- Senior Design Group 5

Solar-Powered Venturi Aeration for Semi-intensive Tilapia Aquaculture in Developing Countries

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Abstract

We have designed an economically advantageous aeration system for a small tilapia aquaculture pond located in developing equatorial countries. Currently little to no aeration is used in these regions resulting in lower fish densities, higher risk of losing a crop, and consequently lower profits. Our aeration system needed to provide enough oxygen to both increase the number of fish in the pond and reduce the risk of losing fish due to low oxygen conditions.

The aeration systems analyzed were vertical pumps, pooled step cascades, paddlewheels, venturi aerators, and diffusors. The power systems analyzed were line, human, wind, solar/compressed air, solar/battery, and gas generators. All systems were compared to each other on the basis of functional, technical, environmental, social, and economic aspects. While many of these systems would work in our target environment, a venturi aerator paired with a solar/battery system is the recommended alternative.

In order to test the validity this alternative we developed a 1:400 scale model. While the model system was capable of delivering dissolved oxygen, there were too many uncontrollable variables and unforeseen testing environmental conditions for the results of our tests to be indicative of the performance of our full system. The scale model had a K_{la} of 0.3. There is little existing data for venturi K_{la} but a higher performance is expected from the full size system.

The full size venturi solar/battery system will proved the desired 800 g of oxygen per day at a cost of \$0.49/kg O2 with a capital cost of \$1067. The system provided several secondary benefits such as pond mixing and resiliency to changing environmental conditions. This provides the additional safety required considering the risks at high fish densities.

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List of Acronyms

DO – Dissolved Oxygen
FAO – Food and Agriculture Organization of the United Nations
FCR – Feed Conversion Ratio
K_{la} – Mass Transfer Coefficient of Oxygen
NPC – Net Present Cost
OTR – Oxygen Transfer Rate
PCSC – Pooled Circular Stepped Cascade
PTO – Power Take-Off
SAE – Standard Aeration Efficiency
SOTR – Standard Oxygen Transfer Rate
USAID – United States Agency for International Development

1.0 Introduction

1.1 Design Problem

Our team has been commissioned by Dr. Hillary Egna, director of Aquafish Innovations at Oregon State University to design an aeration system for use in warm water pond aquaculture in developing countries. She has asked that our system be self-contained as access to line power is unreliable and brown outs are common; it must be robust, requiring minimal maintenance; and it must be priced appropriately for small scale farmers. Our initial objective is to design a system for implementation in Kenya, though we are optimistic that the system will be robust enough for various developing nations. However, the power system most suited to Kenyan implementation may not be as good an alternative in other regions.

The pond for which we are designing is a common size and shape in our target region. It is a tilapia pond with a 200 m^2 surface area, a water depth of 1.5-2 m, and a total volume of 300-400 m^3. Under current practices, farmers achieve approximately 3 tilapia per cubic meter; with aeration this density can more than double to 7 tilapia per cubic meter. These ponds have no water flow and will have a significant algae population which is a source of food for the tilapia.

1.2 Background

1.2.1 Aquaculture

Aquaculture is the farming of fish, crustaceans, and mollusks for human consumption or recreation. This practice dates as far back as 500 B.C.E. where the Chinese documented methods of cultivating fish. Currently about 27% of fish consumed globally is farmed (Campbell and Pauly, 2013). While most of this global aquaculture production occurs in developing nations, aquaculture accounts for less than 1% of the protein production in Kenya (Kaliba et al., 2007). Kenya has implemented systems to encourage growth in aquaculture resulting in a 10% annual increase in national production over recent years (Bostock et al., 2010).

1.2.2 Environmental & Social

Aquaculture has been encouraged by many nations for its sustainability and high rates of return. The FAO and the USAID each have extensive reports on the implications of aquaculture for developing nations, especially their economies, as well as follow up programs on the implementation of these systems (FAO, 2005:AquaFish, 2014). Tilapia is often chosen to be grown in aquaculture systems for its resilience. They feed on various organisms from plants to insects, including algae and aquatic insects but can also be fed high protein fish feed. They have a low FCR of about 1.6; this means it takes 1.6 kilograms of feed to produce one kilogram of fish. This is a sustainable FCR when compared to that of cattle which is around 10 (Siddiqui et al. , 1988). Pond aquaculture is sustainable because it is a closed system. In a closed system waste is recycled by organisms such as algae which in turn produce food for the fish. This creates less need for external resources such as space, water, or nitrogen; no additional space is needed to produce crops as feed or to manage the waste; by cleaning itself, the system does not require a continuous supply of clean water, fish waste decreases the amount of fertilizer needed to grow algae as a food source.

1.2.3 Aeration

Aeration is the process of adding oxygen to water. Aeration is used worldwide in waste treatment plants as high oxygen content in the water encourages the growth of the numerous microorganisms needed for the processes that cause degradation of wastes. It is also used in intensive aquaculture systems to increase the maximum fish density in a pond. Most aeration techniques are similar; the goal is to increase the surface area and time of contact between water and air. Standard forms include fountains, bubblers, and surface agitators. In a pond system algae and tilapia live symbiotically, however, without sunlight the algae stop producing oxygen while both the algae and the fish continue to use up oxygen. At night, this results in insufficient levels of dissolved oxygen in the water for the tilapia. Without an aeration system to offset this respiration, the tilapia density is restricted to 3 tilapia per m^3. With moderate aeration the density can more than double to 7 Tilapia per m^3.

2.0 Technical Alternatives

In the absence of line electricity, our design includes a power system as well as a source of aeration. Since the function of the power system is independent of the aerator, power systems and aeration systems were analyzed separately. This was done by comparing the systems based on important design or functional criteria with a decision matrix or score card. From the top rated alternatives of each group, the most compatible overall design was chosen.

2.1 Criteria for Evaluation

Each set of alternatives was analyzed according to five categories: functionality, technical, environmental, social, and economic. Various criteria were scored in each category including some distinct to each matrix (aerator effects on algae or a power system's location suitability). The overall categories were each weighted against each other. Criteria within each category were then weighted against the other criteria within that category and the category total was normalized to the category weight.

Functionality was weighted at 35% of the total score. This category considered the major details of the system's applicability to our target environment. For example, one criteria considered in this category for power systems was local suitability. Solar powered systems scored quite well due to the regular day lengths and high average solar radiation level. However, wind power scored poorly due to the low average wind speed in inland Kenya where most aquaculture is currently practiced.

Similarly, economics accounted for 35% of the total score. This is one of the most important design challenges. If costs are unreasonable for our target customer then the system cannot and will not be implemented. The topics addressed in this category were capital cost including installation of the system, operational costs, and replacement costs. For example, batteries have limited functional lifespans and are comparatively expensive to purchase and replace so it was important to address this when grading systems that incorporated batteries.

The Environmental, Social, and Technical categories each received 10% weighting. The low weight of these categories does not mean they are unimportant; they are simply not categories or criteria that will render the system entirely unsuitable. For example, farmer acceptance from the social category: all systems could be made acceptable, some would require less convincing or education and some are more familiar to farmers. The technical category differed from functionality in that it examined the state of the technology; level of development and scalability as opposed to the use for our specific application. Newer technologies or systems that have little documentation regarding their use in aquaculture may score lowly in this category. However, that doesn't mean it is inherently inappropriate for our target usage. As such, this category was given a low overall weight. Subtle characteristics of each system are compared in these lower weight categories.

Each alternative was designed to meet the same criteria for ease of comparison. Aerators were designed to supply 2 mg/l of oxygen to the pond over a 4 hour period of operation resulting in an oxygen transfer rate of 0.2 kg/hr. The transfer efficiency at the worst case situation for the pool of 25ºC and 4 mg/l of dissolved oxygen is 40.5% of standard transfer rates and aeration efficiencies, this efficiency would go up at lower temperatures and down at higher DO concentrations. This efficiency and needed actual oxygen transfer were used to design all aerator alternatives. Similarly all power systems were designed for a set energy need of 2 kW-hr. This is the energy applied to the aerator and did not account for any losses within the power system itself, such as with battery charging or inverter efficiencies, these were accounted for in designing the poser system to output the above need. The starting value of 2 kW-hr was based on the need determined by initial aerator design calculation averages. These values may not be those used in the final design but allowed for comparison between alternatives for the purpose of analysis and determining the best alternative.

Table 1: Matrix of Power Systems showing overall scores can be found at the end of section 2.2. **Table 2:** Matrix of Aerators showing overall scores can be found at the end of section 2.3. The complete matrices with criteria scores can be found in **Appendix C**.

2.2 Power System

2.2.1 Line Power

Very few private citizens in rural Kenya are on the grid (Lee et al., 2014). Many, however, are not off grid but fall under a new definition of "under grid" living within 600 m of a power line. This is the result of a concerted effort by the Kenyan government over the last decade to connect all of Kenya by getting all public buildings, schools, clinics, etc., on the national grid (Lee et al., 2014). For these "under grid" homes and businesses it is significantly less expensive than originally believed to obtain a connection to the national power supply, around $400. Kenya Power also works with other agencies and countries to provide easy, low interest loans to individuals seeking to use this source of consistent energy. Once connected, energy costs are very low, $1.33 a month connection fee and $0.03 a kW-hr (Kenya Power, 2014). The grid has also improved in recent years in consistency, there are still brown outs but they are becoming shorter and rarer.

This alternative scored the highest of all alternatives in the Power System matrix. However, it was not considered as a power system for our final design. We wished to know what the cost would be so it could be provided to clients and customers while having a fully developed, self-contained alternative as a main power system option.

2.2.2 Human Power

This method placed fifth out of six when ranked via the decision matrix, it had very high annual costs and no real benefits to the farmer. The system consisted of a bike and a converter that would translate the mechanical energy of pedaling into electrical energy to power the aerator pump or motor. In order to keep the capital cost down biking was to be done at night to prevent the need for batteries to store power until the aerator was used. A total of 10 hours of biking generating 200 W (Martin, 2012) would be needed to produce the 2 kW-hr the power systems were compared for. The minimum wage for unskilled labor was $0.54 per hour in 2013 (Mywage.org, 2014). At this wage, paying for the needed 10 hours a night of labor would cost $162 a month and $2000 if run every day for a year. This cost is higher than the value of the aeration based on the value of fish.

2.2.3 Wind Power

Wind turbines are a good sustainable energy source option because they are a renewable energy that does not require additional inputs once operational. Turbine sizes range from 0.3 kW to 8000 kW. Western

Kenya has enough wind to power a 300 to 500 W wind turbine if placed at a great enough height. The radii of these turbines range between 1 and 1.5 m; this creates a sweep area between 3.14 and 7.07 m^2. This area is correlated to the wind power density of a given location; this value increases with height as wind speed increases. The largest constraints with wind turbines are their inefficiencies at converting this wind power. While the wind power density of western Kenya is roughly 80 W/m^2 (at 40 m hub height), turbine efficiencies are around 30% (Hirahara et al., 2015); a 300 W system with 1.5 m radius could feasibly produce about 170 Watts of power. In some places, including Kenya, there is less wind at night. If power is needed at night then the turbine can be connected to batteries as needed. Two sources of difficulty are the height needed and the level of locational dependency.

