

DESIGN GUIDE FOR RECIRCULATING AQUACULTURE SYSTEM

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**Prepared for Sioux Indian Reservation
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1

PROJECT OBJECTIVES

1. Develop a design guide capable of assisting in the implementation of a commercial fish production facility that can produce 100,000 pounds of fish annually utilizing water reuse technology.
2. Provide a knowledge base on the existing geothermal well and how it may be utilized to produce electricity.

2

BACKGROUND & OVERVIEW

2.1 Overview of aquaculture

Most fish and crustacean aquaculture is undertaken in earthen ponds or large tanks with flowing water. Pond culture requires large areas of flat land and significant quantities of clean groundwater. Flow-through tank aquaculture requires less land but needs more water per pound of fish produced to maintain good growing conditions within the tank. In many areas of the United States, aquaculture is not possible in ponds or flow-through tanks because of limited water supply or an absence of suitable land. Recirculating aquaculture systems re-use water over and over, cleaning the waste from the water and providing oxygen to the fish. Because water is reused, recirculating fish production systems utilize only a fraction of the water required by traditional fish production techniques. A small domestic well producing three to five gallons per minute, when coupled with the proper recirculating technology, can be used in the production of hundreds of thousands of pounds of fish annually. Recirculating aquaculture production systems seems ideal for the conditions of the Sioux Indian Reservation. There is no doubt that fish can be reared in great quantities and at high densities in recirculating systems. However, the economic viability of growing fish in recirculating systems is not as certain. For every successful application of recirculating fish production technology, there are several that have failed. Before one begins to raise fish with recirculating technology, one must understand the important principles at work within the technology being used. In almost every successful application, highly technological solutions that have been evaluated and incorporated into the aquaculture systems.

The most important consideration in recirculating systems design is the development of an efficient water treatment system. Recirculating production systems must be designed with a number of fundamental waste treatment processes. These processes, referred to as "unit processes," include the removal of waste solids (both feces and uneaten feed), the conversion of ammonia and nitrite-nitrogen (a non-toxic form of dissolved nitrogen), the addition of dissolved oxygen to the water, and the removal of carbon dioxide from the water. With less robust species, and depending upon the volume of new water used, a process to remove fine and dissolved solids, as well as a process to control bacterial populations, may need to be applied. Figure 2.1 shows these unit processes and some common components used to perform these operations.

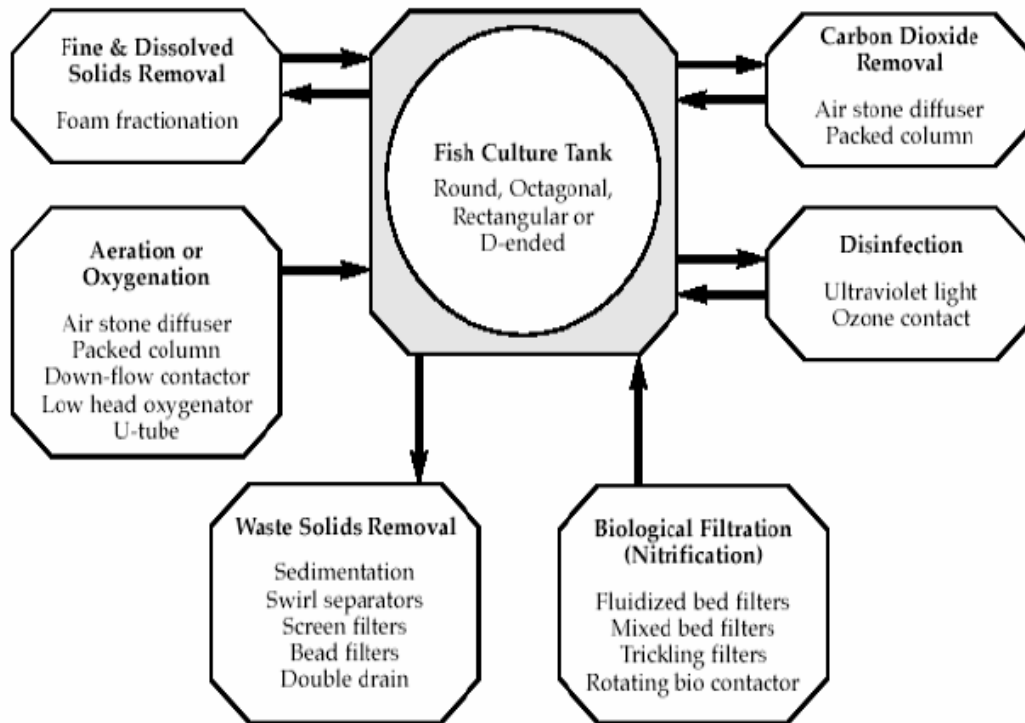


Figure 2.1 Required unit processes and typical components used in recirculating aquaculture production systems (Source: Losordo, et al., 1998).

2.1.1 Waste Solids Removal

Fish should be fed pelleted diets. These diets are made of protein, carbohydrates, fat, ash and moisture. Large quantities of these feeds are not assimilated by the fish and produce an organic waste excreted as fecal solids. These fecal solids and uneaten feed, when digested by bacteria in the recirculating system, use oxygen and produce dissolved ammonia ($\text{NH}_3 + \text{NH}_4$). Waste solids need to be removed quickly from the tank and waste treatment system. Waste solids are generated as suspended solids and dissolved solids. Suspended solids are both settleable and non-settleable in characteristics. Settleable solids weigh more than water and are usually larger in size than suspended solids. Settleable solids are easier to remove from the system as they tend to settle out of suspension from the water column more quickly than suspended solids. The method of removing settleable solids from a fish tank depends upon the level of turbulence within the fish tank. In tanks with a circular flow pattern and minimal agitation, settleable solids can be removed as they accumulate in the bottom center of the tank. These solids can be removed from the tank in a low flow waste discharge. Center drains with two outlets are often used for this process. These “double drain” systems divide the flow leaving the tank into a small pipe carrying settleable solids, and a larger pipe with a higher flow rate that removes non-settleable solids from mid depths of the tank.

2.1.2 Ammonia-Nitrogen Control

A large portion (30 percent to 50 percent) of the diet fed to the fish is protein. Protein is made up of carbon, oxygen, hydrogen and nitrogen. When protein is digested by fish, urea and ammonia-nitrogen ($\text{NH}_3 + \text{NH}_4^+$) are excreted. Ammonia-nitrogen also is referred to as total ammonia nitrogen (TAN). The un-ionized portion of TAN, NH_3 , is extremely toxic to fish. The amount of TAN in the un-ionized form depends to a large extent, upon the pH of the water. At a pH of 7.0, less than one percent of the TAN is in the toxic form, while at a pH of 9.0 over 40 percent is in the un-ionized (toxic) form. In recirculating systems, an extremely effective way of controlling ammonia toxicity is through the control of pH. A primary consideration in the design of water treatment systems for fish culture is to minimize the tank concentration of TAN. In general at pH values of less than 7.8, most species will tolerate TAN concentrations of 1 to 2 mg / L. As fish are fed, TAN is continuously generated and must be either flushed from the tank or removed by some unit process.

Recirculating systems generally replace less than 10 percent of the total system volume per day with new water. As such, not enough water can be flushed through the tank to control the build-up of harmful ammonia-nitrogen. To counteract this, the water treatment system of a recirculating production system must have a unit process designed to either remove or convert ammonia-nitrogen to a less toxic nitrogen compound.

In almost all cases, ammonia removal from the system by so-called “physico / chemical” processes is not economically feasible (e.g. ion exchange columns). The process most often used is a biological one and it is referred to as biological filtration or biofiltration. In biofiltration, a process called nitrification occurs. This is a process in which toxic ammonia-nitrogen is converted to non-toxic nitrate nitrogen by naturally occurring “nitrifying” bacteria. In biofiltration, a “media” with a large surface area is provided for nitrifying bacteria to attach and multiply. One type of bacteria, referred to as Nitrosomonas, uses ammonia-nitrogen (NH_3) to grow and convert the ammonia-nitrogen to nitrite-nitrogen (NO_2). In turn, the nitrite-nitrogen is converted to nitrate-nitrogen (NO_3) by another type of nitrifying bacteria called Nitrobacter. Nitrate-nitrogen is generally non-toxic to most cultured fish and the concentration is usually controlled with the relatively low level of water exchange that occurs in recirculating systems.

Sand, plastic, and other inexpensive substrate materials are commonly used as biofiltration media. How the media is set up within the filter and the conditions in which the bacteria come in contact with the water affect the efficiency of the biofiltration process. Biofilters are very diverse in design. Some contain media (sand and plastic beads) that are continuously mixed within a column of water (fluidized bed and mixed bed bead filters). Some submerge the media in water in a fixed position and flow the water up or down through the media. Still others, referred to as trickling filters, hold the media out of the water and pass water over the media as in a shower, such that the water trickles over the media and attached bacteria. As the water flows through the biofilter, the ammonia is converted to nitrate and the outflowing water is lower in ammonia-nitrogen concentration than the inflowing water.

2.1.3 pH and Alkalinity

The measure of the hydrogen ion (H⁺) concentration of water, known as pH, indicates the degree to which water is acidic or basic. The pH of water affects the state of many other water quality parameters, like the toxicity of ammonia-nitrogen already mentioned. For this reason, pH is an important parameter to be monitored and controlled. The pH of a system should be maintained between 7.0 and 8.0. Alkalinity is a measure of the capacity of water to neutralize acidity. Bicarbonate (HCO₃⁻) and carbonate (CO₃⁻) ions are the main sources of alkalinity in water. Water that is high in alkalinity tends to resist changes in pH, which is desirable. Nitrification produces acid and removes alkalinity. Operators of recirculating systems will continually add alkalinity, usually in the form of hydrated lime, quick lime or baking soda to maintain a neutral pH value. The alkalinity of a recirculating fish production system should be maintained above 100 mg / L as CaCO₃ at all times.

2.1.4 Dissolved Oxygen Control

The fish and the bacteria in the biofilter utilize oxygen while they grow. For good fish growth and a healthy biofilter, the dissolved oxygen (DO) concentration in the tank and biofilter should be maintained above 5 and 2 mg / L, respectively. To maintain an adequate DO concentration in the system, oxygen must be continuously added. Conversely, carbon dioxide is produced by the fish and bacteria as they grow, and must be removed. Carbon dioxide can inhibit the respiration of the fish and reduce growth. The carbon dioxide level in the tank should be maintained at 20 mg / L or less.

2.1.5 Dissolved Oxygen Addition

To avoid DO levels declining to dangerous concentrations (< 2.0 mg / L), the rate of DO additions to the system must match the rate of respiration by the fish and bacteria. The rate at which oxygen is supplied to the system usually defines the intensity of fish culture (kg fish/m³ tank). The term aeration refers to adding oxygen to water from air (air is 21 percent oxygen). The term oxygenation refers to adding oxygen to water from gaseous oxygen (95 percent to 100 percent oxygen). Either method may be used; however, there may be more risks associated with using aeration because DO levels would not be as high as in an oxygenation system.

Aeration Systems

Adding atmospheric air into the fish tank does not generally work because the oxygen concentrations are less, which would mean only 2/3 the amount of fish could grow in the same size tank. The amount of oxygen carried to the tank is limited by the flow. For this reason, aeration usually takes place directly in the fish tank. The most efficient aeration devices move water into contact with the air. Common aeration devices include paddle wheels, propeller-aspirators, and vertical-lift pumps. These devices are not often used in

recirculating systems. They are generally too large or create too much turbulence in the fish tank. Aeration is usually provided to fish tanks using air diffusers. Diffused aeration systems provide low pressure air from an air blower to some form of diffuser device at the bottom of a culture tank. These diffusers produce small air bubbles within the tank that rise through the water column. Oxygen is transferred to the water as the bubbles rise. The smaller the bubbles and the deeper the tank, the more oxygen is transferred. For this reason, most fish tanks are at least one meter (3.28 ft) deep. Membrane diffusers seem the most promising for this application.

Oxygenation Systems

In very intensive fish production systems, the rate of oxygen consumption by fish and bacteria will exceed the capabilities of aeration equipment to diffuse oxygen into the water. At these fish densities, pure oxygen gas is used to increase the rate of oxygenation. The use of pure oxygen gas promotes rapid transfer of oxygen into water even when tank dissolved oxygen concentrations are near the saturation concentration ($\approx 7 \text{ mg / L}$).

When using pure oxygen gas, oxygenation is most commonly done in the water returning from the treatment system or in a “side-stream” pumping loop from the fish culture tank. Properly designed oxygenation equipment will transfer 80 percent to 95 percent of the oxygen into the water. In contrast, oxygen added to the tank with common airstone diffusers is not an efficient process (less than 30 percent efficient).

Oxygenation systems are much more expensive to maintain and must be recharged, whereas aeration systems are more maintenance-free. A cost benefit analysis should be performed to determine which system is more practical in this application.

2.1.6 Carbon Dioxide Control and Removal

Carbon dioxide (CO_2) is produced through the respiration of fish and bacteria and will accumulate within recirculating systems if not removed at a rate equal to its production. Elevated carbon dioxide concentrations are not greatly toxic to fish when dissolved oxygen is at saturated levels in the tank. For most aquacultured fish, free carbon dioxide concentrations should be maintained at less than 20 mg / L in the tank to maintain good fish growth conditions.

