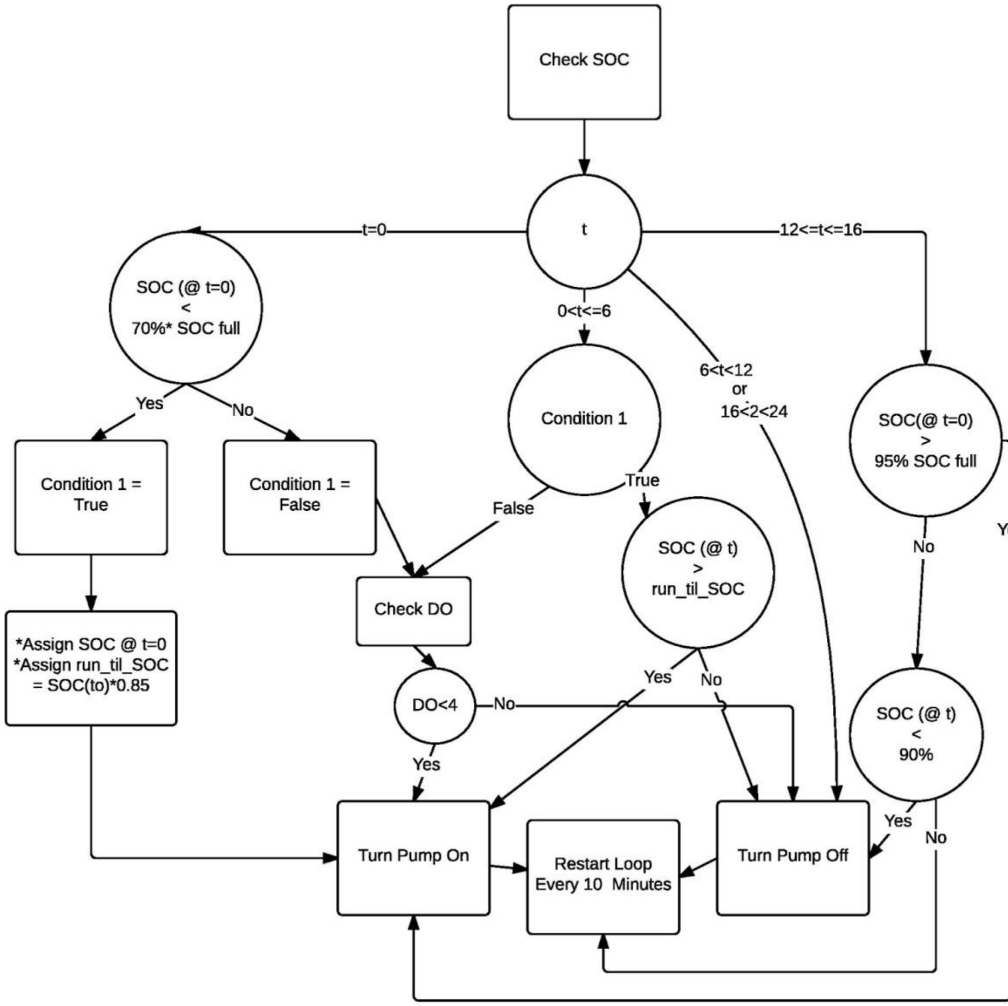

Figure 17: Logic of the arduino system control to maximize aeration while conserving battery power

The arduino logic shown above is the logical flow chart used to translate our objectives into the arduino interface. The left branch of the logic tree is our cloudy day/low battery clause which says that once beyond a certain state of charge battery discharge is a constant 15 % each night. The iddle section of the tree is the dissolved oxygen sensing which allows for efficient utilization of an already limited power supply. The right side of the tree has to do with discharging excess energy throughout the day when the battery is fully charged early in the day.

2.7 Synthesis of Technologies

The diaphragm pump was the best fit for our design, because when compared with other pumps, it was able to provide us with the desired flow rate at the given pressure..It also made less noise when compared with other pumps, and more importantly it was in our price range. The rubber/epdm diffusers produced similarly sized bubbles when compared with ceramics and also had less maintenance concerns. Choosing a battery is an interplay between cost and efficiency. Despite the efficiency of lithium ion batteries, lead acid were chosen for their budget compatibility and discharge regime. Ridgid tubing is resistant to human and animal degradation, but can not fluctuate with the water levels like the flotation design requires.

3. Economic Considerations

3.1 Pump

The model we have picked is two BOYU ACQ 906 up will cost us around a 160 dollars, and that would be perfect considering the budget we had for this part of the design. compared to the other options we had, this pump was the cheapest way of meeting our pressure and flow requirements. All the other designs have failed in providing the effective flow rate at the given pressure for the budget we have. Initially we had two main candidates to our design the centrifugal pump and the diaphragm piston pump, however comparing the two pumps proved that the diaphragm pump is more compatible to our design[22][23][24].

12 Volt Air diaphragm pump for BOYU ACQ-906

Table 2: BOYU ACQ-906

Voltage	12 volts DC battery
Power/ Battery	60 watts power
Flow rate	50 L/min Max
Maximum pressure	0.12 Mpa Max
Size	253*124*148 mm

Price	80 dollars

Oase Aquarius Universal centrifugal 1400 Pump - 1400 GPH

Table 3: Oase Aquarius Universal- 1400 Gallons Per Hour

Max. Flow rate	3 cfm
MAX head	10.2 ft
Power	80 watts

Price	119 dollars

3.2 Tubing

3.2.1 Economical aspects reinforced clear vinyl

Reinforced clear vinyl is very strong tubing. It can take a 120 psi for ¼ inch tubing and it costs $0.92 USD per foot [6]. This means that we can put higher pressure air into the lines if needed.

3.2.2 Economical aspects PVC pipe

Economical PVC pipe is very easy to come by since it is the standard piping choice for drinking and wastewater around the world. PVC pipes are the cheapest at about $0.20 USD per foot [7].

3.2.3 Economical aspects Black Vinyl

Prices for Black vinyl tubing makes it seem to be the middle price range at $0.49 USD at price per foot [6]. While this price is in a good range, it is the weakest tubing choice in terms of durability from being cut by animals.

3.3 Battery

As we can see in the following table taken from *A Comparison of Lead Acid to Lithium-ion in Stationary Storage Applications* the table shows the comparison between the two types of lead acid batteries and lithium-ion batteries [9]. We see that lithium-ion batteries are the most expensive up front cost though they have little maintenance and they have a high energy density.

Table 4: Battery Technology Comparison

Table 2: Battery Technology Comparison

	Flooded lead acid	VRLA lead acid	Lithium-ion (LiNCM)
Energy Density (Wh/L)	80	100	250
Specific Energy (Wh/kg)	30	40	150
Regular Maintenance	Yes	No	No
Initial Cost ($/kWh)	65	120	600[†]
Cycle Life	1,200 @ 50%	1,000 @ 50% DoD	1,900 @ 80% DoD
Typical state of charge window	50%	50%	80%
Temperature sensitivity	Degrades significantly above 25°C	Degrades significantly above 25°C	Degrades significantly above 45°C
Efficiency	100% @20-hr rate 80% @4-hr rate 60% @1-hr rate	100% @20-hr rate 80% @4-hr rate 60% @1-hr rate	100% @20-hr rate 99% @4-hr rate 92% @1-hr rate
Voltage increments	2 V	2 V	3.7 V

3.4 Diffusers

Table 5 is given below to show the varying costs and concerns of all the diffuser technologies. To find the most value of flow rate per dollar the metric of (ft^3/m)/$ was calculated. This gives very high values for the rubber tubing, but has hidden cost in that pump flow rate requirements are much larger to provide the necessary flow rate. In the same way the rubber membrane has a slight hidden cost due to higher pressure requirements. The sweetwater and aluminum oxide have a 0.25 psi pressure requirement which allows them to be compatible with low pressure economical blowers.

Table 5: Summary of Various Diffuser Specs
(Lifespan estimated based off of fouling and listed product details)

	Size Metric	CFM (ft^3/m)	Cost ($)	Lifespan	Major Advantage	Major Concern	cfm/$
Sweetwater	1.5x1.5x6 in^3	0.5	11.29	1.5-2 years with regular clean	-Compatible with blowers -Time Tested	-Cleaning -Fragility	0.044
Rubber Tubing	Per Foot	0.1-0.6	1.51	1 year	-Shapeable to pond -Compatible with blowers	-Cleaning -High Pressure Requirements	0.23
AntiMicrobial	Per Foot	0.1-0.6	2.45	1 year	-Shapeable to pond -Compatible with blowers	-Cleaning -High Pressure Requirements	0.14
Bioweave	Per Foot	0.2-0.6	37.00	1 year	-Self Weighted	-Degradation	0.011
Rubber/EPDM	8x1.5 in	0.7	15.69	1-2 year	-Easy to Clean	-Higher psi requirements	0.045
Aluminum	6x1.5 in	0.75	13.00	2-3 year	-Compatible with blowers -Flame clean -Rugged		0.058

Overall the total cost of diffusers is minimal in comparison to the pump and battery costs. However compatibility the potential for diffusers to drive a larger pump purchase is a real possibility and one that should be accounted for within calculations.

3.5 Solar

Monocrystalline solar cells come with the highest efficiency and not surprisingly the highest price. Polycrystalline is the next most efficient with thin film cells close behind. Polycrystalline solar cells are more readily available as ready to install panels when searching through the online marketplace. If there are space constraints a higher efficiency technology may be preferred. Also some monocrystalline solar cells offer a 25 year warranty. Some online packages throw together the charge controller, mounting screws/plates, and the cell which is added convenience for a slightly higher price [21].

4. Component Environmental and Social Considerations

4.1 Pump

4.1.1 Environmental/Social aspects of Single acting reciprocating:

Single acting reciprocators have really minimal environmental concerns, However lubricant oil that is used for the piston could leak through the valves, and that could be hazardous for the environment and the fish. If the pump where to be moved from place to place, oil could spill everywhere. the main dilemma that we could face is that the lubricant could not be detected in the pond and we won't be able to control the leak. Depending on how much air we want to pump the size of the pump could vary, to pump a lot air we need a bigger heavier pump, which makes it harder to be stolen. Noise could be due to a lot of factors one of which being the piston loses all the lubricant, another could be due to a failure in the inlet valve where air could be leaking out as the piston pushes down [25].

4.1.2 Environmental/ Social aspects of Double acting reciprocating:

Just like the single piston the lubricant in the double acting pump could leak out from the valve as well, and that could pollute the water and affect the fish. Another form of environmental concern is the noise pollution. The pump being so loud could affect the mating of birds in that area, the fish in the water, and all other animals in that area. The vibration that it can produce can affect the structure of the pond and everything that surrounds it. The double acting pump has a lot social implications because the noise it produces while it is working, can disturb the farmers sleep cycle, since it will be operating from 12am to 6am. The vibration produced by the pump could tear down the farmer's house. However the pump could be so big and heavy, that makes it hard to be stolen.

4.1.3 Environmental/social aspects of Diaphragm reciprocating:

Just like all the other reciprocates, the main and only concern is the leak of the lubricant from the piston. How ever due to the sizes and variety of this particular pump, other environmental constraints need to be taken into consideration. With big and more complex ones, there are gases that are being used in moving the piston [26], and the leakage of these gases could be hazardous. However since we are looking for a smaller pump, we can disregard these potential environmental impacts. The diaphragm seems to make no noise as long as the parts are working well and are in good conditions. Since the diaphragm will be small there is a great possibility that it could be stolen. This is a factor that we need to take into consideration if we were to choose this particular pump, unless we attach them to the main body of the design.

4.1.4 Environmental / social aspects of Rotary Pumps:

Some of the pump parts are made up of iron and digging for iron could be an environmental pollution. The pumps could have no noise at all. They are much quieter than the double piston pump which would make them socially adaptable. Vibration is also not as much of an issue, consequently decreasing the noise of the whole system.

4.1.5 Environmental/ social aspects of Centrifugal pumps:

The centrifugal pump can vibrate and make large amounts of noise. These noises can be maintained if the system is kept in a good condition. However we do not need to worry about oil leakage because there is no need to use lubrication or other hazardous liquid. If the system were to be kept in good conditions the noise from the vibration could be contained and limited. the vibration made by the impeller could damage the pump if not controlled. Since the pump that we will be using is of smaller size, burglary could be a potential risk, however we can attach it to our floater and minimize the risks [27].

4.2 Tubing

4.2.1 Environmental / social aspects reinforced clear vinyl

The environmental impact of vinyl tubing is very high, vinyl is made from Polyvinyl chloride which is a cariogenic and can release dioxins in the environment. This means the fumes from the production of it or burning of it can cause cancer. Also there is very little recycling of it so most goes into landfill where it will not biodegrade. [28]

4.2.2 Environmental/ Social aspects rigid PVC pipe

The environmental impact of PVC pipe is very similar to Vinyl tubing since the base chemical is the same which means PVC pipe has a low ability to be recycled and and high environment and human health impact during the manufacturing process [28].

4.2.3 Environmental/ Social aspects Black vinyl

Black vinyl has the same environmental impact as Clear vinyl but it has the added benefit that the black pigment help to prevent algae growth within the tubing and could help with solar degradation of the tubing [6].

4.3 Battery

4.3.1 Environmental/ Social aspects of lead acid

The main environmental impact of Lead Acid batteries is that they require large amounts of raw materials to make the batteries at the same storage level as other batteries which means a larger impact from the material gathering process. Also the manufacturing process is very energy demanding and can cause a lot of population to be made. Lead Acid environmental impact is mitigated in the USA since 97% of lead acid batteries are recycled.

4.3.2 Environmental/ social aspects of lithium-ion

Lithium-ion has its own environmental impacts in that lithium mines are very energy intensive. Also the large amount of copper and aluminum in the batteries has a large environmental impact in its mining and processes. Lastly lithium-ion recycling is at the very initial stages [9].

4.4 Diffuser

Most diffusers are non-toxic and do not pose an environmental risk. Nevertheless environmental considerations must be made in regards to cleaning of the ceramic diffusers.

For cleaning of diffusers muriatic acid is used or hydrochloric acid. This chemical has long term health implications for people frequently in contact with it. The chemical can have adverse corrosive effects on the respiratory tract and human tissue [29]. Precautionary measures must be taken for human health safety to prevent contact or inhalation of the hydrochloric acid. Measures could include safety goggles, latex gloves, plastic apron, etc. In regards to social issues none of the diffusers cause noise disruptions. The only aeration device that might cause a social outcry would be a gas motored pump or motor aspirator or a large paddlewheel aerator creating noise complaints. The only possible social concerns would be theft of the diffusers. The need to swim to them might be a hindrance for thieves looking for a quick and easy job.

4.5 Solar Panel

Most of the environmental impacts of solar are from the manufacturing process of the photovoltaic cells themselves. Many types of photovoltaics use hydrochloric acid, acetone, nitric acid, etc. Most environmental hazard exposure would be in manufacturing and not at the aquaculture farm [30]. The major social consideration would be anti-theft. Our flotation device would be anchored to the pond bottom and in the center of the pond. On the flotation device itself the panel would be bolted down to prevent a quick theft. Theft is the major social consideration.

5. Regulatory Considerations

We anticipate future regulations, but currently the developing world is where the product would be used. On average these countries do not have many environmental regulations. The regulations that would need to be included into the design of the aeration system are related to components of the system. For example the battery concerns are lead acid so there are environmental regulations regarding the disposal of them in the U.S. Transportation of some lead acid batteries is regulated to make sure no spills occur. Also consideration for the the fact that there will be a battery on a floating platform and the risk of the fluids contaminating the pond need to be taken into account. Future research into international trade regulations will be necessary before mass production of the design.

6. Technologies Chosen

Matrix

Using the decision matrix we were able to evaluate which technologies were outstanding. The highlighted technologies were the winners within their respective technology categories.

Table 7: Total points by parts.

Parts	Total points (out of 100)

Glass bonded Silica	52
Tubing	51
Rubber/EPDM	61
Aluminum Oxide	60
Nickel	41
Lead Acid	55.5
Lithium Ion	54.5
PVC ridge	51
Black Vinyl Tubing	45.5
Reinforced clear Vinyl Tubing	46.5
Single Acting Pump	52
Double Acting Pump	51
Diaphragm Pump	52.5
Rotary pump	46.5
Centrifugal Pump	49

V. Experimental Results at Oregon State Salmon Lab

1. Scaled Down System Components

To test the system J2MH chose the smaller scaled system to be applied to the salmon lab and test the efficiency of it. The system was made up of:

- 1.EPDM disk diffuser
- 1. DC 12 volts battery
- 1.BOYU 903 pump
- 2-Solar panels
- 1- Oxidation Reduction potential (ORP)
- 1. Charge controller
- 1-Arduino

If you go to Appendix VI you will see the circuit diagram for the testing model. The circuit uses the arduino to turn the pump on and off through the use of a relay to activate the relay. The circuit uses a transistor due to the fact that the arduino does not have the power to activate the relay by itself.

2. Experimental Setup

J2MH assumed a fish density of 5 fish/m^3, and algae concentration of 560 mg/l. To construct the uptake of Oxygen by the fish, glucose was added to the pond. Two stimulation were done, 14.6 g of glucose per night to simulate the 150 gram fish, and 17 g of glucose per night to simulate the 250 gram fish size. The glucose was mixed in 2 liters of water, and placed in a plastic bottle with an adjustable dripper, the apparatus was set to drip once every 2-3 seconds. The readings were taken twice a day at 7 am and 5 pm every day.

3. Experimental Results

This table represents the dissolved oxygen readings in the water after adding glucose. Each stimulation of glucose level was added for 3 days. The readings were taken in two locations next to the surface donated by location "one" and at depth denoted by location "two". (Refer to table 8)
We have used the open circuit voltage to determine the state of charge when we were adding glucose, refer to Appendix XII for the open circuit voltage v.s Residual capacity figure

Table 8: Dissolved Oxygen Testing Results

Glucose rate	Date	Time	Time Location	
			one	two
			DO	DO
150g	2/22/2016	1700	2.1	2.1
	2/23/2016	700	13	12
	2/23/2016	1700	14.1	11
	2/24/2016	700	13.7	14.5
250g	2/24/2016	1700	11.7	12.3
	2/25/2016	700	9.45	9.95
	2/25/2016	1700	9.2	8.7
	2/26/2015	700	12.3	12.2

VI. System Selection

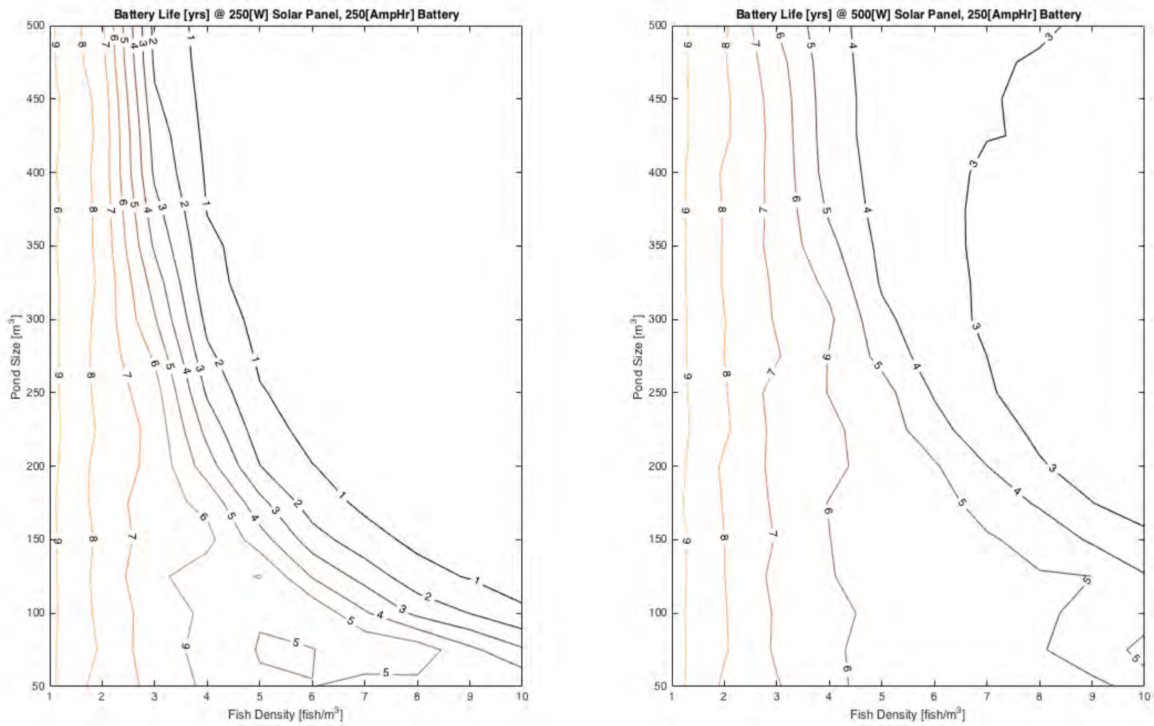

Figure 18: The effect of doubling solar panel size, increases battery's lifetime

1. J_2MH Modeling Software

Initially our design was sized through handwritten calculations based upon real world data from Ghana testing ponds. This method of calculation (represented in figure 18) was sufficient for sizing a system to a specific known fish density and pond volume. The next level analysis was to see how differing inputs like component sizing, real world weather data, pond volume, etc. affected dissolved oxygen, fish health, and the economics of the system. By incorporating these inputs and outputs into a modeling framework simulation and sensitivity could be computed hundreds to thousands of times with ease.

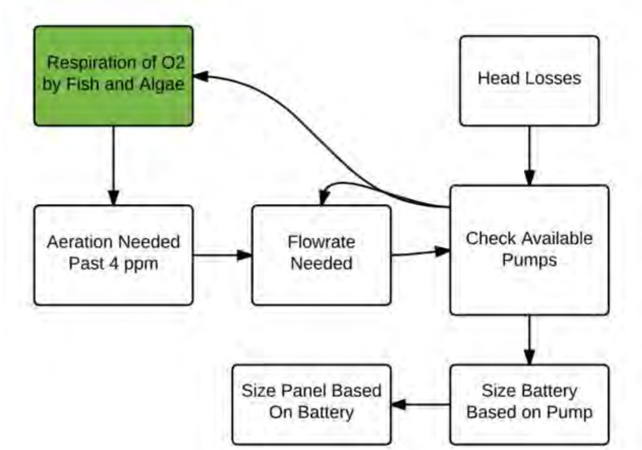

Figure 19: Initial method of component sizing calculations

The J_2MH modeling software allows for swift and efficient consulting work with farmers from around the world. With a quick download of a local area's yearly weather data the user can process how DO concentrations, fish weight and stress, and battery state of charge will be projected over the course of a year. For a given initial capital investment cost, the consultant can tell farmer what the stocking rate of the the pond will be. Conversely the consultant has the ability to report the cost of achieving a specific final fish harvest weight.

The model also offers the ability for the J_2MH *Consulting Firm* to update and improve upon previous system designs. For the current chosen models various arduino system control logics were tested. While keeping all other values constant, the resulting performance of the system could be correlated with which logic helped accomplish fish health goals and to increase the net present value of the system. The input and output parameters and equations used in the model are shown in figure 18.

2. Inputs & Outputs

2.1 Inputs

1. Solar Insolation
    a. Location- datasets are used from NASA Surface meteorology and Solar Energy renewable energy resource web site (6.0) based on **latitude and longitude**
    b. The datasets retrieved:
        i. Insolation [kW/m^2] at 3 hourly intervals
        ii. Cloud Amount [%] at 3 hourly intervals
        iii. Monthly Averaged Insolation on a Horizontal surface
    c. Both 3-hourly datasets are interpolated to find the hourly values. A random number function generates a number between 0-1 which is then compared to the [%] cloud amount at that time. If the random number is less than cloud amount, then insolation is for that time is multiplied by 0.4. Finally a maximum multiplier for each month is used to calibrate the randomized hourly insolation results so that they are representative of the monthly averaged insolation (kWh/m^2/day). The effects of cloud cover can be observed in the simulated insolation data shown in Figure 20.