A large benefit of a wind turbine is its lifespan and minimal maintenance. Once installed and operational the only maintenance needs include inspection on the blades and bolts and greasing as necessary. With the ability to also withstand substantial storms, the lifespan of a wind turbine is about 20 years. (Energy.gov, 2014). The electronics for these systems are relatively straight forward and do not add to the cost which is about $1.20 per watt of the turbine. The metal required for supporting the tall structure is about the price of the turbine. Creating concrete foundations and raising the tower are the most intensive, and expensive, aspects of a turbine installation. Aside from this difficulty, renewable energies are still welcomed by residents of rural Kenya (Kenya.gov, 2014).

2.2.4 Solar/Compressed Air

The biggest disadvantage of a battery system is the recurring cost for replacing them. A potential alternative form of energy storage is to compress air. In accordance with the ideal gas law, it is possible to store the same mass of air in a significantly smaller volume if brought up to a high pressure. This system consists of a solar array, a compressor, and a high pressure air tank. The compressor runs during the day when solar radiation is prevalent. There are a few important disadvantages to this system. First, it is only compatible with diffused air aeration. Secondly, there is the high capital investment required to purchase high volume pressure tanks in the 200 psi range. Third, it takes more work to pump a volume of air to 200 psi than any of our other systems. As such, a higher power compressor is needed. Lastly, the volume of air you need to store becomes unreasonable if your aeration method has poor Oxygen Transfer Efficiency. Despite these disadvantages, the technology scored quite well in our matrix. The lack of recurring cost, minimal maintenance, and the lack of need for large battery arrays allowed it to stay competitive. Ultimately the high installation cost made this option unrealistic for developing nations even though it scored high overall.

Table 1: Matrix of Power Systems showing overall scores.

	Weight	Solar Air	Solar Battery	Human	Wind	Diesel	Line
Functionality	35	26.6	29.4	25.0	23.1	29.4	25.4
Technical	10	9.5	9.5	9.3	9.0	9.3	9.3
Environmental	10	9.8	8.0	9.6	9.6	5.6	8.2
Social	10	8.1	7.0	5.4	8.2	5.8	7.1
Economic	35	23.8	18.9	20.3	18.9	23.8	29.4
Overall	100	77.8	72.8	69.5	68.8	73.8	79.4

Our chosen design for power systems was Solar Battery. This system and its benefits will be described in detail in section 3.0.

2.3 Oxygen Delivery

2.3.1 Paddlewheels

The most commonly used aerators are paddlewheels (Tucker, 2005). These have paddles located on a cylinder that rotates to splash the water and create bubbles increasing the surface area and contact time of the water and air, causing oxygen transfer. Paddlewheels have been adapted for use with PTO, diesel or gas engines, and electric motors. Aeration efficiencies vary with changes in structure including changes in diameter, depth, paddle size and shape, and rotation speed. One intensive study determined that the paddles should reach 10-15 cm into the water, the hub should have a 0.9 m diameter, and the paddles should have a width of 10-15 cm and should be staggered around the hub. With these specifications SAE could range between 2.0 and 2.5 kg O_2/kW-hr (Tucker, 2005).

Maintenance needs are higher than other aerators. However, they are quite robust; they have been in production for many years and their designs have been refined. They are mass produced and there are multiple suppliers to Africa making them reasonably accessible to rural areas. The largest maintenance would be associated with a diesel engine power source. Electric motors require less maintenance and are more efficient (Bankston et al., 1995).

2.3.2 Pooled Circular Stepped Cascade

A method for employing circular stepped cascade aeration was developed in 2010 and further modified in 2013 with the design of PCSCs (Kumar et al. , 2013). These methods involve a six tiered system with water pumped through the middle and allowed to fall over the steps, PCSCs have barriers on the edges of each step to modify the flow path and retain the water longer. PCSCs have been found to have SAEs exceeding 3 kg O_2/kW-hr with increasing SAE as the radius of the cascade base increases. A Standard

Oxygen Transfer Rate (SOTR) of 0.161 kg O_2/ hr was observed by the designers in a 1.2 m base radius system with a flow rate of 600 l/min (Kumar et al. 2013). These systems have a low outlay cost and low maintenance costs due to only have one motorized component, the pump.

The system designed to employ this aeration method involved three independent units consisting of a 1.2 m cascade with two pumps each with a flow rate one third that of the design tests, 200 l/min. This is because pumps with a higher flow rate are larger, more expensive, often need more maintenance, and draw higher powers. The SOTR adjusts linearly as the flow rate is change, meaning each cascade in this system will have an SOTR of 0.107 kg O_2/ hr. When adjusted for temperature and dissolved oxygen concentration our goal OTR, 0.2 kg O_2/ hr, is not met. However, if run for 6 hours the system would provide the 2 mg/l DO specified for our designs. Each pump is $200 and each cascade is $50, with additional piping and connection costs the total system cost is $1400.

This system ranked quite high in our Alternatives Matrix, it is our second choice aerator design due to its low maintenance needs and comparatively low capital costs.

2.3.3 Diffusion

Diffused air aeration systems function by pumping air through a porous media at the bottom of a pond. These small bubbles rise through the water column and oxygen diffuses through the surface boundary into the water. Diffusion systems are extremely dependent on the depth of the aerator and the size of the bubbles. Large pore diffusion systems see oxygen transfer efficiencies of less than 5% while finer pore systems can reach 10-15% efficiency per meter depth (Sanitaire, 2014). However, micropore diffusors can expect oxygen transfer efficiencies of 40% to 50% at 1 m depth and upwards of 80% at 6 m depth (Point Four Systems, 2014). This comes with higher initial cost and pressure requirements. Diffusion has advantages including that it is pumping air instead of water, it is capable of aerating water through the entire water column, and does not have any moving parts outside of those in the pump.

2.3.4 Vertical Pumps

Vertical pump aerators in their most simple form are a submerged electric motor with an attached impeller suspended just under the water's surface using floats. These pumps are often in the 0.5 to 5 horsepower range running at 115/220 V. Vertical pumps are not good at circulating deep water as they pull water from the surface and throw it into the air around the pump; the same water is often pumped repeatedly. This prevents good lateral distribution of oxygenated water and does not prevent stratification (Rogers, 2010).

Since vertical pump aerators move water, it is important to look at both how much water moves through them and how well that water is aerated. For example, the 0.5 HP Splash 2001 pump manufactured by

Creel Pump, Inc. cycles approximately 2 m^3/minute (Creel Pump, Inc., 2001). Given a pond volume of 400 m^3, it would take this pump only 125 minutes to cycle through a volume of water equivalent to the pond's volume, however much of this water would not be pumping for the first time and some water would not pass through the pump. While processed water volume is comparable among models on a per horsepower level, the SAE between manufactures fluctuate significantly. In 1987, Boyd and Ahmad tested the SAE of a variety of aeration methods for the purpose of catfish farming (Boyd and Ahmad, 1987). Among the test subjects were 6 vertical pumps ranging from 0.33 to 10 HP. Calculated SAE for the pumps ranged from 0.73 kg O_2/kW-hr to 1.5 kg O_2/kW-hr (Boyd and Ahmad, 1987). There was no correlation between size and SAE some models just performed poorly. In another paper, Boyd cited the average SAE of vertical pump aerators to be 1.4 kg O_2/kW-hr with a 15 pump sample size (Boyd, 1998). Pump details were not given. Creel lists the SAE of their Splash 2001 as 2.7 kg O_2/kW-hr (Creel Pump, Inc., 2001). While it could be that the technology really has improved this much over the years it is likely that the Creel will not operate at advertised values in a real environment.

Table 2: Matrix of Aerators showing overall scores

	Weight	**Paddle Wheel**	**Vertical Pump**	**PCSC**	**Diffuse (Battery)**	**Diffuse (Air)**	**Venturi**
Functionality	35	26.2	27.5	28.5	31.1	31.1	31.1
Technical	10	8.5	8.3	8.0	9.0	9.0	8.0
Environmental	10	7.0	6.3	9.5	6.1	6.1	5.9
Social	10	7.2	6.3	7.3	7.0	7.0	6.9
Economic	35	22.4	23.8	22.4	23.8	19.6	29.4
Overall	100	71.2	72.1	75.7	77.0	72.8	81.3

Our chosen design was a Venturi aeration system. This system and its benefits will be described in detail in section 3.0.

3.0 Solar/Battery Powered Venturi Aerator

The chosen alternative is a solar powered venturi aerator. The aeration system will consist of two separate, identical units. This is to create a continuous circulation loop as well as double the total oxygen added. This set up can be seen in **Figure 1**. Customers could purchase the units independently and have a half-sized aeration system if that met their needs and budget. Each unit consists of a submersible pump, connecting pipes, and two venturi nozzles set in parallel as shown in **Figure 2**. The nozzles will be Mazzei Injectors model 1078 (**Figure 3**). The pump will be a Tunze Turbelle Stream 6125. The pump moves 12000 L/hr and draws 22W. Based on flow rate and nozzle characteristics this system should have an Oxygen Transfer Rate at our pond conditions of 0.2 kg-O2/hr. A modular system was chosen for the ease of scalability, provide more uniform aeration, and to address the limitations of pump and nozzle size. The power system (one system powering both units) will consist of a 100 watt solar panel charging a 75Ahr 12V battery. The system will also include a DC-AC inverter and a charge controller. Energy need has been calculated based on the complete system being run for four hours each night.

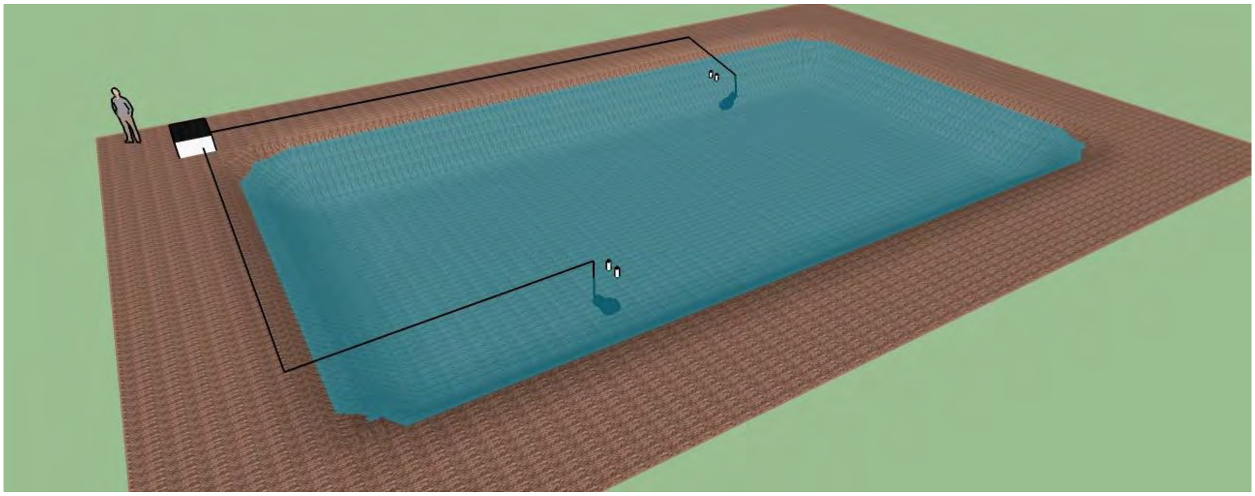

Figure 1: Pond set up with two aeration modules

Since the power system is designed to be sufficient under lowest monthly average light conditions, the solar panel will be operating in excess the majority of the year. With charge control technology to ensure the battery is always charged first, the pump could be run during the day on this surplus energy. This would increase the DO in the water creating a better environment for the fish. Alternatively, this surplus could be used to charge small devices like cell phones or lanterns.