Carbon dioxide is usually removed through some form of gas exchange process. That is, either water is exposed to air in a “waterfall” type of environment, or air is mixed into the water to remove excess CO_2 gas using airstones or some other form of aeration (e.g., a surface aerator). One of the most common methods of CO_2 removal in recirculating systems is the use of a packed column aerator (PCA). This device is similar to a trickling biofilter tower consisting of a plastic media and a water distribution device at the top of the reactor. A low pressure air blower is usually used to introduce an upward air-stream from the bottom of the PCA to remove CO_2 from the column.

2.1.7 System Monitoring and Alarms

The proper management of fish production systems is essential to their profitability. For recirculating production systems, because of the high fish stocking densities, close attention to management details is critical to the success of the operation. Because of the intensity of production and potential for rapid changes in water quality, certain parameters and system operations must be closely monitored. Table 2.2 lists some water quality and operational parameters, monitoring methods and frequency, and requirements for automation and alarming.

Table 2.2. Parameters requiring monitoring, methods, and frequency of monitoring and alarm requirements.

Parameter	Monitoring Method	Frequency	Alarm
Dissolved Oxygen	DO Meter	Continuous	+
pH	pH Meter	Daily	-
Carbon Dioxide	Wet Chem./pH Meter	As needed	-
Alkalinity	Wet Chemistry	Every Other Day	-
Temperature	Thermocouple	Continuous	+/-
TAN	Wet Chemistry	Daily	-
NO ₂	Wet Chemistry	Daily	-
NO ₃	Wet Chemistry	Weekly	-
Tank Water Level	Mech. / Elect.	Continuous	+/-
Recycle Water Flow	Mech. / Elect.	Continuous	+/-

+ = requires automated alarming; - = does not require alarming; +/- = optional (Source: Losordo, 1997)

2.1.8 Production Management

The economic success of a recirculating system depends on keeping the productivity of the system at or near the design maximum. However, there are tradeoffs between the maximum sustainable fish growth rate and the maximum stocking rate for the system. If the system is stocked beyond the design capacity and the fish are fed at the optimum feeding rate, the water treatment system will become overwhelmed and the fish will grow slowly due to poor water quality. On the other hand, under the same stocking conditions, if the operator is limited by the water treatment capacity of the system, and feeds below the optimum rate for the fish population, the fish grow will grow slowly to their market size. Meanwhile, the operator continues to pay for electricity for water pumps and air blowers, heating and cooling, oxygen storage tank rental, debt service and labor. The following section reviews some important considerations in recirculating tank production systems stock management.

Stocking Number and Density

In evaluating recirculating systems production capabilities, the unit most often used is maximum tank or system stocking (kg/m^3 or lbs./gallon). However, in terms of production potential, this unit of measure is meaningless. Fish can be held at very high stocking densities when fed only enough to maintain their base needs. Underfed fish use less oxygen and produce less waste. Therefore, the stocking rate of a system (fish/m^3) and ultimate maximum fish density (kg/m^3) achieved within a tank should be defined by the maximum feed rate ($\text{kg feed}/\text{hr}$ or day) that the system can accommodate without wasting feed and still maintain good water quality. This maximum feed rate capacity will be a function of the water treatment system's design, type of fish being grown, and type of feed. More research should be performed to an efficient method to determine the maximum feed rate.

Stock Management

To maximize the production capacity of a recirculating system, keeping the stocking density within the system near the maximum design capacity is important. This is attempted in recirculating fish culture systems with a number of techniques. Fish are rarely stocked as fingerlings and grown to market size in the same tank. This "batch culture" process does not utilize the production capacity of the culture tank and water treatment system to its fullest economic potential. Fish are usually grown to an intermediate size, then removed from the tank, often graded into size classes, and moved to a larger tank or multiple tanks. Grading fingerlings (juvenile fish) at least once in the growout process will reduce the tendency for large fish to out compete small fish for feed.

In almost all cases, especially in systems with common water treatment systems, a quarantine/nursery system for isolating fingerlings before introduction into the growout system is recommended. The quarantine/nursery tank (Q tank) and water treatment components should be physically isolated from the other tanks and water treatment systems. Time in the Q tank can be used to grow the fish in a nursery environment, while being checked for diseases. The quarantine period usually lasts three to six weeks while qualified personnel inspect and treat the fish for diseases.

Feeding Systems

Feed costs are usually the single largest variable expense in the production of fish. Selecting the appropriate diet, pellet size, feed amount and feeding frequency is important to the productivity and efficiency of the operation. The age and size of the fish will affect the diet formulation and feed rate. Using high-quality, low-waste diets can improve water quality and increase the maximum feeding rate that the recirculating system is capable of handling. Feeding fish two or three times per day as much as they will consume in 15 to 20 minutes (satiation) will produce excellent fish growth. However, in recirculating systems, the addition of this much feed at any one time may stress the water treatment

system's capacity to process waste and provide oxygen. Most likely, the rate of oxygen consumption will exceed the system's ability to add oxygen to the water, and the DO concentration will decline in the tank. To avoid this, feeding should be spread over a longer period of time. This usually is done with some type of automatic feeding device.

A commonly used type of automatic feeder is called a "demand" feeder. Demand feeders train fish to activate a mechanism to release feed. Fish learn to bump a probe that extends below the surface of the water when they want to eat. Although demand feeders can provide for good fish growth, they are not problem-free. If the tank DO concentration declines to dangerous levels, fish will come to the surface of the tank in search of oxygen. With the fish population swimming at the surface of the tank, the demand feeder probe gets bumped, dumping feed into the tank and worsening the situation.

In small tank or quarantine/nursery tank applications, belt feeders can be used. Belt feeders resemble a window shade or conveyor belt. The belt feeders are mechanically driven by a spring when pulled back to the fully extended position. The spring rewinds the belt onto an axle, dropping feed into the tank as the belt is rewound. Belt feeders have conveyor type (endless) belts and are either spring or electric motor driven. These feeders work on the same principle, with the feed falling off the belt as it rounds an axle at one end of the feeder. In large scale or grow out tank applications, timed automatic feeders are used. These feeders drop feed into, or spread feed across the culture tank at timed intervals. Automated feeders can be filled manually from bags or by feed delivery systems from bulk storage. The timing mechanism provides feeding intervals as short as 15 minutes. Automatic feeders are usually powered by alternating current (AC) and some are computer controlled. Smaller units are usually direct current (DC) battery driven.

2.1.9 Recirculating System Economics

While considerable resources have been expended on recirculating systems in the private sector, there is very little data available on the economics of fish production in commercial recirculating systems. The North Carolina Fish Barn project has provided a non-biased look at some of the capital and operational costs of these production systems. This section takes a brief look at some of the important areas to be considered when evaluating recirculating fish production technology for commercial operation.

From a variable cost (feed, fingerling, electricity, and labor cost) standpoint, the cost of producing fish in recirculating systems is not that much different from other production methods. Where pond culture methods require a great deal of electricity (at least 1 kW / acre of pond) for aeration during the summer months, recirculating systems have more even and steady electrical loads over the entire year. While it may appear that recirculating systems require more labor than ponds (in system upkeep and maintenance), the difference would be minimal if the long hours of nightly labor for checking oxygen in ponds, moving emergency aerators around, and harvest effort are taken into account. Feed cost is an area in which recirculating systems can actually have an advantage. Tank production systems generally can produce a better feed conversion ratio than pond systems. This is mainly due to the fact that the producer can monitor the fish population and feed consumption more accurately in tank systems. Using the particle trap

technology that has been used in the North Carolina Fish Barn system, feeding can be even more precisely controlled. Given that feed is the largest single variable cost item in fish production, close attention to feeding can yield a major economic advantage for the recirculating production system. The problem with recirculating technology is that the capital cost of these systems is higher.

Comparing the production capacity per dollar invested in recirculating production systems with other fish production methods is critical to making an informed economic evaluation. Pond production systems in the Southeast cost approximately \$0.90 per pound of annual production to build (including land costs of \$1,000 / acre). That is, a system capable of producing 100,000 pounds of fish per year (21 acres of ponds on 25 acres of land) will cost approximately \$90,000 for land, construction, and equipment. In the past, it was not uncommon to hear of a recirculating system capable of producing 100,000 pounds of fish per year costing an operator upwards of \$400,000, when bought as a “turnkey” facility from an entrepreneur. That is \$4 invested per pound of annual production. From the results of the North Carolina Fish Barn project, we have estimated that a production system, including land and building, will cost between \$2.50 to \$2.75 per pound of annual production capacity; 2.75 to 3 times the cost of pond production systems. Then why build and operate a recirculating system? The answer lies in the past and in the future.

Many people live on farms that have been operated by families for generations. Many of these farms in North Carolina as well as New Jersey have limited water supplies. As some of the traditional crops become less economically viable, family farms are looking for a means to diversify their production. In a sense, this is both a business and personal decision. Because of the personal nature of the decision, expectations for economic return may not be as high as in a purely business-driven decision. Additionally, from a purely business point of view, recirculating systems look attractive in placing production of a high-valued product (ornamental or tropical fish) or the production of warmwater food fish species in or near major markets. The economic analysis must be made whether to raise the fish in a warmer climate and ship to the market or to raise the fish in a recirculating facility in or near the market.

Tilapia is a warmwater species that has become the favored fish for rearing in recirculating systems in the United States. Tilapia grows best at 80° F to 85° F and will die at temperatures lower than 55° F. This limits the year-round production of tilapia out of doors to only the warmest areas of the United States (Florida, southern Mississippi, Louisiana, and California, and Arizona). Although it is possible to grow tilapia indoors in colder climates such as, South Dakota, it may not be the most practical. The tilapia market is for live product for ethnic markets in the West and Northeast, as well as Canada. These markets currently are paying \$1.50 to \$2 per pound farm-gate (FOB the farm). Tilapia fillets also are marketed by several of the larger supermarket chains. The price to the farmer / processor is not as appealing as is the price of live product, as tilapia yield only 36 percent of the total fish weight as fillets, and processing entails additional investment and labor. The tilapia grower needs to calculate a break-even cost by dividing production cost (\$ / lb. round weight) by 0.36 and adding the cost of processing and packaging. In most cases, calculated cost of producing fillets will be greater than what the market is willing to pay the grower for fillets. Tilapia are currently being raised and

processed in other countries where production costs are significantly lower than in the United States. More information on Tilapia and alternative fish can be found in Appendix D.

Sections 3, 4 and 5 provide detailed specific information on the equipment, procedures and economics involved in a recirculating fish hatchery system.

3

DESIGN DESCRIPTION

A successful water reuse system should consist of tanks, filters, pumps, and instrumentation. This system is being designed to produce 100,000 lbs. of Tilapia annually. Tilapia was selected because of its rapid growth cycle and its market potential, which has increased 20 to 30% per year since 1993. Currently, most Tilapia is being supplied by off-shore sources. As discussed previously, however, growing tilapia may not be the most practical in South Dakota.

A typical recirculating aquaculture system consists of several systems and subsystems, which are described in this section. The selection of components was driven by many factors, ranging from cost to operational advantages in technology. The overall goal was to develop a facility and to standardize processes that could be replicated by others, with allowances for modifications to fit other site-specific characteristics. While the design described herein can be used as a model for the design of a system, aquaculture is a rapidly developing science and the latest technological advances should be factored into a final design. Site specifics, such as climate, availability of reliable water and power sources, and water chemistry are just a few of the factors that could effect the decision to continue in planning a project.

3.1 Site Description

The site location and description is very subjective and has not been determined yet. Villagers and project leads should be involved in this decision making process. Figure 3.1.1 depicts the overall view of the surrounding area. Figure 3.1.2 is a representation of a typical building layout of four circular culture tanks and two grow-out tanks. In June of 2005 a group of students traveled to the site to perform surveys of the area which can be seen in Figure 3.1.1. The team spent a week at the site obtaining elevations and determining the locations of various sections of the project.