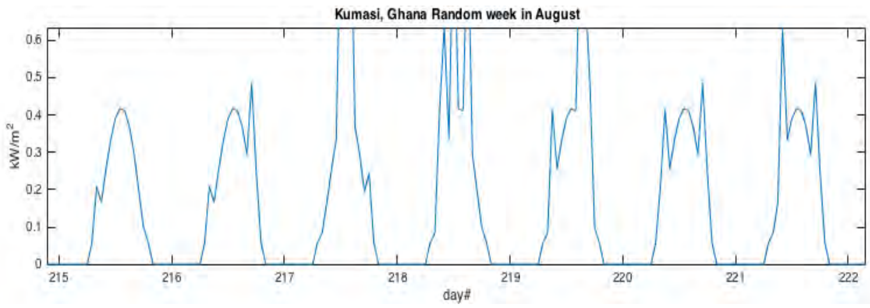

Figure 20: Insolation fluctuating throughout throughout week in Ghana

2. Solar Panel
a. The solar panel's rated output **Watts** are used to determine amount of charge going to the battery based on Insolation for the given time.
b. Solar Panel Cost = 1.44[$/Watt]***Watts**

3. Battery
a. The battery's **AmpHours** are used to determine state of charge and storage capacity
b. Battery Cost = 1.39[$/Ah]***AmpHours**
4. Pump
. The pump's manufacturer rated power draw **[Watts]** is used, unless pump has been tested
a. When testing results for multiple pump sizes, the air flow should be adjusted accordingly. (Air flow as a function of pump power draw [(m^3/h)/(kWh)]
b. Unless otherwise stated, the power draw and air flow for the pump have been set at 185 Watts and 8.1 m^3/h, respectively.
5. Hours of Pump Operation
. The **start time** and **end time** for running the pump must be set
a. A start time of 2am and end time of 6am are used for all of the results given unless otherwise stated.
6. Control Logic
. This input allows for quantitative analysis between various control logics

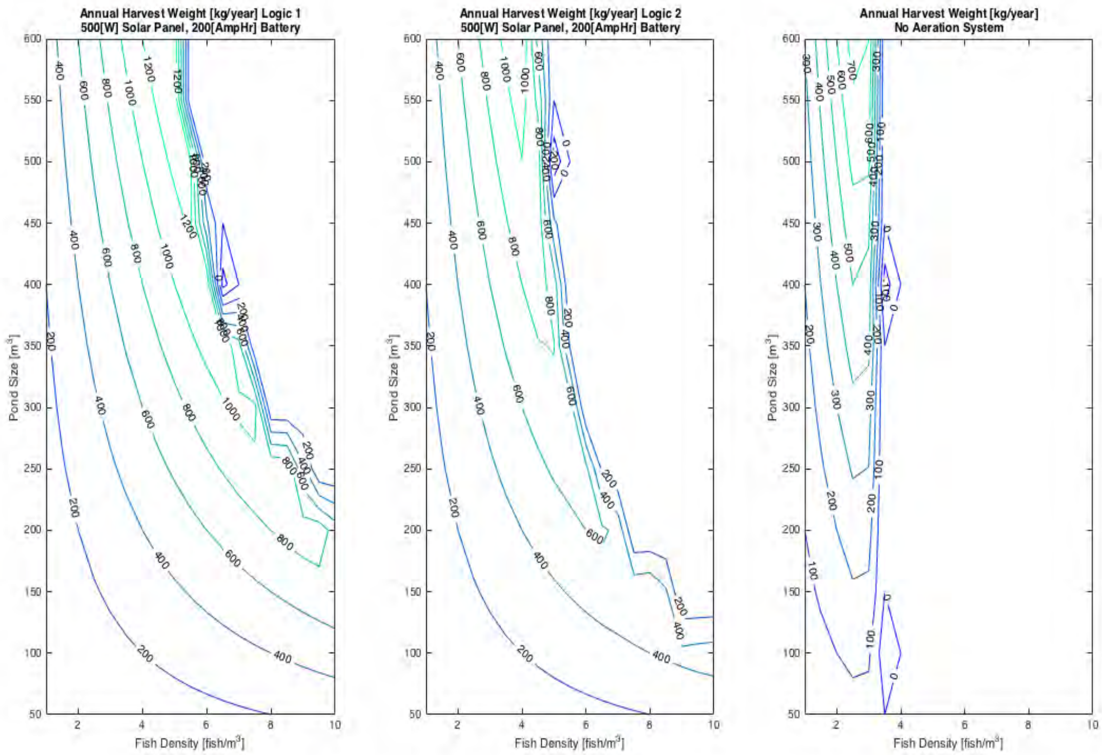

Figure 21: Final Fish Weight as a Function of Logic Performance, Ponds Size, and Fish Density

7. Charge Controller

a. This input allows for quantitative analysis between MPPT and PWM charge controllers

b. MPPT is more efficient at transferring incoming solar panel energy to the battery due to its dynamic and frequent search for optimal solar harvesting. Unsurprisingly the MPPT charge controller is roughly 170 $ more expensive.

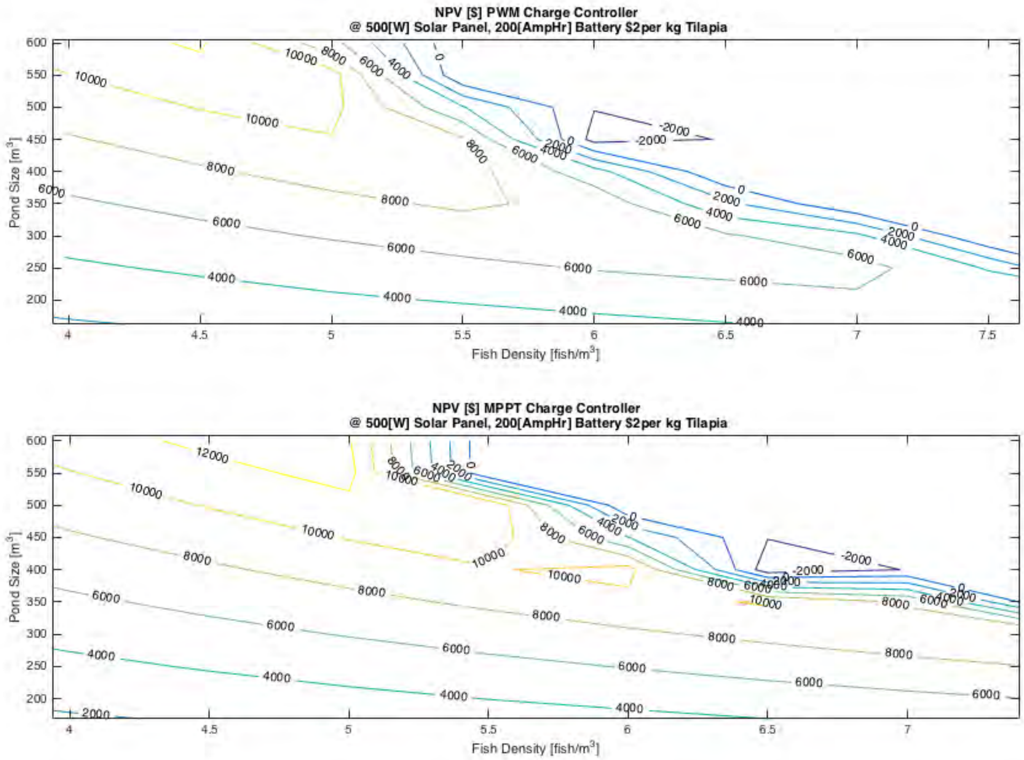

Figure 22: NPV as a function of charge controller type component sizing

8. Pond Size

a. Pond Volume [m^3] as an input variable, provides the opportunity to determine the most appropriate size system and stocking density for any given pond size.

9. Fish Stocking Density

a. Fish Stocking Density [#fish/m^3] is used to determine the rate of oxygen being consumed.

10. Tilapia's Market Price

. Tilapia's Market Price [$/kgfish] is a sensitive variable that plays a large role in the profitability of the system

2.2 Outputs

1. Dissolved Oxygen Concentration in Pond

a. At 17:00 hrs daily the dissolved oxygen concentration is set to:

i. DO(@t=17:00)= 5.25 + (0<=random#<=1)*3.75

b. Between 17:00 and 8:00 the DO demand is (0.6 mg02)/(kg fish)

2. Initial Capital Cost

. Initial Capital Cost=Battery Cost+Solar Panel+Pump Cost ($200)+charge controller+non-variable fixed costs ($250);

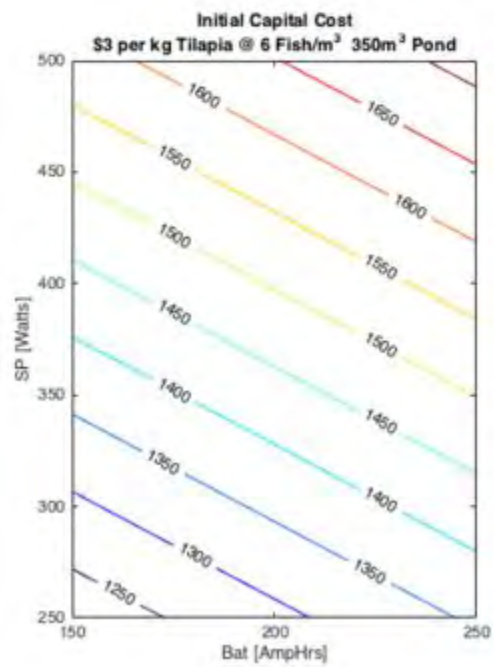

Figure 23: Initial Capital Cost Based Upon Solar Panel and Battery Sizes

3. Battery Life

a. Battery Life is an estimate based on the amount of time a battery spends at any given State of Charge (SOC) the course of one year

b. Operating @ SOC > 80% results in Battery Life > 5 years

c. Operating @ SOC <20% results in Battery Life < 1 year

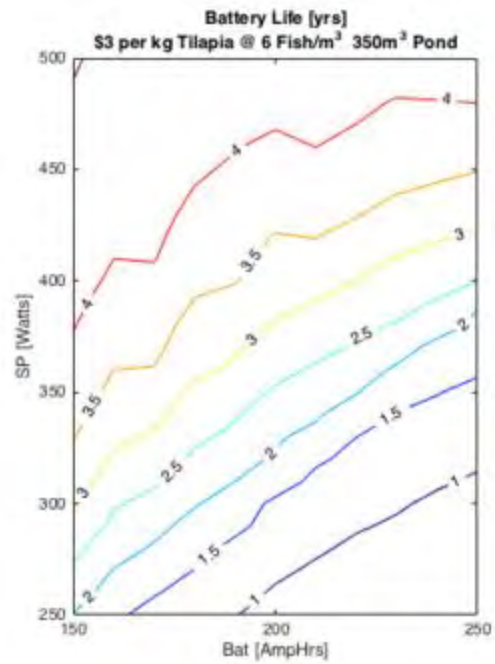

Figure 24: Battery life as a function of component sizing

4. Net Present Cost

a. The net present cost output is the net present value of all things causing a negative cash flow. This includes initial cost and replacement of components.

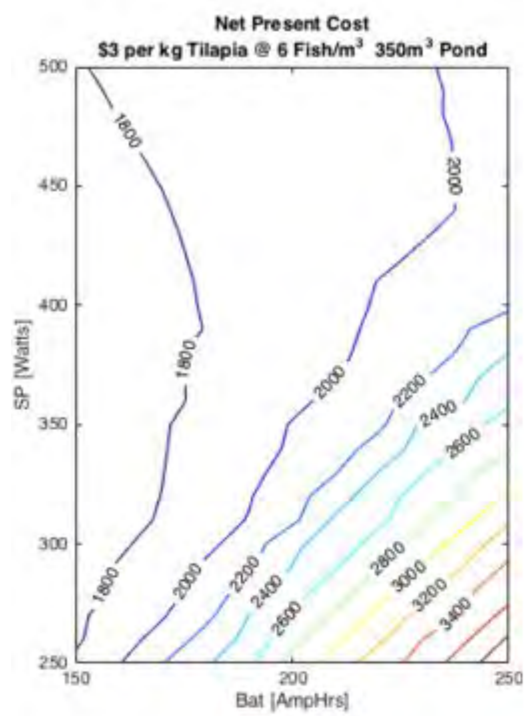

Figure 25: Net present value base dupon Solar Panel and Battery sizing

5. #hrs/yr DO<2.35mg/L

6. #hrs/yr DO<1.25mg/L

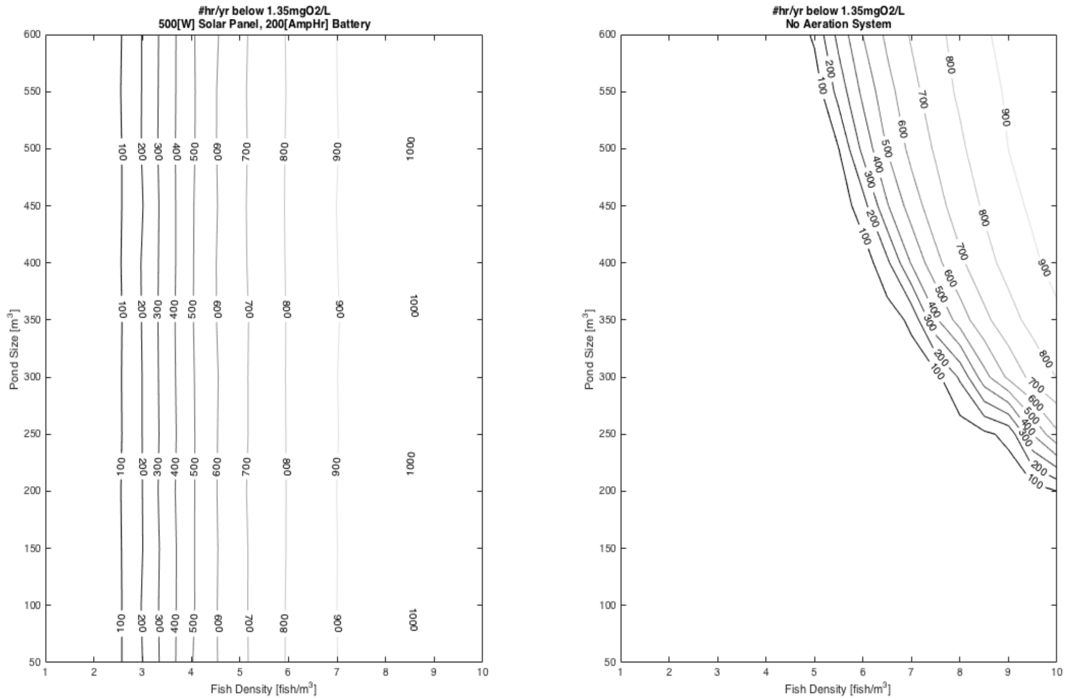

Figure 26: Hours spent below 1.35 mg/L for aerated and non-aerated systems

7. Annual Harvest Weight
8. kgO2/$ Net Present Cost
9. # of Mortality Events

a. The number of mortality events affects the final fish harvest density. Each mortality event reduces the harvestable fish weight by 5% of the stocking density. More information can be found in the Net Present Value Overview Section 3.1.

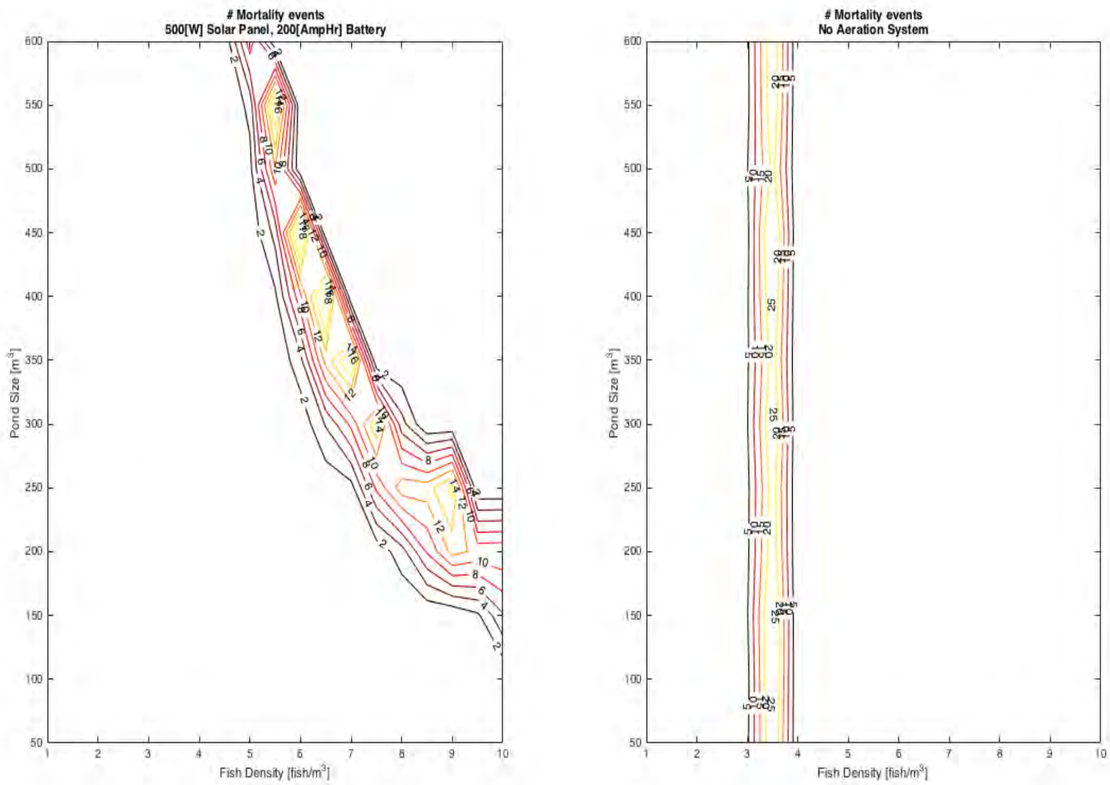

Figure 27: Number of mortality events over a year for an aerated and non-aerated system

10. Die Off Events

a. Although not plotted, the Die-off events occur for all fish densities greater than the peak ridge in the mortality events plot above.shown

11. 10 year Additional Total Annual Revenue

. For n=0-->10, sum((Total Annual Revenue-1260)/(1+discount rate)^n)

a. This is the summed revenue accounting for the present value

12. Net Present Value

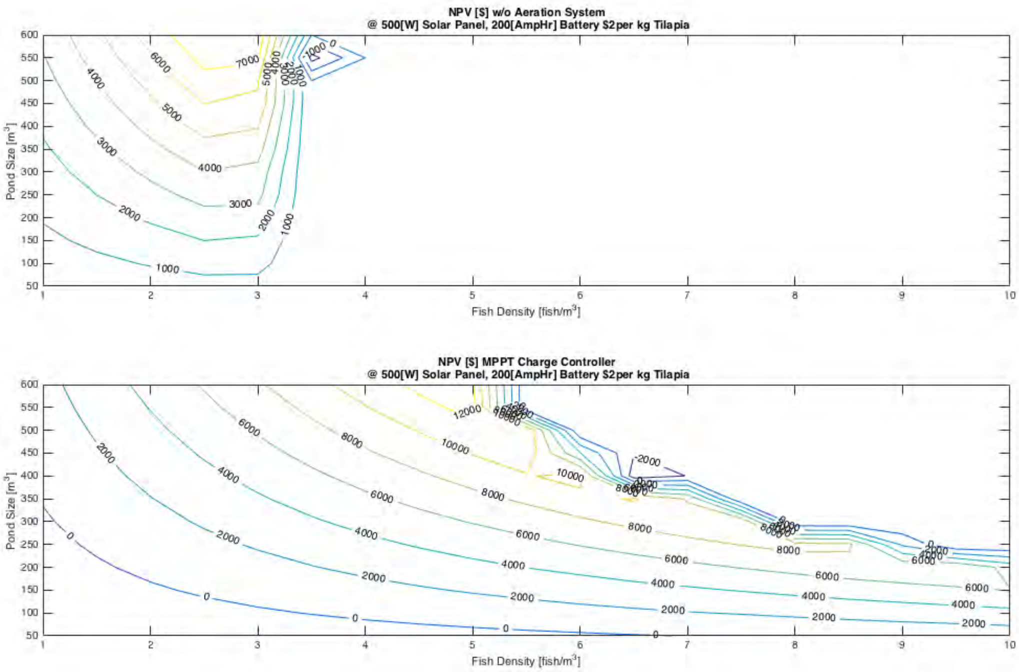

Figure 28: NPV gain comparison between aerated and non-aerated system

VII System Economics

1. Introduction

When it comes down to it farmers order of questions will most likely be firstly "How will this system help me?" And "How much will this cost?". The technology selection and system optimization above prove the feasibility of the design to fulfill farmer's objectives of sustained fish health and increased productivity. This section will provide insight into the short and long term financial impacts of a J_2MH solar aeration system.

2. Initial Capital Cost

The two most influential economic metrics are net present value and initial capital cost. Net present value provides insight into the how valuable an investment over time is in present day value. Initial capital cost is just as important due to the fact that no matter how attractive an investment is, a farmer might not be able to afford anything past a certain initial cost. For this reason the J_2MH Consultant Firm will offer two systems with known fish sustaining capabilities, initial cost, and net present values.

The two systems offered (10.1 and 10.2) for the clients due to that fact that we wanted to provide a cheap economical start up cost system that might be easier for a farmer to buy. As well as provide a system that has the most bang for its buck and is a better investment for the farmer NPV wise.

Table 9: System Differences

System	Solar Panel	Battery	Charge Controller	Price
10.1	250w	200 Ahrs	PWM	$1064
10.2	500w	250 Ahrs	MPPT	$1482

3. Net Present Value

3.1 Net Present Value Overview

To define net present value(NPV) an understanding of cash flows must first be reached. A cash flow is the sum of all losses and gains financially for a specific year. The present value for a specific year is the value of the cash flow in today's terms with a discount rate influence. The net present value for a system is the summed present values up until the time period of interest. This metric is helpful for determining the financial benefit of an investment over the long term.

The positive inputs for the cash flow come purely from the revenue of fish at the end of a growing season. It is an important distinction to make that the positive cash flow due to our system is not the total money received from a harvest. The system's positive cash flow is due to the difference in between total fish revenue from an aerated pond and a control pond with no aeration. In other words the profit made by an aerated pond is only due to the fish saved from mortality events or due to the increased productivity of a pond. With the J_2MH modeling software consecutive days spent below a critical dissolved oxygen (DO) level (1.35 mg/L) was tracked. Using this, a method of assigning a percentage fish mortality was created. The figure below shows the ability of matlab to track consecutive days spent below critical DO levels throughout the year.

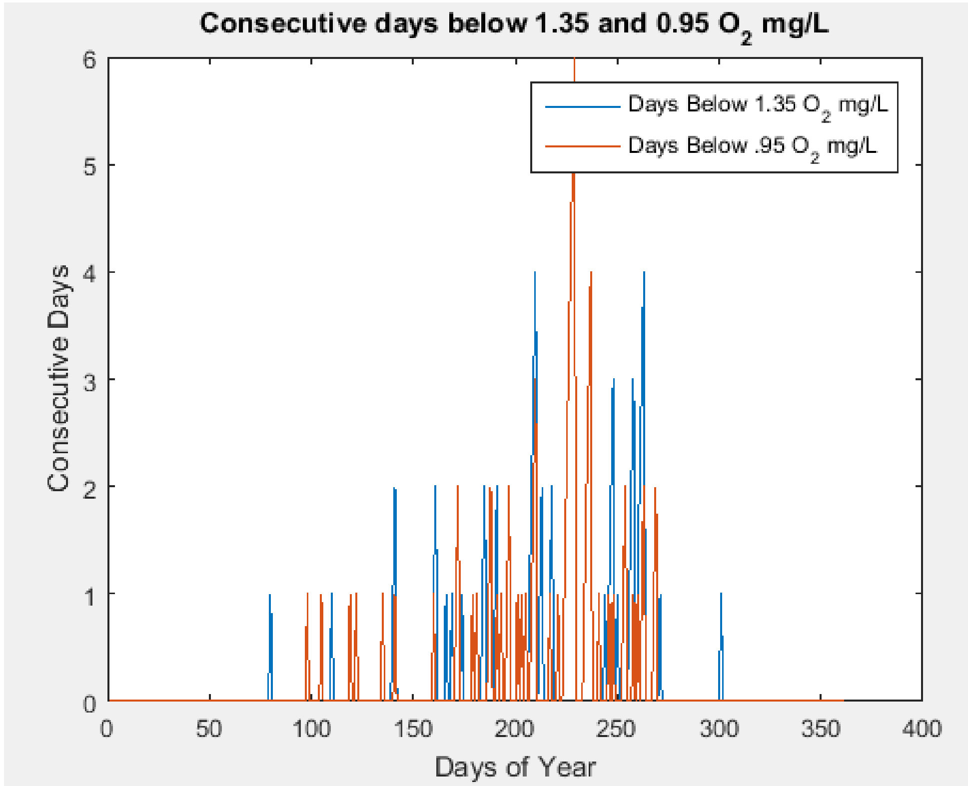

Figure 29: Consecutive days below 1.35 and 0.95 mg/L Oxygen

A baseline pond with no aeration was chosen in order to compare cash flows with an aerated pond. The baseline pond size was kept equivalent to the aerated pond while the fish stocking rate was varied. The fish stocking rate was optimized to give the farmer the most money. All systems were compared against this baseline for an accurate NPV calculation.