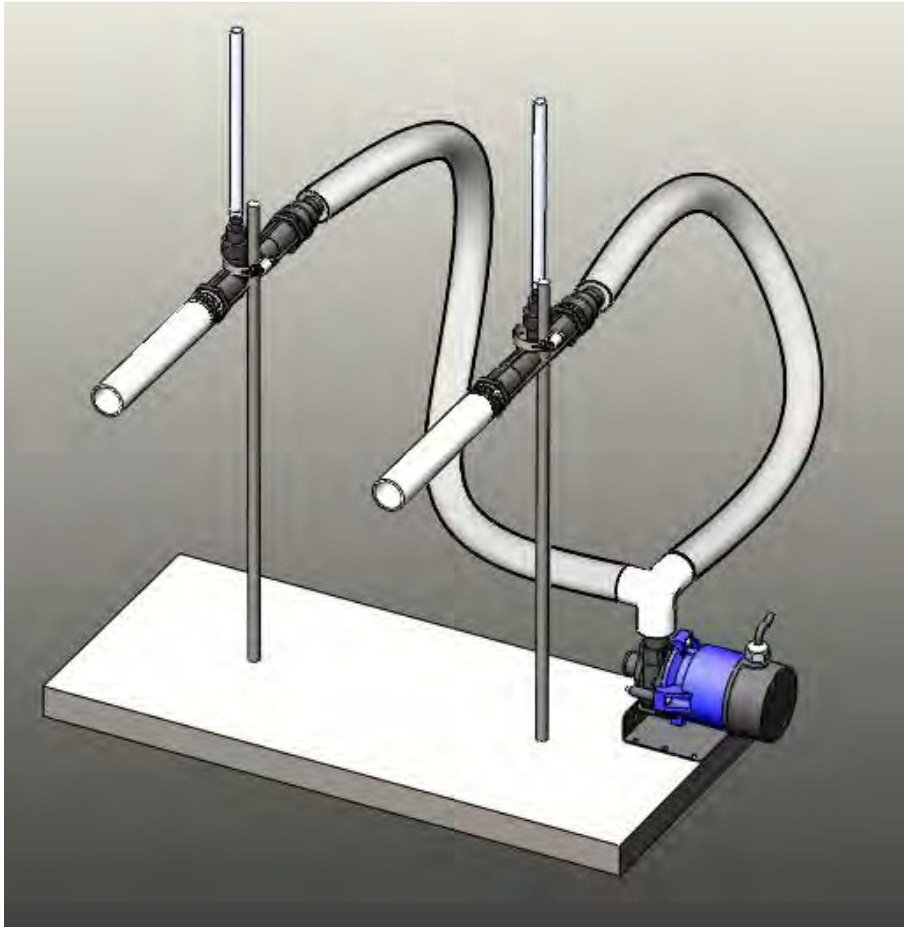

Figure 2: Aeration module

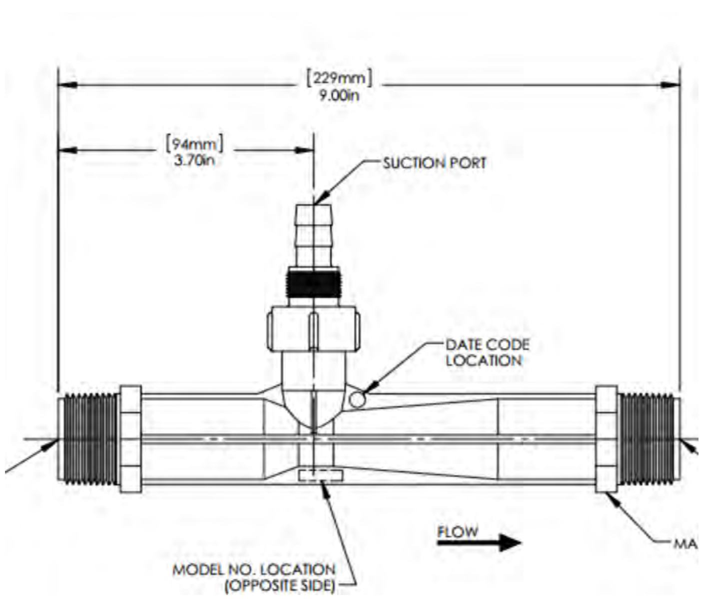

Figure 3: Venturi nozzle - Mazzei Injectors model 1078

3.1 Technical Constraints

The primary technical constraint inherent to warm water aquaculture systems is low oxygen transfer efficiencies. This is the result of high temperatures that decrease the saturation concentration of oxygen in the water. Combined with the need to maintain 4 mg/l of DO at all times to ensure fish health, the gradient is decreased even more. At 25ºC the saturation concentration of oxygen is around 8.6 mg/l. Our minimum allowable design DO is 4 mg/l, the resultant efficiency of this system compared to a system at 0 mg/l DO is 40% (Boyd, 1998), greatly increasing the transfer rate needed to obtain a desired level of aeration.

Further efficiency related difficulties are the result of the nature of venturi aerators. These aerators have highly variable OTRs depending on the internal nozzle dimensions, the flow rate of water, the size and placing of holes for air entrainment, and the length of the tube after the air enters the flow. OTR also depends on the number and arrangement of nozzles. All of these characteristics combine to make it difficult to compute accurately or find specific values for the aeration efficiency of venturi aerators. As a result, the system must be built above need to account for possible errors in theoretical calculations, at least until empirical data is gathered for the specific nozzle and configuration.

When using a solar battery system there are several important aspects to consider. The applicability of solar power is bound by the amount of solar radiation a location receives on a day to day basis. Secondly, the amount of solar radiation a location receives is dependent on the time of year. Nairobi Kenya gets upwards of 6000 W-hr/m^2-day for many months but in June and July only see on average 4250 Whr/m^2-day (Barman, 2011). In order to ensure functionality of the solar array during all times of the year it must be sized so the system can function on 4250 W-hr/m^2-day. While the wattage rating of a solar panel is already accounting for the energy conversion efficiency of the technology when exposed to 1000 W/m^2 it is important to note that readily available solar cells are only about 15% efficient (Barman, 2011). Along with the solar panels a charge controller will be needed to regulate the output going to the batteries.

There are many types of batteries in use today. The two technologies we determined were most likely to succeed and compared to each other were lead acid-and lithium-ion. Deep cycle lead-acid batteries are easier and cheaper to purchase and have well established supporting technologies when coming to meters and regulators but have short cycle lifespans and are sensitive to over discharging. Lithium-ion batteries deliver a more consistent voltage, are not as vulnerable to damage due to fully discharging, and have more charge cycles over their operational life than lead-acid batteries. However, they were much more expensive, required more expensive supporting technology, and in the sizes we required could only be purchased from a few manufacturers, none of which would be purchasable anywhere but online (Armand

and Tarascon, 2008). Due to being more available and the necessity of replacing the batteries every few years, we chose lead-acid batteries for our design.

A battery system comes with one particularly important benefit when harnessing renewable energy such as solar; it allows the system to function even if the amount of solar radiation for the day drops below the designed minimum. The batteries are only going to be 30-40% discharged each night. This means that the system could run 2 to 3 nights in a row, even with no sun, at the expense of reducing the lifespan of the batteries. Even a few unusually cloudy days in a row should provide enough of a recharge to prevent batteries from fully discharging.

3.1.1 Concerns Addressed

Through the development of this design a few key concerns came to our attention regarding the use of a pump, theft, and environmental factors. The first concern addressed was that of fish safety. Small fish are susceptible to being injured by the suction and flow of a pump. One mitigating factor is a screen placed over the pump inlet; however, the strength of the suction may still be enough to overpower the fish. Adjusting flow rate is a viable solution to this problem. While this may cause a lower DO transfer, the smaller fish do not demand as much oxygen and with a proper concentration of algae aeration may not be necessary. The pumps effect on the earthen pond is also of concern. With the pump near the floor of the pond scouring may occur near the inlet and outlet of the pump. The pond floor also often consists of an anoxic layer; mixing this into the system will only raise the need for DO. These problems are addressed by lifting the pump off the pond floor. Our design will have the pump lifted of the pond floor by 0.2 meters, the angle of the nozzle will also be insufficient to cause scour at the outlet.

There is also a concern for pump fouling. The pump's potential to foul will be reduced by its elevation above the earthen floor. Additionally, a bend will be placed on the pump's intake to ensure that the water is not being taken from the sediment rich floor. Fouling of the air intake must also be avoided. A tube pointing straight up may get clogged so a bend will be placed in the tube so it is not facing vertically. With these aspects taken into account, yearly cleaning will be sufficient to keep the pump system working efficiently.

The surrounding environment also raised concerns. With a system based on solar two things are apparent: it will only work when the sun is out and expensive equipment will be vulnerable. To address the fluctuation in solar intensity, the entire system has been design for the worst case scenario. This is in the months of June through August when the solar intensity is two thirds as much as in peak solar months. If a storm were to occur, the batteries for the system will last three days without recharging. One of the best ways to account for proper solar intensity is to plan harvests properly. It is left up to the farmer to plan for fish reaching full size in months of high solar intensity.

The expensive electronics of this system must be protected from theft. Strategic installation will resolve this issue. The solar panels are the most vulnerable since they must sit out to operate. These can be installed in such a manner that removal of the panel can only be achieved by its destruction. The rest of the electronics, including the batteries, will be placed in a metal lock box. The bulk and weight of this combined set up is a significant theft deterrent. Also by simply being out of sight, the chances of theft are greatly reduced. A similar benefit will be obtained by the pump since it is submersible and will remain below the water level.

3.1.2 Demonstration Model & Testing

To prove the viability of our system we designed a 1:400 scale model that utilized the same technology as our full system. The primary goals of this model were to determine if any unforeseen challenges might arise in the building and use of our system, prove functionality, and collect data on the aeration efficiency of venturi aerators. Due to the disparity in scale between the systems, the power system was not directly scaled down but instead redesigned to be suitable for our model system.

Our model pump system consisted of two different sized Mazzei venturi injectors, a variable speed Jebao DC-3000 24VDC electric pump, an aluminum chemistry stand to secure the venturi at the desired depth and angle in the water, flexible vinyl tubing, and PVC pipe.

Our model power system consisted of an Aleko 100 Watt 24V solar panel, two UB12100-S 12V 10 Ah batteries in series, a Geoking GS-1024 charge controller, three 10 A fuses, a 24V to 5V USB charger, and a Raspberry Pi single board computer connected to a relay for the purpose of timing when the pump would run. The entire power system was wired with 12 AWG stranded wire.