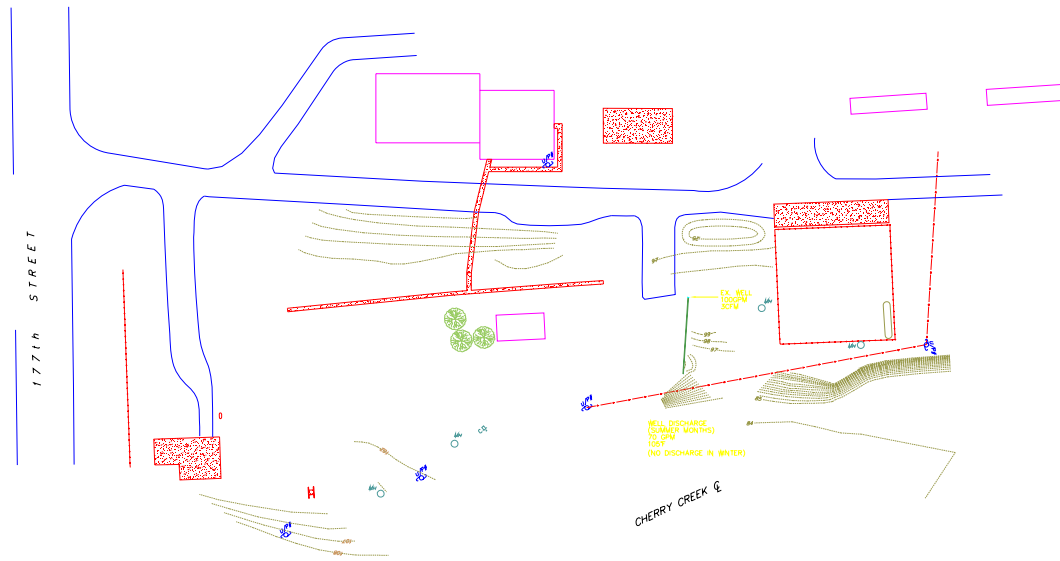


Figure 3.1.1 Site Layout

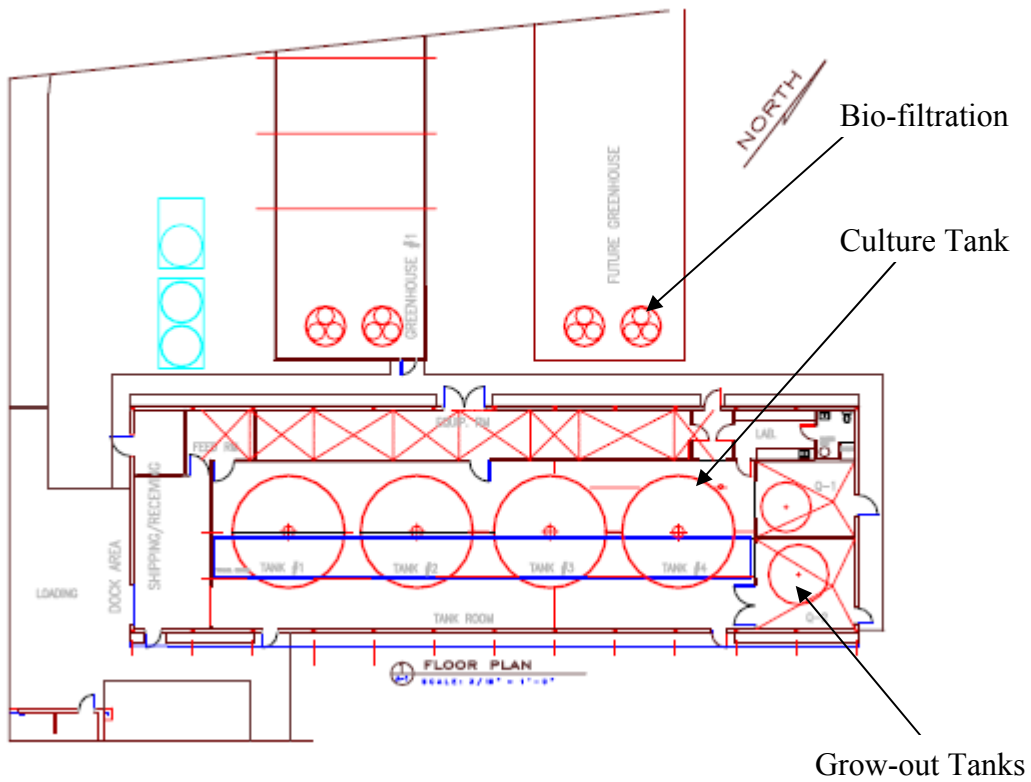


Figure 3.1.2 Typical Building Layout

3.2 Water Treatment System Design and Layout

3.2.1 System Design Overview

The forthcoming text is a scenario based off the Cumberland County College Fish Barn, most of the design criterion can be used for this application; however, more calculation must be performed.

Four water treatment systems should be utilized within the facility and are of similar layout but sized appropriately to the tank system it serves. Four growout tanks should be identical in size and capacity (23 ft. diameter x 6 ft. deep, 18,500 gallons). Growout Tanks 1 and 2 may share a common water treatment system, as can Growout Tanks 3 and 4. The quarantine/nursery tanks, Q-1 and Q-2, (12 ft. diameter x 6 ft. deep, approximately 4,000 gallons) each have a separate water treatment system to provide isolation of potential disease-causing organisms that could be introduced into the growout system.

Circular tanks are good culture vessels because they provide virtually complete mixing and a uniform culture environment. When properly designed, circular tanks are essentially self-cleaning. This minimizes the labor costs associated with tank cleaning. Typically, water is introduced into a circular tank at the perimeter and is directed tangential to the tank wall. The incoming water imparts its momentum to the mass of water in the tank, generating a circular flow pattern. The water in the tank spins around the center drain, following an inward spiral to the center of the tank. Centrifugal forces and the inward, spiraling flow patterns transport solid wastes to the center drain area where they are removed. Once the mass of water in the tank is set into motion, very little energy is required to maintain its velocity. The momentum of the water circling the center drain helps sustain the circular flow. The primary disadvantage of circular tanks is that they do not use space efficiently. A circular tank of a given diameter will have about 21% less bottom culture area than a square tank whose sides are the same length as the diameter of the circular tank. This means that if circular tanks are used there will be 21% loss of potential production are in a given amount of space.

A typical growout tank system layout is shown in “elevation” view in Figure 3.2.1.1. This diagram shows the fiberglass tank (A) with the particle trap (B) set in the concrete tank foundation (floor). Using the tank water level as a reference elevation, water flows from the particle trap through two separate pipes to the sludge collector (C) and the standpipe well (D) where they are rejoined. The flow proceeds through the drum screen filter (E) towards the biosump, which is not shown on this diagram. Gravity flow is used as much as possible to carry water through the treatment processes. While this can be viewed as an energy savings feature, the greater advantage is the improvement in solids removal. In general, solids are larger and more easily removed by gravity settling and/or mechanical screening processes before they are subjected to the shearing forces of a centrifugal water pump impeller.

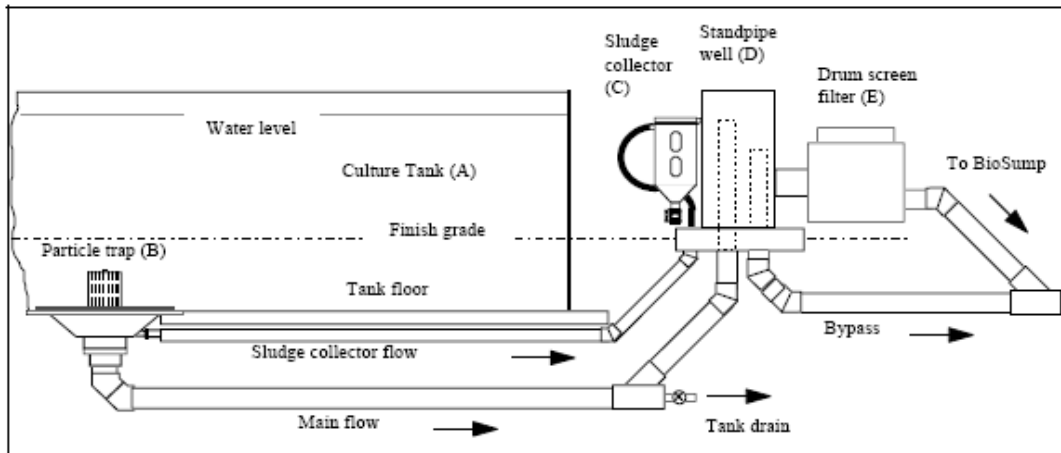


Figure 3.2.1.1. Elevation view of tank system, particle trap, sludge collector, standpipe well and drum screen filter (after Hobbs et al. 1997).

Settleable solids are removed rapidly within the culture tank by the particle trap that is shown in detail in Figure 3.2.1.2 (EcoTrap 250, AquaOptima AS, Trondheim, Norway). Studies have shown that fecal solids and uneaten feed are removed from the tank within minutes of settling to the flat bottom of the culture tank. The EcoTrap has two outlets through which water flows from the culture tank. Settleable solids are captured by the particle trap as they pass beneath a plate located in the tank center just above and parallel to the tank bottom. The uneaten feed and fecal solids are collected in a circular bowl within the particle trap and are removed via a 10 gpm flow stream designated Flow “B”.

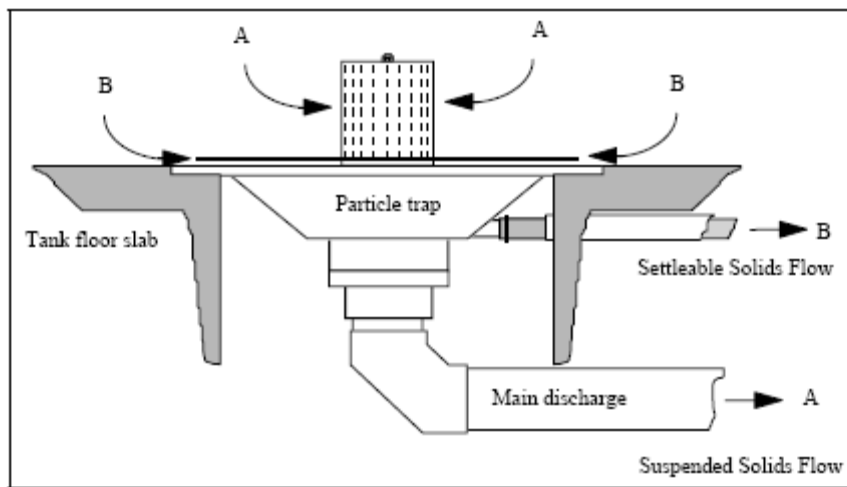


Figure 3.2.1.2. The EcoTrap particle trap showing high solids / low flow stream B and high flow / low solids stream A, (after Hobbs et al. 1997).

The settleable solids that are captured by the particle trap, Flow (B), are removed from the flow stream in a “sludge collector” or settling cone external to the tank as shown in Figure 3.2.1.3. Clarified water overflows the inner weir of the sludge collector (C) and flows to the adjacent standpipe well.

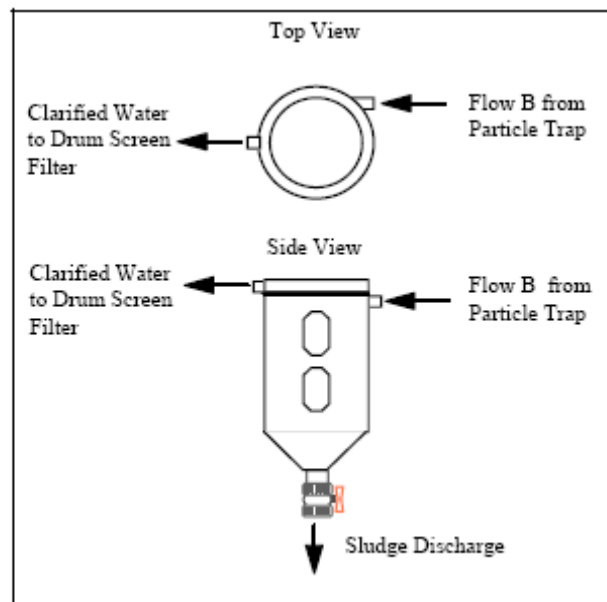


Figure 3.2.1.3. Sludge Collector that works in conjunction with the EcoTrap to remove settled waste solids from the flow stream (3B).

Suspended solids are carried in Flow stream “A”, shown in Figure 3.2.1.2, through the elevated strainer of the particle trap (A), at a design rate of 270 gpm per tank. The settleable solids and suspended solids flow streams from both tanks come together in the standpipe well (D), combine, and continue on, at a combined rate of 560 gpm, to a drum screen filter (E) (Hydrotech 802, Water Management Technologies, Inc., Baton Rouge, LA, USA). At this point, solids larger than the size of the screen on the drum screen filter (40 microns) are removed by the intermittent high-pressure rinse spray to a waste stream. Screened water leaves the drum screen filter (E) and exits through the discharge pipe that splits the stream to the two 10 ft diameter biosumps (F) shown in Figure 3.2.1.4. A built-in bypass around the Hydrotech filter directly to the biosump, which maintains consistent, flow in the event that the drum filter backwash operation fails.