3.1.1 Net Present Value Factors

The net present value of a solar aeration device varies greatly based upon many factors. An extremely high initial cost can result in a negative NPV. The pond volume, stocking rate, concentration of algae, and fish oxygen consumption rate varies the needed sizing of components. Routine repair and replacement of parts is another player in NPV.

The interaction between the solar panel and the battery life warrants a closer analysis. When the solar panel is undersized the battery can not consistently reach full charge. The battery life is significantly diminished the longer the battery spends in a lower state of charge [4]. Investing in increased solar panel size makes sure that the battery will stay in a higher state of charge for a longer period of time. A balance in between

increased solar panel cost versus overall system lifetime battery replacement cost was investigated using the Matlab J_2MH software.
The figure given below shows the sensitivity of annual fish harvest weight as a function of battery and solar panel size. Past a certain battery voltage the increase in annual fish weight is almost solely responsive to solar panel size. This figure proves the point of the disproportionate influence of the solar panel on system functioning.

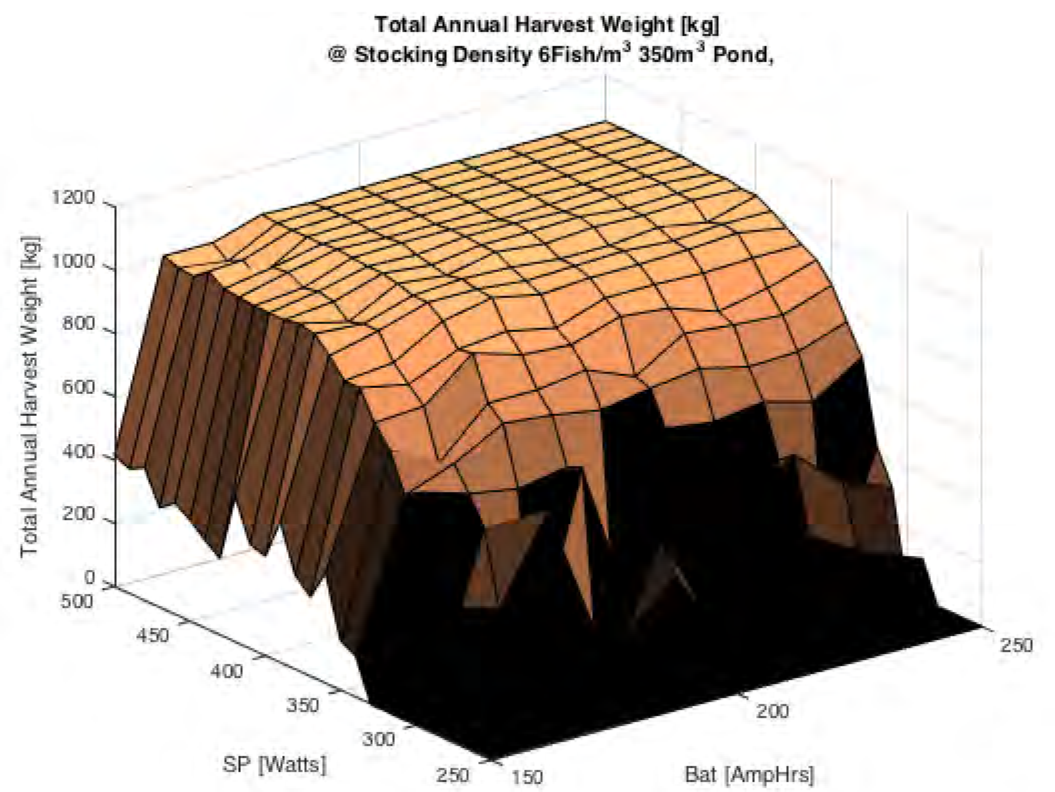

Figure 30: Sensitivity of Ann. Fish Harvest Wt. to Component Sizing

3.2 Net Present Value Results

The table below shows the 10 year NPV based upon two different systems. One system (10.1) has a PWM charge controller and a 200Ahr battery. The initial capital cost is slightly less than the second system shown in table 11. The net present value of the system is highly dependent upon the market value of fish. A fish market value of 3.5 $/kg fish weight was reported for Ghana [31], while Hillary Egna quoted a common value of 1 $/kg fish weight. The market value of tilapia in any location will determine the quality of the investment of the J_2MH system.

Table 10: System 10.1 Simulated for varying fish market values

Fish Stocking Density (fish/m^3)	Market Value ($/kg)	Solar Panel (W)	Battery (Ahrs)	Charge Controller	Cap Cost	10 Year NPV ($)
5	3	500	200	PWM	1470	5400
5	2	500	200	PWM	1470	700
5	1	500	200	PWM	1470	-4000

Table 11: System 10.2 Simulated for varying fish market values

Fish Stocking Density (fish/m^3)	Market Value ($/kg)	Solar Panel (W)	Battery (Ahrs)	Charge Controller	Cap Cost	10 Year NPV ($)
6	3	500	250	MPPT	1720	8050
6	2	500	250	MPPT	1720	2440
6	2.5	500	250	MPPT	1720	5250
6	1	500	250	MPPT	1720	-3200

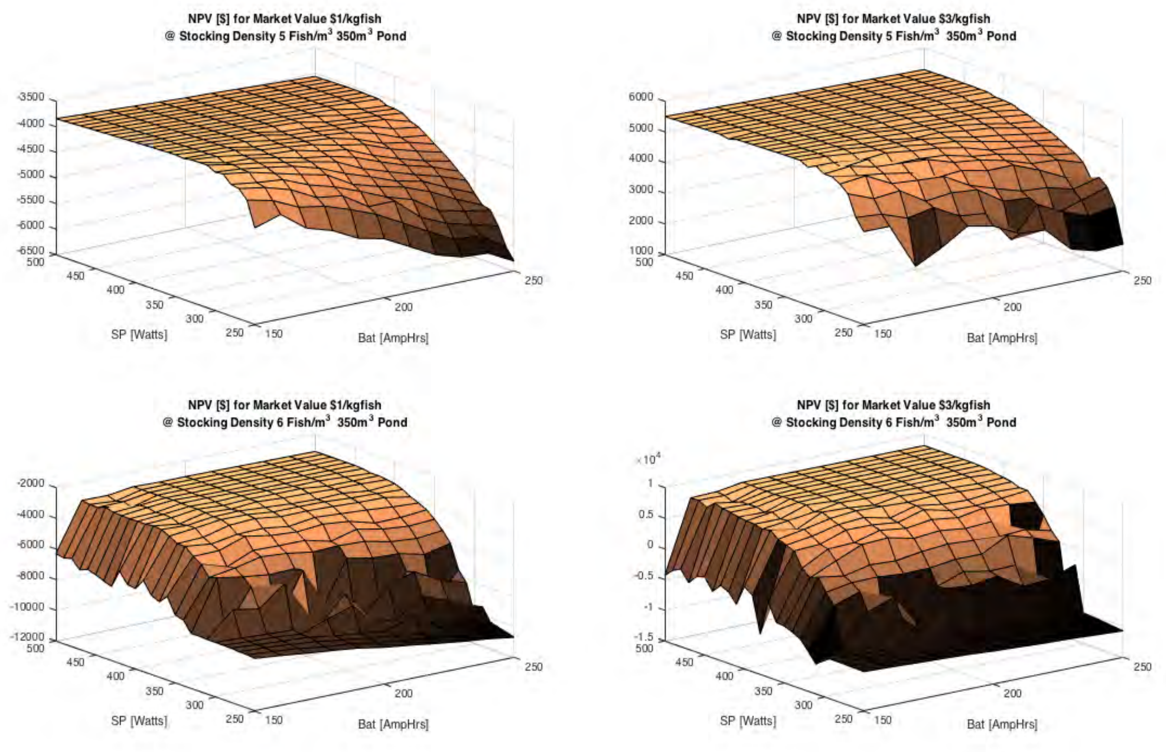

Figure 31: Representation of Sensitivity of NPV to Battery and Solar Panel Sizing

The figure above shows how NPV is affected by varying solar panel and battery size. Once again when market value of fish is low it is nearly impossible to maintain a responsible investment.

4. Economic Conclusion

There were a variety of important factors that came out of the economic analysis. Firstly it was found that the system functioning, in terms of final fish weight and net present value, responded more dramatically towards an increase in solar panel size versus an increase in battery size. If extra funds are available, the J_2MH consulting group feels confident that they will be spent effectively to increase net present value and fish production. Secondly the importance of fish market value was amplified when running the model with varying values. The system design remains profitable roughly around a value of 2 $/kg while the system remains attractively profitable around a market value of 3 $/kg. The third most important conclusion of the analysis is that the system design is profitable beyond a certain a point and that values for the system were reached. Using a fish market Value of 2.5 the system costs and NPVs are as follows:

Table 12:

System	Fish Stocking Density (fish/m^3)	Market Value ($/kg)	Solar Panel (W)	Battery (Ahrs)	Charge Controller ($)	Capital Cost ($)	10 Year NPV ($)
10.1	5	2.5	500	200	PWM	1470	3700
10.2	6	2.5	500	250	MPPT	1720	5250

VIII. Conclusion

Team three's final design consists of a centralized flotation system. The float contains a solar panel(500W) roof for rain deflection with battery(250 Ahr), pump (135 L/m), and charge controller housed underneath it. The centralized flotation makes theft more difficult and is self contained and out of the way of foot traffic. The pump has been sized to meet the pressure requirements due to depth of water and head loss of piping and diffusers. The rubber EPDM diffusers were chosen to meet our flow rate requirements while providing low maintenance through their self cleaning properties. A monocrystalline solar panel was chosen for its increased efficiency and the battery was sized to allow for an optimized battery life to increase net present value. The diffusers in our system are buried at a depth of 1 meter below the pond bottom to increase oxygen transfer efficiency and more effectively use the power that the solar panel provides. The J_2MH control logic offers roughly four days of extremely cloudy weather. During periods of normal insolation the logic

Our projects major advantages are its anti-theft properties, low price point when compared with systems on the market, and depth efficiency innovation with an increased resiliency to periods of cloudy weather.The *J_2MH* Matlab software offers flexibility in consulting work in areas across the globe and ability to swiftly optimize system design. The *J_2MH Consulting Firm* feels that our design will be effective at increasing productivity, decreasing fish die off risk, and be competitive in the current solar powered aeration market.

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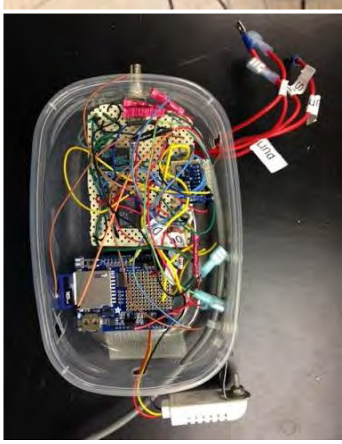
Appendix I: Design picture



Appendix II: Problem Statement

J_2MH Problem Statement

Aquaculture is a growing field that is already playing a key role in world food supplies. Many of the earth's residents depend on aquaculture for physical and financial sustenance. Some of the technical challenges facing semi-intensive aquaculture today are nutrient recycling/disposal, water consumption, aeration, and profitability of small scale farmers.

The environment which we are designing for is a tropical to subtropical climate in rural areas with no access to line-power electricity . We are assuming high levels of incoming solar radiation. The water bodies in this region are assumed to be unlined earthen ponds with algae.

The problem as we see it is to design an aeration system that can tackle low dissolved oxygen (DO) levels due to the respiration of fish and algae during the night. As a result of this higher densities of tilapia can be raised with less die off events. One side of the problem is to engineer a robust and intelligent aeration system to address fluctuating DO levels. The other side of the design is to provide an affordable product with a high NPV and low payback period. In order for the design to be scalable it must have simple operation, maintenance, and instructions for non-engineers. In summary the problem is to create a design that is financially viable, marketable, and increases aquaculture yields through intelligent aeration technology.

The oxygen delivery system for tilapia fish that we will be designing for will be based on the following conditions:

- A stocking rate of 4 tilapia/m3
- A maximum weight of 200 g per fish
- An average DO level of no less than 4 ppm in the pond
- Solar intensities characteristic of Ghana
- No access to electrical line-power
- A goal parts cost of less than 750 USD for full scale model
- Theft prone rural environment
- Awareness of safety, environmental, and regulatory laws
- Cultural sensitivity
- A healthy algal population (I.E. no algal blooms to consume all oxygen)
- Design to work within 15 degrees latitude of the equator
- Design for a 15m x 30m x 2m pond size

Appendix III

BOYU 20 Year NPV Calculation

	BOYU 20 Year NPV Calculation			
Year	Discount Rate	Cash Flow	Present Value	NPV
0	0	-876	-876	-876
1	0	-20	-17	-893
2	0	-20	-15	-908
3	0	-20	-13	-921
4	0	-180	-102	-1024
5	0	-270	-134	-1158
6	0	-20	-9	-1167

7	0	-310	-117	-1284
8	0	-20	-7	-1290
9	0	-362	-102	-1393
10	0	-180	-45	-1437
11	0	-20	-4	-1442
12	0	-20	-4	-1445
13	0	-530	-86	-1532
14	0	-20	-3	-1534
15	0	-20	-2	-1537
16	0	-230	-25	-1561
17	0	-362	-34	-1595
18	0	-20	-2	-1597
19	0	-310	-22	-1619
20	0	-20	-1	-1620

Rotary Vane 20 Year NPV Calculation

	Rotary Vane 20 Year NPV Calculation			
Year	Discount Rate	Cash Flow	Present Value	NPV
0	0	-1576	-1576	-1576
1	0	-20	-17	-1593
2	0	-20	-15	-1609
3	0	-20	-13	-1622
4	0	-20	-11	-1633
5	0	-270	-134	-1767
6	0	-20	-9	-1776
7	0	-150	-56	-1832
8	0	-20	-7	-1839
9	0	-362	-103	-1942
10	0	-20	-5	-1947
11	0	-20	-4	-1951
12	0	-20	-4	-1955
13	0	-370	-60	-2015

14	0	-20	-3	-2018
15	0	-20	-2	-2020
16	0	-70	-7	-2028
17	0	-362	-34	-2061
18	0	-20	-2	-2063
19	0	-150	-11	-2073
20	0	-20	-1	-2075

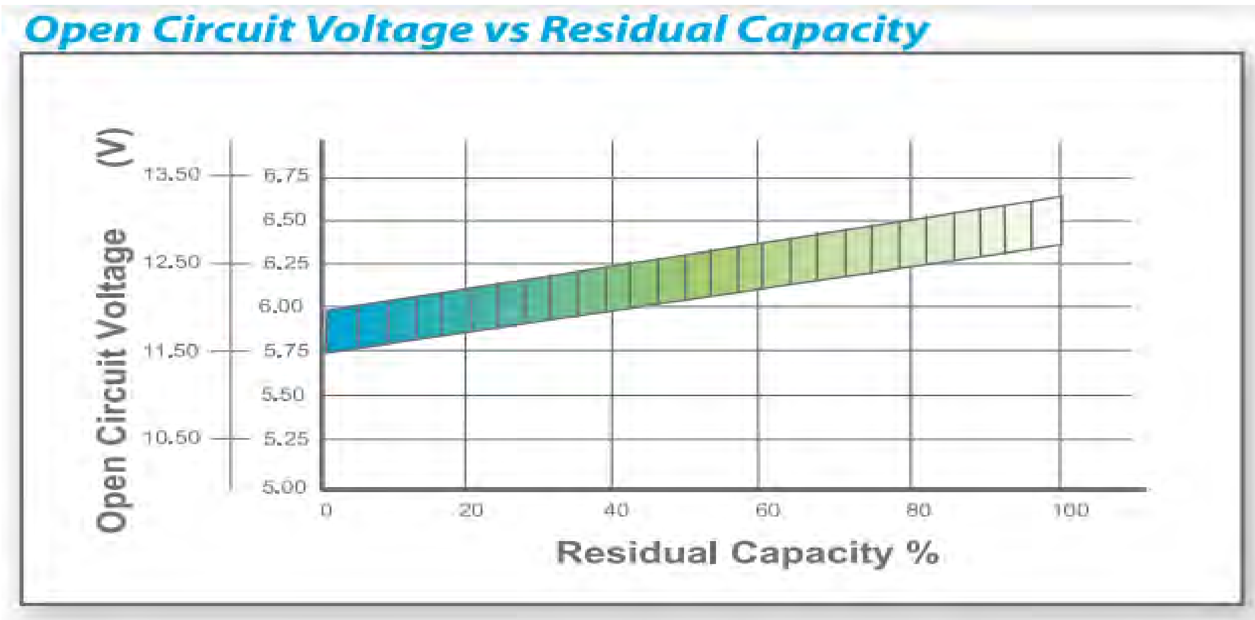
Appendix IV

Synthesis:
A 20 year NPV calculation was done to evaluate whether it would be a better economic decision to invest in a more expensive and longer lasting pump vs. a cheaper pump with a shorter lifespan. Through the NPV calculation we found that despite the low lifespan of the BOYU pumps, the NPV at 20 years without revenues included was -1620 vs. -2070 dollars. In summary it is cheaper to buy the BOYU pumps and replace them every three years when compared with a more expensive and durable rotary vane pump.

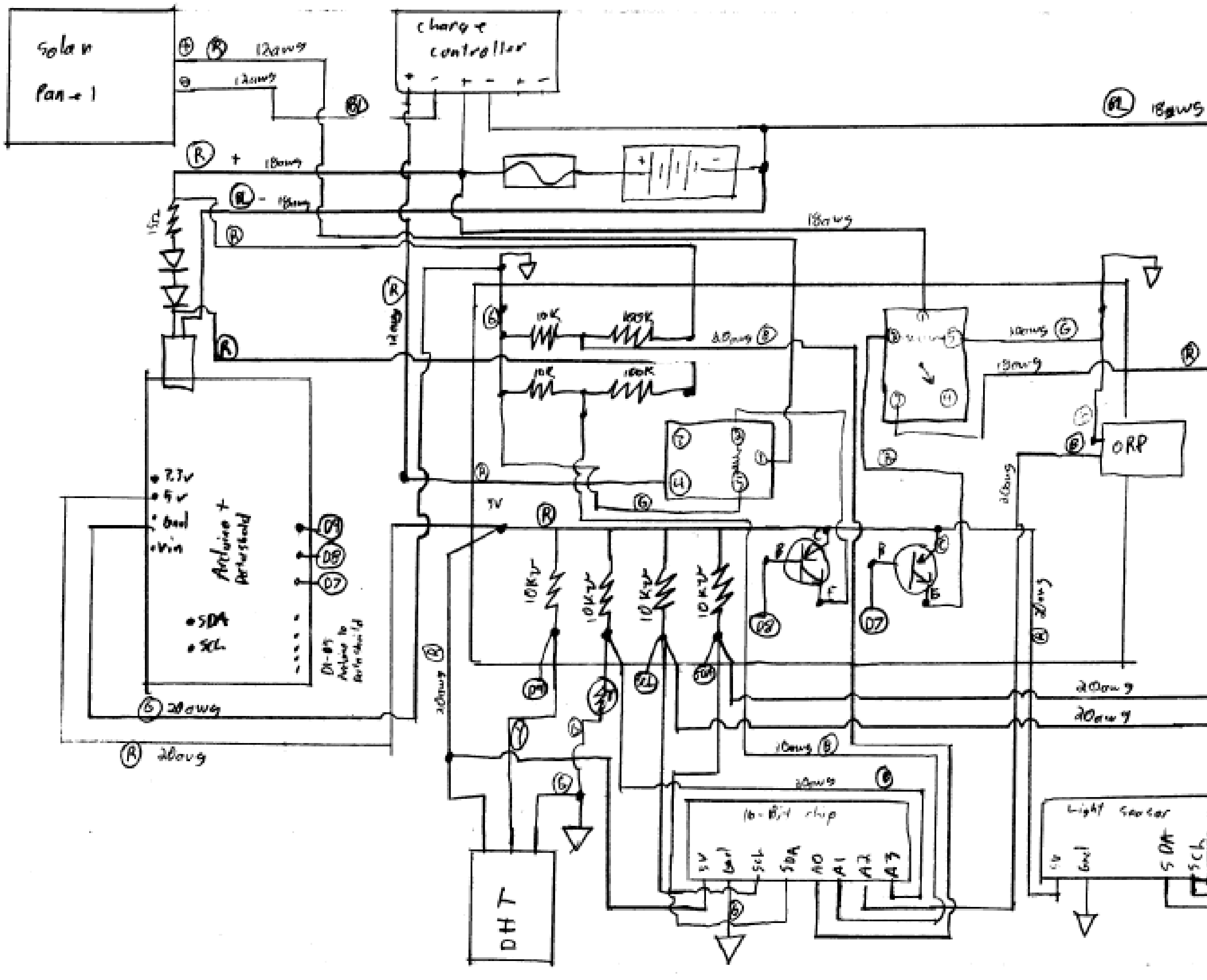
Table 8: Lifespan of Components

	Lifespan (Years)	Initial Investment
EPDM Diffusers	6	100
BOYU Pumps	3	160
Trojan 175 Ahr Battery (57%)	4	250
AQ5 Rotary Vane	20	860
Tubing	6	30
Charge Controller	15	50
Solar Panel	25	215
Plywood	8	25
Flotation Foam	8	67

Appendix V.


Open Circuit Voltage vs Residual Capacity
Open Circuit Voltage (V)
13.50
12.50
11.50
10.50
6.75
6.50
6.25
6.00
5.75
5.50
5.25
5.00
0
20
40
60
80
100
Residual Capacity %

Appendix VI



Appendix VII

Table : Full Scale Model Prices

Fixed Parts	Price ($)
2 BOYU ACQ 906 & 1 BOYU ACQ 903	220
Electronics	25
Plywood/Base	23

Charge Controller	50
Diffuser	80
PVC Pipe	40
Foam	67
500 W Solar Panel	560
Electronics	25
Miscellaneous	50
Total Cost of Fixed Parts	1140
<u>Variable Parts</u>	
250 Ahr Deep Cycle Lead Acid battery	330
200 Ahr Deep Cycle Lead Acid battery	300
PWM Charge Controller	30
MPPT Charge Controller	200
System 10.1 Total	1470
System 10.2 Total	1670

Appendix VIII
Design Calculations

-

Appendix IX
Matrix diagram

An excel file has been added to the thumb drive, that has our matrix diagram.

Interim Technical Report

BEE 469 TEAM 3

Technology Review and Design Selection

Members:
Michael Link
Hassan Salem
Jeremiah Rich

Table of Content

1. Executive Summary

Providing an adequate supply of oxygen for fish to increase productivity can be a limiting factor for small scale aquaculture farmers in the developing world. This report describes components of a solar powered diffuser aeration system and the process and reasoning by which team three came to a decision on choosing an aeration system.
The general process of design specification was to first analyze all the different sub-technologies of components like the solar panel, pump, diffuser, and battery and to evaluate each of these categories based upon economic, technical, social, and environmental decision criteria. Components were also judged based off of their ability to meet flow rate, power, pressure, and budget requirements. For pumps, the diaphragm technology scored highest on the decision matrix. Two BOYU ACQ 906 (200 L/min) diaphragm were chosen to meet budget and engineered requirements. Flexible membrane diffusers scored the highest on the decision matrix. Rubber epdm disc diffusers were chosen for their self cleaning ability and flow rate requirement compatibility. Deep cycle lead acid batteries (75 Ahr) were chosen for their affordable cost and variable power discharge regime. A monocrystalline panel (150W) was chosen for its increased efficiency and power requirement compatibility. Based on input from Hillary Egna, team three designed for all components to be on a flotation device to decrease risk of theft and to keep wires and technology out of human traffic. Through the research process it was found that oxygen transfer efficiency of diffusers increases by 2.5 percent per foot of water depth. Because of this team three's final design consists of diffusers that are buried one meter below the bottom of the pond encased in pvc. *JMH Consultant Engineers* final design consist of a float with panel,

battery, pump, and tubing centrally located in the pond that leads to buried diffusers for increased efficiency with a total parts cost of 900 dollars.

2. Introduction

Aquaculture is an increasingly popular way of producing protein and providing physical and financial sustenance across the globe. According to the world health organization twenty percent of the world's population receives at least twenty percent of their dietary protein from fish, with some cultures relying on fish entirely [1]. The challenges facing the aquacultural industry presently are nutrient recycling, water consumption, aeration, and profitability of small scale farmers. The profitability of small scale farmers is directly tied to their ability to keep fish healthy, minimize die off risk, and to increase stocking densities of fish.