Our model pond consisted of a 1 m^3 inflatable swimming pool. Many steps were taken in order to make the testing conditions similar to those of our full scale system target environment. The entire experiment was conducted in a greenhouse set to 25 ºC. Electric water heaters were used to ensure the pool's water maintained a 25 ºC temperature as well. Algae were added to achieve real world concentrations and sodium sulfite was added to simulate fish respiration at varying biomasses. The largest challenge was that of daylight; trying to replicate an environment that receives 4.5 to 7 peak solar hours per day in a location that, on average, only receives 2.5 peak solar hours per day this time of the year. Furthermore, the greenhouse was covered in 50% shade cloth, further decreasing solar energy input. In order to combat this challenge, three 400 Watt high pressure sodium grow lights were set up on a 12 hour cycle. The lights were on from 6:00 PM to 6:00 AM so simulated "night" would be during the day, making it easier to collect readings at the predicted pre-dawn minimums.

There were many unforeseen challenges during testing. First, the limited spectrum of the high pressure sodium bulbs was not sufficient to charge the batteries via the solar panel even with the natural light available through the shade cloth. After the power system was moved outside to confirm it was actually working, the aerator itself was moved to line power to provide a more consistent testing environment. Furthermore, even with the grow lights it was challenging to get the algae to function in a diurnal cycle. Even during the simulated day at the lowest fish biomass the DO decreased due to the algae respiring more than they photosynthesized.

Regardless of the challenges during testing a lot of valuable information on the functionality of venturi aerators was collected. Variables tested in our experiments were pump flow rates, venturi angle, length of pipe extending off the venturi, and venturi size. Modifying the venturi angle and length of pipe allows for air injection deeper into the pond giving the bubbles additional time to diffuse oxygen as they rise. Our tests concluded that a 0.3 m length of pipe and an angle 25 º down from the surface of the water provided the best oxygen transfer. Longer lengths of pipe meant more bubbles colliding, forming larger bubbles, and consequently reducing surface area for diffusion. The amount of air injected was similar between the two systems but the longer length resulted in a lower K_{la}.

Of the two injectors tested, the smaller nozzle (584) provided a higher K_{La}. While the larger injector circulated a higher volume of water, total air injected and consequently, DO added to the water, were lower. This was a function of our pump which was unable to test the full breadth of rated flow for the larger venturi. The smaller venturi was known to be more appropriate for the model system but the full size nozzle was tested for comparison purposes.

3.2 Economic Considerations

Our venturi system consists of 2 Tunze Turbelle Stream 6125 pumps (Tunze, 2014), each connected to 2 Mazzei 1078 1" diameter venturi injectors (Mazzei Injector, 2014). PVC pipe will be used to bring water pumped from the bottom of the pond up to and through the venturi nozzles located near the surface of the pond. The Mazzei injectors are a significant portion of the aerators cost. However, they are also a good candidate for 3D printing. The aerator capital costs break down is shown in **Table 3**.

Table 3: Aerator capital cost breakdown per component

Component	Price
2x Tunze turbelle stream 6125	$412
4x Mazzei 1078 1" injector	$208
PVC piping	$100
Total	**$720**

Each Tunze pump has a 22 w power draw. With two pumps running for 4 hours that is a 176 W-hr daily demand. In order to ensure enough stored charge to accommodate for cloudy days we have chosen a 30% depth of discharge. Since these pumps are 110 V AC and our batteries are 12 V DC we will need to include an inverter. For our initial design purposes we are calculating with an 80% efficient inverter. That means our deep cycle lead acid battery must be rated for about 730 W-hr . The UPG UB12750 is rated for 75 A-hr at 12 V (UPG Battery, 2014). Watt-hours can be calculated by Ah x V, giving us a 900 W-hr rating. That is sufficient for our system. At 30% depth of discharge, we can expect about a 1500 cycle lifespan on our batteries (Northern Arizona Wind & Sun, 2014). That means they would need to be replaced at least every 4 years if run every night.

We can estimate the power requirement of our solar array based on the watt-hour demand of our system divided by the number of peak sunlight hours in the day. Peak sunlight hours are determined by dividing the amount of solar radiation in a day by 1000 W/m^2. Using our minimum case of 4250 W-hr/m^2-day (Barman, 2011) we get 4.25 peak sunlight hours. We assumed that the process of charging the batteries is 75% efficient (Curtis Instruments, 1981). This gives us a watt hour requirement of 235 W-hr. We must also include the inverter 80% efficiency again for a total of 293 W-hr. 293 W-hr /4.25 hours = 69 watts. Therefore, a 69 W solar system should be sufficient for this system. Since 69 W is an odd wattage that would be more expensive than a mass produced size, we will size for a 100 W system. ECO-Worthy offers 100 W 0.66m^2 panels for $82 (eco-worthy, 2014).

A charge controller will also be required in order to ensure that the battery is safely and correctly charged. The Aleko LM119 12V controller costs $35 and meets our needs (ALEKO). Additional wiring will be needed to connect everything. We are estimating this at $50. Lastly, an inverter is required to bring the 12 V DC up to the 110 V AC our pumps require. While we have not picked an exact model we anticipate another $50 for the inverter. The capital cost for the power system break down is shown in **Table 4**.

Table 4: Power system capital cost breakdown per component

Component	Price
1x UPG UB12750 75 A-hr 12 V battery	$130
1x ECO-Worthy 100 W solar panel	$82
1x Aleko LM119 charge controller	$35
misc. wiring	$50
1x 12 v DC to 110 v AC inverter	$50
Total	**$347**

This gives a total capital cost of $1067, assuming we purchase the venturis, with a recurring cost of $130 every 4 years to replace the battery and $412 every 5 years to replace the pumps. Maintenance costs on this system are minimal. Tunze recommends that the pump be cleaned once a year but it can be done with only a screw driver (Bulk Reef supply, 2014). With this in mind, an estimated annual maintenance cost of $15 was determined.

The average inflation rate in Kenya since 2005 is 11% (Kenya Inflation Rate, 2014). As such, we will apply a discount rate of 15% to evaluate our system over a 10 year period. NPC can be found in **Table 5**.

Table 5: NPC of system

Year	Cost
0	$1067
1	$15
2	$15
3	$15
4	$130
5	$412
6	$15
7	$15
8	$130
9	$15
10	$15
NPC	$1443

Over the 10 year life span the system will add 800 g of oxygen per day. That is 800 g/day x 365 days/year x 10 years for 2920 kg. That means that our system provides oxygen at a price of $0.49/kg O_2.

3.3 Environmental Considerations

Most environmental impacts to consider are the result of aquaculture itself and are not dependent on the method or presence of aeration, though the impacts of the unit are examined. In Kenya the limited government oversight and lack of funding for conservation efforts have caused problems for natural bodies of water as a result of commercial aquaculture. Over-extraction of water has led to drainage of wetlands and lakes in several regions causing habitat loss and loss of ecosystem function and services (Mwanja et al., 2007). This practice is not sustainable. Genetic diversity loss has also been recorded in some native tilapia populations (Ndiwa et al., 2014), caused by the escape of cultured species from aquaculture ponds and the capture of native fish for breeding and harvest. A third impact of Kenyan aquaculture is the potential for parasites in farmed fish to cause human disease. This also occurs with wild caught fish though and can be prevented by proper storage and cooking (Lima dos Santos and Howgate, 2011).

3.3.1 Production

The environmental impact of added aeration begins with the production of the aeration unit. Plastics like vinyl tubing, PVC, polypropylene, and those used in the pump housing are derived from crude oil whose extraction and processing has significant chemical and energy consequences (Baitz 2004)**.** The wiring in the pump, charge controller, timer, and between systems also have plastics based insulative coatings that have the same problems (Socolof et al. 2008). The wires themselves are likely copper and, depending on the level of virgin to recycled metal, also have extraction and processing impacts in the areas of energy use and chemical release (CopperWire 2005). Solar panels again have impacts due to raw material extraction; chemical exposure and energy usage are the primary impacts, however, energy use is offset by panels producing 10-17 times the energy need to build them over their lifetimes (Good Company, 2008). The batteries are also a significant source of energy consumption and chemical release during their production, however, it has been shown that lead acid batteries have lower energy use and emissions during production than nickel, sodium, and lithium based batteries (Lead, 2014).

3.3.2 Operation

The chosen aerator itself will have limited environmental impacts during use. The venturi nozzle and the pump do not pose any environmental risks during use as a result of their construction and materials. The greatest impact from a traditional pump is the energy usage, which in this case is low and derived from a renewable source. The increased circulation and surface agitation will, however, have the positive impact of preventing algal mats from developing and of making the pond a poor choice for insects to lay eggs and hatch larvae.

Solar-battery power systems have more impacts than venturi aerators, though still low due to the renewable nature of solar power. The source of negative impacts is the lead-acid batteries. If left exposed to poor weather they have the potential to corrode and leak their chemicals into the soil and the pond. This can lead to a build-up of lead in the environment and in the fish themselves (Van der Kuijp et al., 2013).

3.3.3 Post Design Life

The future of each component after it has reached the end of its design life also has the potential to play a significant role in the system's environmental impact. The availability of proper waste disposal and recycling in Kenya is an issue. Items like the pipes and tubing can be recycled but rarely are, if they were to be repurposed by the farmer or in the village it would have a positive economic and environmental impact (Baitz 2004). All wiring and electronic components can be resold to a refurbisher but this may be difficult depending on how isolated the farm is. There is currently very little government control of electronic waste though it is a listed concern of several governmental departments. If items are not resold they are likely to simply be dumped where they will release harmful chemicals like mercury, not to mention the economic loss to the farmer (Mureithi et al. 2008). There has been research into the use of old solar panels to make new panels showing a two thirds reduction in energy input need, this is an underutilized possibility that would hopefully grow over the design life of the panel making it a viable option (Good Company, 2008**)**. There are battery recycling facilities in Kenya and organizations that collect used batteries (Chloride Exide, 2014).However, the farmer would have to take the initiative to get these organizations to come, an incentive for this is that there is often money available for recycling as the recycled items have value. There are also some control and safety issues within these recycling plants, one in Kenya is facing issues as a result of lead being released into the nearby town, a serious health risk (Were etal, 2009). All components can be recycled or repurposed decreasing their environmental impact with a small amount of effort on the part of the farmer.

3.4 Social Considerations

Aquaculture has the potential to increase per capita incomes for all Kenyan households (Kaliba et al., 2007) Aquaculture provides a sustainable way to grow fish as a farmer and aquaculture farming practices can be integrated into existing farming systems (Kaliba et al., 2007). Additionally, if men already have jobs then aquaculture is a viable source of income for Kenyan women. (Ndanga et al., 2013)

Pond aquaculture is more efficient than other farming practices and conserves water compared to other aquaculture methods. Tilapia are able to convert 1.6 kilograms of feed into one kilogram of fish with one of the lowest FCR of protein sources for people; this ratio could save thousands of dollars and thousands of acres of land when compared to cattle's FCR of 10 (Siddiqui et al, 1988). The pond systems conserve water through natural recycling of nutrients which algae feed off, in-turn, the fish feed off of the algae. The Kenyan government and supporting governments know the potential of aquaculture and are actively researching best practices.