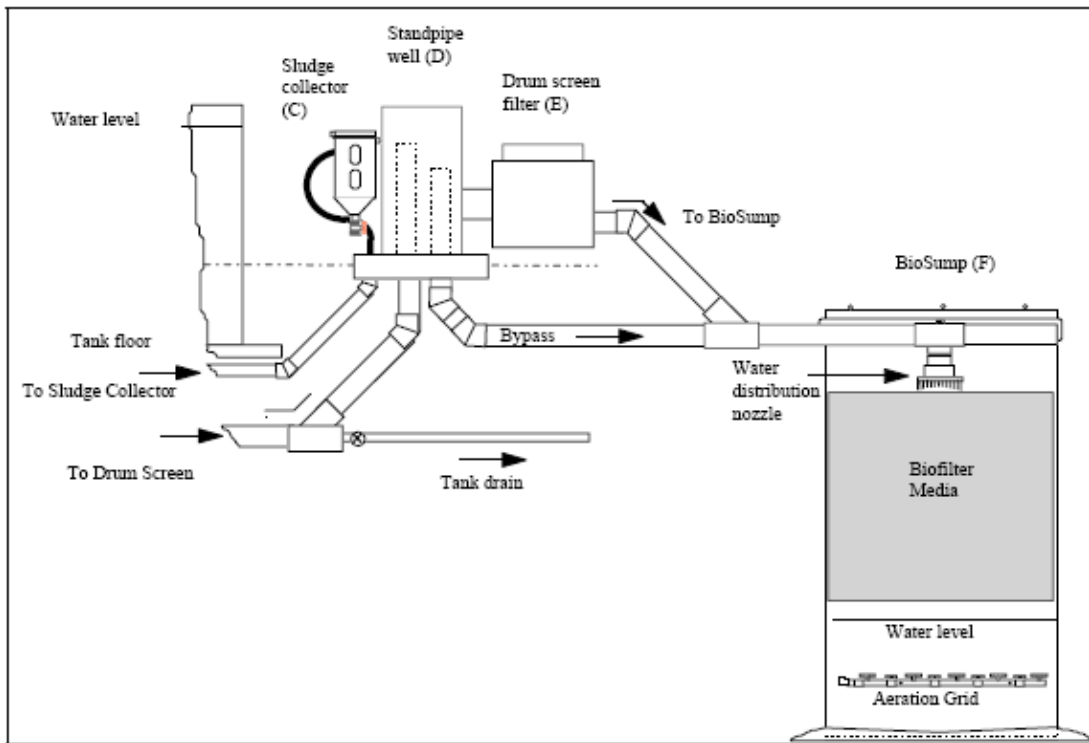


Figure 3.2.1.4. Tank, sludge collector, drum screen filter and biosump biofilter layout (after Hobbs et al. 1997).

The water is distributed over the top of the biosump microbead media with a distribution plate and/or nozzle. The water passes downward through 18 inches of polystyrene biofilter media (Modern Polymers, Inc., Cherryville, NC, USA) that has a specific surface area of $4000 \text{ m}^2/\text{m}^3$.

The ammonia is converted to nitrate at a (design) rate of approximately $0.2 \text{ g TAN} / \text{m}^2 / \text{day}$ by the bacteria attached to the media. Carbon dioxide is removed from the downward cascading water stream by a 1/3 hp “High Pressure, Direct Drive Radial Blade Blower” (Dayton, Model 7C483, W.W. Grainger, Inc.) which provides 175 cfm @ 5 in. static pressure just above the bead media for carbon dioxide removal and aeration. At the bottom of the biosump, the water collects to a depth of approximately 3 ft. and has a residence time of 6 minutes. A “grid” of flexible membrane diffusers (FlexiDisc, EnviroQuip International, Inc., Cincinnati, OH, USA) provides aeration in each biosump with a supply of 45 cfm of air. A 1.5 hp regenerative blower (Sweetwater Model S45, Aquatic Eco-Systems, Inc., Apopka, FL, USA), provides the air to the aeration grids in the biosumps at a rate of 90 cfm (@ 40 in H_2O pressure, total flow to both biosumps) to liberate carbon dioxide and add dissolved oxygen. Water is then pumped from the bottom

of each biosump with two – 4.5 hp centrifugal pumps (G) (Model S45A, Aquatic Eco-Systems, Inc., Apopka, FL, USA) at a rate of 160 gpm each through oxygen injection components to each tank (Figure 3.2.1.5). For each tank, two down-flow bubble contactors (H) (Oxygen Saturator Model OY110, Aquatic Eco-Systems, Inc., Apopka, FL, USA,) are used. Water flows into the top of the down-flow bubble contactors, is mixed with gaseous oxygen, and exits the bottom in a pressurized (5-15 psi) flow stream for delivery to the culture tank. The oxygenated water re-enters the culture tank through two vertical manifolds (I) (EcoFlow Model 110, AquaOptima AS, Trondheim, Norway) that allow for even distribution of the water from top to bottom in the tank water column.

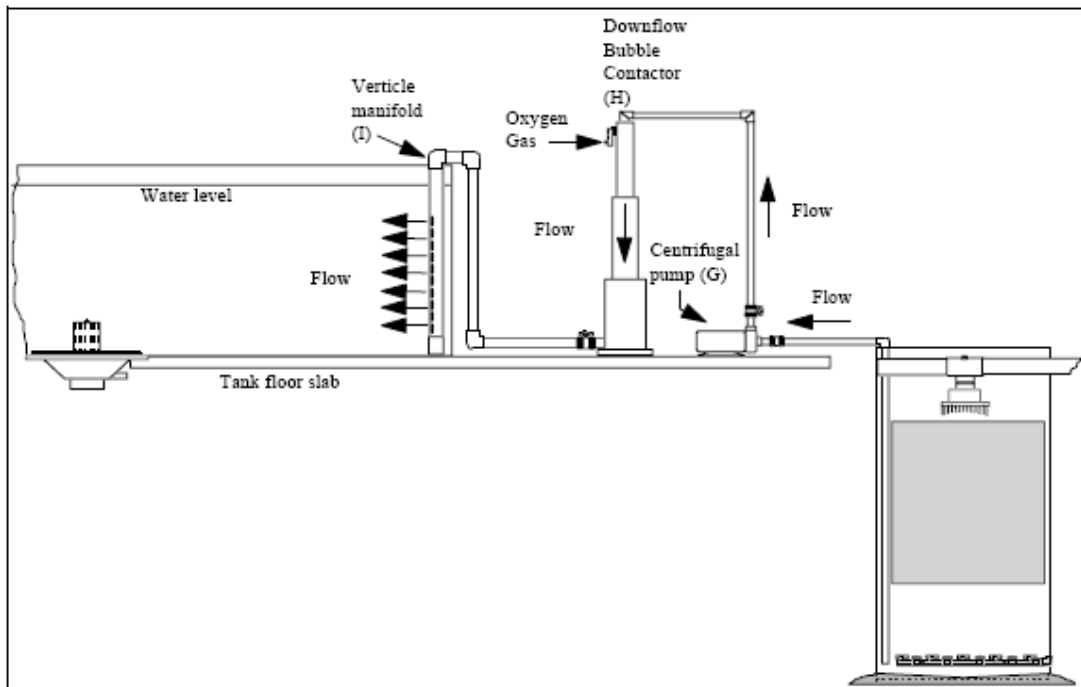


Figure 3.2.1.5. Fish culture tank, downflow bubble contactor and biosump biofilter (after Hobbs et al. 1997).

3.2.2 Water Treatment System Design and Operational Characteristics

As stated previously, this design scenario has four water treatment systems. Each water treatment system is sized to maintain good water quality at a specified maximum daily feed rate delivered to the associated tanks. The following is a description of the operational characteristics of the growout tank water treatment system previously described.

Design Characteristics

The water treatment system for growout Tank 1 and 2 or growout Tank 3 and 4 is designed to remove or neutralize the waste created by approximately 200 lbs. of fish feed per day (38% protein by weight). The system was designed to have the capacity to treat, renovate and recycle water back to each culture tank at a rate of 280 gpm. Much of the system component sizing is dictated by the daily feed amounts required to grow the specified biomass of fish in each culture tank. Table 3.2.1 lists some important sizing and design characteristics per unit of feed input to the growout system.

Table 3.2.1 Design characteristics per unit of feed input.

Category	Units	Design Rate
New water used per unit of feed added	$\frac{\text{gal of new water / day}}{\text{lb feed / day}}$	$\frac{13 \text{ gal}}{\text{lb feed}}$
Recycle flow rate per unit of feed added	$\frac{\text{gal of recycle water / min.}}{\text{lb feed / day}}$	$\frac{2.8 \text{ gal / min.}}{\text{lb per day}}$
Aeration per unit of feed added	$\frac{\text{Cfm blowers}}{\text{lb feed per day}}$	$\frac{1.65 \text{ cfm}}{\text{lb per day}}$

The design flow rate through the treatment system was based upon mass balance analysis and experience with smaller systems of similar design. Depending upon the species of fish, this design procedure often results in a flow rate that produces a hydraulic retention time of 55 – 60 minutes in the culture tank. In this case the design hydraulic retention time was 66 minutes. While this would not maintain appropriate water quality for some of the more sensitive species, the flow rate has proven to be appropriate for Tilapia (*Oreochromis niloticus*) culture in this specific system design. Less retention time might be required for other species at similar stocking rates.

4

GEOHERMAL WELL

Section 1:

Considering and Planning for a Geothermal Aquaculture System

When considering using a geothermal well for aquaculture, many parameters need to be assessed before the system can begin to be planned out. To start off, the most important areas of concern are water quality as a result of the well and the local environment. Understanding these two aspects of the targeted area will allow for the selection of the type of crop (fish) to be raised as well as the type of system that will be used. From there the rest of the system can be put in place. Another way of selection could be to select the desired crop and then proceed with steps to alter and control the current water quality and environment, if need be, to accommodate that crop.

I. Assessing Water Quality and Selecting the Crop

Water quality includes the water temperature as well as the water parameters such as hardness and turbidity, etc. resulting from the well. This is important in order to maintain a healthy and productive living environment for the crop. After the water quality and temperature are assessed and known, the crop may be selected accordingly. Alternatively, if a certain crop is desired and the water temperature and parameters do not meet the requirements of the desired crop then steps to alter the temperature, either by heating or cooling the water, or steps to alter the parameters, typically by some type of mechanism, needs to be taken.

In this project the first step performed was selecting a crop according to what resources were available to the EWB chapter as well as the current markets of that crop in America. Since there was a successful Tilapia hatchery currently established in the area and the market for Tilapia was found to be rapidly growing in America, it was determined that Tilapia would be the desired crop. The local hatchery would provide the EWB chapter with the expertise on the crop and the market for the Tilapia showed economic success for the reservation.

As a result of selecting the crop first, the water parameters then needed to be altered to suit the conditions needed for an effective and productive environment for the Tilapia. Research showed that Tilapia needed to be grown at temperatures of about 85° F for the most rapid growth of the fish. This means that the nature temperature from the well needed to be altered to suit this condition.

The geothermal Red Scaffold well located on the Cheyenne River Sioux Reservation in South Dakota has been found to contain water temperatures ranging from 118°F in

October at 15 gpm to 104° F in December at 60 gpm. When calculating the energy required for heating the water in the system and maintaining it at 85° F temperature, it is recommended to use the lowest temperature possible from the well, 104° F. (Smith, 2) If 85° F temperatures can be maintained at the coldest possible extreme, it can be maintained all year round.

Another issue with the water quality was the parameters of the water, and if it was healthy enough for the Tilapia. The important water parameters coming from the well include turbidity and total suspended solids. In order to ensure that the levels of these parameters in the water reach conditions suitable for the Tilapia, a reverse osmosis unit has been proposed for the cleansing of the water which will be discussed later in the next section. This piece of equipment has been proposed by Keenon Aquatics, a company that specializes in fish farming, however, it may be possible that this piece of equipment is not necessary at all since the water may already exist at levels required by the Tilapia. The other parameters such as pH, nitrate levels and dissolved oxygen can be regulated in the fish hatchery itself.

II. Assessing the Local Environment and Selecting the System

Depending on the local environment, it may be better to choose one type of hatchery opposed to another. In the fish hatchery business two main, inland hatcheries exist, pond hatcheries and re-circulating aquaculture systems (RAS). The pond hatcheries are much more affordable since they involve very little mechanical equipment and act much like a natural pond. The RAS however much more expensive provide many more benefits that are necessary in this particular situation. Therefore the RAS has been selected for the type of system to be used and will be further discussed below.

Open pond systems and other once through systems require high flow rates to maintain clean water at levels high enough for the fish to survive. If the water was ran straight from the well it would be possible to build one of this systems, however, as seen in the next section it is important for a reverse osmosis system to be used. This reverse osmosis unit can only produce a max flow rate that is much lower than that which is required for a once through system.

Studies performed by Virginia Tech's Department of Fisheries and Wildlife Sciences show that the RAS saves on much space for the same number of crop. This is because fresh water is constantly being pushed through the tanks of the fish, constantly removing and harmful substances in the water and everything is kept under a controlled environment allowing a greater density of fish per volume. For example, for 100,000 lb of fish per year, using an outdoor pond system it would be necessary to use about 20 acres of open pond to grow that amount of fish, where as the RAS only requires about 5,000 square feet of land.

Using this type of system (RAS) it is also possible for warm water fish such as Tilapia to be grown in colder climates such as in South Dakota. Typically in areas such as this it is more common to find Trout as the crop, however, since Tilapia has already been

determined for the type of crop to be grown as stated above, a RAS is necessary for the growth of that crop since the indoor facilities and constant flow of water will allow for heat to be constantly passed through the system to maintain temperature levels of about 85° F when local temperatures drop below zero. It is recommended that an efficient heat retaining enclosure be used for this environment to facilitate in lowering the amount of energy required to heat the tanks.

Section 2:

Purifying the Water to Reach Tilapia Standards via an RO Unit

When determining what steps to be taken to ensure the water quality was up to the living standards required for Tilapia, the expertise of the Aqua Technology, a company that specializes in the equipment for fish hatcheries, was requested. This company had returned a suggestion to use a reverse osmosis system as a one pass method that could be used to purify the water to ensure healthy water quality levels for Tilapia. According to this company it is important to use this system to treat the brackish water containing high levels of bicarbonate and sodium which originate from the well. Also installing a R.O. unit would allow for future venture opportunities such as a water bottling facility.