The senior undergraduate class in the Biological and Ecological Engineering department has been tasked with designing aeration systems for aquaculture farmers in the developing world. The major challenge of the design is providing a system that is user friendly, cost effective, and one that optimizes all the parts for maximum use of harvested solar energy. The environment designed for consists of earthen ponds located on property outside of city line power. The earthen ponds contain algae and tilapia. During the day the algae photosynthesize and provide oxygen to the pond and act as a food source for the fish. At night the algae and fish start consuming oxygen. This diurnal fluctuation is very dangerous for farmer's crop due to the possibility of toxically low dissolved oxygen levels. The design problem is to create a system that can provide aeration off the grid reliably and to still be economically feasible.
The oxygen delivery system for tilapia fish that we will be designing for will be based on the following conditions:

- A stocking rate of 4 tilapia/m3
- A maximum weight of 200 g per fish
- An average DO level of no less than 4 ppm in the pond
- Solar intensities characteristic of Ghana
- No access to electrical line-power
- A goal parts cost of less than 750 USD for full scale model
- Theft prone rural environment
- Awareness of safety, environmental, and regulatory laws
- Cultural sensitivity
- A healthy algal population (I.E. no algal blooms to consume all oxygen)
- Design to work within 15 degrees latitude of the equator
- Design for a 15m x 30m x 2m pond size

Through successful implementation of our robust and economically feasible design, local farmers will be able to increase productivity and decrease the risk of fish kills.

The major components of any aeration system consists of a power source, an air pump, a battery if storage is necessary, and an aeration device. Through individual research over the past few weeks the JMH Consulting firm has narrowed their focus based off of quantitative and qualitative analysis. This document is a summary of JMH Consulting Firm's research and the recommended engineered design for accomplishing the goals set forth in the problem statement.

3. Design Overview

Team three's three design alternatives consist of a centralized flotation system. The float contains a solar panel roof for rain deflection with battery, pump, and charge controller housed underneath it. The centralized flotation system primary purposes are to make theft more difficult and to have the system self contained and out of the way of foot traffic for the farmers. Dr. Hillary Egna stressed the need for anti-theft capabilities and the desire for an out of sight out of mind system without wires running every which way from the shore. All three alternatives prioritize this with a centralized float for all aeration equipment. The design consists of a deep cycle lead acid battery, DC diaphragm pump, and flexible membrane diffusers..

The top candidate in the battery category is a deep cycle lead acid battery. All design alternatives utilize this battery due to its cost and lack of need for complete discharge every time the power supply is engaged. Battery life will be optimized by using the top 40 percent of its capacity. In the case of emergency where sunlight hasn't come for two to three days, full discharge is possible. For optimum battery life a more conservative discharge of power is needed. In terms of diffusers, ceramics and rubber EPDM membrane have come to the forefront of the decision making process with flexible membrane being the ultimate choice. Both technologies produce similarly sized bubbles [2] and can be categorized as fine pore diffusers. Pump technology was narrowed down to centrifugal blowers, piston, and diaphragm pumps with diaphragm pumps winning. Both flotation devices will house our component choices in battery, pump, panel, and diffusers despite the differing alternative structural designs.

Where the three design alternatives differ is in the oxygen delivery system. All designs use diffusers, however the lines and mechanisms for distributing the diffusers varies. In figure 1 design alternative 1 is shown. This design consists of modular PVC triangles that have foam pads fitted to their shape in order to keep them afloat. An anchor for these could be easily made with rebar or some weight sunk to the bottom. The advantage of this design its flexibility in conforming to elongated or oddly shaped ponds and its material simplicity. Presumably PVC and foam would be readily available in most countries. Due to the low cost and widespread availability of materials, the triangle floats could be scaled up and manufactured in countries around the world. The triangle's piecewise construction can also make for easy shipping and installation/construction.

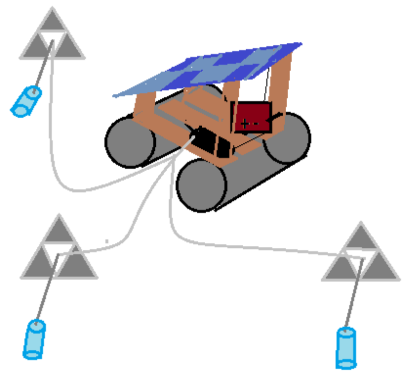


Figure 1: Design Alternative 1 with triangle floats for diffuser distribution

Design alternative 2 is shown in the figure below. It consists of a centralized pontoon float with four pvc pivoted legs. The piping in this design provides the correct depth of diffuser placement by having a non locked pivot close to the float and a locked pivot at the elbow. This ensures that the elbow will touch the pond bottom surface with the diffuser angled to avoid fouling in the muddy detritus layer. The legs will either house tubing to transport air to the diffusers or be the tubing themselves. The major advantage of this design is to not have any tangling tubing to deal with. One component difference could be using the legs as pressurized pipe to pump air across a rubber membrane diffuser with higher pressure requirements. The design is self contained and the legs can pivot back upon themselves to fold onto the float. This attribute makes harvesting fish, maintenance, and transport of the system much easier when compared with a heavily tubular design. Handles on the sides of the float would be an added transportation benefit for the end user.

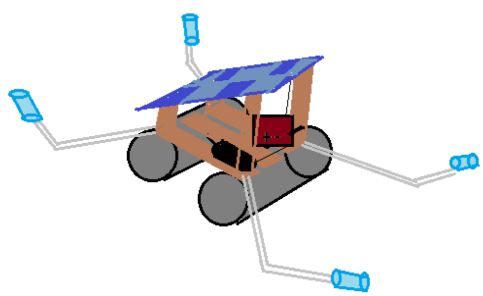


Figure 2: Design Alternative 2 with pvc jointed arms for diffuser submersion

Design alternative 3 consists of the same flotation device, but with lines running directly to submerged pvc pipes in the pond floor. The figure below shows the proposed diffuser housing design.

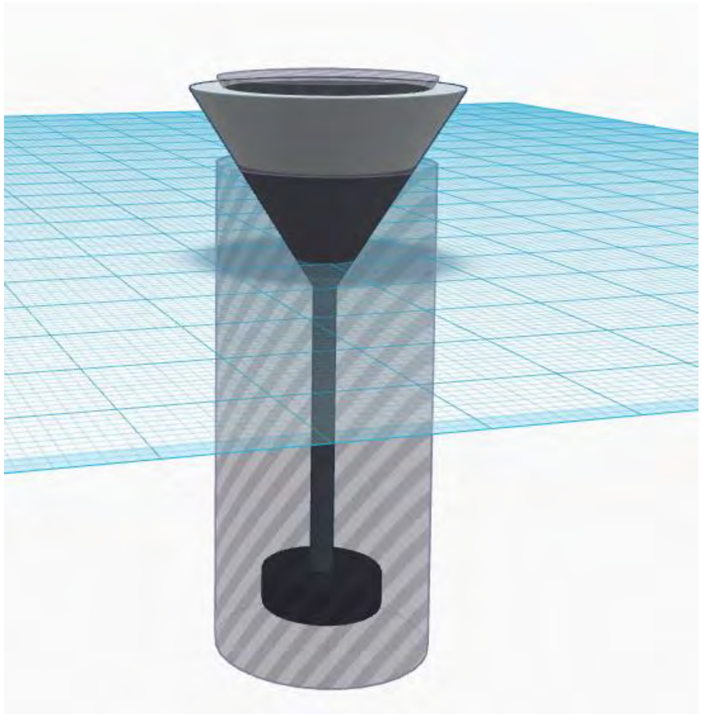


Figure 3: Proposed diffuser housing

The main function of the buried pvc diffuser housing is to increase oxygen transfer efficiency. With increasing depth comes increased time for the bubble to rise to the surface and transfer its gaseous contents. The cone at the top functions to spread the bubbles so they can aerate a higher surface area water column and in order to keep particles from settling into the bottom of the chamber. The disc diffuser is located at the bottom of the pvc pipe. Before fulls scale production testing would be necessary for optimum maintenance regimes for the conical diffuser. There is concern of fish causing turbidity around the cone and inadvertently adding detritus to the bottom of the tube. The cone element is attached to rigid pvc and the diffuser allowing for easy removal. Scrubbing the diffuser and a scooper for the bottom of the pipe is all that would be necessary. Specific cleaning frequencies would need to be investigated in the future.

Ultimately the *JMH* consulting firm chose a flotation system with polyethylene tubing leading to the buried pvc piping. With a limited budget it was necessary to use the solar power efficiently. The buried diffuser design increased oxygen transfer efficiency which helped lessen the total amount of air needed to be pumped into the pond.

4. Design Requirement Calculations

The *rate of oxygen consumption* was estimated from Ghana pond data when the aeration equipment was shut off. The rate of oxygen consumption was scaled up to the designed fish density of 4 fish/m^3 and the 200 gram tilapia sale weight. Using the oxygen transfer efficiency we were able to estimate amount of air needed to be pumped down in order to keep the dissolved oxygen above 4 ppm. Head loss due to depth of water, diffusers, and tubing was calculated and used in combination with flow rate to determine a pump that would meet the flow/pressure requirements.

Due to the flow rate of the initial design calculations being unrealistic for economical pumps, the calculations were redone assuming a migration of fish towards the diffusers. By doing this the same amount of oxygen was needed for the fish, while the amount of algae respiration was decreased. The pump was also designed to be turned on for a longer amount of time to decrease flow rate. The full design calculations can be found in the appendix I will be presented. In addition the figure below describes the calculation process by which we sized our design components.

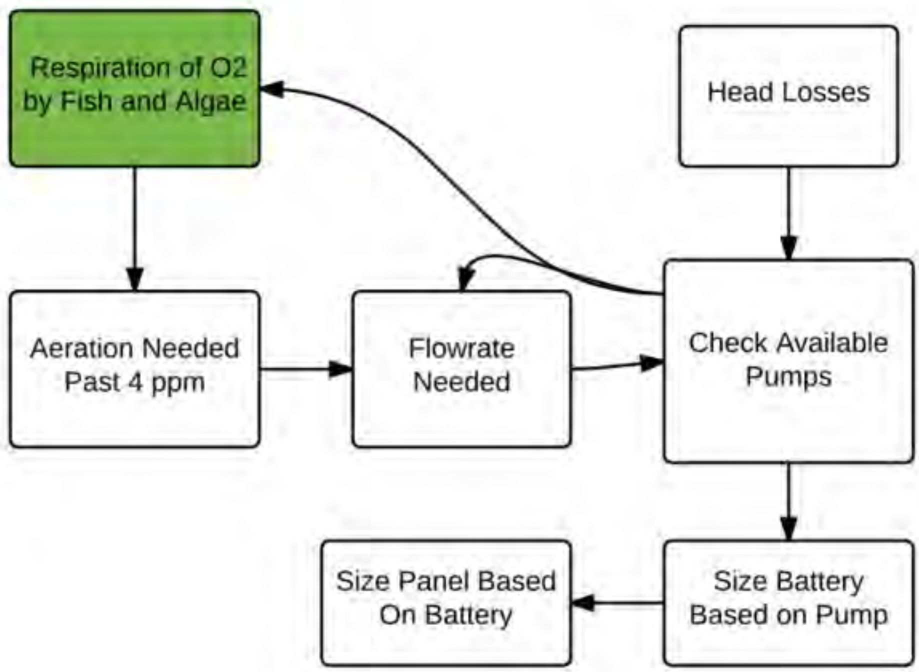


Figure 4: Flow diagram of logic used to size the aeration system

After finding an economically viable pump, a battery was chosen based upon the power draw of the pump. Based on panel efficiency, insolation, and power needed to charge the battery the size of panel was determined.

Table 1: Design Calculation Results

	Flow Rate	Total Pressure Requirements	Size of Panel	Battery Draw	Oxygen Transfer Eff.
Units	L/min	lb/in^2	m^2	Ahr	%
Value	200	3.85	0.85	75	16.5

5. Matrix of Design Alternatives

A decision matrix was made to evaluate the technological alternatives based upon four categories. The major categories were economic, social, environmental and technical aspects of the system. The weighting for each of these are shown below.

	Sub Category	Points
Economic (40 points total)		
	Operation/ Maintenance	10
	Lifetime	10
	Installation Costs	4
	Initial Capital Investment	15
	Salvage Value	1
Social (10 points total):		
	Theft	5
	Noise	2
	Trained Worker Availability	3
Technical (40 points total):		
	Efficiency of parts (metric varies)	10
	Battery Efficiency Unit	
	Diffuser Efficiency SOTE	
	Durability	10
	Reliabilty/Consistency	7
	Availabilty of Materials	4
	Simplicity/Repairability	9
Environmental (10 points total):		
	Oil Leakage	4
	Battery Flood Risk	4
	Greeness of Energy Production	2

Figure 5: Point values for corresponding evaluation criteria

Higher points symbolize a higher viability of the technology for our design. Economic was given a large percentage of the points because money matters, especially for small scale farmers. No matter what the NPV of our product, many small scale farmers will not be able to afford a large initial capital investment. Technical was also given high weight because if the design does not meet the deliverables of higher fish densities and decreased die off risk, it fails the objective. The specific scores of each technology can be found in appendix IV.

6. Survey of Technologies and Technological Constraints

6.1 Pump

6.1.1 Single Acting Pump:

Single acting pump uses one piston to pump air, with an inlet and an outlet to allow the air in and out. The force of pressure sends air out through the outlet. The inlet opens as the piston is moving up allowing air to get in. As the piston move down again the valve in the inlet closes preventing the air to escape, and the air will be forced to leave the pump through the outlet by force of pressure [3].

6.1.2 Double Acting Reciprocating:

Just like the single acting, double acting uses pistons to pump air. However double acting uses two pistons instead of one to pump air, and has an inlet and outlet on each side, so it can pump more air. Double acting reciprocating pumps, pump twice the amount of air in every crank cycle. These pumps are extremely large. Double acting reciprocating pumps can produce a lot of vibration, as they have been called earthmovers back in the day [4].

6.1.3 Diaphragm Reciprocating:

The diaphragm reciprocator shares the same working principle as the single acting reciprocating. However this pump uses a diaphragm that is connected to a piston. The movement of the diaphragm causes a difference in air pressure and moves the air into and out of pump [5].

6.1.4 Rotary Pumps:

Rotary pump is part of the positive displacement, and it can keep a constant flow of liquid in every revolution of the element part. Rotary pumps include the ears, lobes, rotary pistons, vanes, and screws. The popularity of this design is due to its high viscosity performance, compact design, and its ability to contain high differential pressure [6]. To move Fluids and these pumps uses the rotary movement of its parts to move it.

For instance the rotary screw pumps moves the liquid towards the discharge cavity by the rotary motion of the screw. Vanes are being used to pump air, but these pumps are usually big and too expensive for us to use. These pumps are mainly used in pumping lubricated liquid and fluids with high viscosity, and they are not of a good fit with our design.

6.1.5 Centrifugal Pumps:

This pump is from the dynamic family of pumps; they operate by developing a high velocity and converting the velocity to pressure. Centrifugal pumps use the centrifugal force to pump liquid and air. The centrifugal pump has an impeller at the heart of the system; the rotation of the impeller creates a centrifugal force the pushes the liquid/ air into the discharge tube. The rotation of the impeller creates a negative pressure at the center of the impeller, this negative pressure sucks in liquid/air into the centrifugal pump.

Of the options left, a Centrifugal pump is in our price range, but does not meet the pressure that the *JMH engineers* needed, and had a low flow rate of 1.32 CFM.

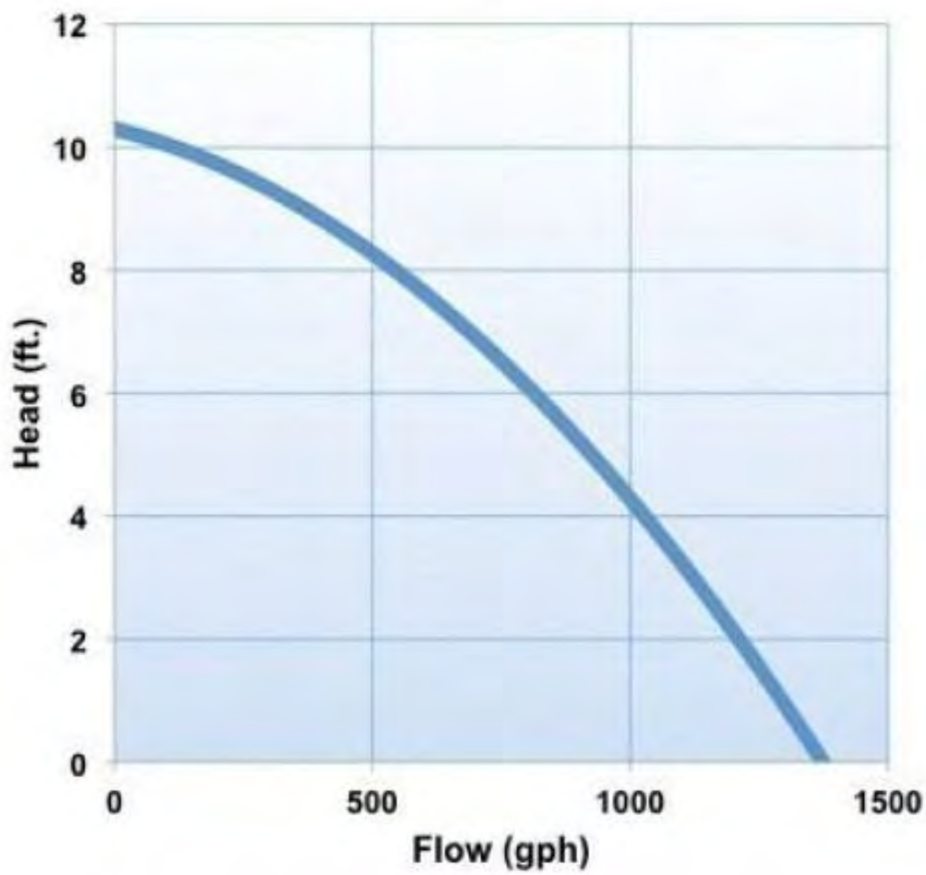


Figure 6: Centrifugal pump curve

A single piston pump was another alternative as well, however having a price range of 100 dollars made pump selection limited.

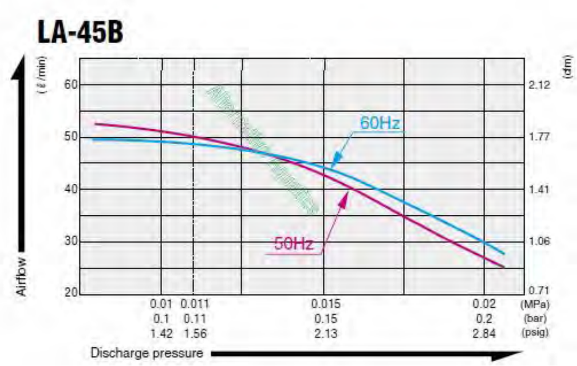


Figure 7: Linear Piston Pump curve.

As figure 7 shows, to pump air at 2.84 PSI the air flow provided is only 26 l/min, when we need a flow rate of 62 L/min. The Pump we have picked is the best fit because it met all the technical requirements. As the graph below shows the ACQ 906 will meet our pressure requirement of greater than 0.025 Mpa. When using two of these pumps the flow rate requirement of 200 L/min.

Модель	Уровень шума	Размер сепаратора	Вес	Размер
ACQ903	50dB(A)	6x10	2Kg	220x110x140
ACQ903A	50dB(A)	8x10	2Kg	220x110x140
ACQ906	60dB(A)	10x10	3Kg	250x120x160
ACQ908	60dB(A)	12x10	4.5Kg	235x140x170

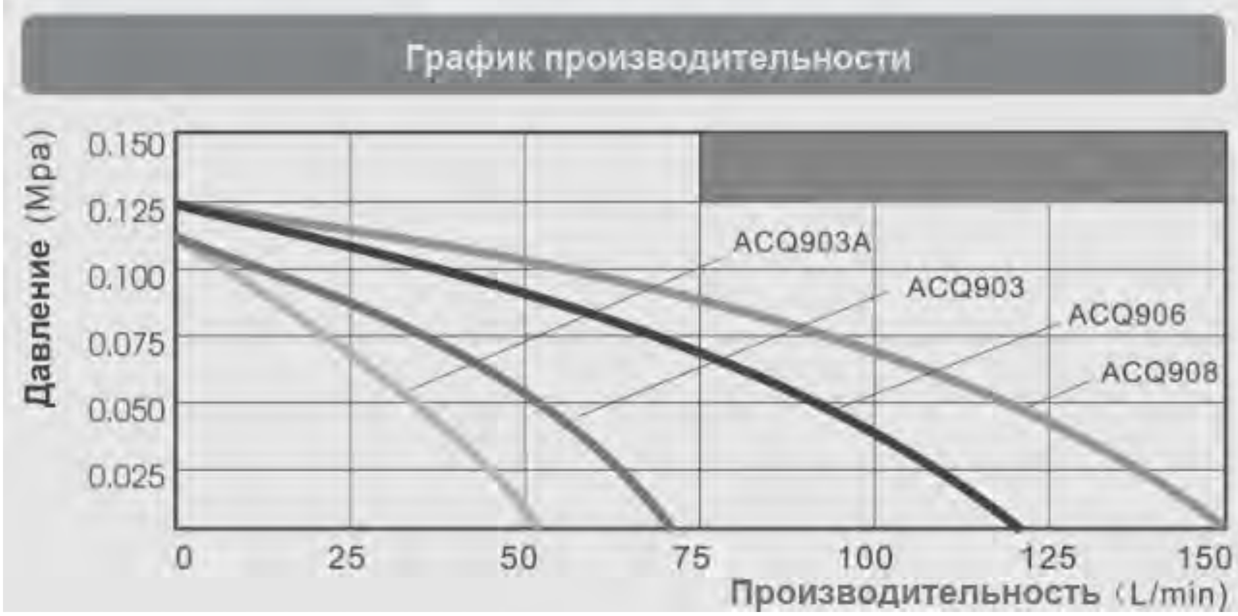


Figure 8: Diaphragm pump curve

6.2 Tubing

Air tubing is very important for the design because it is through the air tubing that the pressurised air goes from the pump to the diffuser. This makes it one of the critical components, and gives it the highest likelihood of being damaged. This is due to the fact that the air tubing will be stretched over the ground and through the water which gives it the possible of being tampered by animals chewing on it or brokened by human traffic stepping on it and breaking it. With the designed float this risk would be minimized.

6.2.1 Reinforced Clear Vinyl Tubing

This a very popular choice for air tubing. This type of tubing is upgrade from the standard clear vinyl tubing that one thinks of when first thinking of air tubing for fish. The reinforced part comes from synthetic fibers woven into Polyvinyl chloride, this means it can take larger pressures and is more resistant to cutting from animals.

This works for the design since we need a air hose that is resistant to cutting by animals the downfall is that it reinforced tubing is over engineered for the pressure requirements we need [7].

6.2.2 PVC Rigid pipe

PVC pipe is a rigid pipe made from solidified Polyvinyl chloride. The fact of PVC pipe is that it is rigid so it can be buried and also the since it is rigid it is more resistant to tampering from animals. thouh durability of PVC can degrade with solar exposure unless buried or painted.

Figure 17: PVC pipe [8]

6.2.3 Black vinyl Tubing

Black Vinyl Tubing is very similar to the clear vinyl tubing in its technical aspects such as pressure rating which is a max pressure of 40 psi for ¼ inch tubing [7].

Figure 9: Air tubing [9]

6.2.4 Air Tubing Conclusion

In conclusion the air tubing choices to choose from in this report all have their strong points. This means that the final choice of piping for our teams design will have to be done with discussion and further calculations. There is a possibility of using multiple types depending on where in the system the tubing is needed.

6.3 Battery

Batteries are very important to the design because they are what will store the solar energy produced by the solar panels during the day and release the energy for use by the pump during the early morning hours. The different types of batteries that are being considered are deep-cycle flooded lead acid, deep-cycle valve regulated lead acid, lithium-ion, and nickel-cadmium batteries.

6.3.1 Lead acid Batteries:

Lead acid batteries have been around for over 100 years and are one of the dominant batteries on the market. They are made up of a cathode and anode within an acid solution to hold the electrical charge typically H_2SO_4 there are several different types of lead acid batteries. The ones that will be covered in this report are the flood lead acid and sealed/valve regulated lead acid (VRLA).

6.3.1.1 Differences between Flood Lead Acid and Valve regulated lead acid

Flood lead acid batteries and valve regulated lead acid batteries have very similar design aspects but flood lead acid have a few more design criteria than Valve Regulated Lead Acid. The requirements for flood lead acid batteries are one an upright orientation to prevent electrolyte leakage, two they require ventilated environment to diffuse gases created during cycling and lastly they require routine maintenance of electrolyte [10]. Lead acid batteries will work due to them being readily available and the ability to work with solar power.