3.4.1 Government

Kenyan government has not implemented specific policies or incentives regarding aquaculture, however, they do realize the potential of aquaculture. The USAID funded an Aquaculture Collaborative Research Program examining the economic potential of aquaculture and Kenya's government has been a part of it. Another ambition of the Kenyan government is to have a power supply to the entire nation. Between a multitude of plans and policies (Least Cost Power Development Plan, Rural Electrification Master Plan, Sessional Paper No. 4 of 2004, The Energy Act of 2006, The Feed-in Tariff Policy, The Kenya National Climate Change Response Strategy, Kenya Vision 2030) it is clear that the Kenyan government is determined to supply power through consistent means such as renewable energies to all of their citizens (Kenya Fact Sheet, 2014).

With this attempt to provide electricity to the nation, Kenyan government has focused on large scale wind farms that enhance the grid. ("Electrifying Kenya", 2014) Regardless of this, as of 2010, Kenya was the world leader in the number of solar panels sold per capita. Off-grid solar installations were growing faster than standard line-in grid connection. To make this process cheaper and even faster the founder of M-PESA has developed M-KOPA. This program supplies 4-watt rooftop panels with charging capabilities at discounted prices and with a pay-as-you-go period ("Kenya's M-KOPA", 2014). The M-KOPA system targets low income earners in Kenya it had 1000 units sold in the first four months of production and is a growing program.

4.0 Design Summary

A solar battery powered venturi aerator is the recommended design for cost effective aeration of semi-intensive tilapia aquaculture ponds. The unit is designed for use in developing nations where line power is not available or not reliable. Line power has the potential to be a less expensive system in locations where an existing, relatively reliable grid is nearby, a venturi aerator would still be recommended in that case. The complete unit consists of two pumps and four venturi nozzles set up in two modules at opposite corners of the pond. A power system consisting of a 100 W solar panel, a charge controller, 75 A-hr worth of 12 Volt lead-acid battery, a timer, and an inverter will provide energy to run the system for four hours each night. The unit can be run for longer in systems with more algae or higher fish biomass, however, if run for longer time periods the batteries will experience deeper discharge and shorter lifespans. If run for four hours the aeration unit will put in 0.8 kg of O_2, increasing the DO by as much as 4 mg/L. Energy beyond that needed to recharge the batteries during the day will provide additional aeration during the day when available as well as making it possible to charge small household devices. The system will cost \$1067 to install if nozzles are purchased, if the nozzles are printed using a 3D printer the price could decrease by as much as \$200. Small loans are available in many developing nations, including Kenya, for farmers looking to improve their businesses. Recurring costs include $15 annually for maintenance as well as $130 every 4 years to replace the batteries and $412 every 5 years to replace the pumps. Resale of the original items for use in less demanding systems could recoup some of the replacement costs.

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Appendices

Appendix A – Original Design Problem as stated for BEE 469 Senior Design

Aquaculture is of growing significance in satisfying the need for food. Technically there are many challenges in large-scale aquaculture systems, including water consumption, quality of discharge, and maintenance of conditions for optimal growth of the target species. In this project you will address the technical issue of provision of oxygen to a system raising tilapia for human consumption. The system you are designing should be suitable for a location where line-power electricity is not available. You are to design an oxygen delivery system to be demonstrated in a 2 m^3 tank that will contain 3-5 tilapia throughout their life cycle. Your design should balance cost (initial and operations), environmental sustainability, robustness, and feasibility. You will build your solution and it will be tested under real-world conditions as would be found in Corvallis Oregon in March, and should be shown to be suitable to year-round operation in Corvallis. You will be provided a $500 budget for hardware and shipping required to build your device. All orders must be sent electronically to Kathleen Martin, and be authorized by an instructor. You may make no more than 10 purchases, where a "purchase" is a single list of items to be obtained, or a single submission of receipts to be reimbursed, potentially from multiple vendors (to void excessive burden on Kathleen). For computation of shipping costs, note that the department has Amazon Prime.

Some of the challenges are:
1. Robust operation under highly variable climatic conditions.
2. Wide spatial-temporal variation in oxygen demand.
3. Variation in the configuration of existing aquaculture systems.
4. Many regulatory issues involving multiple Govt. agencies.
5. Multiple stake holders and operators with differing needs and abilities.

The overall goal of this project is to design, develop and evaluate different options for aquaculture pond aerators to meet all applicable regulations while minimizing the economic costs and environmental impacts of the proposed design. The proposed design must strive to minimize the need to alter existing aquaculture practices.

At a minimum your design must include the following elements:
1. Meet the safety and environmental regulatory requirements.
2. Meet functionality constraints in terms of water usage patterns and existing agricultural practices.
3. Incorporate measures to conserve water, harvest water, improve water reuse/recycle and reduce discharge.
4. Consider climatic factors in your design.
5. Economic considerations in all designs (Capital versus operating costs, comparison to current state of affairs).
6. Scalability to accommodate different funding scenarios.

Completion of this project will include the provision of a complete, buildable design with supporting calculations demonstrating feasibility, evaluation of the net present value of the design, and a comprehensive life-cycle analysis.

Appendix B – Costs of each system

Power System costs and lifespan

	Paddle Wheel	Vertical Pump	PCSC	Diffuse Battery	Diffuse Air	Venturi
Capital	$600	$800	$1350	$1200	$2000	$500
Annual	$20	$15	$10	$10	$10	$10
Lifespan	high	high	high	high	high	high

Aerator costs and lifespan

	Solar Air	Solar Battery	Human	Wind	Diesel	Line
Capital	4500	1500	150	2200	150	400
Annual	5	350	1950	200	520	40
Replacement	never	difficult	never	low	low	never

Appendix C – Full matrices

Aerator Matrix	Weight	Paddle	Vertical	PCSC	DiffuseB	DiffuseA	Venturi
Functionality							
Robustness	1	10	9	9	9	9	9
Integration with Existing	2	10	10	9	8	8	10
Appropriate for Target Volume	4	3	7	9	9	9	8
Algal Effects - both ways	2	5	5	4	4	4	5
Ease of Harvesting	2	10	10	8	10	10	10
Fish Health	4	10	8	10	10	10	10
Affected Area	4	6	6	6	9	9	10
Power System Adaptability	3	9	9	9	10	10	9
Maintenance	3	7	8	8	9	9	8
Daily Work	2	9	9	9	9	9	9
Total	27	202	212	220	240	240	240
Normalize	35	26.2	27.5	28.5	31.1	31.1	31.1
Technical							
Developed	1	10	9	8	9	9	8
Scalable	3	8	8	8	9	9	8
Total	4	34	33	32	36	36	32
Normalize	10	8.5	8.3	8.0	9.0	9.0	8.0
Environmental		2.2	1.8	3.2	1.6	1.6	1.6
SAE - brake power	3	6.6	5.4	9.6	4.8	4.8	4.8
Other	1	8	9	9	10	10	9
Total	4	27.8	25.2	37.8	24.4	24.4	23.4
Normalize	10	7.0	6.3	9.5	6.1	6.1	5.9
Social							
Theft Risk	4	4	4	6	4	4	6
Farmer Acceptance	5	10	8	8	9	9	7
Noise Pollution	1	6	7	9	9	9	10
Total	10	72	63	73	70	70	69
Normalize	10	7.2	6.3	7.3	7.0	7.0	6.9
Economic							
Capital Costs	2	7	6	3	4	1	8
Operational Costs	2	4	6	8	8	8	8
Lifespan & Replacement	1	10	10	10	10	10	10
Total	5	32	34	32	34	28	42
Normalize	35	22.4	23.8	22.4	23.8	19.6	29.4
Overall	100	71.2	72.1	75.7	77.0	72.8	81.3

Power System Matrix	Weight	Solar Air	Solar Battery	Human	Wind	Diesel	Line
Functionality							
Robustness	1	4	4	9	7	8	5
Integration with Existing and Aerators	2	4	10	6	10	9	10
Resiliency	4	6	6	8	6	10	7
Locational Suitability	4	10	10	9	3	8	4
Maintenance	2	9	9	8	8	6	10
Daily Work	2	10	10	1	10	8	10
Total	15	114	126	107	99	126	109
Normalize	35	26.6	29.4	25.0	23.1	29.4	25.4
Technical							
Developed	1	8	8	10	9	10	7
Scalable	3	10	10	9	9	9	10
Total	4	38	38	37	36	37	37
Normalize	10	9.5	9.5	9.3	9.0	9.3	9.3
Environmental							
Emissions	2	10	10	10	10	1	6
Disposal	2	10	6	9	10	8	10
Other - alternative dependent	1	9	8	10	8	10	9
Total	5	49	40	48	48	28	41
Normalize	10	9.8	8.0	9.6	9.6	5.6	8.2
Social							
Government Stance	2	7	7	10	9	7	9
Theft Risk	4	7	5	4	10	4	8
Farmer Acceptance	5	9	8	4	7	7	5
Noise Pollution	1	10	10	9	5	4	10
Total	12	97	84	65	98	69	85
Normalize	10	8.1	7.0	5.4	8.2	5.8	7.1
Economic							
Capital Costs	2	2	5	9	3	9	7
Operational Costs	2	10	6	1	7	4	9
Lifespan & Replacement	1	10	5	9	7	8	10
Total	5	34	27	29	27	34	42
Normalize	35	23.8	18.9	20.3	18.9	23.8	29.4
Overall	100	77.8	72.8	69.5	68.8	73.8	79.4

Appendix D – Model Results

Formal Test Results

Hours since Nightfall	Monday (50g)		Tuesday (100g)		Wednesday (150g)		Thursday (200g)		Friday (250g)	
	DO (ppm)	Temp (ºC)	DO (ppm)	Temp (ºC)	DO (ppm)	Temp (ºC)	DO (ppm)	Temp (ºC)	DO (ppm)	Temp (ºC)
2	5.7	24.6	4.5	24.3	1.8	24.7	0.6	24.1	0.4	24
3	6	24.7	4.9	24.6	1.7	24.4	8.8	23.1	1.9	24.3
4	5.7	24.6	4.3	23.6	1.5	24.2	0.2	24.1	2.4	24.6
5	5.6	24.4	4.4	24.5	1.3	24.3	0.3	23.9	2.1	24.5
6	5.5	24.5	4.3	24.6	1.1	24.1	0.2	24.5	1.8	24.4
7	5.5	24.6	5.1	24.1	1.1	23.9	0.7	24.6	2.9	24.3
8	6.1	24.7	5.3	24	1.6	23.9	1.4	24.4	4.6	23.9
9	4.6	24.9	5.6	24.8	3.3	24.3	2.7	24.2	4.8	24.4
10	6.0	24.3	6.2	24.5	4.5	24.1	3.5	24.1	5.2	24.5
11	6.0	24.2	6.6	24.2	5.0	24.0	3.9	24.3	5.0	24.2
12	6.1	24.4	6.4	24.2	3.5	23.6	4.9	24.3	-	-
Energy	156 W-hr		184 W-hr		184 W-hr		212 W-hr		212 W-hr	

Note: Grey writing indicates bad data. Green blocks indicate that the aerator was running.