When searching for a reverse osmosis unit several companies were contacted to obtain quotes on the system. The companies included Rain Dance Water Systems, Excel Water Technologies, Remco Engineering and Aquatechnology. When evaluating these quotes the cost, effectiveness and efficiency were all taken into account. It was eventually determined that the Rain Dance Water Systems would be most adequate since it was effective, cheap and the most efficient since its size was as close as possible to what was needed. This system costs \$20,898, free shipping and includes three years of replacement filters. It is able to produce about 25,000 gallons per day.

The data on this system as reported from Rain Dance Water Systems indicates that the water that will go into the system will be purified to levels well above that required by the Tilapia. In fact the water would also be pure enough to drink. It is questionable whether or not the water could actually be used for the Tilapia straight from the well and further investigation into the topic would be required to determine that.

This system has been projected to be placed on the second concrete slab north of the well where the water would be pumped to there and then from there the water would be pumped to the fish hatchery at the proposed location at the third concrete slab north of the well.

Section 3:

Utilizing the Gas from the Well to Facilitate Energy Cost

Considering the well contained natural gas that could be utilized as a form of energy, ways of harnessing that source were looked into. The natural gas contained in the well was found to consist of mostly methane gas, therefore a turbine to ignite this methane gas

was considered. This turbine would then be used to power about 15 KW of the fish hatchery which would ease the energy requirements and costs for the facility.

The system that was determined to be used for the combustion and utilization of methane gas was a cogeneration system for its efficiency of up to and exceeding 85% in combusting the gas for energy. Different vendors were researched in order to determine the best deal on the system. These vendors included Integrated Power Systems International, Inc., Vector Cogen, Powernet, PureEnergy and Elliot Energy Systems. Of these five vendors it was determined that PureEnergy, contact name Jim Olsen, provided the best equipment for the situation.

These co-generation systems are capable of producing up to 15 kWh of energy and are able to either work as a stand alone unit or can be used in cooperation with a grid, which will be necessary as explained later. The price on this system goes for about \$29,953 but has been promised to be discounted to \$23,962. Also optional external switchgear/paralleling controls go for \$1,900/unit.

Upon implementation of this system it will be placed on the first concrete slab about 50 feet from the well. The gas would then be combusted for energy in the cogeneration system and then feed to certain components in the fish hatchery as described in more detailed in the following.

5

ELECTRICAL

The fish hatchery will be utilizing the methane gas from the well to power as much of its enclosure and machines as possible. The remainder of the power will be supplied from the utility service.

To organize the incoming electricity, the hatchery is divided into two panels. Panel #1 is used for the cogenerator while Panel #2 is used for the service feeder. It is assumed that the reservation uses the standard 120/240 single phase service.

The maximum output of the cogenerator system is 15 kilowatts (kW) withstanding a 125 amp (A) load at 120 volts (V). Although the max load capacity is 125 A, the load capacity cannot handle a full load therefore it is limited to only 120 A. The cogenerator system will be powering the Reverse Osmosis unit on an 80 A breaker, the main lighting on a 20 A breaker, and a receptacle on a 20 A breaker. Michael Colburn from Dimewater Inc. was consulted about the breaker selection for the R.O unit. The R.O. motor runs at 31 A but is rated for 40 A. Due to random spikes when it is turned on, the 80 A breaker was selected in accordance with the Square D slide chart. The outlets of the fish hatchery are run on two 20 A breakers. The remaining amps provided by the cogenerator unit are harnessed to power the interior and exterior lighting of the site.

For panel #1, a 150 A single phase service panel was selected to enclose the 120 amps of breakers. Because the methane gas flow fluctuates and other basic malfunctions occur, a transfer switch can be used when to prevent technical difficulties such as power loss or disruption of daily operation. The transfer switch will substitute the cogenerator power in Panel #1 with the service feeder in case of low power from the cogenerator unit. Eight pumps and other minor items compose the remaining load. Each of these pumps have a five horsepower motor and operate at a full load of 19.8 A but are rated at 25 A. Using the Square D standards, the pumps are sized with a 60 A breaker each. Another 20 A breaker is used for the remaining outlets in the facility.

Panel #2 holds a maximum capacity of 800 A. The overall load of the fish hatchery is 520 A but there is space for expansion in the selected panel. All of the components can be found in the Square D catalog found at their website (<http://www.squared.com/>). The transfer switch is from Global Power Products and can be ordered from their website (<http://www.gppmb.com>). The model numbers of the suggested components can be found in the table below.

Model No.	Component
HOM280CP	80 A breaker-SD
HOM220 20A	20 A breaker-SD
HOM30M150C	150 A single phase service panel-SD
HOM260 60A	60 A breaker-SD
HCW 1450-8 series E1 type 1	800 A single phase service panel-SD
G15BR	150 A transfer switch-GPP

SD = Square D product

GPP = Global Power product

Every anticipated load or electrical device that will consume power has been organized into a chart displaying the name, voltage measured in volts, load measure in amps, and power output measured in kilowatts. The total power consumed is only an estimate because all of the known devices are not on the list. Once all appliances and machines are selected for the entire structure, considering the detailed specifications of each, the load can be calculated or looked up in the Winco, Inc. Load Chart. Power (kW) can be calculated as voltage (V) multiplied by current (A). The total power consumed can be added to the total power supplied from the co-generator, which is negative, to find the total amount of power needed to be supplied from another source.

A backup generator is a smart way to protect the fish hatchery against power loss. The auxiliary power back ups the primary source of electric power with an alternate source. There are several factors to consider when purchasing a backup generator. Generators are available in a variety of sizes with various features and options. Backup generators can be portable or standby, have a range of power ratings, manual or electric start, have different fuel types, and can be used or new. An establishment of this size would need a standby backup generator with a capacity of 50 kW with an estimated price of \$10,000. Fuel type is one of main deciding factors in this case. Generators commonly run on gasoline, diesel, propane, or natural gas. Low power and portable units usually use gasoline while larger units use the other three types of fuel. Cost of fuel and its availability need to be considered. Diesel fueled generators are cheaper; however diesel fuel is more expensive. Natural gas generators are usually more expensive but the fuel is cheaper. Some questions that need to be answered are:

- How often does the power go out at the reservation?
- Where is the closest natural gas, propane, diesel supplier?
- How much does the fuel cost?
- How much does it cost to transport fuel to or store at reservation?
- How plentiful is the fuel in the area?

These questions answered will help decide what kind of backup generator to buy. Diesel fueled generators are recommended because of longer life, lower maintenance, and improved fuel consumption.

Recommendations for backup generator for the reservation fish hatchery:

Table 1. Generator Options

Generator Type	Size [kW]	Cost
Katolight Standby Diesel Generator Model #: D50FGH4	50	\$9,500
Onan Natural Gas Generator Model No” 55.0EN15R1786D	55	\$8,500
Perkins Fully Packaged Diesel Generator Set	55	\$10,999
John Deere Sound Attenuated Diesel Generator Set W/ Trailer	50	\$22,258.95
Guardian Elite Commercial Line Liquid- Cooled Standby Natural Gas Generator	50	\$10,199.99

My recommendation is the Perkins 55 kW Fully Packaged Diesel Generator Set. If the generator won't be used that often, a used generator will be sufficient. My second recommendation would then be the Katolight 50 kW Standby Diesel Generator. These recommendations are based on the assumption that diesel fuel is more accessible.

6

HEAT LOSS

South Dakota's climate is ever changing, but for the tilapia in the proposed fish hatchery to grow efficiently, somewhat constant conditions must be provided. For this reason, serious considerations must be made to the operating temperature of the water being pumped from the well to the tanks, the water in the tanks, and the ambient temperature of the fish hatchery enclosure.

The maximum temperature of water that the reverse osmosis (RO) unit can handle is 85° Fahrenheit (F). Water comes out of the well at 105° F. A 6 foot, 20 tube heat exchanger was previously chosen to lower the temperature of the well water to 85° F. Water coming out of the outlet of the RO unit will also be at this temperature, but there is some distance that the water must travel between the RO unit and the fish hatchery. The Tilapia in this fish hatchery are best bred in water at a temperature of 85° F, so it is important to keep the water at this temperature.

If PVC tubing is to be used to transport the purified well water, heat loss considerations must be made. Heat loss in a cylindrical pipe or tube is given by the following equation.

$$q = \frac{(T - T_{\infty})}{\sum R} [=] \text{Watts}$$

Whereas q is the heat lost by the water per meter of pipe, T is the temperature of the water in the pipe, T_{∞} is the outside temperature and $\sum R$ is the sum of all the thermal resistances in the pipe. The resistances in an un-insulated pipe are the convection resistance between the water and the PVC, the conduction resistance through the thickness of the pipe, and the convection resistance between the PVC and the soil it is buried in.

There are many material-specific characteristics used in this calculation. The convection resistance between the PVC and the well water is dependant on the thermal conductivity of the PVC and the turbulence of the water. Thermal conductivity can be described as how well the material can transfer heat. It was this characteristic that was used in selecting a material for the water piping, since PVC has a low thermal conductivity (5.11 W/m K). Copper piping has a much higher thermal conductivity (140 W/m K) and would lose heat much faster, lowering the temperature of the well water and increasing the amount of energy that would need to be spent on keeping the water at 85° F.

Another important factor in the heat loss calculations of the water is the depth of the soil that the pipes will be buried in. The average wind speed for this region of South Dakota

can be up to 13 miles per hour, which can greatly increase the amount of heat lost by the water. Since soil is a good insulator, the pipes must be buried at a sufficient enough depth so that wind currents won't affect the heat lost by the pipes. After some research it was found that a depth of 1 foot was sufficient enough to neglect the effect of wind.

Extensive calculations were done to determine the heat lost by the water in the PVC piping under 1 foot of soil. These calculations were done at an outside temperature of 10° F, which is the average minimum temperature for this region of South Dakota. The heat lost per meter of pipe is approximately 2.92 Watts, which results in a negligible temperature change. This furthers the assumption that soil is a good insulator, and that we would not need to worry about the heat lost by the water over the short distance between the well and the fish hatchery.

These principles are not trivial, however. The same calculations can be applied to the enclosure that will house the fish hatchery. For the sake of simplicity and cost effectiveness, it was decided to use a prefabricated roofed vinyl enclosure for the hatchery. The tentative dimensions for this enclosure are 100 feet long by 64 feet wide by 24 feet tall.

The following master equation was used as a basis for calculation.

$$q = hA(T_{Inside} - T_{Outside})$$

Whereas q is the heat lost by the enclosure, h is the convective heat transfer coefficient of the enclosure material to the air, and A is the outside surface area of the structure. Many assumptions were made for this calculation, but all were on a best case scenario basis. Assuming a low heat transfer coefficient for the material of the enclosure from typical values of vinyl and other polymers, and also neglecting wind effects, the heat lost from an enclosure of this size would be 8.85 Kilowatts during the coldest months of the year. Neglecting wind effects is a very large assumption, since the wind speed is at least 11 mph on average in South Dakota.

Since a prefabricated vinyl enclosure would lose close to 10,000 Watts of energy to the environment, serious considerations must be made to a more cost effective solution. It would take even more than 10 KW of electricity to keep the temperature of the fish hatchery constant, because of the efficiency of radiators and space heaters.

Future work must be done to find a more cost effective solution for housing the fish hatchery, because of heat energy lost to the environment. Heat loss considerations must also be made to the actual tanks within the enclosure, to keep them at a constant 85 F while maintaining the air at room temperature. To examine all aspects of energy consumption, length of piping must be tabulated from site surveys and the required pump head must be calculated.