6.3.2 Lithium-ion Batteries:

Lithium-ion Batteries are a fairly new technology and become widely accepted in the 1990's. The basic concept of the battery is that lithium ions travel back and forth between the anode and cathode in electrolytes made of lithium polymer. Lithium-ion batteries will work for the design due to their ability to be discharged a larger portion of the energy in the battery while retaining service-life. Lithium-ion will not work due to high fragility and price of the batteries.

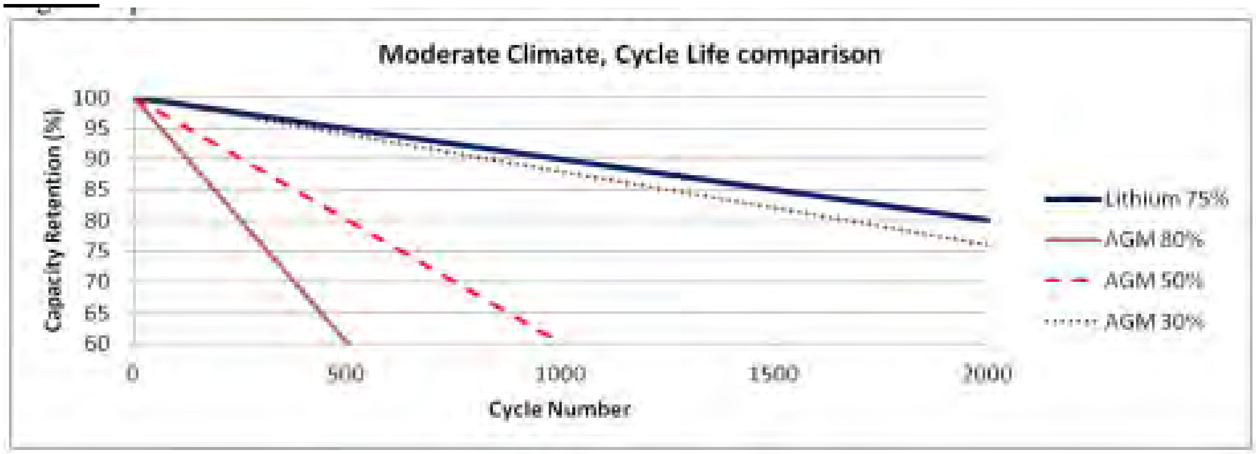


Figure 10:Comparing battery life with energy discharge. [10]

6.4 Diffuser

This section is an intensive look at available diffuser aeration technology and gives a qualitative and quantitative analysis to differentiate which technology could meet our project goals. Team three's focus has been on diffusers because of the intense power and capital cost needs of surface aerators like paddle wheels and fountains. Air diffusers have a low upfront cost when compared with paddle wheel aerators [11] and are compatible with solar systems because they can aerate with less horsepower needs [12]. The basic principle behind all diffusers is pushing a gas through a membrane to divide that gas into small bubbles that travel up the water column while exchanging the gas with the water. The main diffusers covered in this section are the glass bonded silica, aluminum oxide, EPDM/rubber membrane, and diffuser tubing. These were evaluated based on volume output, bubble size, cost, maintenance requirements, and longevity.

Gasses that are commonly diffused are pure oxygen, air, and ozone. One application of diffuser aeration is in municipal wastewater treatment to increase bacterial degradation of nutrients in an aerobic environment or to pump ozone into the drinking water to disinfect it as a final treatment. This technology is also used in aquaculture to meet the demand of respirating fish, bacteria, and algae.

Diffuser performance over the long run is directly related to fouling, basin geometry, placement of diffuser, operator expertise, and the quality of the preventative operations and maintenance program. There are two types of fouling. Type I includes particles from the air clogging the diffuser while type II involves a biofilm taking root on the diffuser surface [13]. When you look at differing prices of air diffusers there are a few common characteristics that drive the resale price. These factors include durability/lifespan, frequency of servicing, oxygen transfer efficiency, energy requirements, bubble size, compatibility with ozone and pure oxygen, and parts/materials cost. As bubble size decreases you get higher surface area and oxygen transfer efficiency, but you lose the mixing effects of larger bubbles. The major aeration diffusers on the market are glass bonded silica ceramics, rubber tubing, BioWeave, EPDM/rubber, and aluminum oxide diffusers. BioWeave was initially researched, but a Pentair representative said that the material would quickly degrade within an earthen pond. A brief overview of each of these diffusers except BioWeave is given in the following sections with elaborations on their corresponding technological constraints.

6.4.1 Glass Bonded Silica:

The glass bonded silica diffuser stone is one of the most ubiquitous diffusers on the market. The modern diffuser is machined from a solid block of glass bonded silica and produces a medium/fine bubble. This type of diffuser is categorized as a subsurface aeration system [13] and is usually suspended right above the bottom surface of the body of water.
One of the drawbacks of ceramic stone diffuser is that they are apt to clogging/fouling from bacterial growth. For most soft water applications the diffusers only has to be cleaned once a year. For cleaning regimes one can either soak the ceramics in a acid bath, pump them with anhydrous HCL, or scrub them carefully with a brush [14][15]. The stones are quite fragile and should be handled with care [16]. The glass bonded silica diffuser has an air resistance of less than 0.25 psi which helps save on start up power needs and saves on energy consumption throughout its lifetime. The dust and particles collected from the air that are pumped downward primarily pass through the diffuser due to the pore size being large enough for air particles to pass (30 microns). This reduces the need for air filters on the pump housing. One rectangular diffuser of 1.5 x 6 in can provide up to 0.5 cubic feet of air per minute [11]. This type of diffuser stone can either be manufactured as a cylinder, rectangular cuboid, disk, or plate.

Glass Bonded Silica	

Figure 16: Glass bonded silica diffusers

6.4.2 Rubber/EPDM Membrane:

EPDM stands for ethylene propylene diene monomer and is a type of rubber. This material is most common in the roofing and wastewater sectors. The membrane can be found in many modern wastewater facilities across the country. The technology's major advantage is the ease of cleaning and resistance to fouling. The rubber membranes can be cleaned by increasing the pressure to all to slough off the biofilm or to divert all pressure to one diffuser. Another cleaning method is to simply pull it out of the water and rub the biofilm off with your hand [17]. The technology consists of a sheet of rubber that has hundreds of pores cut into it. When pressure/airflow is applied the membrane pores expand and release the air. This is advantageous because while the membrane sits idle it is much harder for biofilms to form on smooth rubber surfaces when compared with porous ceramics. The bubbles are slightly larger than the standard ceramic airstones [1]. According to a pentair representative rubber membrane diffusers are still compatible with air despite the catalog saying they are best used with pure oxygen. The EPDM membranes have a minimum pressure requirement of 0.5-0.6 psi [18]. The biggest technological constraint is the pressure requirement. In order to use these diffusers a higher back pressure is needed when compared with ceramic diffusers.

Rubber/EPDM Membrane	

Figure 11: Rubber/EPDM Membrane

6.4.3 Aluminum Oxide:

Aluminum oxide air stones are an alternative to the glass bonded silica air stones. They are in the same category of ceramics as glass bonded silica but are inherently more strong and resistant to breakage. The aluminum oxide ceramic is made of the same material that grinding stones are. Users do not have to worry about breaking the diffuser in half due to its strength [19]. One website claims that aluminum oxide diffusers have 3x times the lifespan of the glass bonded silica [20].The aluminum oxide can be cleaned with muriatic acid. If preferable the material can resist high heat so the burning of algae or bacteria for cleaning purposes is also an option. Caution should be taken to ensure no excess heat touches the plastic connectors.The resistance to air is 0.25 psi so the product is compatible with low pressure blowers [20]. The product also has anti-corrosive properties [21].

Alumina Oxide	

Figure 12: Alumina Oxide diffuser

6.4.4 Rubber Tubing:

Diffuser tubing is just as it sounds and consists of a flexible tube that is porous in nature. This design allows for easy mobility and can help aerate non-traditionally shaped ponds.

The most common types of tubing are rubber/polymer, paper, and bioweave tubing. The rubber tubing is often weighted so that it sinks to the bottom of the tank. Pentair tubing outputs 3 mm diameter bubbles. It can be perforated on only one side or release bubbles from the whole surface. Some of these tubes are equipped with antimicrobial properties. Some rubber tubing requires higher psi. Bioweave tubing is constructed with woven polyester fiber material and is claimed to last for "years" [11]. A Pentair representative said that the components would not be a fit for our project because they would rapidly biodegrade. There is also disposable paper tubing that is often used in shrimp aquaculture. Although this product is cheap it requires routine purchasing and lower lifetimes.
The major drawback of all tubing technology is the maintenance inconveniences. In a pond with high biological activity fouling is inevitable. The sweetwater stones the and aluminum oxide are the only diffusers that can use a acid bath. For this case scrubbing of the tube would be the most effective cleaning measure [12]. Overall the fouling and intensive cleaning regimes coupled with high pressure requirements make this diffusion method not do-able.

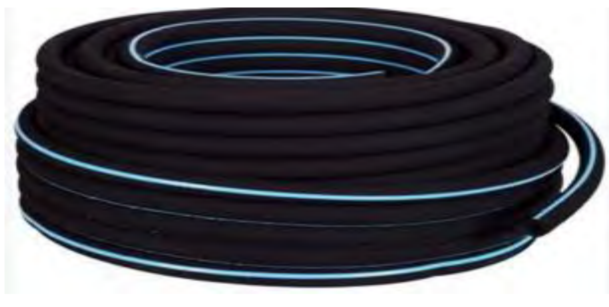
Rubber Tubing	

Figure 13: Rubber Tubing

6.5 Solar Panel Overview

A solar panel is made by combining the effects of multiple solar cells. Each solar cell takes radiant solar light, excites electrons within, and converts that energy into electrical current. The two main groupings of solar panels on the market right now are crystalline and thin film technology.

The grouping of crystalline includes both monocrystalline and polycrystalline. Monocrystalline solar cells have slightly higher solar conversion efficiency (20% versus 15%) than polycrystalline, but for all intensive purposes the two are interchangeable. Monocrystalline solar panels are slightly more expensive as well due to the purity of the silicon and the waste of some silicon during the manufacturing process. Polycrystalline silicon wafers are poured into a square mold after heating versus a four sided cutting process of the crystal. Of the silicon based solar cells on the market, roughly ninety five percent of them are comprised of crystalline silicon [24].

The other solar cell grouping on the market is thin film technology. In 2011 thin film solar cells represented five percent of all the cells on the market. The technology is expected to jump from 7-13% solar conversion efficiency to 16% efficiency. The manufacturing of this technology is basically thin layers of semi-conducting materials layered on top of eachother. Thin film solar cells lend themselves towards mass production and are more flexible which allows them to be placed in unique ways [24]. Due to mono and polycrystalline panels being similar in efficiencies, the emphasis on which to use is less of a technology consideration, as much as it is a watts per dollar consideration. The main logic on panel selection is what panel can provide the energy needed for aeration at the lowest price.

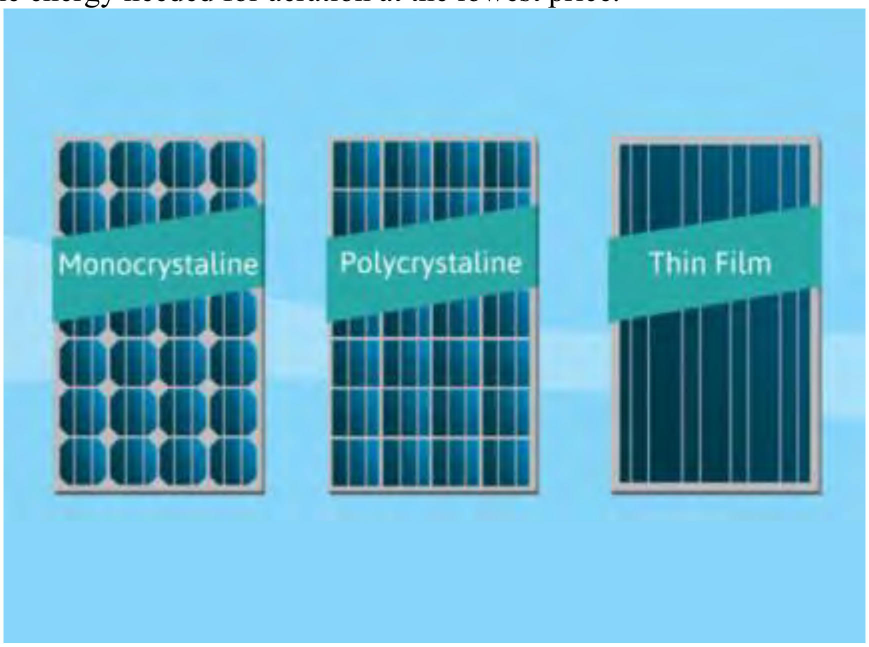


Figure 14: Various solar cell technologies [1]

6.6 Charge Controller and Arduino

Charge controllers are essential to taking in the energy harvested by the solar panel and optimizing what current and voltage to use to get the most amount of power to the battery and pump. Most charge controllers are basic in their function of turning on and off at a set time and turning off at set thresholds of battery. Resiliency to days of low solar insolation is very important for the system design because the fish may be unable to handle repeated days of low dissolved oxygen

Arduinos are microcontrollers that will help the *JMH* system to store and analyze data from testing, determine where power goes, and to control the on off switches for various parts of the design. Another key process for the arduino will be to make the design intelligent enough to perform well under a variety of situations. The logic chart presented below represents what programs the arduino will be expected to follow.

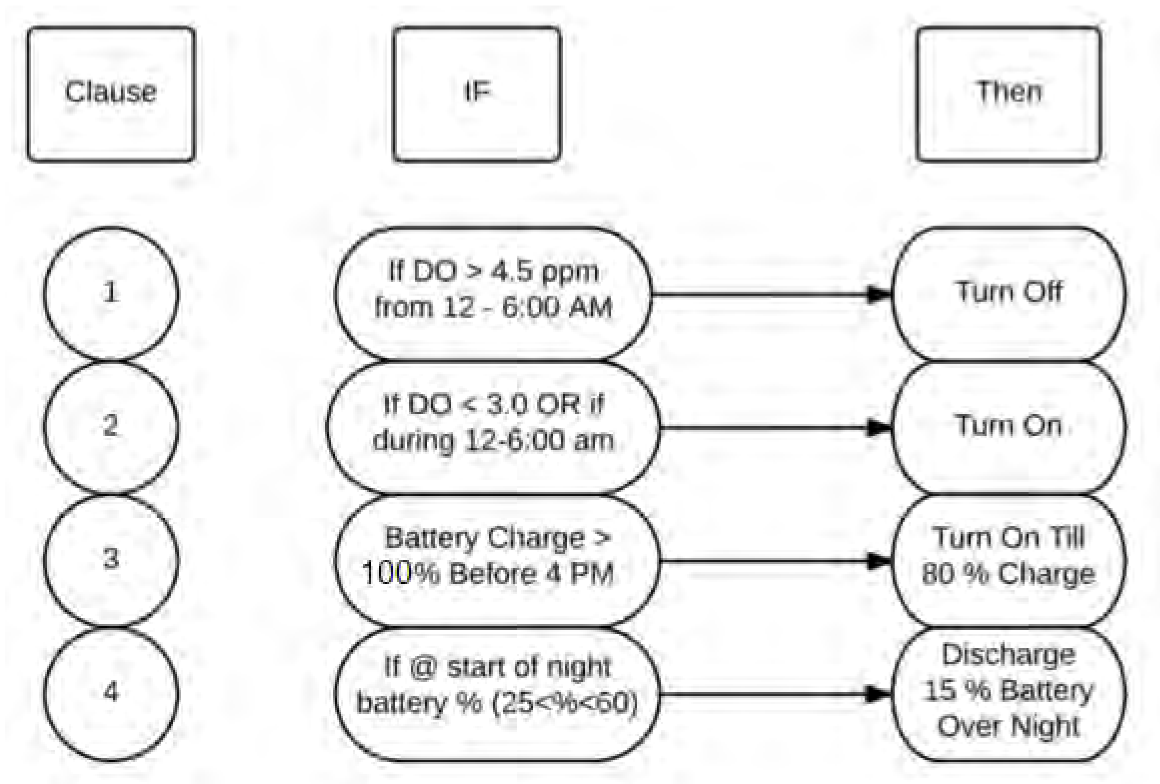


Figure 15: Logic of the arduino system control to maximize aeration while conserving battery power

Clause Meanings:

1. If during the night the dissolved oxygen(DO) stays above 4.5 ppm or that the pond is aerated enough to reach that concentration, the arduino will switch the pump off to conserve power.
2. If the DO is below 3 ppm at any time or if it is during the designed aeration hours the pump will be turned on.
3. If the battery charge is greater than 100 percent and it is before 4:00 pm then the pump will turn on until the battery charge is depleted to 80 percent. If the battery reaches 100 % by 10:00 am, then the surplus of power throughout the day would be used to increased dissolved oxygen.
4. With a 40 perecent nightly discharge and a lower limit for the battery charge of 15 percent in emergency situations, there is an available 45 % of battery charge for consecutive cloudy days. If at the start of the night the battery does not have a charge greater than 60 % then the cloudy clause of 15 % discharge per night will be enacted.

6.7 Synthesis

The diaphragm pump was the best fit for our design, because when compared with other pumps, it was able to provide us with the desired flow rate at the given pressure..It also made less noise when compared with other pumps, and more importantly it was in our price range. The rubber/epdm diffusers produced similarly sized bubbles when compared with ceramics and also had less maintenance concerns. Choosing a battery is an interplay between cost and efficiency. Despite the efficiency of lithium ion batteries, lead acid were chosen for their budget compatibility and discharge regime. Ridgid tubing is resistant to human and animal degradation, but can not fluctuate with the water levels like the flotation design requires.

7. Economic Considerations

7.1 Pump

The model we have picked is two BOYU ACQ 906 up will cost us around a 160 dollars, and that would be perfect considering the budget we had for this part of the design. compared to the other options we had, this pump was the cheapest way of meeting our pressure and flow requirements. All the other designs have failed in providing the effective flow rate at the given pressure for the budget we have. Initially we had two main candidates to our design the centrifugal pump and the diaphragm piston pump, however comparing the two pumps proved that the diaphragm pump is more compatible to our design[25][26][27].

12 Volt Air diaphragm pump for BOYU ACQ-906

Table 2: BOYU ACQ-906

Voltage	12 volts DC battery
Power/ Battery	60 watts power
Flow rate	125 L/min Max
Maximum pressure	0.12 Mpa Max
Size	253*124*148 mm

Price	80 dollars

Oase Aquarius Universal centrifugal 1400 Pump - 1400 GPH

Table 3: Oase Aquarius Universal- 1400 Gallons Per Hour

Max. Flow rate	3 cfm
MAX head	10.2 ft
Power	80 watts

Price	119 dollars

7.2 Tubing

7.2.1 Economical aspects reinforced clear vinyl

Reinforced clear vinyl is very strong tubing. It can take a 120 psi for ¼ inch tubing and it costs $0.92 USD per foot [7]. This means that we can put higher pressure air into the lines if needed.

7.2.2 Economical aspects PVC pipe
Economical PVC pipe is very easy to come by since it is the standard piping choice for drinking and wastewater around the world. PVC pipes are the cheapest at about $0.20 USD per foot [8].

7.2.3 Economical aspects Black Vinyl
Prices for Black vinyl tubing makes it seem to be the middle price range at $0.49 USD at price per foot [7]. While this price is in a good range, it is the weakest tubing choice in terms of durability from being cut by animals.

7.3 Battery
As we can see in the following table taken from *A Comparison of Lead Acid to Lithium-ion in Stationary Storage Applications* the table shows the comparison between the two types of lead acid batteries and lithium-ion batteries [10]. We see that lithium-ion batteries are the most expensive up front cost though they have little maintenance and they have a high energy density.

Table 4: Battery Technology Comparison

Table 2: Battery Technology Comparison

	Flooded lead acid	VRLA lead acid	Lithium-ion (LiNCM)
Energy Density (Wh/L)	80	100	250
Specific Energy (Wh/kg)	30	40	150
Regular Maintenance	Yes	No	No
Initial Cost ($/kWh)	65	120	600[t]
Cycle Life	1,200 @ 50%	1,000 @ 50% DoD	1,900 @ 80% DoD
Typical state of charge window	50%	50%	80%
Temperature sensitivity	Degrades significantly above 25°C	Degrades significantly above 25°C	Degrades significantly above 45°C
Efficiency	100% @20-hr rate 80% @4-hr rate 60% @1-hr rate	100% @20-hr rate 80% @4-hr rate 60% @1-hr rate	100% @20-hr rate 99% @4-hr rate 92% @1-hr rate
Voltage increments	2 V	2 V	3.7 V

7.4 Diffusers
Table 5 is given below to show the varying costs and concerns of all the diffuser technologies. To find the most value of flow rate per dollar the metric of (ft^3/m)/$ was calculated. This gives very high values for the rubber tubing, but has hidden cost in that pump flow rate

requirements are much larger to provide the necessary flow rate. In the same way the rubber membrane has a slight hidden cost due to higher pressure requirements. The sweetwater and aluminum oxide have a 0.25 psi pressure requirement which allows them to be compatible with low pressure economical blowers.

Table 5: Summary of Various Diffuser Specs
(Lifespan estimated based off of fouling and listed product details)

	Size Metric	CFM (ft^3/m)	Cost ($)	Lifespan	Major Advantage	Major Concern	cfm/$
Sweetwater	1.5x1.5x6 in^3	0.5	11.29	1.5-2 years with regular clean	-Compatible with blowers -Time Tested	-Cleaning -Fragility	0.044
Rubber Tubing	Per Foot	0.1-0.6	1.51	1 year	-Shapeable to pond -Compatible with blowers	-Cleaning -High Pressure Requirements	0.23
AntiMicrobial	Per Foot	0.1-0.6	2.45	1 year	-Shapeable to pond -Compatible with blowers	-Cleaning -High Pressure Requirements	0.14
Bioweave	Per Foot	0.2-0.6	37.00	1 year	-Self Weighted	-Degradation	0.011
Rubber/EPDM	8x1.5 in	0.7	15.69	1-2 year	-Easy to Clean	-Higher psi requirements	0.045
Aluminum	6x1.5 in	0.75	13.00	2-3 year	-Compatible with blowers -Flame clean -Rugged		0.058

Overall the total cost of diffusers is minimal in comparison to the pump and battery costs. However compatibility the potential for diffusers to drive a larger pump purchase is a real possibility and one that should be accounted for within calculations.

7.5 Solar

Monocrystalline solar cells come with the highest efficiency and not surprisingly the highest price. Polycrystalline is the next most efficient with thin film cells close behind. Polycrystalline solar cells are more readily available as ready to install panels when searching through the online marketplace. If there are space constraints a higher efficiency technology may be preferred. Also some monocrystalline solar cells offer a 25 year warranty. Some online packages throw together the charge controller, mounting screws/plates, and the cell which is added convenience for a slightly higher price [24].

7.6 Economic Synthesis:

The full scale model is roughly 150 dollars over team three's internal budget of 750 dollars. A summary of the estimates for solely the parts of the aeration system design is given below.

Table 6: Full Scale Model

Parts	Mass (kg)	Price ($)	Citations
2 BOYU ACQ 906	6.0	160	[28]
Trojan Deep Cycle Lead Acid battery	46.3	250	[29]
1 Monocrystalline Solar Panel	12	205	[30]
Charge Controller	N/A	50	[31]
Plywood/Base	24	24	[32]
Diffuser	N/A	80	[33]
PVC Pipe	N/A	40	
Foam	N/A	67	[34]
Total	115.4	876*	*Arduino not included in full price

While over budget the solar aeration system compared to the price of an entry level design on the market is still only ⅕ of the price. Some of the lowest solar aeration systems on the market run about five to six thousand dollars [24].

The major contributors to the total price are the battery, solar panel, and the pumps. If the pump performs as the pump curve claims, then it is already one of the lowest priced quality pumps on the market. Sizing up of the battery is crucial to extending its lifetime. Deep cycle lead acid batteries have decreased lifetimes when discharge fully more often. Staying consistently at a state of charge from 50-70 percent is where the *JMH* engineers focused their research to ensure a moderate life span at a reasonable cost. The arduino is not included in the total cost of the above design. Any extra capital should be focused on increasing the size of the panels. Based off of in class discussions, a larger solar panel could allow for the battery to be charged more quickly and to aerate the pond with the excess power during the day. Also, harvesting adequate amounts of solar energy becomes a possibility even on cloudy days with a larger panel.