Situational effectiveness cannot be proven due to the extreme low DOs at nightfall. This was the result of the grow lights not providing enough energy to the algae and an insufficient algae population. We were able, however, to get the DO up to 5 ppm by dawn every day.

K_{la} Test Results

Speed (pump)	Angle (º)	Length (ft)	K_{la} (hr^{-1})
4	25	0	0.2
5	25	0	0.23
6	25	0	0.25
7	25	0	0.28
8	25	0	0.25
7	25	2	0.28
7	25	1	0.3
7	15	1	0.26

The values fall in a narrow range and insufficient time passed during testing for concrete results. The testing model was based off the highest K_{la}, 0.3. This K_{la} was the result of pump speed 7 with a 1 ft extension and an angle of 25º. More involved testing would be required for more accurate and precise results that could be extrapolated to a broader set of circumstances.

Appendix E - Design Calculations

Design Calculations

BEE 470 - Winter 2015

Team 5 - LR^2
Robin Castle
Larajean Lanzen
Ryan Niest

Table of Contents:

- In Progress:

kla -
Today 13 FEB 2015, We will be testing our model in different configurations to obtain kla. Power calculations are based on general power needs of the pump (and additional components)

Environmental Costs -
A detailed analysis of environmental costs will be availible in the form of an LCA. This will be included in our final report

- Calculated Volume of Model Pool

flow rate: $0.01297 \frac{m^3}{min}$

time to fill: 83.3 minutes

↳ $0.01297(83.3) = \underline{\underline{1.08\ m^3}}$ in testing pool

- Required Algae: $500 mg/m^3$

- Oxygen Need:

  The following is based on a paper developed by Culberston and Pedrahita. (and a model produced by their findings.

- Fish Density: 7/m^3
- Initial DO: 5 ppm
- Desired DO: We want 5ppm restored by the start of the next day.
  We also would like to Note when DO falls below 4ppm (hopeful to acrate to maintain above 4ppm)
- ~~Process~~Run Model at 50, 100, 150, 200, 250 g/fish
  - calculate ΔDO from begining to end (0→24hrs)

Results: (at testing scale)

fish mass (g)	Required DO (ppm)	Notes
50	-0.27	Negative = no aditional DO needed
100	2.95	3.78ppm at 20hr
150	4.19	4.06 ppm at 16hr
200	7.78	4.20 ppm at 14hr
250	9.64	3.89ppm at 2hr

O_2 Input (Full Scale)

O_2 input per hour

4 - Nozzles
2 - Pumps

Pump: 200 L/min - no losses

Nozzle: Fluid Flow: 100 L/min
Outlet Pressure: Max: 0.05 kg/cm², 50 cm depth

Air Suction: 97.3 L/min Fluid, 0.35 kg/cm² Poutlet
52.3 L/min air

Total: 210 L/min air

Conversion from total air drawn in to dissolved oxygen retained is difficult. Dependent on many factors, no specific data available. System was designed based on SAEs provided in literature that also listed flow rates. Testing is to be conducted to determine actual Standard Oxygen Transfer Rates and K_La's.

Scaling

The main obsticle faced with scaling was the venturi nozzle. Limited information was available on the percent of the air drawn in by a nozzle that is retained as DO under standard, or any other, conditions. Even less was available about if that percent is dependent on nozzle dimensions or flow rate. This lack of information prevents accurate scaling.

As a solution to the above dilema, two nozzles and a variable speed pump were purchased. Testing will be done to determine Kla under various conditions. This testing is scheduled for this weekend.

Parameters to be scaled

- Kg O_2 input

Method

- 400 m^3 to 1 m^3, 0.25%
- Drop from 4 to 1 nozzle (circulation pattern not scaled)
- Determine how conversion efficiency scales
- Find a combination of duty cycling, a smaller nozzle, and flow rate to properly meet O_2 demand in small pool.

Demonstrated but not scaled

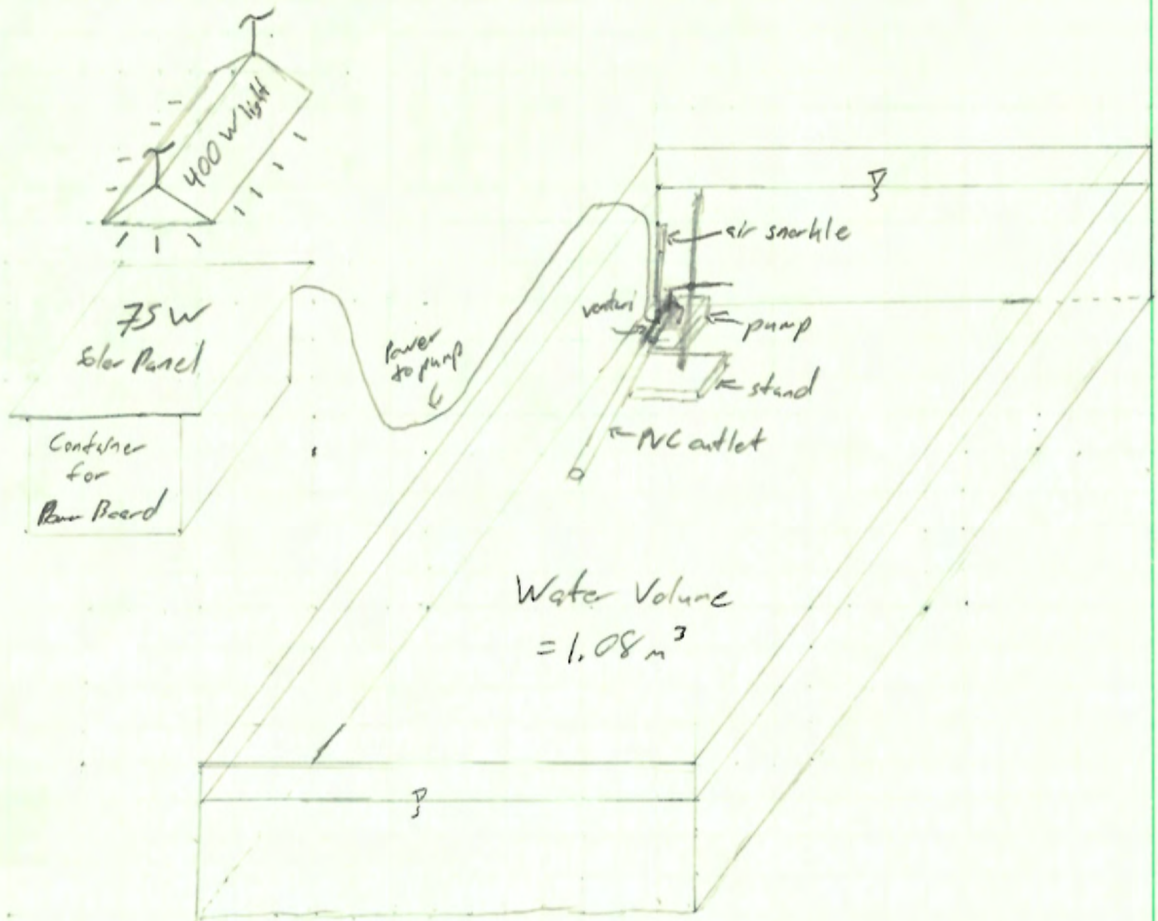
- Power system
- Secondary uses
- Theft Protection
- Adaptability

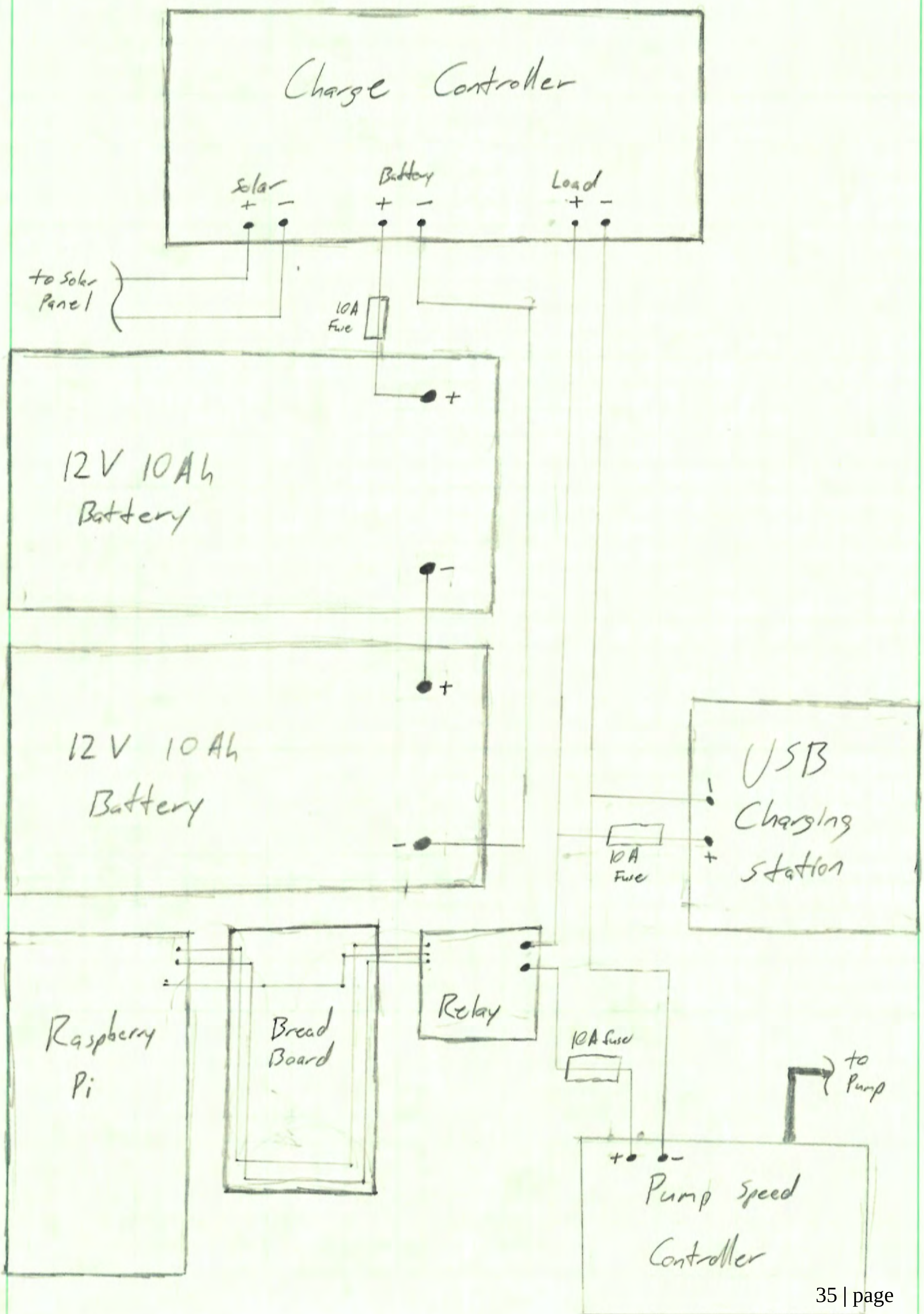
Model O_2 Input

Full Scale × 0.0025 = Demo Need
Need = Air Suction × Efficiency × Duty Cycle

At test scale, Model Provides max DO needed: 9.64 ppm (see "Oxygen Need" sheet)

Model System




Charge Controller
Solar
+ −
Battery
+ −
Load
+ −
to Solar Panel
10A Fuse
+
12V 10Ah Battery
−
+
12V 10Ah Battery
−
USB Charging station
−
+
10A Fuse
Raspberry Pi
Bread Board
Relay
10A fuse
to Pump
+ −
Pump Speed Controller

Model System

Power System Design

—Solar Panel

Panel Specs: Wattage: 75 W Voltage: 24 V Area: $0.64\ m^2$

Note: Produces 75 W when exposed to $1\ kW/m^2$

Light Source: 400 W high Pressure Sodium bulb

12 hour Duty Cycle

Question: Under this light source, how much is our panel sending to battery?