EWB - South Dakota - Water Heating Calculations

Uninsulated Pipe

ID of Pipe (cm)	3.00	Outside Temp (C)	-12.22	Density (Kg/m ³)	995
Area of pipe (m ²)	0.00283	(K)	260.93	Cp (KJ/kg K)	4.179
OD of Pipe (cm)	4.00	Initial Water Temp (C)	29.44	Viscosity (Kg/m s)	0.00000769
Area of pipe (m ²)	0.00503	(K)	302.59	Pr	5.2
length of pipe (m)	10.00	Thermal Cond., k (W/m K)	5.11	n	0.3
Flow Rate (gpm)	20	Conv. Coeff., h (W/m ² K)	47903.73618	Re	69290.88813
Flow Rate (m ³ /s)	0.0012618	k of soil (W/m ² K)	0.14	Nu	281.2352418
Mass Flow (kg/s)	1.255491	h of soil (W/m ² K)	1.4		
Velocity (m/s)	0.44627046	Distance Underground (m)	1.00		
		Final Water Temp (C)	0		
		(K)	273.15		
		volume of enclosure (m ³)	153600		

*look up k for PVC
Calculations

r1 (m)	0.03	Heat Loss	2.92100766	W
r2 (m)	0.04	Change in Water Temp.	0.000556733	K
A1 (m ²)	0.00283			
A2 (m ²)	0.00503			
Alm (m ²)	0.003822127			
R1 conv (K/W)	0.007383091			
R2 cond (K/W)	0.51200474			
R3 conv (K/W)	142.1026278			
Rtot (K/W)	142.6220156			
q (W/m)	0.292100766			

EWB - South Dakota - Water Heating Calculations

Vinyl Enclosure

Thermal Conductivity (W/m K) 0.10

HT Coeff (W/m² K) 10.00000
*assumed

Outside Temp (C) -12.22

(K) 260.93

Inside Temp (C) 25.00

(K) 298.15

k of air (W/m² K) 0.14

h of air (W/m² K) 50 *assumed

area of enclosure (m²) 14272

volume of enclosure (m³) 153600

*look up k for PVC
Calculations

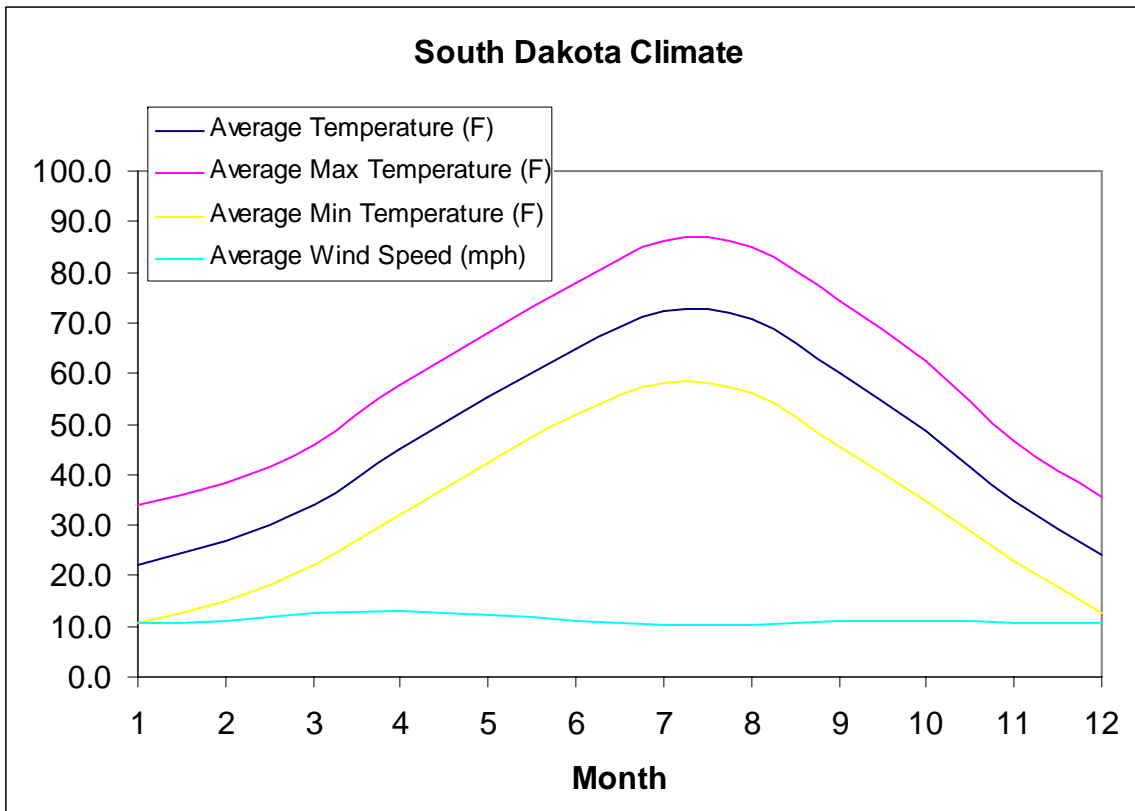
Heat Loss 8853.397333 W

R_{tot} (K/W) 0.004204036
q (W) 8853.397333

Climate Information

-Based on Weather Patterns in Rapid City, SD, 50 miles east of Sioux Reservation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Avg. Temp. (F)	22.3	26.7	34.1	45.1	55.2	64.8	72.2	70.6	60.0	48.7	34.8	24.2	46.6
Avg. Max Temp. (F)	33.8	38.2	45.9	57.9	68.1	77.8	86.2	85.1	74.4	62.5	46.7	35.6	59.4
Avg. Min Temp. (F)	10.7	15.2	22.2	32.2	42.3	51.7	58.2	56.1	45.4	34.9	22.8	12.7	33.7
Avg. Wind (mph)	10.7	11.1	12.6	13.1	12.2	10.9	10.1	10.2	11.0	11.2	10.8	10.5	11.2



7

REFERENCES

“An Aquaculture Education and Commercial Demonstration Facility.” Cumberland County Collage Fish Barn. Vineland, New Jersey.

“Choose the Right Back-up Generator, Power Outages, Safety & Emergencies - Backup Generators.”

"Climate Information for South Dakota." Climate Zone. 2003. Cia World Fact Book. 2 Feb. 2006 <<http://www.climate-zone.com>>.

Geankoplis, Christie J. Transport Processes and Separation Process Principles. 4th ed. Upper Saddle River, Nj: Prentice Hall, 2003. 235-356.

Hinshaw, Jeffrey M. ‘Trout Farming – Carrying Capacity and Inventory Management’ SRAC Publication No. 222. July 2002.

Nadel, Brian, “TV Power Consumption,” http://reviews.cnet.com/4520-6475_7-6400401-3.html Accessed Feb. 2, 2006.

Popma, Thomas and Michael Masser. ‘Tilapia – Life History and Biology’ SRAC Publication No. 283. March 1999.

"PVC (Poly Vinyl Chloride)." Poly Vinyl Chloride Specifications. 2003. Engineering Laboratories, Inc. 7 Feb. 2006 <<http://www.plasticballs.com>>.

“Winco, Inc. Load Chart,” <http://www.wincogen.com/LoadChart.shtml> Accessed Jan. 31, 2006.

Wyk, Peter. “Chapter 4 - Principles of Recirculating System Design.” Harbor Branch Oceanographic Institution.

Appendix A

Heat Transfer Process

Heat Transfer Process

Carolyn Braun

ABSTRACT

Heat Transfer Process is part of the Engineers Without Boarder's South Dakota Project. This project is still ongoing. The Heat Transfer Process still has to be built. This paper will inform you of the problem, solution options and final design.

INTRODUCTION

Engineers Without Boarders is working with an Indian Reservation to build a fish hatchery. There is a well on site that produces water and gas. The water coming out of the well is 105°F at a rate of 20gal/min. 20gal/min is approximately 1.25kg/s. The fish hatchery needs the water to be at 85°F. The problem was to cool the well water from 105°F to 85°F.

MAIN SECTION

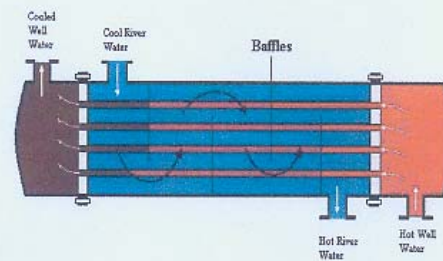
FIRST SOLUTION

The first solution was to utilize the river that is on site. The river's water temperature is approximately 75°F. One idea was to submerge PVC piping in the river. It was found that PVC piping had a very high thermal conductivity. This means that it will not dissipate heat very well at all. It was found that Copper had a very low thermal conductivity; this made it the best choice. Next, it was decided to take copper piping and submerge it in the river. After doing the calculations, the length of the pipe would be 23.11ft. It was found that the volume of river water to flow around the pipe to cool down the well water would have to be 438.8gal/min. At the time of investigation, the flow of the river was less than 438.8gal/min.

SECOND SOLUTION

The second solution was to use a radiator system. The idea of a radiator is to cool down water while using less piping. This idea would use less volume of river water to cool down the well water. One thing that must be kept in mind, the river water's exit temperature would be hotter than when it entered the radiator system. After doing the calculations the pipe would have to be 6.37ft long. There would be twenty 1/8 inch pipes. The well water would be broken up in this way to cool the well water faster. 1/8 inch pipes have the most surface area. The more surface area there is the more heat the water will lose.

The volume of the well water going through the 1/8 inch pipes would be 1gal/min. Due to the set up of the radiator system the river water would have to flow around the pipes at 0.657gal/min. This volume of river water is much easier to produce. The river water would exit at 100°F.



CONCLUSION

This proves to be the best solution to cool the hot well water. Since the well water at 105°F was running off into the river, the excess hot river water from the radiator will not hurt or change the existing environment.

ACKNOWLEDGMENTS

I would like to thank Dr. Krishan Kumar Bhatia an Assistant Professor for Mechanical Engineering at Rowan University.

REFERENCES

1. Nusselt Correlations for Internal Flow, High Re# (Incropera and DeWitt, 3rd Edition, 8.60)

ACRONYMS

FIRST SOLUTION:

T_{inf} : The river water

T_i : The well water temperature at inlet

T_o : The well water at outlet

V_{dot} : Volume of well water

k_{Cu} : Thermal Conductivity of Copper

d : diameter of piping

t : thickness of piping

Re : Renold's Number

m_{dot} : The mass flow rate of well water

$V_{dotcool}$: Volume of cool river water

T_2 : Temperature of well water at exit

T_3 : Temperature of river water at inlet

T_4 : Temperature of river water at exit

A_t : Area of piping

L_t : Length of piping

V_{dotc} : Volume of cool river water

SECOND SOLUTION:

T_1 : Temperature of well water at inlet

APPENDIX

The Third Page is the first solution calculations. The Fourth Page has the second solution calculations. The following couple of pages show calculations that proved various ideas would not work.

$$kJ := 1000J$$

Properties of Water at 350K

$$\rho := 995 \frac{\text{kg}}{\text{m}^3} \quad C_p := 4.179 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \quad \mu := 769 \cdot 10^{-6} \frac{\text{kg}}{\text{m}\cdot\text{s}} \quad k := 620 \cdot 10^{-3} \frac{\text{W}}{\text{m}\cdot\text{K}} \quad Pr := 5.20$$

Properties of Copper

$$k_{Cu} := 400 \frac{\text{W}}{\text{m}\cdot\text{K}}$$

Given Data

$$T_{inf} := 294.26\text{K} \quad T_i := 313.56\text{K} \quad T_o := 302.59\text{K} \quad \dot{V} := 20 \frac{\text{gal}}{\text{min}} \quad d := 1\text{in} \quad t := 0.0625\text{in}$$

Calculations

$$\text{area} := \frac{\pi \cdot d^2}{4} \quad \dot{V}_w := \frac{\dot{V} \cdot d}{\text{area}} \quad Re_w := \frac{\rho \cdot \dot{V}_w \cdot d}{\mu} \quad \dot{m} := \dot{V} \cdot \rho$$

$$Re = 8.184 \times 10^4 \quad \dot{m} = 1.255 \frac{\text{kg}}{\text{s}}$$

Nusselt Correlations for Internal Flow, High Re# (Incropera and DeWitt, 3rd Edition, 8.60)

$$n := 0.3 \quad N_{ui} := 0.023 \cdot Re^{\frac{4}{5}} \cdot Pr^n \quad h_i := \frac{N_{ui} \cdot k}{d} \quad h_i = 7.843 \times 10^3 \frac{\text{W}}{\text{m}^2\cdot\text{K}}$$

Now, I will evaluate the resistance to heat transfer for the inside and through the copper tube:

$$AR_c := \frac{1}{h_i} \quad AR_c = 1.275 \times 10^{-4} \text{m}^2 \frac{\text{K}}{\text{W}} \quad AR_{con} := \frac{t}{k_{Cu}} \quad AR_{con} = 3.969 \times 10^{-6} \text{m}^2 \frac{\text{K}}{\text{W}}$$

The internal resistance is 2 orders of magnitude greater than the copper's. So, I will ignore the conduction resistance. Also, the external difference is assumed to be small.

$$\Delta T_1 := T_i - T_{inf} \quad \Delta T_2 := T_o - T_{inf}$$

$$q := \dot{m} \cdot C_p \cdot (T_i - T_o) \quad q = 57.556 \text{ kW} \quad T_{lm} := \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \quad T_{lm} = 13.056 \text{ K}$$

$$\dot{A}_w := \frac{q}{h_i \cdot T_{lm}} \quad \dot{A}_w := \frac{A}{\pi \cdot d} \quad L = 23.112 \text{ ft}$$

$$\Delta T_{cool} := 0.5\text{K}$$

$$\dot{m}_{cool} := \frac{q}{C_p \cdot \Delta T_{cool}} \quad \dot{m}_{cool} = 27.546 \frac{\text{kg}}{\text{s}} \quad \dot{V}_{cool} := \frac{\dot{m}_{cool}}{\rho} \quad \dot{V}_{cool} = 438.8 \text{ gpm}$$

$$\text{kJ} := 1000\text{J}$$

Properties of Water at 305K

$$\rho := 995 \frac{\text{kg}}{\text{m}^3} \quad C_p := 4.179 \frac{\text{kJ}}{\text{kg}\cdot\text{K}} \quad \mu := 769 \cdot 10^{-6} \frac{\text{kg}}{\text{m}\cdot\text{s}} \quad k := 620 \cdot 10^{-3} \frac{\text{W}}{\text{m}\cdot\text{K}} \quad \text{Pr} := 5.20$$

Properties of Copper

$$k_{\text{Cu}} := 400 \frac{\text{W}}{\text{m}\cdot\text{K}}$$

Given

$$T_1 = 313.56\text{K} \quad T_3 := 294.26\text{K} \quad \dot{V} := 1 \frac{\text{gal}}{\text{min}} \quad t := 0.0625\text{in}$$

$$T_2 := 302.59\text{K} \quad T_4 := 310.95\text{K} \quad d := .125\text{in}$$

Calculations

$$\text{area} := \frac{\pi \cdot d^2}{4} \quad \dot{V}_{\text{area}} := \frac{\dot{V}}{\text{area}} \quad \text{Re} := \frac{\rho \cdot \dot{V} \cdot d}{\mu} \quad \dot{m} := \dot{V} \cdot \rho$$

$$\text{Re} = 3.274 \times 10^4 \quad \dot{m} = 0.063 \frac{\text{kg}}{\text{s}}$$