8. Environmental and Social Considerations

8.1 Pump

8.1.1 Environmental/Social aspects of Single acting reciprocating:

Single acting reciprocators have really minimal environmental concerns, However lubricant oil that is used for the piston could leak through the valves, and that could be hazardous for the environment and the fish. If the pump where to be moved from place to place, oil could spill everywhere. the main dilemma that we could face is that the lubricant could not be detected in the pond and we won't be able to control the leak. Depending on how much air we want to pump the size of the pump could vary, to pump a lot air we need a bigger heavier pump, which makes it harder to be stolen. Noise could be due to a lot of factors one of which being the piston loses all the lubricant, another could be due to a failure in the inlet valve where air could be leaking out as the piston pushes down [36].

8.1.2 Environmental/ Social aspects of Double acting reciprocating:

Just like the single piston the lubricant in the double acting pump could leak out from the valve as well, and that could pollute the water and affect the fish. Another form of environmental concern is the noise pollution. The pump being so loud could affect the mating of birds in that area, the fish in the water, and all other animals in that area. The vibration that it can produce can affect the structure of the pond and everything that surrounds it. The double acting pump has a lot social implications because the noise it produces while it is working, can disturb the farmers sleep cycle, since it will be operating from 12am to 6am. The vibration produced by the pump could tear down the farmer’s house. However the pump could be so big and heavy, that makes it hard to be stolen.

8.1.3 Environmental/social aspects of Diaphragm reciprocating:

Just like all the other reciprocates, the main and only concern is the leak of the lubricant from the piston. How ever due to the sizes and variety of this particular pump, other environmental constraints need to be taken into consideration. With big and more complex ones, there are gases that are being used in moving the piston [37], and the leakage of these gases could be hazardous. However since we are looking for a smaller pump, we can disregard these potential environmental impacts. The diaphragm seems to make no noise as long as the parts are working well and are in good conditions. Since the diaphragm will be small there is a great possibility that it could be stolen. This is a factor that we need to take into consideration if we were to choose this particular pump, unless we attach them to the main body of the design.

8.1.4 Environmental / social aspects of Rotary Pumps:

Some of the pump parts are made up of iron and digging for iron could be an environmental pollution. The pumps could have no noise at all. They are much quieter than the double piston pump which would make them socially adaptable. Vibration is also not as much of an issue, consequently decreasing the noise of the whole system.

8.1.5 Environmental/ social aspects of Centrifugal pumps:

The centrifugal pump can vibrate and make large amounts of noise. These noises can be maintained if the system is kept in a good condition. However we do not need to worry about oil leakage because there is no need to use lubrication or other hazardous liquid. If the system were to be kept in good conditions the noise from the vibration could be contained and limited. the vibration made by the impeller could damage the pump if not controlled. Since the pump that we will be using is of smaller size, burglary could be a potential risk, however we can attach it to our floater and minimize the risks [38].

8.2 Tubing

8.2.1 Environmental / social aspects reinforced clear vinyl

The environmental impact of vinyl tubing is very high, vinyl is made from Polyvinyl chloride which is a cariogenic and can release dioxins in the environment. This means the fumes from the production of it or burning of it can cause cancer. Also there is very little recycling of it so most goes into landfill where it will not biodegrade. [39]

8.2.2 Environmental/ Social aspects rigid PVC pipe

The environmental impact of PVC pipe is very similar to Vinyl tubing since the base chemical is the same which means PVC pipe has a low ability to be recycled and and high environment and human health impact during the manufacturing process [39].

8.2.3 Environmental/ Social aspects Black vinyl

Black vinyl has the same environmental impact as Clear vinyl but it has the added benefit that the black pigment help to prevent algae growth within the tubing and could help with solar degradation of the tubing [7].

8.3 Battery

8.3.1 Environmental/ Social aspects of lead acid

The main environmental impact of Lead Acid batteries is that they require large amounts of raw materials to make the batteries at the same storage level as other batteries which means a larger impact from the material gathering process. Also the manufacturing process is very energy demanding and can cause a lot of population to be made. Lead Acid environmental impact is mitigated in the USA since 97% of lead acid batteries are recycled.

8.3.2 Environmental/ social aspects of lithium-ion

Lithium-ion has its own environmental impacts in that lithium mines are very energy intensive. Also the large amount of copper and aluminum in the batteries has a large environmental impact in its mining and processes. Lastly lithium-ion recycling is at the very initial stages [10].

8.4 Diffuser

Most diffusers are non-toxic and do not pose an environmental risk. Nevertheless environmental considerations must be made in regards to cleaning of the ceramic diffusers. For cleaning of diffusers muriatic acid is used or hydrochloric acid. This chemical has long term health implications for people frequently in contact with it. The chemical can have adverse corrosive effects on the respiratory tract and human tissue [40]. Precautionary measures must be taken for human health safety to prevent contact or inhalation of the hydrochloric acid. Measures could include safety goggles, latex gloves, plastic apron, etc. In regards to social issues none of the diffusers cause noise disruptions. The only aeration device that might cause a social outcry would be a gas motored pump or motor aspirator or a large paddlewheel aerator creating noise complaints. The only possible social concerns would be theft of the diffusers. The need to swim to them might be a hindrance for thieves looking for a quick and easy job.

8.5 Solar

Most of the environmental impacts of solar are from the manufacturing process of the photovoltaic cells themselves. Many types of photovoltaics use hydrochloric acid, acetone, nitric acid, etc. Most environmental hazard exposure would be in manufacturing and not at the aquaculture farm [41]. The major social consideration would be anti-theft. Our flotation device would be anchored to the pond bottom and in the center of the pond. On the flotation device itself the panel would be bolted down to prevent a quick theft. Theft is the major social consideration.

9. Regulatory Considerations

We anticipate future regulations, but currently the developing world is where the product would be used. On average these countries do not have many environmental regulations. The regulations that would need to be included into the design of the aeration system are related to components of the system. For example the battery concerns are lead acid so there are environmental regulations regarding the disposal of them in the U.S. Transportation of some lead acid batteries is regulated to make sure no spills occur. Future research into international trade regulations will be necessary before mass production of the design.

10. Technologies Chosen

Matrix

Using the decision matrix we were able to evaluate which technologies were outstanding.

Table 7: Total points by parts.

Parts	Total points (out of 100)
Glass bonded Silica	52

Tubing	51
Rubber/EPDM	61
Aluminum Oxide	60
Nickel	41
Lead Acid	55.5
Lithium Ion	54.5
PVC ridge	51
Black Vinyl Tubing	45.5
Reinforced clear Vinyl Tubing	46.5
Single Acting Pump	52
Double Acting Pump	51
Diaphragm Pump	52.5
Rotary pump	46.5
Centrifugal Pump	49

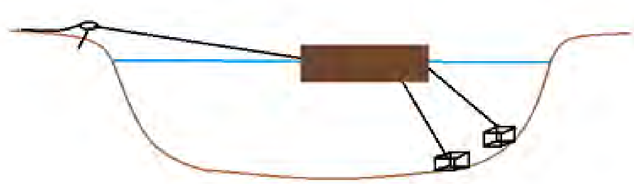


Figure 16 Final design

Figure 12 is showing the final design of the aeration system and how the floating platform will be secured to the bottom of the pond by two cinder block and to the side of the pond with any anchor and lock.

11. Conclusion

Team three's final design consists of a centralized flotation system. The float contains a solar panel(150W) roof for rain deflection with battery(75 Ahr), pump (200 L/m), and charge controller housed underneath it. The centralized flotation makes theft more difficult and is self contained and out of the way of foot traffic. The pump has been sized to meet the pressure requirements due to depth of water and head loss of piping and diffusers. The rubber EPDM diffusers were chosen to meet our flow rate requirements while providing low maintenance through their self cleaning properties. A monocrystalline solar panel was chosen for its increased efficiency and the battery was sized to allow for a 40 percent discharge to increase battery life. The diffusers in our system are buried at a depth of 1 meter below the pond bottom to increase oxygen transfer efficiency and more effectively use the power that the solar panel provides. In the future our group will be programing the arduino and also will be testing and refining the prototype and to allow for system resiliency in periods of bad weather.

Our projects major advantages are its anti-theft properties, low price point when compared with systems on the market, and depth efficiency innovation. With the increased resiliency to periods of cloudy weather the *JMH Consulting Firm* feels that our design will be effective at increasing productivity, decreasing fish die off risk, and be competitive in the current aeration market.

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Appendix I

The design calculation is attached to this document.

Appendix II
The decision matrix is attached to this document.

JMH Problem Statement

Appendix III

JMH Problem Statement

Aquaculture is a growing field that is already playing a key role in world food supplies. Many of the earth's residents depend on aquaculture for physical and financial sustenance. Some of the technical challenges facing semi-intensive aquaculture today are nutrient recycling/disposal, water consumption, aeration, and profitability of small scale farmers.

The environment which we are designing for is a tropical to subtropical climate in rural areas with no access to line-power electricity . We are assuming high levels of incoming solar radiation. The water bodies in this region are assumed to be unlined earthen ponds with algae.

The problem as we see it is to design an aeration system that can tackle low dissolved oxygen (DO) levels due to the respiration of fish and algae during the night. As a result of this higher densities of tilapia can be raised with less die off events. One side of the problem is to engineer a robust and intelligent aeration system to address fluctuating DO levels. The other side of the design is to provide an affordable product with a high NPV and low payback period. In order for the design to be scalable it must have simple operation, maintenance, and instructions for non-engineers. In summary the problem is to create a design that is financially viable, marketable, and increases aquaculture yields through intelligent aeration technology.

The oxygen delivery system for tilapia fish that we will be designing for will be based on the following conditions:

- A stocking rate of 4 tilapia/m3
- A maximum weight of 200 g per fish
- An average DO level of no less than 4 ppm in the pond
- Solar intensities characteristic of Ghana
- No access to electrical line-power
- A goal parts cost of less than 750 USD for full scale model
- Theft prone rural environment
- Awareness of safety, environmental, and regulatory laws
- Cultural sensitivity
- A healthy algal population (I.E. no algal blooms to consume all oxygen)
- Design to work within 15 degrees latitude of the equator
- Design for a 15m x 30m x 2m pond size

Appendix IV

Synthesis:

A 20 year NPV calculation was done to evaluate whether it would be a better economic decision to invest in a more expensive and longer lasting pump vs. a cheaper pump with a shorter lifespan. Through the NPV calculation we found that despite the low lifespan of the BOYU pumps, the NPV at 20 years without revenues included was -1620 vs. -2070 dollars. In summary it is cheaper to buy the BOYU pumps and replace them every three years when compared with a more expensive and durable rotary vane pump.

Table 8: Lifespan of Components

	Lifespan (Years)	Initial Investment
EPDM Diffusers	6	100
BOYU Pumps	3	160
Trojan 175 Ahr Battery (57%)	4	250
AQ5 Rotary Vane	20	860
Tubing	6	30
Charge Controller	15	50
Solar Panel	25	215
Plywood	8	25
Flotation Foam	8	67

Table 9: BOYU 20 Year NPV Calculation

	BOYU 20 Year NPV Calculation			
Year	Discount Rate	Cash Flow	Present Value	NPV
0	0	-876	-876	-876
1	0	-20	-17	-893
2	0	-20	-15	-908
3	0	-20	-13	-921
4	0	-180	-102	-1024
5	0	-270	-134	-1158
6	0	-20	-9	-1167
7	0	-310	-117	-1284

8	0	-20	-7	-1290
9	0	-362	-102	-1393
10	0	-180	-45	-1437
11	0	-20	-4	-1442
12	0	-20	-4	-1445
13	0	-530	-86	-1532
14	0	-20	-3	-1534
15	0	-20	-2	-1537
16	0	-230	-25	-1561
17	0	-362	-34	-1595
18	0	-20	-2	-1597
19	0	-310	-22	-1619
20	0	-20	-1	-1620

Table 10: Rotary Vane 20 Year NPV Calculation

	Rotary Vane 20 Year NPV Calculation			
Year	Discount Rate	Cash Flow	Present Value	NPV
0	0	-1576	-1576	-1576
1	0	-20	-17	-1593
2	0	-20	-15	-1609
3	0	-20	-13	-1622
4	0	-20	-11	-1633
5	0	-270	-134	-1767
6	0	-20	-9	-1776
7	0	-150	-56	-1832
8	0	-20	-7	-1839
9	0	-362	-103	-1942
10	0	-20	-5	-1947
11	0	-20	-4	-1951
12	0	-20	-4	-1955
13	0	-370	-60	-2015
14	0	-20	-3	-2018
15	0	-20	-2	-2020
16	0	-70	-7	-2028
17	0	-362	-34	-2061

18	0	-20	-2	-2063
19	0	-150	-11	-2073
20	0	-20	-1	-2075

Memorandum:

All the Memos have been gathered in a pdf file in the USB drive.

Meeting Munites:

JMH
Consultant Engineers

Date

Date	Time	Proposed Date of Next Meeting
03/13/2015	02:00 pm	N/A

Present

Jeremiah	Hasan	Jon	Michael
Y	Y	Y	Y

Review of Last Meetings Deliverables

Deliverables	Completed? If Not Why?
1. Edit diagrams 2. Edit Citation	Completed

Prioritized To-Do List for This Meeting

- 1. Editting.
- 2. Submit.
-

Items Discussed and Tasks Accomplished During Meeting

Discussed how to edit the citation.

To-Do List for Next Meeting [Item(responsible party/date to be completed)]

JMH
Consultant Engineers

Date

Date	Time	Proposed Date of Next Meeting
03/12/2015	10:00 am	03/13/2015

Present

Jeremiah	Hasan	Jon	Michael
Y	Y	Y	Y

Review of Last Meetings Deliverables

Deliverables	Completed? If Not Why?
1. Finish the Final report	We had to do add new variables to the report.

Prioritized To-Do List for This Meeting

- 1.add the new Variables.
- 2. Submit The Final Design

Items Discussed and Tasks Accomplished During Meeting

Finish the adding the new Variable, and submit the final report.

To-Do List for Next Meeting [Item(responsible party/date to be completed)]

1. Review the Final report.

JMH

Consultant Engineers

Date

Date	Time	Proposed Date of Next Meeting
03/11/2016	10:00 am	03/12/2016

Present

Jeremiah	Hasan	Jon	Michael
Y	Y	Y	Y

Review of Last Meetings Deliverables

Deliverables	Completed? If Not Why?
1. Finish the Final Report	We had to do a lot of adjustments for Interim report

Prioritized To-Do List for This Meeting

- 1.Fix the inter report.
- 2. Add the new variables.
- 3 Finish the submit the final report.

Items Discussed and Tasks Accomplished During Meeting

To update the Final Report

To-Do List for Next Meeting [Item(responsible party/date to be completed)]

1. Research Blank (Michael)
2. Model the Universe (Jon)

JMH
Consultant Engineers

Date

Date	Time	Proposed Date of Next Meeting
1/14/2016	4:00 pm - 5 pm	1/19/2016

Present

Jeremiah	Hasan	Jon	Michael
No	Yes	Yes	Yes

Review of Last Meetings Deliverables

Deliverables	Completed? If Not Why?
1. FIgure out the 3-D printing (Michael) 2. Brainstorm Ideas for the diffuser functionality. (Jon)	1. Yes 2. Yes

Prioritized To-Do List for This Meeting

- 1 Finalize the Memo.
- 2 Discuss the testing site in Corvallis.
- 3 Discuss state of charge monitoring.

Items Discussed and Tasks Accomplished During Meeting

We discussed about the 3 tasks above.

To-Do List for Next Meeting [Item(responsible party/date to be completed)]

1. Tube sizing and fittings.(Michael, Hasan)
2. Enter Corvallis data into model(Jon)
3. Check coefficients for the DO model.
4. Research continuous state of charge model.

JMH
Consultant Engineers

Date

Date	Time	Proposed Date of Next Meeting
1/30/16	1:00pm-11:00	1/31/16

Present

Jeremiah (Leader)	Hasan	Jon (Communicator)	Michael
n	y (4-11)	y (1-6)&(8-11)	y (1-6)&(8-11)

Review of Last Meetings Deliverables

Deliverables	Completed? If Not Why?
1. kLa testing	1. completed 2 tests

Prioritized To-Do List for This Meeting

- Discuss ORP probe connection
- test arduino / battery management logic
- research arduino logic for reading sensors
- wiring diagram
- discuss feasibility of simulation software for wiring diagram
- flow rates for diffuser
- discuss kLa testing pre Salmon lab
- discuss kLa testing

Items Discussed and Tasks Accomplished During Meeting

Determined we can get ORP connection from Radio Shack
Determined and implemented DO concentrations on an hourly scale
made model that adds DO when pump is on
added Arduino logic to model
tested model under various conditions (pond size, SOTE, DO demand,

To-Do List for Next Meeting [Item(responsible party/date to be completed)]

1. incorporate kLa and concentration effect on DO added by pump (in matlab Model)
2. develop additional arduino logic for evaluation
3. decide factors for choosing logic and PV, battery, pump sizing based on new results
    a. 10 year costs
    b. %time DO<3.5
4. review cost equations
5. research LTspice

items 1-4 should be addressed next meeting
item 5 Jon- before next meeting (1/31)

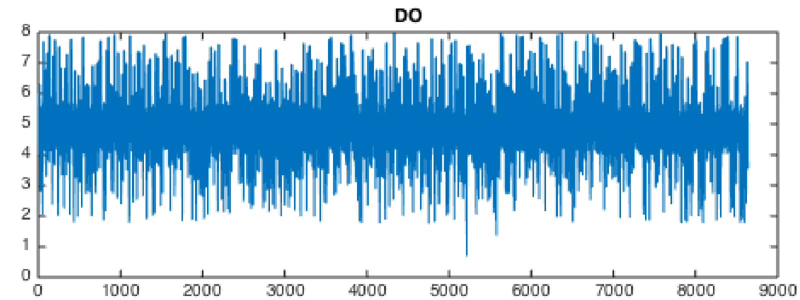
Input

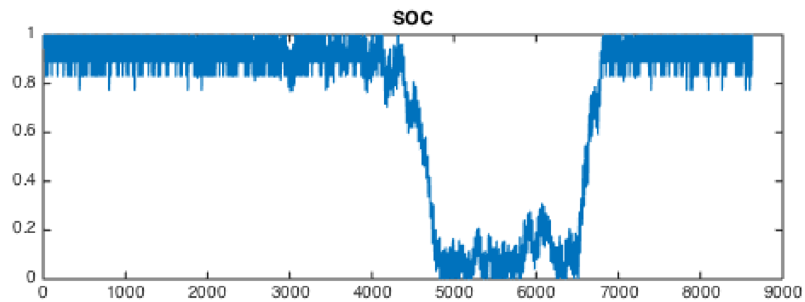
Run #	SP Watts	Bat AmpHrs	Pump kW	Start Time	End Time	Arduino Logic	Charge Controller	SOTE	Volume aerated
1	150	175	120	-	-	1	MPPT	17.5	360
2	150	175	120	20	6	none	MPPT	17.5	360

Output

Run #	O2kg/$	10 year cost	%time DO<3.5	%time DO<2	Bat Life (yrs)
1	23.74	844.6150	0.0747	0.0045	7.2
2	10.60	2834.00	0.0153	0.00194	0.4

Run #1


DO
0
1
2
3
4
5
6
7
8
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


SOC
0
0.2
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0.6
0.8
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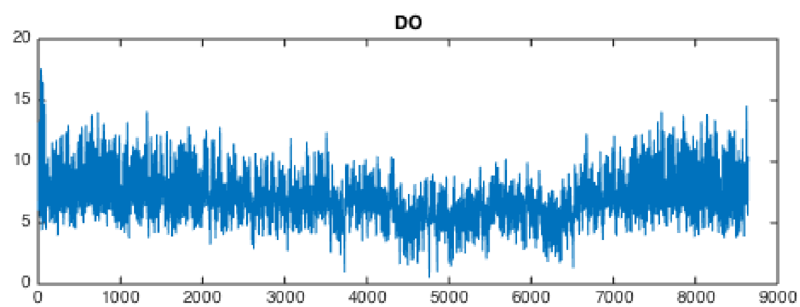
2000
3000
4000
5000
6000
7000
8000
9000

Run #2


DO
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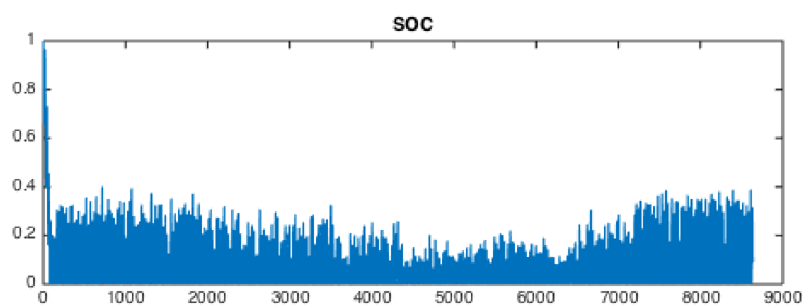
5
10
15
20
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


SOC
0
0.2
0.4
0.6
0.8
1
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

JMH
Consultant Engineers

Date

Date	Time	Proposed Date of Next Meeting
1/7/16	3:30 PM-4:30 PM	1/8/16

Present

Jeremiah	Hasan	Jon	Michael
Y	Y	Y	Y

Review of Last Meetings Deliverables

Deliverables	Completed, If Not Why?
1. Read Scientific Articles	1. No, Negligence

Prioritized To-Do List for This Meeting

- Figure out cone design
- Pontoon vs. Square Float
- Blueprint design plans

Items Discussed and Tasks Accomplished During Meeting

Completion of above to do tasks

To-Do List for Next Meeting [Item(responsible party/date to be completed)]

1. Read DO scientific paper (Michael)
2. Blueprint Calculations (Jeremiah/In the next week)
3. Make Cone 3-D designs (Team/by next Friday)

JMH
Consultant Engineers

Date

Date	Time	Proposed Date of Next Meeting
2/21/2016	4 pm	2/22/2016

Present

Jeremiah	Hasan	Jon	Michael
		Y	Y

Review of Last Meetings Deliverables

Deliverables	Completed? If Not Why?
1. Deliverable 1 2. Deliverable 2	

Prioritized To-Do List for This Meeting

- Get code working
- Flotation preliminary design

Items Discussed and Tasks Accomplished During Meeting

To-Do List for Next Meeting [Item(responsible party/date to be completed)]

JMH
Consultant Engineers

Date

Date	Time	Proposed Date of Next Meeting
1/25/16	4-6pm	--

Present

Jeremiah	Hasan	Jon	Michael
n	n	y	y

Review of Last Meetings Deliverables

Deliverables	Completed? If Not Why?
1. kLa testing 2. Deliverable 2	

Prioritized To-Do List for This Meeting

- determine kLa for setup

Items Discussed and Tasks Accomplished During Meeting

- setup test
- mix chemicals
- run system
- collect data
- clean-up

To-Do List for Next Meeting [Item(responsible party/date to be completed)]

plot data and determine kLa (Jon)

JMH
Consultant Engineers

Date

Date	Time	Proposed Date of Next Meeting
1/31/16	4:30	

Present

Jeremiah	Hasan	Jon	Michael
y	y	y	y

Review of Last Meetings Deliverables

Deliverables	Completed? If Not Why?
1. Arduino logic added 2. DO model added	1. yes 2. yes

Prioritized To-Do List for This Meeting

- Wiring diagram

Items Discussed and Tasks Accomplished During Meeting

Review of leader meeting

To-Do List for Next Meeting [Item(responsible party/date to be completed)]

JMH
Consultant Engineers

Date

Date	Time	Proposed Date of Next Meeting
2/1/16	2-4	2/3/16

Present

Jeremiah	Hasan	Jon	Michael
y	y	y	y

Review of Last Meetings Deliverables

Deliverables	Completed? If Not Why?
1. Deliverable 1 2. Deliverable 2	

Prioritized To-Do List for This Meeting

- step down 12 v to measure on Arduino
- mount diffuser

Items Discussed and Tasks Accomplished During Meeting

assembled circuit board with resistors and tested voltages
mounted and assembled diffuser

To-Do List for Next Meeting [Item(responsible party/date to be completed)]

learn arduino coding (everyone/yesterday)

JMH
Consultant Engineers

Date

Date	Time	Proposed Date of Next Meeting
2/1/16	2-4	2/3/16

Present

Jeremiah	Hasan	Jon	Michael
y	y	y	y

Review of Last Meetings Deliverables

Deliverables	Completed? If Not Why?
1. Deliverable 1 2. Deliverable 2	

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To-Do List for Next Meeting [Item(responsible party/date to be completed)]

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Individual Report

JMH

Consultant Engineers

Individual Research Report

BEE 469 TEAM 3

Technology Review for Batteries and Air hoses

Jeremiah Rich

10/23/14

Abstract

Aquaculture is a growing field that is already playing a key role in world food supplies. Many of the earth's residents depend on aquaculture for physical and financial sustenance. Some of the technical challenges facing semi-intensive aquaculture today are nutrient recycling/disposal, water consumption, aeration, and profitability of small scale farmers. As

Ecological Engineers we have been charged with designing an aeration system for this small scale farmers. This research report goes through a review process looking at the technical, environmental, social and economic considerations for different technologies to design an aerations systems for fish ponds. The technologies reviewed in this report include Battery types and types of air hoses used with diffuser aeration technology.