*Assumption: 100% of bulb light going to panel. This is not the case.

$\frac{\text{light Produced}}{\text{area of panel}}$ $\frac{400W}{0.64 m^2} = 667 \frac{W}{m^2} \times 12$ hour duty cycle $= 8004 \frac{Wh}{m^2}$

Divide by 1kW to get effective hours of 75 W produced

$\frac{8004 \frac{Wh}{m^2}}{1000 \frac{W}{m^2}} = 8.004$ hours $\times$ 75 W = Panel produces 600 Whr per day

↳ Losses: • Lead-acid Charging efficiency ≈ 75%

• PWM charge controller efficiency ≈ 80%

600 Whr × 0.75 · 0.80 = $\boxed{\text{360 Whr delivered to battery}}$

—Battery

Question: What is daily Watt hour Load on battery?

Pump: Wattage Draw: 25 W Voltage: 24 V Amp: 1.04 A Duty cycle: 4 hours

Charge Controller: Wattage: ? W Voltage: 24 V Amp: <6 mA Duty cycle: 24 hours

USB Charger: iPhone 6 battery size: 6.9 Whr

Battery charging efficiency = 75%

24V → 5V down step efficiency = 80%

Pump: 1.04 A × 4 hours × 24 V = 99.8 Whr load

Charge controller: 6 mA × 24 hours × 24 V = 3.46 Whr load

USB Charger: $\frac{6.9 \text{ Whr}}{0.75 \cdot 0.80}$ = 11.5 Whr load

$\boxed{\text{total Daily load} = 115 \text{ Whr}}$

- Battery cont.

Question: How much does our battery pack store?

2x 12V 10Ah batteries in series

* note: Batteries in series add voltage but Ah stays the same.

Battery pack total

24V 10 Ah Battery pack

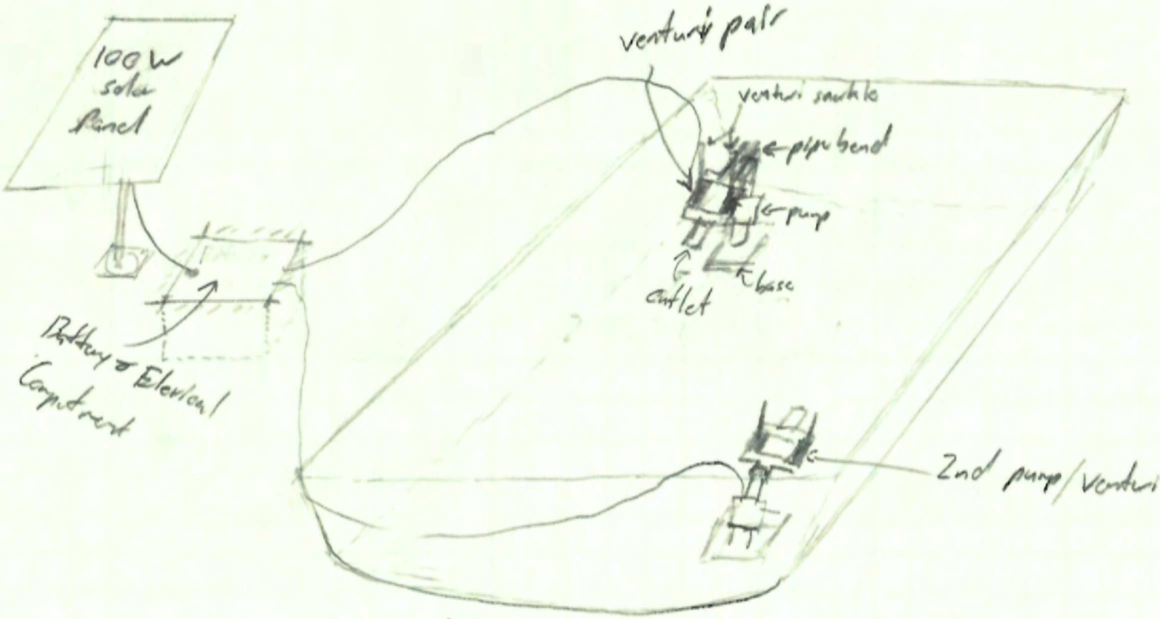
$$24V \times 10Ah = \boxed{\text{240 Whr total battery Storage}}$$

Question: What is our percent Depth of Discharge?

Desired Model D.o.D <= 50%

$$D.o.D. = \frac{\text{Battery load}}{\text{Battery Storage}} \times 100$$

$$\frac{115\text{ Whr}}{240\text{ Whr}} \times 100 = \boxed{\text{47.9\% Depth of Discharge}}$$



depth = 1-2 m

Volume = 200-400 m^3

Full Scale

Power System Design

— Solar Panel

Panel Specs: Wattage 100W voltage 12V

Note: Produces 100 W when exposed to 1 peak solar hour $\left(1 \frac{kW}{m^2}\right)$

Question: Under lowest light conditions, how much is panel sending to batteries?

*Assumption: Lowest monthly average peak solar hours in Nairobi is 4.25 hours. Using this worst case scenario.

Panel Production = Wattage rating × peak solar hours.

$$100\text{ W} \times 4.25\text{ hr} = 425 \text{ Whr per day}$$

↳ Losses: · Lead-acid charging efficiency ≈ 75%

· PWM charge control efficiency ≈ 80%

$$425 \text{ Whr} \times 0.75 \times 0.80 = \boxed{255 \text{ Whr delivered to battery minimum}}$$

— Battery

Question: What is daily watt hour load on battery

Pumps: 2x 22W voltage: 110VAC duty cycle: 4 hours

↳ note: must include 80% inverter efficiency for DC→AC

Charge Controller: 7 W voltage: 12V DC Amp: 6mA duty cycle: 24 hours

USB Charger: iPhone 6 battery size: 6.9 Whr

Battery charging efficiency: 75%

12V-5V downstep efficiency: 85%

$$\text{Pump: } \underbrace{2}_{\text{2 pumps}} \times (22\text{ W} \times 4 \text{ hours}) / \underbrace{0.80}_{\text{inverter efficiency}} = 220 \text{ Whr load}$$

$$\text{Charge Controller: } 6\text{ mA} \times 24 \text{ hours} \times 12\text{ V} = 1.73 \text{ Whr load}$$

$$\text{USB Charger: } \frac{6.9 \text{ whr}}{0.75 \cdot 0.85} = 10.8 \text{ Whr load}$$

$$\boxed{\text{total daily load} = 233 \text{ Whr}}$$

Full Scale

- Battery Cont.

Question: how much does our battery store?

1x 12V 75 Ah battery

$12V \times 75\,Ahr = \boxed{900 \text{ whr total battery storage}}$

Question: What is our percent depth of discharge?

Desired D.o.D <=30%

$$D.o.D = \frac{\text{Battery load}}{\text{Battery storage}} \times 100$$

$$\frac{233 \text{ whr}}{900 \text{ whr}} \times 100 = \boxed{25.9\% \text{ Depth of discharge}}$$

Full Scale

12/13

Economic Calculations

Aerator Components

		Replacement life cycle
2x Tunze turbelle Stream 6125 pumps	: $412	10 years
4x Mazzei 1078 1" injectors	: $208	20 + years
PVC Pipe, fittings, cement	: $20	20 + years
2x pump mounting base/weight	: $40	20+ years

Power System Components

1x UBG UB12750 75 Ah 12V Battery	: $130	8 years
1x ECO-Worthy 100W Solar Panel	: $82	20+ years
1x Aleko LM119 charge controller	: $35	20+ years
1x 12VDC to 110VAC inverter	: $50	20+ years
Wiring, fuses, timer	: $40	20+ years
Installation: Solar & Electrical box	: $50	20+ years.

Note: Replacement lifecycle based on system running ~50% of the year. Not running when fish are small.

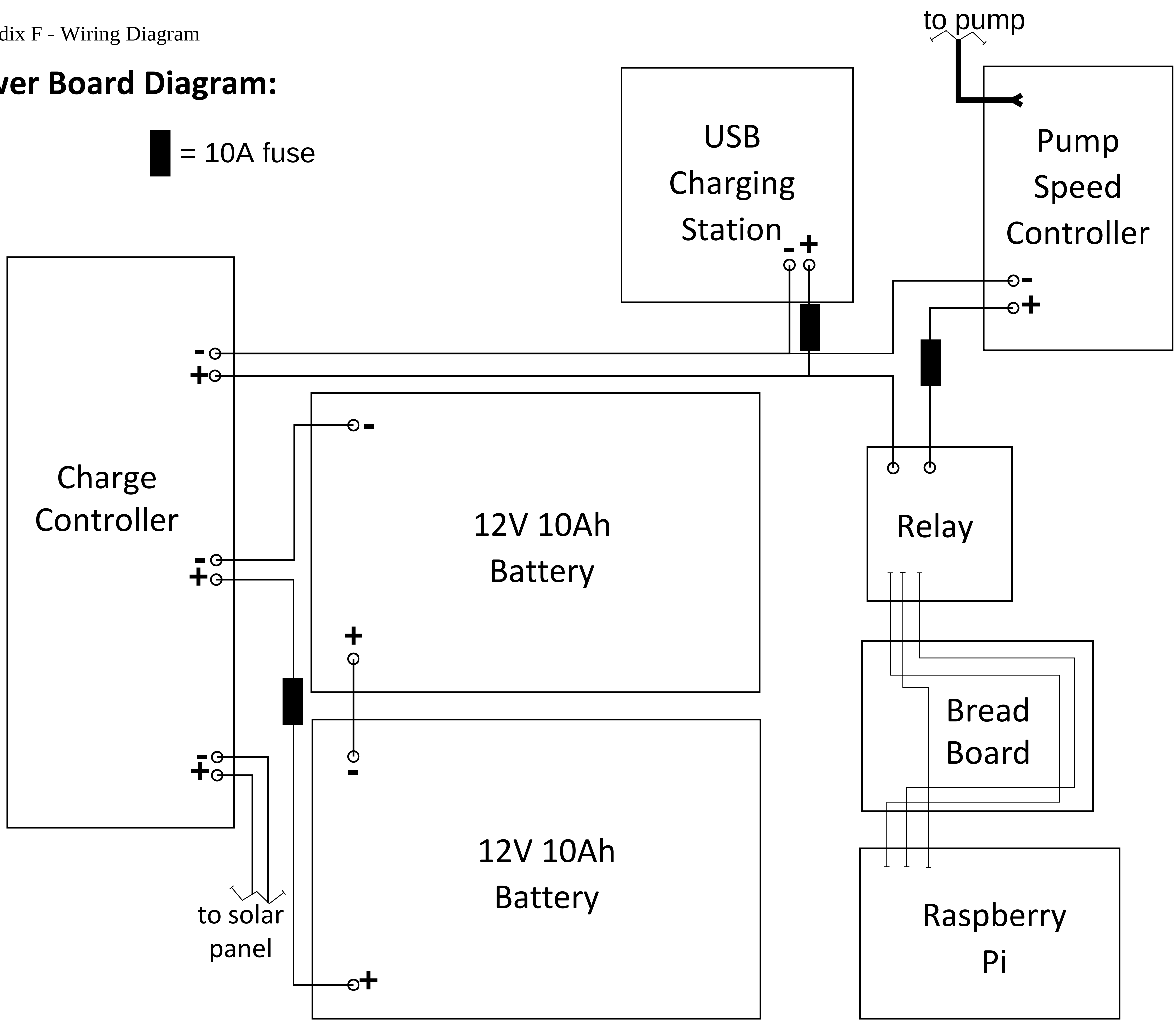
Annual maintenance labor time & parts : $15
(~2 hours)