Nusselt Correlation for Internal Flow, High Re# (Incropera and DeWitt, 3rd Edition, 8.60)

$$n := 0.3 \quad \text{Nui} := 0.023 \text{Re}^{\frac{4}{5}} \cdot \text{Pr}^n \quad h_i := \frac{\text{Nui} \cdot k}{d} \quad h_i = 3.014 \times 10^4 \frac{\text{W}}{\text{m}^2 \cdot \text{K}}$$

Now I will evaluate the resistance to heat transfer for the inside and through the copper tube:

$$\text{ARc} := \frac{1}{h_i} \quad \text{ARc} = 3.317 \times 10^{-5} \frac{\text{m}^2 \cdot \text{K}}{\text{W}} \quad \text{ARcon} := \frac{t}{k_{\text{Cu}}} \quad \text{ARcon} = 3.969 \times 10^{-6} \frac{\text{m}^2 \cdot \text{K}}{\text{W}}$$

The internal resistance is 2 orders of magnitude greater than the copper's. So, I will ignore the conduction resistance. Also, the external resistance is assumed to be small.

$$\Delta T_1 := T_1 - T_4 \quad \Delta T_2 := T_2 - T_3$$

$$q := \dot{m} \cdot C_p \cdot (T_1 - T_2) \quad q = 2.878 \text{ kW} \quad T_{\text{lm}} := \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \quad T_{\text{lm}} = 4.929 \text{ K}$$

$$\dot{A}_w := \frac{q}{h_i \cdot T_{\text{lm}}} \quad \dot{L}_w := \frac{A}{\pi \cdot d} \quad L = 6.371 \text{ ft}$$

$$\Delta T_c := T_4 - T_3$$

$$\dot{m}_{\text{dotc}} := \frac{q}{C_p \cdot \Delta T_c} \quad \dot{m}_{\text{dotc}} = 0.041 \frac{\text{kg}}{\text{s}} \quad \dot{V}_{\text{dotc}} := \frac{\dot{m}_{\text{dotc}}}{\rho} \quad \dot{V}_{\text{dotc}} = 0.657 \text{ gpm}$$

Appendix B

Equipment to Measure and Maintain Healthy Water for Tilapia

Prior to introducing new fry into the hatchery, it is important to make sure the water quality in the system is up to Tilapia living standards. Otherwise the newly introduced fish will not be able to live and much invested capital will be wasted. A good rule of thumb to ensure the fish will not become seriously ill due to their new environment is to place a few into the system for about a week prior to introducing the whole bulk.

After the fish hatchery is up and running and the water is cycling through the system it is very important and critical to maintain healthy water for the fish. This is the best way of preventing disease and parasites. Known diseases for Tilapia include Trichodina, Chilodon, and Ichthyophthiriasis. Parasites include bacterial fin rot and Saprolegnia. In order to prevent these, the water needs to be carefully monitored daily to ensure that the parameters stay consistently healthy. Important parameters for Tilapia include dissolved oxygen, pH and ammonia as well as temperature to name a few. Devices needed to monitor these parameters were investigated.

PH Meters

PH meters are important in measuring the acidity in the water. Acidity that is too high or low will harm and possibly kill the fish. Below is a table displaying pH equipment that may be used to measure this parameter.

<u>Company</u>	<u>Name</u>	<u>Part No.</u>	<u>Price</u>
Aquatic Eco-Systems	Mini pH checker	98103	\$28.90
Extech-Direct	Waterproof ExStik pH meter	PH100	\$89.00
Extech-Direct	Extech Waterproof Palm pH Meter	W504-7811	\$159.95

Mini pH checker

The manufacture claims that this pH meter is very accurate. This device is very inexpensive and basic.

Aquatic Eco-Systems
2395 Apopka Blvd
Apopka, FL 32703
Orders: 877-347-4788
Tech Support: 407-886-3939
Email: aes@aquaticceco.com

Waterproof ExStik pH meter

This pH meter is a little more expensive than the Aquatic Eco-System but it may be worth the investment due to its user friendly features. It features an indicator that tells the user when it's time to replace the pH electrode and when it's time to recalibrate the meter. This device is also waterproof.

Extech Waterproof Palm pH Meter

Although this is the most expensive of the three pH meters, it has the capability of either being hand held or wall mounted. The advantage of the meter being mounted on the wall is that it can be left in the water at all times and it would be easier to detect a change in pH. This device is also waterproof.

Extech-Direct
2911 South Shore Blvd.
Ste. 170 League City, TX 77573
1-800-899-224
281-334-0766
Sales Ext. 291 Order Status Ext. 221

Dissolved Oxygen Meters

Dissolved Oxygen meters or DO meters are important in monitoring the levels of oxygen available in the water for the fish to consume. Typically, Tilapia are hardy fish and require much lower levels of DO than other farm raised fish.

<u>Company</u>	<u>Name</u>	<u>Part No.</u>	<u>Price</u>
Aquatic Eco-Systems	EcoSense DO200 by YSI	YDO200	\$228.00

EcoSense® DO200

This is an economical version of the quality and results expected from YSI. The rugged housing is IP65 splash-resistant, and the large LCD simultaneously displays parts per million or percent saturation and temperature (°C only). Easy-to-replace, screw-on cap membranes have a fast response time and are low-stirring dependent. Nine-volt battery life is typically 450 hours; indicator warns when battery level is low. Detachable probe and cable assembly sold separately below. One-year warranty on meter , six-month warranty on probe.

Ammonia Meter

The ammonia meter is important for measuring the ammonia (NH₃), nitrate (NO₃) and nitrite (NO₂) all of which are interrelated to each other since each can be converted to the other. Too much of the ammonia and nitrate is harmful and deadly to the fish.

<u>Company</u>	<u>Name</u>	<u>Part No.</u>	<u>Price</u>
Aquatic Eco-Systems	Ammonia Meter Kit	LM1999	\$1,055.00

Ammonia Meter Kit

This meter kit measures total ammonia directly in ppm or mg/l. With its pH probe and conversion chart, you will quickly know that all-important un-ionized ammonia concentration. The kit includes a pH Plus Direct meter (**LM1936**), temperature probe, pH probe, ammonia probe, buffer solutions, case, 9V battery and complete instructions. Replacement ammonia reagents and probes can be found under ion selective electrodes. One-year warranty on meter and probe.

Appendix C

Market for Tilapia in the United States:

This summary briefly explains the going rates for tilapia on the consumer market in 1999 as well as the production costs for tilapia for 1998.

Below is the *going rate* of tilapia on the market in the USA in 1999 according to University of Arizona, Tuscon:

	Pond-side/Processor (\$/lb)	Wholesale (\$/lb)	Retail (\$/lb)
Whole Live Fish	4.85 -14.55	6.17 -16.54	8.82 - 22.05
Whole Frozen Fish	2.43 - 4.41	4.41 - 5.18	4.85 - 11.03
Whole Fresh Fish	5.07 - 6.62	6.62 - 8.82	8.82 - 19.85
Fillets, fresh	11.03 - 15.44	13.23 - 17.64	17.64 - 26.46
Fillets, frozen	10.58 – 14.88	12.12 – 17.19	15.44 - 25.36

The grade of the fish, or the size of one whole fish, largely contributes to the range in prices as well as the location it is being sold at. The larger each fish, the greater the fish can be sold for per lb of that fish. Fish of 700 – 800 g bring the highest prices per lb. The size of fillets average about 4 to 6 oz. or 0.25 to 0.375 lb. Therefore fresh fillets can be found to be sold about \$4.41 to \$9.92 *retail price*; \$2.65 to \$5.58 for *pond-side*, again depending on the grade and the size of the fillet.

In 1998 the *production rates* of tilapia cost from \$1.20/lb to \$1.80/lb for whole live fish. For fillets the *production cost* ranged from \$3.75/lb to \$5.63/lb (According to the Iowa State University Department of Animal Ecology). Comparing these prices to the going rates that tilapia is sold at during these two years, yields a profit of \$3.65/lb – 12.75\$/lb for whole live fish and a loss of \$1.10/lb to \$0.05/lb for fresh fillet if the fish were sold pond-side.

The market demand for tilapia is increasing every year as more and more people become aware of it, but as this demand increases, imports for other countries increase as well. According to the University of Arizona, of the total market of tilapia in the United States, 12% by volume comes from domestic farmers while the other 88% is imported. The percent of imported fish is believed to increase in the year 2005. In the United States it is not recommended to produce fillets of tilapia. This is due to the cheap labor found in other countries that allow those countries to import fillets at low costs and sell at low costs. It is believed that the market for filleted tilapia in the US for domestic farmers is near impossible and may only be possible for domestic farmers located near large metropolitans. Instead it is recommended that domestic farmers produce whole fresh or frozen fish. Most domestic tilapia is found in the southern latitudes of the United States and it is very rarely raised in places such as the Dakotas.

Appendix D

Tilapia

Tilapia is a fish that is native to the Nile River in Africa, and is the second most farmed freshwater fish to the carp. The reason for the extensive farming is tilapia has a high tolerance to poor quality water and it eats a wide range of natural food organisms. The weakness of tilapia, and the reason why it may not be the best choice of fish to farm in South Dakota, is that being a tropical fish, it has a low tolerance for cold water. Tilapia will stop feeding when water temperatures drop below 63 degrees Fahrenheit, and cannot survive in water temperatures below 50 degrees Fahrenheit. The optimum water temperature for tilapia for growth is 85 to 88 degrees Fahrenheit. At this temperature tilapia grow about three times faster than they would at 72 degrees. Female tilapia produce about 600 fry at optimum temperature compared to 250 per female at 75 degrees.

South Dakota's Climate

South Dakota obviously has a much colder climate than does Africa where tilapias are native to. July is the warmest month for South Dakota with average temperatures from 1998 to 2005 ranging from 70.9 degrees Fahrenheit in 2004 to 77.4 degrees in 2002. These average temperatures for the warmest month in South Dakota are still about 10 degrees below the optimum temperature required for tilapia. The coldest month in South Dakota from 1998 to 2006 is January with average temperatures ranging from 16.2 degrees Fahrenheit in 2004 to 32.5 degrees in 2006. South Dakota winters over the last eight years range from a brisk 26.9 degree average for the winter of 2000 to a frigid 15.3 degree average for the winter of 2001. The warmest average summer over the last eight years was the summer of 2002 when the average temperature was 72.8 degrees Fahrenheit. The coldest summer over the same span was the summer of 2004 when the average temperature was 66.3 degrees Fahrenheit. The summer of 2004 was also the fifth coldest summer in the last 110 years. Average temperatures for the whole year in South Dakota over the last eight years range from 45.9 degrees Fahrenheit in 2000 to 47.8 degrees in 1999. For 2005, the average temperature was 47.4 degrees Fahrenheit meaning that the water temperature for the tilapia would need to be raised about 40 degrees on average in order for the tilapia to live in optimum temperatures. Monthly temperatures along with winter, summer and annual temperatures can be found in the appendix.

Alternative Fish

Raising the temperature of water an average of 40 degrees Fahrenheit for the year will not be a cheap task, so an alternative fish species that is better suited for colder climates

might be a better idea. Fish that are native to Lake Superior and the surrounding rivers which are in the same ballpark for climate include: brook trout, brown trout, lake whitefish, muskellunge, northern pike, rainbow trout, small mouth bass, walleye, white perch, yellow perch, and salmon. Of these fish, trout and salmon are the two most commonly raised in hatcheries, and rainbow trout is the most commonly farmed coldwater fish in the country.

Tilapia probably isn't even the best warm water fish to farm in South Dakota. Channel catfish are the most widely farmed fish in the United States accounting for about two percent of the total fish consumption. The optimum water temperature for channel catfish is ten degrees less than it is for tilapia which should save a bundle in heating costs throughout the year. Channel catfish also have a high quality and very tasty meat with a mild flavor and are able to survive in less than perfect environmental conditions. Reasons as to why channel catfish are the most widely farmed fish in the United States include: high tolerance to water temperature variations, rapid growth in water above 74 degrees Fahrenheit, high tolerance to crowding, adaptability to natural and artificial farming systems, high feed conversion values, well-known growing requirements, and readily available eggs, fingerlings and adults. The one drawback with channel catfish farming is that the DO concentration needs to be monitored regularly because channel catfish are more sensitive to DO depletion than other species.

Rainbow Trout

Rainbow trout are native to the Pacific coast of North America and have been successfully introduced in every continent except Antarctica. They belong to the salmon family and can grow to about 10 pounds. The reason why rainbow trout have become the most widely farmed coldwater fish is that they grow rapidly to a large size, are good at survival, adapt easily to artificial feed, have a high quality flesh that makes their market demand and value high, have well known growth requirements, and can be easily obtained as eggs, fingerlings and adults. The current estimated private commercial production of rainbow trout is estimated at 48 million pounds annually and the leading state for rainbow trout production is Idaho because of coldwater springs that provide a constant 59 degree water source.