Table of Contents

1. Introduction:

It has been asked of our design group to build an aeration system to aid fish farmers in the developing countries to keep oxygen level in their ponds above critical levels. An estimate of the price has been given and the project will stay in this budget. The goal of the design project is to build a durable and reliable system that uses renewable energy as its power source.

The team has a budget of 750 dollars to design this system and the team has been asked to be considerate with the price and budget of the system. Batteries are very important for the design of an aeration system especially for a system that will be powered by solar power , so all energy required for the air pump will be supplied by stored electrical power in the batteries. We have estimated the the battery should cost about 150-200 dollars due to the fact that the batteries should cost about a fourth of the budget. are one of the three large price items along with the pump and solar power and meet all the criteria of our design.

This report will cover the different types of batteries that might be used with this design for the storage of electrical energy produced from solar panels to run the aeration pump at the early morning hours (2am-6am). The report will also cover different types of air supply hoses that could be used to move transmit the compressed air from the pump to the diffuser stones.

2.1 Batteries

Batteries are very important to the design they are what will store the solar energy produced by the solar panels during the day and release the energy for use by the pump during the early morning hours.

2.1.1 Lead acid Batteries:

Lead acid batteries have been around for over 100 years and are one of the dominate batteries on the market. They are made up of a cathode and anode with a acid solution to hold the electrical charge typically H_2SO_4 there are several different types of lead acid batteries the ones that I will cover are the flood lead acid and seal/valve regulated lead acid (VRLA).

2.1.1.1 Differences between Flood Lead Acid and Valve regulated lead acid

Both groups of lead acid batteries have very similar design aspects but Flood lead acid as a few more design criteria then Valve Regulated Lead Acid, they are one flood lead acid batteries require an upright orientation to prevent electrolyte leakage, two they require ventilated environment to diffuse gases created during cycling and lastly they require routine maintenance of electrolyte[1].

2.1.1.2 Environmental/ Social aspects

______The main environmental impact of Lead Acid batteries is that They require large amounts of raw materials to make the batteries at the same storage level as other batteries which means a larger impact from the material gathering. Also the manufacturing process is very energy demanding cause a lot of population to be made. Thou with Lead Acid environmental impact is mitigated in the USA since 97% of lead acid batteries are recycled.

2.1.1.3 Economical aspects:

Lead Acid batteries are the cheapest battery option for energy storage for initial cost they require more maintenance than other batteries. There is also the fact that lead acid batteries have to have a larger total charge to have the same life cycle as compared to lithium-ion batteries (1).

2.1.2 Lithium-ion Batteries:

______Lithium-ion Batteries are fairly new technology becoming widely accepted in the 1990's. The basic concept of the battery is that lithium ion travel back and forth between the anode and cathode in electrolytes made of lithium polymer.

2.1.2.1 Environmental/ Social aspects

______Lithium-ion has its own environmental impacts in that lithium mine is very energy intensive. Also the large about of copper and aluminum in the batteries which has a large environmental impact in its mining and processes. Lastly lithium-ion recycling is at the very initial stages.

2.1.2.2 Economical aspects:

As we can see in the following table taken from *A Comparison of Lead Acid to Lithium-ion in Stationary Storage Applications* the table shows the comparison between the two types of lead acid batteries and lithium-ion batteries. we see that lithium-ion batteries are the most expensive up front cost though they have little maintenance and they have a high energy density.

Table 2: Battery Technology Comparison

	Flooded lead acid	VRLA lead acid	Lithium-ion (LiNCM)
Energy Density (Wh/L)	80	100	250
Specific Energy (Wh/kg)	30	40	150
Regular Maintenance	Yes	No	No
Initial Cost ($/kWh)	65	120	600[1]
Cycle Life	1,200 @ 50%	1,000 @ 50% DoD	1,900 @ 80% DoD
Typical state of charge window	50%	50%	80%
Temperature sensitivity	Degrades significantly above 25°C	Degrades significantly above 25°C	Degrades significantly above 45°C
Efficiency	100% @20-hr rate 80% @4-hr rate 60% @1-hr rate	100% @20-hr rate 80% @4-hr rate 60% @1-hr rate	100% @20-hr rate 99% @4-hr rate 92% @1-hr rate
Voltage increments	2 V	2 V	3.7 V

2.1.1 Nickel Cadmium Batteries:

Nickel Cadmium have been used for applications since the 1932 with the Shlecht and Ackermann sintered plate design(2). About 40% of NiCd batteries are used for the rail industry. They have become widely used for portable power and are resistant to higher temperatures the lead acid. The main down fall of NiCd is that the batteries are one cycle meaning that they have to be fully discharged before it can be recharge otherwise the battery life is greatly reduced.

2.1.3.1 Environmental aspects

NiCd Batteries have a very high environmental impact since Cadmium is a heavy metal that properly the environment if not properly disposed of. (2) Also NiCd batteries require more float charge since they can lose 2-5% of this energy at room temp compared to lead acid.

2.1.3.2 Economic/Social aspects:

NiCd Batteries of very efficient in their ability to be recharge and that they have a long life span. Though they have a high initial cost than lead acid and the fact that the return for extracting energy from the system is very low allow 60% of energy put into the batteries (2).

2.1.4 Battery conclusion

From the the analysis of the different types of batteries we can throw out NiCd batteries due to the impactability of the cycle life and high environmental impact. Also from the graph in appendix 1 we see the to get a cycle life from lead acid battery to be the same as lithium-ion it would have to be 2.5 times larger.**[1]** From the data gathered I would choose either a sealed lead acid battery or a lithium ion battery.

2.2 Air Tubing

Air tubing is very important for the design because it is through the air tubing that the pressurised air goes from the pump to the diffuser. This make it one of the critical components, and gives it the highest likelihood of it being damaged. This is due to the fact that the air tubing will be stretched over the ground and through the water which gives it the possible of being tampered by animals chewing on it or brokened by human traffic stepping on it and breaking it.

2.2.1 Reinforced Clear Vinyl Tubing

This a very popular choice for air tubing. This type of tubing is upgrade from the standard clear vinyl tubing that one thinks of when first thinking of air tubing for fish. The reinforced part comes from synthetic fibers woven into Polyvinyl chloride, this means it can take larger pressures and is more resistant to cutting from animals.

2.2.1.1 Environmental / social aspects

The environmental impact of vinyl tubing is very high, vinyl is made from Polyvinyl chloride which is a cariogenic and dioxins in the environment. This means the fumes from the production of it or burning of it can cause cancer. Also there is very little recycling of it so most goes into landfill where it will not biodegrade. [3]

2.2.1.2 Economical aspects:

Reinforced clear vinyl is very strong tubig it can take a 120 psi for ¼ inch tubing and it costs $0.92 USD per foot. [4] this means that we can put higher pressure air into the lines if needed.

2.2.2 PVC Rigid pipe

PVC pipe is a rigid pipe made from solidified Polyvinyl chloride. The fact of PVC pipe is that it is rigid so it can be buried and also the since it is rigid it is more resistant to tamping from animals. thou durability of PVC can degrade with solar exposure useless buried or painted.

2.2.2.1 Environmental/ Social aspects

The environmental impact of PVC pipe is very similar to Vinyl tubing since the base chemical is the same which means PVC pipe has a low ability to be recycled and and high environment and human health impact during the manufacturing process [3].

2.2.2.2 Economical aspects:

Economical PVC pipe is very easy to come by since it is the standard piping choose for drinking and wastewater around the world. From prices I could find PVC pipes are the cheapest at about $0.20 USD per foot.[5]

2.2.3 Black vinyl Tubing

Black Vinyl Tubing is very similar to the clear vinyl tubing in its technical aspects such as pressure rating which is a max pressure of 40 psi for ¼ inch tubing. [4]

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Black vinyl has the same environmental impact as Clear vinyl but it has the added benefit that the black pigment help to prevent algae growth within the tubing and could help with solar degradation of the tubing. [4]

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Prices for Black vinyl tubing makes it seem to be the middle price range at $0.49 USD at price per foot [4]. While this price is in a good range black vinyl tubing is the weakest tubing choice in terms of durable from being cut by animals.

2.4 Air Tubing Conclusion

In conclusion of the air tubing choices to choose from in this report the different opinion all have their strong points. This means that the final choice of piping for our teams design will have to be done with discussion and possibly using multiple type depping on where in the system the tubing is needed.

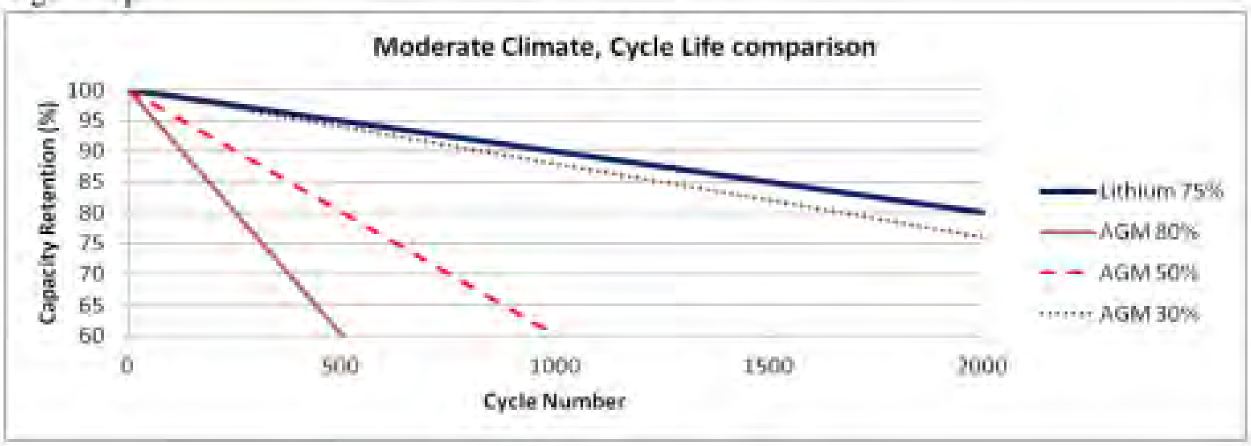
4. Works Consulted

[1] Albright, G (2012) *A Comparison of Lead Acid to Lithium-ion in Stationary Storage Applications*, (AllCell Technologies LLC) http://www.batterypoweronline.com/main/wp-content/uploads/2012/07/Lead-acid-white-paper.pdf
[2] Baxter, R (2006) Energy Storage "A nontechnical Guide",(Pennwell Corporation) Tulsa, Oklahoma

[3] http://www.health.thesfile.com/environmental-risks/environmental-toxins/plastic/

[4] Pentair Aquatic Eco-systems 2015 catalog
[5] http://www.homedepot.com/p/Unbranded-1-2-in-x-10-ft-PVC-Sch-40-Plain-End-Pipe-530048/100113200

Appendix 1



Survey of technology:

Jeremiah Paper

Abstract

Aquaculture is a growing field that is already playing a key role in world food supplies. Many of the earth's residents depend on aquaculture for physical and financial sustenance. Some of the technical challenges facing semi-intensive aquaculture today are nutrient recycling/disposal, water consumption, aeration, and profitability of small scale farmers. As Ecological Engineers our team has been tasked with designing an aeration system for this small scale aquaculture farmers. This research report goes through a review process looking at the technical, environmental, social and economic considerations for different technologies to design an aerations systems for fish ponds in rural developing countries around the equator. The technologies reviewed in this report include the best battery type to use which is recommended to use deep-cycle lead acid batteries. This section will also cover this different types of air hoses used with diffuser aeration technology.

1. Introduction:

It has been asked of our design group to build an aeration system to aid fish farmers in the developing countries to keep oxygen level in their ponds above critical levels. An estimate of the price has been given and the project will stay in this budget. The goal of the design project is to build a durable and reliable system that uses renewable energy as its power source.

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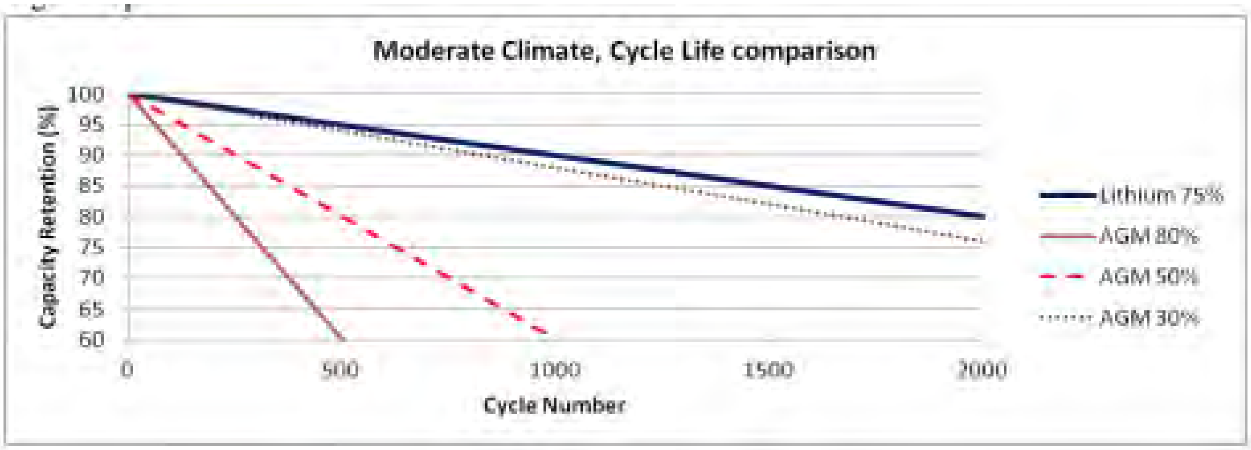


Moderate Climate, Cycle Life comparison
Capacity Retention [%]
100
95
90
85
80
75
70
65
60
0
500
1000
1500
2000
Cycle Number
Lithium 75%
AGM 80%
AGM 50%
AGM 30%

JMH
Consultant Engineers

Individual Research Report

BEE 469 TEAM 3

Technological Review for Air Pumps

Hasan Salem

10/23/14

Abstract:

Aquaculture is a growing field that is already playing a key role in world food supplies. Many of the earth's residents depend on aquaculture for physical and financial sustenance. Some of the technical challenges facing semi-intensive aquaculture today are nutrient recycling/disposal, water consumption, aeration, and profitability of small-scale farmers. As a team of Ecological Engineers we were given the task of designing an aeration system that suits the third world farmers needs. The challenge the team is facing is to assemble the best design that can be within the economical scope of the farmers, and the social and environmental

constraints. The technologies discussed in this report include different air pump types that could be used in the aeration system.

1.Introduction:

It has been proposed to build an aeration system that can aid the farmers in the third world country to keep oxygen flowing through the ponds. An estimate of the price has been laid out, and our design has to be within this budget. The goal of this engineering design is to use renewable energy as source of power, and for the design to be reliable and robust.

The team has a budget of 500 dollars to build the design. With this budget the team is asked to be critical and considerate of their choices. According to our estimations the pump cannot exceed 100 dollars and it should meet all of our criteria.

The same design was done last year, and we are asked to come out with a more efficient more intelligent design. The design is assigned to work from 2 am to 6 am, in these four hours the system is asked to maintain a DO level of at least 4 ppm. The system is expected to work at full potential with no flaws. Since I will be looking for pumps, I have to make sure that the pump is within our economic range, be socially and environmentally acceptable for the region it is applied in, that means minimize noise and not form any kind of pollution.

I will be comparing the different kinds of pumps available to work with. in the market there are three main types of pumps, Centrifugal, Rotary, and Reciprocating pump. Each of on these pumps has its advantages and disadvantages, and they are will be lied in this report. The pump the team is looking for has to discharge at a rate of 2.9 cfm over 6 hours and a power of 50.3 W per pump.

2.1Reciprocating Pumps:

Reciprocating pump is a part of the Positive displacement pumps, and it has four sub categories. The Reciprocating pumps works using pistons, it produce a constant amount of air/ liquid discharge each crank. Increasing the capacity of the pump could be achieved by increasing the piston diameter. [4] However increasing the diameter means more energy is needed to be supplied to the pump, and it will be more expensive. There are three kinds of reciprocating pumps: Single acting reciprocating, double acting reciprocating, and diaphragm reciprocating. While each Reciprocal pump discharge air it is unique way, they all share the same concept. These pumps use the force of pressure exerted by the piston in reducing the space available, forcing air to be discharged.

2.1.1Single acting reciprocating:

Single acting pump uses one piston to pump air, with an inlet and an outlet to allow the air in and out. The force of pressure sends air out through the outlet. The inlet opens as the piston is moving up allowing air to get it, as the piston move down again the valve in the inlet closes preventing the air to escape, and the air will be forced to leave the pump through the outlet by force of pressure. [2]

2.1.1.1 Environmental aspects

Single acting reciprocators have really minimal environmental concerns, However lubricant oil that is used for the piston could leak through the valves, and that could be hazardous for the environment and the fish. If the pump where to be moved from place to place, oil could spill everywhere. the main dilemma that we could face is that the lubricant could not be detected in the pond and we won't be able to control the leak.

2.1.1.2 Economicla aspects:

The price of the single acting reciprocating may vary largely, as it could range from 90 dollars to 1000 dollars, and that could be an issue if we were to decide on getting this pump. However the pump life expectancy is up **to 20 years** once it is used properly. The big range of price is due to the country of manufacturing. if we were to get the pump from somewhere in Asia it would be way cheaper due to the cheap labor in there. Where if we were to get a pump that is being designed in the United States or Europe it would be more expensive. The size of the piston and how much air we want to pump varies as well. To pump more air we need to by a pump with bigger pistons and it would cost us more as well.

2.1.1.3 Social Aspect:

Depending on how much air we want to pump the size of the pump could vary, to pump a lot air we need a bigger heavier pump, which makes it harder to be stolen. Noise could due to a lot factors ones of which the piston loses all the lubricant, other could be due to a failure in the inlet valve where air could be leaking out as the piston pushes down. [3]

2.1.2 Double acting reciprocating:

Just like the single acting, double acting uses pistons to pump air. However double acting uses two pistons instead of one to pump air, and has an inlet and outlet on each side, so it can pump more air. Double acting pump twice the amount of air in every crank cycle, and that makes them the most efficient pumps to be ever build. these pumps are extremely large. Double acting reciprocating pumps can produce a lot of vibration, as they have been called earth movers back in the day, if not installed properly they can tear down buildings.**[4]**

2.1.2.1 Environmental aspects

Just like the single piston the lubricant could in the double acting pump could l can leak out from the valve as well, and that could pollute the water and affect the fish. Another form of environmental concern is the noise pollution. The pump being so loud could affect the mating of birds in that area, the fish in the water, and all other animals in that area. The vibration that it could produce can affect the structure of the pond and everything that surrounds it.

2.1.1.2 Economicla aspects:

Since this pump is really rare these days [5] it is really hard to find the pump that we need for the good price. However my research showed again a huge variety in prices.[6] the big price range is due to the purpose of the pump. These days you can use the double acting pump in pumping air into floats, balls, and bicycles, and these pumps are really cheap. However the pumps that my team could be interested in is out of our economic price range

2.1.1.3 Social Aspect:

The double acting pump has a lot social implication, the noise it produces while it is working, can disturb the farmers sleep cycle, since it will be operating from 2am to 6am. The vibration produced by the pump could tear down the farmer’s house. However the pump could be so big and heavy, that makes it hard to be stolen.

2.1.3 Diaphragm reciprocating:

The diaphragm reciprocator shares the same working principle as the single acting reciprocals. However this pump uses a diaphragm that is connected to a pistol. The movement of the diaphragm causes a difference in air pressure and moves the air into and out of pump.[7]

2.1.3.1 Environmental aspects:

Just like all the other reciprocates, the main and only concern is the leak of the lubricant from the piston. How ever due to the sizes and variety of this particular pump, other environmental constraints need to be taken into consideration. With big and more complex ones, there are gases that are being used in moving the piston [8], and the leakage of these gases could be hazardous. However since we are looking for a smaller pump, we can disregard these potential environmental impacts.

2.1.3.2 Economicla aspects:

The price range of this pump ranges with size of the pump, and the source of power being used to deliver energy. Since we will be using a smaller pump the price seems to be in our economical range.[9]

2.1.3.3 Social Aspect:

The diaphragm seems to make no noise as long as the parts are working well and are in good conditions. Since the diaphragm will be small there is a great possibility that it could be stolen. This is a factor that we need to take into consideration if we were to choose this particular pump, unless we attach them to the main body of the design.

2.2 Rotary Pumps:

Rotary pump is part of the positive displacement, and it can keep a constant flow of liquid in every revolution of the element part. Rotary pumps include the ears, lobes, rotary pistons, vanes, and screws. The popularity of this design is due to its high viscosity performance, compact design, continuous flow regardless of the variation in pressure and its ability to contain high differential pressure. **[10]** To move Fluids and these pumps uses the rotary movement of its parts to move it. For an instance the rotary screw pumps moves the liquid towards the discharge cavity by the rotary motion of the screw. Even though wastewater treatment plants uses Rotary pumps to pump wastewater, however these pumps cannot pump pure water. However vanes are being used to pump air, but these pumps are usually big and too expensive for us to use. These pumps are mainly used in pumping lubricated liquid and fluids with high viscosity, and they are not of a good fit with our design.

2.2.1 Environmental Aspects:

Some of pumps parts are made up of iron and digging for iron could be an environmental pollution.

2.2.2 Economical Aspects:

The prices of Rotary pumps vary from 99 dollars to around 2000 dollars. the cheaper ones are used manually to pump liquid, while the expensive ones have more technology in them.

2.2.3 Social Aspects:

The pumps could have no noise at all, and they could be stationary, however they are not applicable to our design.

2.3 Centrifugal Pumps:

This pump is from Dynamic family of pumps. Centrifugal pumps use the centrifugal force to pump liquid and air. The centrifugal pump has an impeller at the heart of the system; the rotation of the impeller creates a centrifugal force the pushes the liquid/ air into the discharge tube. The rotation of the impeller created a negative pressure at the center of the impeller, this negative pressure sucks in liquid/air into the centrifugal pump.

2.3.1 Environmental Aspects:

The centrifugal pump can vibrate and make noises due to the vibration. These noises can be maintained if the system is kept in a good condition. However we do not need to worry about other form of pollution because all the parts being used are basic with no need to lubricants or other hazardous liquid.

2.3.2 Economical Aspects:

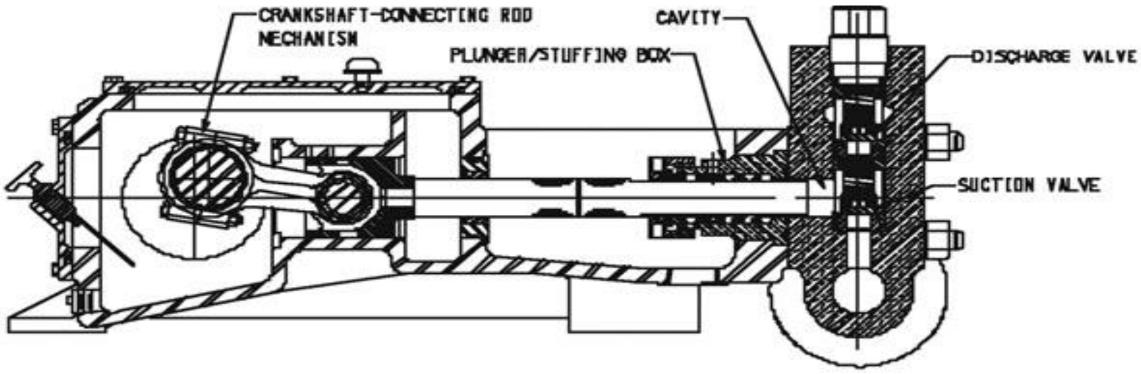
The centrifugal pumps seem to be above our estimated budget with a price ranging from 200 to 1000 dollars **[15]**. However centrifugal blower is an alternative that we can use, the price of it ranges from 60 to 200 **[17].**

2.3.3 Social Aspects:

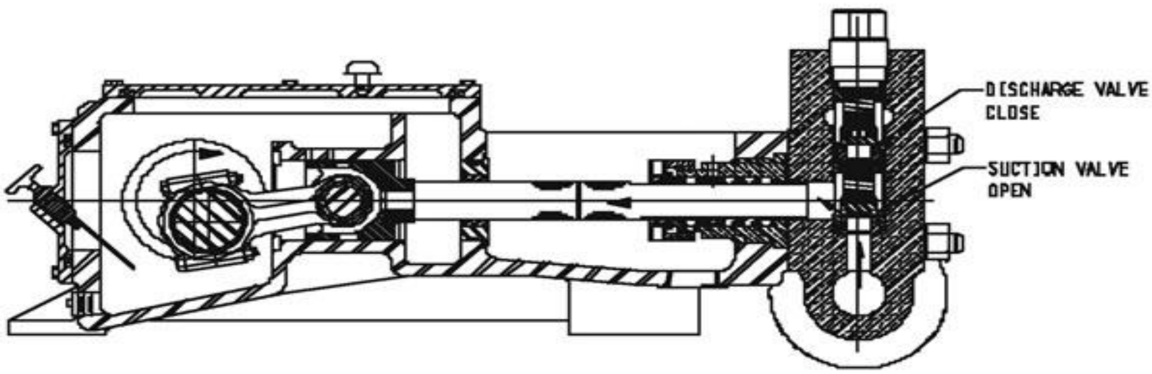
If the system were to be kept in good conditions the noise from the vibration could be contained and limited. the vibration made by the impeller could damage the pump if not controlled. Since the pump that we will be using is of smaller size, burglary could be a potential risk, however we can support it to our floater and minimize the risks. [14]

Since the pump we have chosen is a diaphragm piston pump, a few environmental consideration must be taken into account. Since this pump uses Piston there is a possibility that the lubricant in the piston leaking out if the pump were to be damaged. Another environmental and social constraints could be the noise produced by the pump if there was no enough lubricant or the diaphragm or the pump is to be damaged some how. considering all the other possibilities the Centrifugal pump is the only pump that could score better than the Diaphragm pump in this aspect. Centrifugal pump does not use piston so there is no lubricant to be taken into consideration. However most of these pumps seems to be easily stolen unless they are attached to the body of the design.