IRR: due to the volatile nature of the market high 10 year average inflation (11%), NPV has been modeled with an IRR of 15%

IRR: 0.15

Year	Cost ($)	Initial Install	Replace Battery	Replace Pumps
0	1067	X		
1	15			
2	15			
3	15			
4	15			
5	15			
6	15			
7	15			
8	145		X	
9	15			
10	427			X
NPV	$1,286.62			

Power Board Diagram:



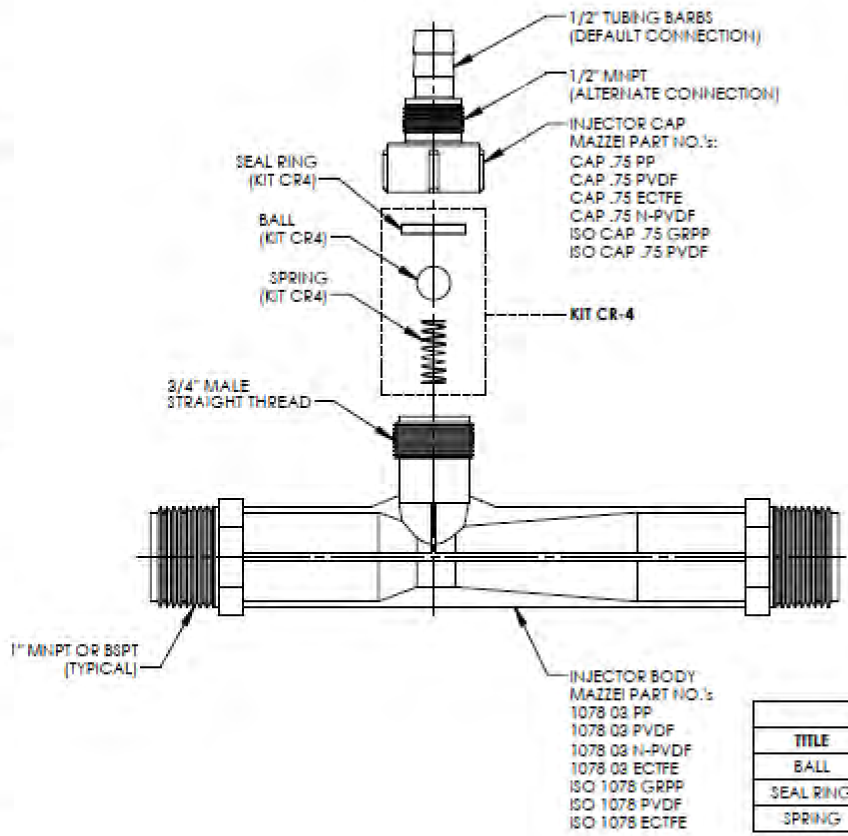
Appendix G – Nozzle Specs

NOTES:

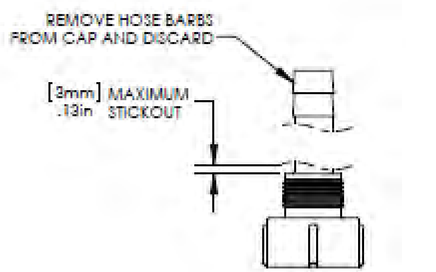
1. MADE IN THE U.S.A.
2. U.S. PATENT No. 5,863,128
3. U.S. No. 3,852,076 AND INTERNATIONAL REGISTERED TRADEMARKS
4. MATERIAL: GLASS FILLED POLYPROPYLENE (PP) OR POLYVINYLIDENE FLOURIDE (PVDF) OR ETHYLENE CHLOROTRIFLUOROETHYLENE (ECTFE)
5. INLET/OUTLET CONNECTION: 1" MNPT OR BSPT
6. SUCTION PORT CONNECTION:

   DEFAULT - 1/2" I.D. TUBING BARB WITH INTEGRATED CHECK VALVE

   ALTERNATE - 1/2" MNPT - SEE ALTERNATE CAP MODIFICATION DETAIL
7. FOR INSTALLATION RECOMMENDATIONS REFER TO MAZZEI TECHNICAL BULLETINS No. 4, No. 5, No. 6, No. 10 AND No. 11, WHICH CAN BE FOUND IN THE "KNOWLEDGE CENTER" AT WWW.MAZZEI.NET.
8. MAZZEI INJECTOR CO., LLC.
   500 ROOSTER DR.
   BAKERSFIELD, CA 93307
   TEL: 661.363.6500
   WEB: WWW.MAZZEI.NET



KIT CR-4	
TITLE	MATERIAL
BALL	TEFLON ® (PTFE)
SEAL RING	KEL-F ® (PCTFE)
SPRING	HASTELLOY C-22



"CAP MODIFICATION DETAIL"
(ALTERNATE)

VENDOR ITEM CONTROL DRAWING

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		mazzei®	TITLE: 1" INJECTOR; MODEL 1078 03
DRAWN:	T.JOHNS		
DATE:	07/19/13		DRAWING NO.: 107803-PP/PVDF/ECTFE
APPROVED:	P. BANKOWSKI	SIZE: A	WEIGHT: N/A · SCALE: 1:2 · REV.: NC · SHEET: 1 OF 2

Injector Performance Table

Air Suction Capacity - *METRIC*

Model 1078-03

mazzei®

Operating Pressure kg/cm²		AIR SUCTION	
Injector INLET	Injector OUTLET	Motive Flow l/min	Air Suction l/min
0.35	0.00	19.9	11.4
	0.07		3.0
	0.14		1.2
	0.21		0.70
	0.28	*(0.28)	
0.70	0.00	28.1	18.9
	0.14		7.6
	0.35		1.9
	0.49		0.73
	0.56	*(0.57)	
1.05	0.00	34.4	22.9
	0.35		6.1
	0.49		3.7
	0.70		1.5
	0.84	*(0.92)	1.0
1.41	0.00	39.7	25.9
	0.35		10.4
	0.70		4.0
	0.84		2.8
	1.05	*(1.22)	1.5
1.76	0.00	44.4	28.7
	0.35		15.7
	0.70		8.7
	1.05		3.5
	1.41	*(1.54)	1.6
2.11	0.00	48.7	33.3
	0.35		21.9
	0.70		9.6
	1.05		5.3
	1.41		2.8
	1.76	*(1.83)	1.1
2.46	0.00	52.6	34.9
	0.35		24.5
	0.70		11.6
	1.05		6.4
	1.41		4.2
	1.76	*(2.11)	2.5
2.81	0.00	56.2	37.7
	0.35		27.3
	0.70		14.8
	1.05		8.9
	1.41		6.1
	1.76		3.8
	2.11	*(2.42)	2.0
3.16	0.00	59.6	40.5
	0.35		29.6
	0.70		18.1
	1.05		10.9
	1.41		7.4
	1.76		5.3
	2.11		3.3
	2.46	*(2.78)	2.1
3.52	0.00	62.8	41.4
	0.35		31.3
	0.70		19.9
	1.05		12.1
	1.41		7.6
	1.76		6.0
	2.11		4.1
	2.46		2.5
	2.81	*(3.00)	1.4

Operating Pressure kg/cm²		AIR SUCTION	
Injector INLET	Injector OUTLET	Motive Flow l/min	Air Suction l/min
4.22	0.00	68.8	43.1
	0.35		36.0
	0.70		27.1
	1.05		16.3
	1.41		11.5
	2.11		6.6
	2.46		4.8
	2.81		3.4
	3.16	*(3.59)	2.1
4.92	0.00	74.3	47.4
	0.35		38.5
	0.70		31.8
	1.05		21.8
	1.41		15.0
	2.11		9.2
	2.81		5.8
	3.16		4.1
	3.52		3.3
	3.87	*(4.14)	2.1
5.62	0.00	79.5	49.8
	0.35		42.2
	0.70		35.3
	1.05		27.2
	1.41		18.6
	2.11		11.8
	2.81		8.0
	3.52		4.8
	4.22		2.9
	4.57	*(4.82)	2.1
6.33	0.00	84.3	53.2
	0.35		45.4
	0.70		38.5
	1.41		23.0
	2.11		13.8
	2.81		9.8
	3.52		7.0
	4.22		4.3
	4.92		2.7
	5.27	*(5.41)	2.0
7.03	0.00	88.8	55.0
	0.35		48.6
	0.70		41.4
	1.41		29.6
	2.11		17.5
	2.81		12.1
	3.52		8.5
	4.22		5.9
	4.92		3.9
	5.62	*(6.05)	2.6
8.44	0.00	97.3	58.8
	0.35		52.3
	0.70		46.2
	1.41		38.7
	2.11		27.1
	2.81		15.8
	3.52		11.8
	4.22		9.0
	4.92		6.6
	5.62		4.8
	6.33		3.1
	7.03	*(7.17)	2.4

**NUMBERS IN PARENTHESIS indicate the injector outlet pressure when suction stops (Zero Suction Point).*

Mazzei Injector Company, LLC
500 Rooster Drive, Bakersfield, CA 93307-9555 USA
TEL 661.363.6500 • FAX 661.363.7500 • www.mazzei.net

Appendix H – Pump Specs

Tunze Turbelle® stream 6125

- For aquariums from 400 to 2,000 litres (105 to 525 USgal.)
- Flow rate: abt. 12.000l/h (3,150 USgal./h)
- Energy consumption: 22W
- Voltage / frequency: 230V/50Hz (115V/60Hz)
- Cable length: 2m (78 in.)
- Dimensions: diam. 90mm (3.5 in.)
- Ejection: diam. 63mm (2.48 in.)
- Magnet Holder with Silence clamp up to a glass thickness of 15mm (1/2")