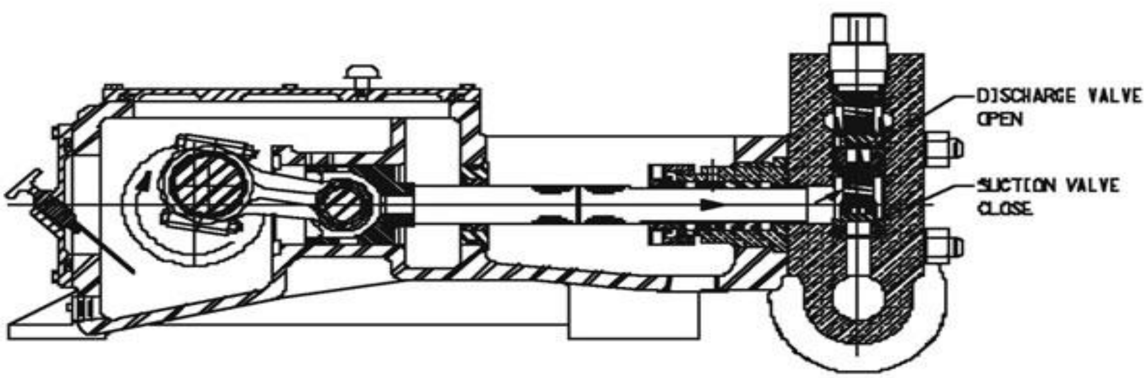
Reciprocating Pump



(A) TYPICAL RECIPROCATING PUMP(PLUNGER)



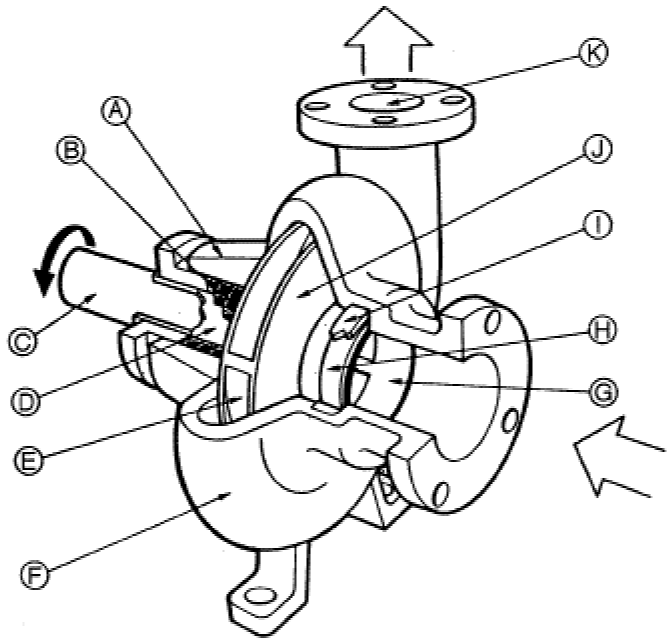
(B) SUCTION STROKE



(C) DISCHARGE STROKE

FIGURE 2. A TYPICAL RECIPROCATING PLUNGER PUMP

<u>Centrifugal Pumps</u>



A Stuffing Box

B Packing

C Shaft

D Shaft Sleeve

E Vane

F Casing

G eye of Impeller

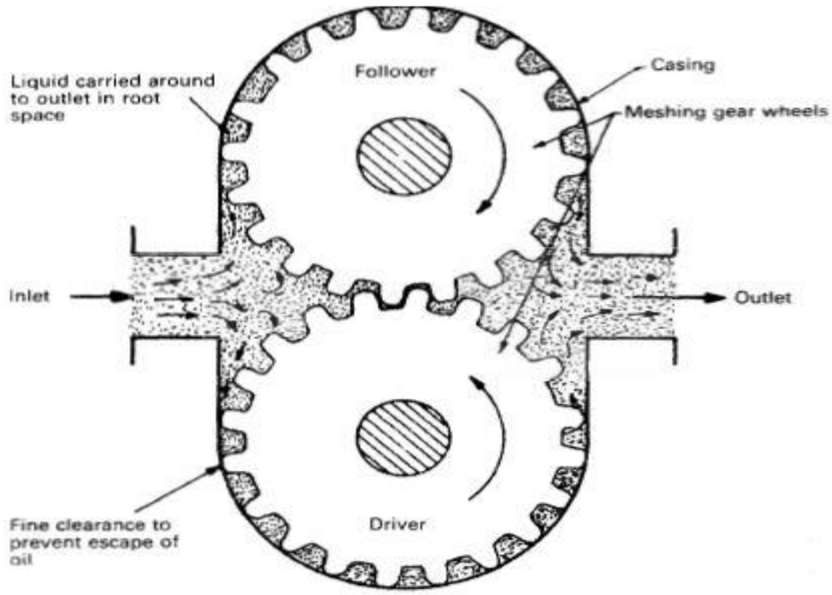
H Impeller

I Casing wear ring

J Impeller

K Discharge nozzle

Rotary Pumps:



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Individual Research Report

BEE 469 TEAM 3

Technology Review for Diffusers and Solar Panels

[redacted]

10/24/15

Abstract:

Aquaculture globally is an increasingly popular way of producing protein and providing physical and financial security. According to the world health organization twenty percent of the world's population receives at least twenty percent of their dietary protein with some cultures relying on fish entirely [13]. The challenges facing the aquacultural industry presently are nutrient recycling, water consumption, aeration, and profitability of small scale farmers. The

profitability of small scale farmers is directly tied to their ability to keep fish healthy, minimize die off risk, and to increase stocking densities of fish.

This document is an intensive look at available diffuser aeration technology and gives a qualitative and quantitative analysis to differentiate which technology could meet our project goals. The main diffusers covered are the glass bonded silica, aluminum oxide, EPDM/rubber membrane, and diffuser tubing. These were evaluated based on volume output, bubble size, cost, maintenance requirements, and longevity. Table 1 in the appendix summarizes the findings of this report on diffuser technologies. Solar cell technology was briefly covered to give a sense of what is available on the market, however our group will evaluate what solar panel we want based off of lowest cost to meet design requirements. The three top solar cell technologies are monocrystalline, polycrystalline, and thin film. These three vary on efficiency, cost, shade tolerance, longevity, and flexibility.

Table of Contents

1. Introduction:

Many people in the developing world turn to aquaculture as a means of supporting themselves financially and physically. Typically these systems consist of earthen ponds located on property outside of line power's reach. The earthen ponds basically consist of algae and tilapia. During the day the algae photosynthesis and provide oxygen to the pond and a food source for the fish. At night the algae start consuming oxygen with fish respiration in addition. This diurnal fluctuation is very dangerous for farmer's crop due to the possibility of toxically low dissolved oxygen levels. The design is to create a system that can provide aeration off the grid reliably and to still be economically feasible. Diffuser aeration systems consist of a power source to supply the air pump which then supplies the diffusers with air.Air diffuser technology seeks to diffuse bubbles into bodies of water to increase dissolved oxygen of water. The amount of power needed to diffuse enough oxygen through the water determines pump sizing, battery size, solar panel size, etc. Optimizing and selecting the most efficient diffuser is essential to an economically feasible and robust design.

Gasses that are commonly diffused are pure oxygen, air, and ozone. One application of diffuser aeration is in municipal wastewater treatment to increase bacterial degradation of nutrients in an aerobic environment or to pump ozone into the drinking water to disinfect it as a final treatment. This technology is also used in aquaculture to meet the demand of respirating fish, bacteria, and algae. In wastewater treatment diffusers have the ancillary effect of providing mixing inside the reactor. Air diffusers have a low upfront cost when compared with paddle wheel aerators [11] and are compatible with solar systems because they can aerate with less horsepower needs [12]. The basic principle behind all diffusers is pushing a gas through a membrane to divide that gas into small bubbles that travel up the water column while exchanging the gas with the water.

Diffuser performance over the long run is directly related to fouling, basin geometry, placement of diffuser, operator expertise, and the quality of the preventative operations and maintenance program. There are two types of fouling. Type I includes particles from the air clogging the diffuser while type II involves a biofilm taking root on the diffuser surface. Fouling of diffusers can be prevented by routine cleaning operations which will be elaborated on in each section below. Historically systems were monitored for fouling by checking for an increase in back pressure but oxygen transfer efficiency drops before a significant reading of back pressure is present. [3]

The rest of this report compares the major diffuser technologies and their respective benefits and/or drawbacks. When you look at differing prices of air diffusers there are a few common characteristics that drive the resale price. These factors include durability/lifespan, frequency of servicing, oxygen transfer efficiency, energy requirements, bubble size, compatibility with ozone and pure oxygen, and parts/materials cost. As bubble size decreases you get higher surface area and oxygen transfer efficiency, but you lose the mixing effects of larger bubbles. The major aeration diffusers on the market are glass bonded silica ceramics, rubber tubing, BioWeave, EPDM/rubber, and aluminum oxide diffusers. A more in depth analysis of each technology is given below with images of diffusers given in appendix 1.

2. Survey of Technologies

2.1. Diffusers

2.1.1. Glass Bonded Silica Diffuser Stones

2.1.1.1. Technology Overview

The glass bonded silica diffuser stone is one of the most ubiquitous diffusers on the market. This technology dates back to the early 1900s when people used ceramic plates[4]. The modern diffuser is machined from a solid block of glass bonded silica and produces a medium/fine bubble. This type of diffuser is categorized as a subsurface aeration system [3] and is usually suspended right above the bottom surface of the body of water.

One of the drawbacks of ceramic stone diffuser is that they are apt to clogging/fouling from bacterial growth. For most soft water applications the diffusers only has to be cleaned once a year. For cleaning regimes you can either soak the ceramics in a acid bath, pump them with anhydrous HCL, or scrub them carefully with a brush [4] [5]. The stones are quite fragile and should be handled with care [14].

Pentair Aquatic Ecosystems among other companies sells the most popular glass bonded silica diffuser on the market called the “Sweetwater” glass bonded diffuser which is a registered trademark. This one is the most popular because of its low price point, quality assurance, low air resistance, and medium to fine bubble production. The Sweetwater has an air resistance of less than 0.25 psi which helps save on start up power needs and saves on energy consumption throughout its lifetime. The dust and particles collected from the air that are pumped downward primarily pass through the diffuser due to the pore size being large enough for air particles to pass (30 microns). This reduces the need for air filters on the pump housing. One rectangular diffuser of 1.5 x 6 in can provide up to 0.5 cubic feet of air per minute.[11] This type of diffuser stone can either be manufactured as a cylinder, rectangular cuboid, disk, or plate.

2.1.1.2. Economic Considerations

A Pentair Sweetwater that is 1.5 inches in width and 6 inches in length costs about ten dollars. According to the pentair website these diffusers are compatible with economical low pressure blowers due to a small air resistance of .25 psi. This opens up a suite of possibilities for decreasing the power needs of the aeration system when compared with other diffuser technologies that need higher back pressure. The overall pressure drop across the sweetwater is negligible in comparison with the rubber membrane diffusers. Less pressure resistance could mean a cheaper blower pump, smaller battery, and a smaller solar panel. Economic considerations should also include time spent cleaning the diffusers, price of acid bath kits, labor costs, and decreased efficiency of the diffuser and consequently higher stresses on pump/battery lives.There will be little to no salvage value for the diffuser at the end of its life.

2.1.2. Diffuser Tubing

2.1.2.1 Technology Overview

Diffuser tubing is just as it sounds and consists of a flexible tube that is porous in nature. This design allows for easy mobility and can help aerate non-traditionally shaped ponds. The most common types of tubing are rubber/polymer, paper, and bioweave tubing. The rubber tubing is often weighted so that it sinks to the bottom of the tank. Pentair tubing outputs 3 mm diameter bubbles. It can be perforated on only one side or release bubbles from the whole surface. Some of these tubes are equipped with antimicrobial properties. Some rubber tubing requires higher psi. Bioweave tubing is constructed with woven polyester fiber material and is claimed to last for “years” [11]. When talking with a Pentair representative she said that the components would not be a fit for our project because they would rapidly biodegrade. There is also disposable paper tubing that is often used in shrimp aquaculture. Although this product is cheap it is unsustainable.
The major drawback of all tubing technology is the maintenance inconveniences. In a pond with high biological activity fouling is inevitable. The sweetwater stones the and aluminum oxide are the only diffusers that can use a acid bath. For this case scrubbing of the tube would be the most effective cleaning measure [12].

2.1.2.2. Economic Considerations

The differing tubing technologies can easily meet our flow rate requirements for this project by multiplying by the appropriate footage. Economic considerations should include time spent cleaning the diffusers/labor costs and decreased efficiency of the diffuser and consequently higher stresses on pump/battery lives. If the tubing is not well maintained the compounding effect could make diffuser tubing cost prohibitive in the long run. The high pressure needs specified in the pentair catalog could also require higher pump capacity and higher initial investment costs.

2.1.3. EPDM/Rubber Membrane

2.1.3.1 Technology Overview

EPDM stands for ethylene propylene diene monomer and is a type of rubber. This material is most common in the roofing and wastewater sectors. The membrane can be found in many modern wastewater facilities across the country. The technology's major advantage is the ease of cleaning and resistance to fouling. The rubber membranes can be cleaned by increasing the pressure to all to slough off the biofilm or to divert all pressure to one diffuser. Another cleaning method is to simply pull it out of the water and rub the biofilm off with your hand [1]. The technology consists of a sheet of rubber that has hundreds of pores cut into it. When pressure/airflow is applied the membrane pores expand and release the air. This is advantageous because while the membrane sits idle it is much harder for biofilms to form on smooth rubber surfaces when compared with porous ceramics. The bubbles are slightly larger than the standard ceramic airstones [5]. According to a pentair representative rubber membrane diffusers are still compatible with air despite the catalog saying they are best used with pure oxygen. The EPDM membranes have a minimum pressure requirement of 0.5-0.6 psi [6].

2.1.3.2. Economic Considerations

A 8 inch rubber polymer diffuser costs 15.69 $ and puts out around 0.7 cfm with a max of 2.5 [5]. These diffusers come with a 1 year warranty from the Pentair website. The decreased fouling risk and inhibition of backflow while idle decrease the possibility of the pump and battery needing to compensate for decreased airflow or increased pressure. Another economic consideration is that less cleaning time and frequency will be required so less labor is needed.

2.1.4. Aluminum Oxide

2.1.4.1 Technology Overview

Aluminum oxide air stones are an alternative to the glass bonded silica air stones. They are in the same category of ceramics as glass bonded silica but are inherently more strong and resistant to breakage. The aluminum oxide ceramic is made of the same material that grinding stones are. Users do not have to worry about breaking the diffuser in half due to its strength [**7**]. One website claims that aluminum oxide diffusers have 3x times the lifespan of the glass bonded silica.The aluminum oxide can be cleaned with muriatic acid. If preferable the material can resist high heat so the burning of algae or bacteria for cleaning purposes is also an option. The resistance to air is 0.25 psi so the product is compatible with low pressure blowers [8]. The product also has anti-corrosive properties [9].

2.1.4.2. Economic Considerations

A aluminum oxide diffuser that is 1.5 inches in width and 6 inches in length costs thirteen dollars. According to the pentair website these diffusers are compatible with economical low pressure blowers. This opens up a suite of possibilities for decreasing the power needs of the aeration system. Less pressure resistance could mean a cheaper blower pump, smaller battery, and a smaller solar panel. Economic considerations should also include time spent cleaning the diffusers, price of acid bath kits, labor costs, and decreased efficiency of the diffuser and consequently higher stresses on pump/battery lives. The decreased risk of breaking parts during cleaning and operation increases lifespan of the product and decreases chance of prematurely shortening the life of the diffuser.

2.1.5. Conclusion

Table 1 in appendix 1 helps to compare some of the most important specs of the various technologies. The technology with the highest cfm/$ value is the rubber tubing. This technology is cheap to manufacture and can release more than adequate amounts of air. The major concern with the tubing though is inconvenience of cleaning it. The compatibility with regenerative blowers and low cost of labor for cleaning could offset this aspect of the product.

Among the other technologies aluminum oxide and rubber/EPDM diffusers stand out. The alumina oxide material has roughly the same cfm/$ value as glass bonded silica, but doesn’t have the fragility of the silica. The rubber/EPDM membrane is attractive for its self cleaning properties, but has a higher air resistance (psi) requirement. This in depth comparison of diffusers has helped bring our group one step closer to selection of a final aeration system design.

2.2. Solar Panels

2.2.1. Technology Overview

A solar panel is made by combining the effects of multiple solar cells. Each solar cell takes radiant solar light, excites electrons within, and converts that energy into electrical current. The two main groupings of solar panels on the market right now are crystalline and thin film technology.

The grouping of crystalline includes both monocrystalline and polycrystalline. Monocrystalline solar cells have slightly higher solar conversion efficiency (20% versus 15%) than poly, but for all intensive purposes the two are interchangeable. Monocrystalline solar panels are slightly more expensive as well due to the purity of the silicon and the waste of some silicon during the manufacturing process. Polycrystalline silicon wafers are poured into a square mold after heating versus a four sided cutting process of the crystal. Of the silicon based solar cells on the market, roughly ninety five percent of them are comprised of crystalline silicon. [10]

The other solar cell grouping on the market is thin film technology. In 2011 thin film solar cells represented five percent of all the cells on the market. The technology is expected to jump from 7-13% solar conversion efficiency to 16% efficiency. The manufacturing of this technology is basically thin layers of semi-conducting materials layered on top of eachother. Thin film solar cells lend themselves towards mass production and are more flexible which allows them to be placed in unique ways. [10]

2.2.2. Economic Considerations

Monocrystalline solar cells come with the highest efficiency and not surprisingly the highest price. Polycrystalline is the next most efficient with thin film cells close behind. Polycrystalline solar cells are more readily available as ready to install panels when searching through the online marketplace. If there are space constraints a higher efficiency technology may be preferred. Also some monocrystalline solar cells offer a 25 year warranty. Some online packages throw together the charge controller, mounting screws/plates, and the cell which is added convenience for a slightly higher price [10].

2.2.3. Conclusion

This section has given a brief overview and knowledge of what solar cells are on the market. Since the prices, efficiencies, and power outputs are all pretty much set in stone (or silicon) our group has decided to wait until our final calculations of power needed to select the appropriate panel at the lowest cost.

3. Conclusion

Throughout this report we have looked at various air diffuser technologies and a brief overview of available solar cells on the market. Looking at the diffusers there are serious maintenance requirement, pressure requirements, price, and air output volume differences between all of them. Based on assigned priorities of economic factors and technical needs of our design, I believe this document and the information presented will help us to narrow our choices of diffusers to one or two. More intensive calculations on pressure and volume output are needed in order to confidently choose a diffuser that will meet our problem statement design constraints. As of now the aluminum oxide ceramic diffuser and the EPDM/rubber membrane are the outstanding diffuser candidates because of their durability and ease of cleaning. Tubing is still a possibility but evaluation of pump sizing to meet higher psi requirements would be needed to determine its economic feasibility. Sweetwater glass bonded silica diffuser stones are still an option if we wanted to save on money and market our design as the most economic. However the cfm/$ when comparing the silica and alumina ceramics is roughly equivalent. Based off of our decision matrix' scoring of each component we can make a decision that fairly evaluates how they compare in social, economic, environmental, and technical aspects. In regards to solar our team will carry out final design calculations and then choose the solar panel that can provide for our power needs at the lowest cost.

4. Appendix 1

Table 1: Summary of Various Diffuser Specs
(Lifespan estimated based off of fouling and listed product details)

	Size Metric	CFM (ft^3/m)	Cost ($)	Lifespan	Major Advantage	Major Concern	cfm/$
Sweetwater	1.5x1.5x6 in^3	0.5	11.29	1.5-2 years with regular clean	-Compatible with blowers -Time Tested	-Cleaning -Fragility	0.044
Rubber Tubing	Per Foot	0.1-0.6	1.51	1 year	-Shapeable to pond -Compatible with blowers	-Cleaning -High Pressure Requirements	0.23
AntiMicrobial	Per Foot	0.1-0.6	2.45	1 year	-Shapeable to pond -Compatible with blowers	-Cleaning -High Pressure Requirements	0.14
Bioweave	Per Foot	0.2-0.6	37.00	1 year	-Self Weighted	-Degradation	0.011
Rubber/EPDM	8x1.5 in	0.7	15.69	1-2 year	-Easy to Clean	-Higher psi requirements	0.045
Aluminum	6x1.5 in	0.75	13.00	2-3 year	-Compatible with blowers -Flame clean -Rugged		0.058

Table 2: Images of Diffuser Categories taken from 'pentairaes.com'

Glass Bonded Silica	
Rubber Tubing and Bioweave	 

Rubber/EPDM Membrane	  
Alumina Oxide	

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Calculations:

Buoyancy Calculation

- Total Mass
  - 116 kg
- Water Displacement Needed
  - 116 L
  - 232 L
- Center of Mass
  - Xcm = 0.75 from side of raft
  - Ycm = 0.241 m from raft base
- Known average wind speed
  - Set moment = 0 about center for given angle
  - known Fg, Fb, solve for Fw

NPV Calculation Process

- Assess multiple systems for best investment in Matlab
  - Vary- Arduino Logic, Charge Controllers, Solar Panel Size
- Determine:
  - Final fish weight
  - % Survival
- Compare total harvest weight while using system and not using system
- Find Low and High budget Systems with optimum NPV

Economic Analysis-NPV

Matlab Model Components:

- Inputs:
    - Solar W, Bat. Ahrs, Pump W, Fish Density
    - Pond Volume, O2 Consumption, Ard. Logic
- Outputs:
    - DO and SOC fluctuation throughout year
    - Battery Life
    - Number of Consecutive Days below mortality DO
    - Fish Weight

NPV Calculation

- Use:
    - Battery life
    - Fish Harvest Weight
    - Lifetimes of Components
- To Calculate NPV
- Groupings
    - PWM & No Ard.
    - MPPT No Ard.
    - PWM & Ard(#)
    - MPPT & Ard(#)
    - PWM & Ard(1) w/500 W solar
    - MPPT & Ard(1) w/500 W solar
    - No system

NPV Winners

System	PWM & Ard Logic 1	Solar Panel (500) PWM Ard Logic 1	Solar Panel (500) MPPT ARD1 (10 fish)
Harvest Fish Size (g)	218.8	248.5	236
Total Fish Weight at Harvest (kg)	581.4	695	944
Battery Life (yr)	4.2	5.8	5.6
NPV ($) 5	2695.7	3966.5	6788.4
NPV ($) 10	4438.1	6373.4	10749.2
Initial Cost	-1062	-1312	-1482
Hotspot m3	200	200	200
Fish Density	7	7	10
Fish Number	1400	1400	2000
Pond Volume @ 4 f/m3	350	350	500

Design Calculations:

A pdf of the design calculation is added to the USB.