What makes them a more logical choice to farm in South Dakota is the fact that they are coldwater fish. The optimum water temperature for rainbow trout is between 55 and 60 degrees Fahrenheit or about 30 degrees less than the optimum water temperature for tilapia. Rainbow trout are also able to tolerate water temperatures up to 75 degrees Fahrenheit which is about as warm as the water in South Dakota should ever get. The average temperature for the months of May, June, September, and October in South Dakota is right around optimum temperature for rainbow trout meaning there would be no need to heat the water, and the months from October to May would require substantially less heating than what would be needed in order to raise tilapia.

The only drawbacks to farming rainbow trout in South Dakota are the possible needs to cool the water in the summer and that rainbow trout are carnivorous and require animal protein in their food which costs more than carbohydrate based foods. The summer months should not cause the water to get too warm to the point that it would be dangerous to the fish, but it will probably raise the temperature above the optimal

temperature making the fish grow and reproduce slower than they would in the perfect conditions.

The Right Fish

The more profitable fish to farm in South Dakota would be the rainbow trout. The year-round heating required in order to raise tilapia is enough in itself to pick rainbow trout over tilapia. The price per pound for tilapia fillets is about the same as the price per pound for rainbow trout fillets, and in quite a few markets the price per pound for rainbow trout is as much as a dollar more than it is for tilapia. The size of a rainbow trout is also larger than the size of a tilapia making the fillets bigger and each fish more profitable. Both fish have the ability to adapt to less than perfect water conditions and are widely farmed throughout the world. A cooling system for rainbow trout is an added cost that would not be needed for tilapia, but the fish can get by without it and implementing a cooling system into the design of the fish farm would still be cheaper than heating the water year-round especially when the water needs to be heated as much as it would need to be in the winter months to raise the tilapia. Hands down rainbow trout would be a better suited fish for South Dakota.

Water Bottling Facility Cost Analysis

Up Front Costs

Water Treatment \$11,682

1 gallon Fill line \$42738

5 gallon Fill line \$21386

Detailed information

appendix 2

appendix 3

appendix 4

Continuous costs

5 gallon Bottles

PET \$3.5 per bottle

Polycarbonate \$4.80

1 gallon HDPE (milk style) bottles

\$.19 per bottle

Caps

5 gallon

500 per case \$92.27

1 gallon

2200 per case \$22.65

Equipment parts

Water Treatment

Filters \$2,128 includes 4

Spare parts kit \$1,116

1 gallon fill line

Spare parts kit \$890

Hot stamp ink \$800

5 gallon fill line

Spare parts kit \$972

Electricity

5 gallon fill line 5kw

1 gallon fill line unknown

Time Frame to Pay off

27 days

appendix 1

Appendix 1

Total cost of equipment \$75806 w/ water treatment
\$64124 w/o water treatment
Total cost with Shipping and installation of water treatment \$85447
Total cost with shipping no water treatment \$68265

Hours of operation
10 hrs per a day
3650 hr per a year

Employees needed (estimated)

Loader	4
Operator	2
Capper	1
Labeler	1
Unloader	4
Total	12

Employee's pay based on \$8 hr

Cost of bottles and caps after shipping
5 gallon 4.00
1 gallon \$.27

Cost per cap with out shipping
5 gallon \$.185
1 gallon \$.0103

Electricity 5.99 cents per kilowatt hour as of august 2005 for commercial businesses in South Dakota

Monthly Break down Costs

Employee's 30days*12people*\$8*10hr=\$28800
5 gallon bottles 30days*10hr*60bottle(.185+4)=\$75330
1 gallon bottles 30days*10hr*300(.27+.0103)=\$25227
Electricity 5kw*.0599*10hr*30days=\$89.85

Monthly Break down Revenue

5 gallon bottles 30days*10hr*60bottle*\$6.25=\$112500
1 gallon bottles 30days*10hr*300bottles*\$1.25=\$112500

Pay off Period

$\$85447 + X(28800 + 75330 + 25227 + 89.85) - X(112500 + 112500) = 0$
 $X = .89$ months or 27 days
 $\$68265 + X(28800 + 75330 + 25227 + 89.85) - X(112500 + 112500) = 0$
 $X = .71$ months or 22 days

15 Gallon Per Minute Spring/Mineral Water Treatment System:

Commercial Multimedia Filter System:

- 5.0 Cubit Feet graded media bed to provide filtration to 10-15 microns
 - Fleck 2750 1" Valve 120/60 HZ (220V/50HZ available upon request)
- Price USD \$1,537.00**

Commercial Activated Carbon Filter:

- 3/4 Cubic Feet Media
 - Fleck 2700 Valve
 - 120V, 60HZ (220V/50HZ available upon request)
- Price USD \$412.00**

500 Gallon Intermediate Water Storage Tank:

- 500 gallon food grade polyethylene storage tank
 - Tank float valve
 - Fittings
 - Customer to provide PVC piping on site
- Price USD \$899.00**

***UV/Ozone Disinfection Package, Rated for 15 GPM. Sys. (includes the following components):**

- 20" Big Blue Housing W/ 5 Micron Cartridge
 - Booster Pump:
304 S.S., 2.0 HP, 230V/60 HZ/1 Phase
 - **UV Disinfection Unit:
15 gpm w/Manual Quartz Sleeve Wiper for Spring Water Applications
 - Corona Discharge Ozone Generator/Air Dryer:
Rated to produce 9 grams/hour @1-2%Concentration
 - Venturi Bypass Assembly:
W/ pressure gauges and Model 878 Kynar Venturi
 - Stainless Steel Pressurized Ozone Contact Chamber, 46 gallon w/ozone off-gas vent
 - Electrical Control Panel w/motor starter, selector switches and indicator lights
 - System is pre-plumbed, pre-wired & pre-tested prior to shipment
 - Skid Mounted Components:
 - 20" Big Blue Housing W/ 1 Micron Cartridge: (Ozone Resistant Material)
- Price USD \$8,834.00**

***OPTIONAL - 0.2 Micron Post-Filter: (Ozone Resistant Material)**

For after the 1 micron filter - price includes 4 ea. 10" 0.2 micron cartridges.

Price USD \$2,128.00 (not included in total)

Ozone System (to IBWA Standards)

**The UV System will provide primary disinfection allowing the ozone to provide a better residual in the bottle. From past storage life tests, manufacturer found shelf life to be much greater at when the UV was used as a primary disinfectant.

Total Water Treatment \$11,682.00

Appendix 2

***Spare Parts Kit:**

Price USD \$1,116.00

***Recommended Water Test Kits:**

- Hardness test kit to check the water softener USD \$30.00
- Chlorine Test Kit USD \$68.00
- Myron-L 3-Range TDS Meter USD \$277.00
- Ozone Test Kit USD \$85.00
- Ozone Residual Testing w/Accuvac vials USD \$428.00
- (12)Accuvac Vials (25 ea/case, \$29.00 ea.) USD \$403.00
- Bacteria P/A test for E.coli & Total Coliform (includes incubator) USD \$1,810.00

Price USD \$3,101.00

***Water Treatment Installation Materials:**

Plumbing, Hardware & Wiring Package for Water Treatment System

Price USD \$1,492.00

***Water Treatment Installation Fee Schedule:**

7 days Start-up fees for the Water Treatment System.

(Of the 5 days, part of 2 days are for travel to and from the project site with 5 days scheduled for installation, start-up and training. Customer to provide at least 2 workers to help with the installation and start up. Install/Start-up labor is billed at \$650.00 per day plus airfare, meal and motel expenses.)

Price USD \$4,550.00

***Crating Charge For Water Treatment Equipment:**

Price USD\$950.00

* indicates options also not included in system price total

PET FILLING LINE

Fully Automatic PET Bottle Liquid Filling/Packaging Line:

45" Diameter S.S. Econo Unscrambler Turntable:

- Standard speed setting is 0 to 7 rpm or 82.5 feet/min

Exclusive Feature:

- Unique floating bearing removes downward thrust on drive armature to ensure long life,

Features:

- Powered by variable speed, sealed, fused/surge protected DC motor w/ 550 inch/lbs torque

- Turntable glides on four rubber, self lubricating bearings for quiet operation

- Turntable base height is 35" adjustable to 40"

- Foot pads are fully articulating and vibration resistant

Crating is an additional \$250

Dimensions: Base footprint: 24" x 24"

Utility requirements: 110 VAC / 6 Amps

Price USD \$3,343.00

Four Head Sanitary Semi-Automatic Filler:

Semi-automatic, sanitary construction, PLC controlled 4 head inline overflow liquid filler is capable of filling a wide range of viscosities from water to oils and soaps. Typical throughput on 32 oz fills is approximately 20 bpm depending on viscosity and operator performance. Overflow configuration is particularly adept in handling very foamy products. Entire machine is stainless steel construction; all valves are 316l construction with viton seals for a wide range of chemical to food grade applications. Valves are designed to meet highest FDA standards for manual cleaning. System uses self priming stainless body FDA approved diaphragm pump rated 30 gpm. Simple single button programmability for convenient "one shot" operation (i.e. filler cycles once then stops and waits for operator to activate cycle again). Program remains in memory when power is shut off. Filler is mounted on all stainless stand with self articulating height adjustable feet. Filler also includes 8' long slide tray with rails and bottle stop for efficient handling of bottles. Standard filler features: "no tools required" S.S.-UHMW nozzle spacers, NEMA-4 sealed panel for full washdown capability. Machine is elegant in construction, designed to perform, and economical to own. Price includes standard nozzles. Overall dimensions: 2' x 2' x 3' H. Air: 80 psi/8cfm electrics: 110v 60hz.

Price USD \$18,344.00

Stainless DC Varispeed Delron Chain Conveyor:

Heavy 12 guage 304 stainless 10' long variable speed conveyor designed as stand alone unit or completely integrated with filling and capping systems for indexing control of thinwall plastic containers as well as other rigid containers. Conveyor is precision manufactured to .002" tolerance and features: high quality low friction chain; close tolerance UHMW wear strips 50% thicker than industry std; "splashproof" liquid tight electrical harness; controller and emergency stop mounted in sealed, stainless, NEMA 4x enclosure; full washdown capable motor; high torque, lubrication free, direct gear drive; sealed, lubrication free, rust free, composite driver bearings; self articulating, 8" adjustable, lagged tripod support legs rated to 2700 lbs; all rails, hardware, endcaps, transition plates included. User friendly adjustment hardware does not require any tools for changeover. Price below is for first 10' section w/ 1/2 HP DC drive & 4-1/2" wide chain; \$2800 each additional 10' section;

Price USD \$4,982.00

Semi-Automatic Hand Held Capper W/Stand:

Pneumatic operated hand held semi-automatic capper designed to provide torque to caps on bottles. Capper provides relief from fatigue and potential carpal tunnel damage associated with overworking the hands and wrists. Heavy duty cast aluminum housing, lock-off lever throttle prevents accidental starts and lightweight nylon handle for operator comfort. Easy to operate with adjustable torque levels and 2 cups for cap control. Also includes stainless steel stand with feet and retractable mount for tool support.

Price USD \$1,993.00

45" Diameter Valueline Accumulation Turntable:

Bottles are placed horizontally on rollers and the applicator is activated by a foot or hand switch. Rollers turn the bottle as the label is dispensed and applied to the bottle

- Handles round containers from 3/8" to 6" in diameter.
- Label size: up to 7-1/8" wide web.
- Label Specification: 5/8" minimum length die cut with 1/8" spacing on a 12" outer diameter roll (max) with a 3" inner core

Options:

- Hot stamp coder (quoted separately)
- Clear label sensor with mounting bracket \$1200
- Additional product carriage \$800

Dimensions: 18" W x 32" L x 25 1/4" H

Utility requirements:

Electric: 110 VAC / 3 Amps

Air: 3 cfm @ 20 psi

Price USD \$3,343.00

Semi Auto Labeler:

Semi automatic labeler with footswitch activation is designed to handle product diameter range of 1/2" to 6" will handle label size range up to 7" wide with 1-1/8" minimum label length.

Price USD\$4,930.00

Hot Stamp Date Coder:

Hot stamp imprinter with mounting bracket, type chase, spacers and 1 roll of ribbon. Does not include type.

Price USD\$3,333.00

Crating For Filling Line

Price USD\$1,580.00

TOTAL BOTTLING LINE PRICE USD \$41,848.00

5 GALLON BOTTLING MACHINE SYSTEM

Pricing Summary:

Infeed Conveyor 10'

Price USD \$1,986.00

Washer/Filler/Cap62

Price USD \$14,940.00

Electrical & Control Package

Price USD \$976.00

PLC Steering Control System:

Output Conveyor 10'

Price USD \$1,912.00

Export Package

- For all machines suitable for long distance sea transport

Price USD \$1,572.00

(1) Year Spare Parts

Price USD \$972.00

Total Five Gallon Bottling Plant Price USD \$22,358.00

*Heat Shrinking Tunnel (optional)

Price USD \$1,640.00

*Inspection Lamp (optional)

Price USD \$416.00

(note: items marked with a * are options and not included in price totals)

Technical Specifications:

Five Gallon Bottle Washer:

Nominal Output:

120 Bottles/Hour

Heating System:

Electrical Heater

Main Power:

380 V (± 10%) 3PH + E + N Auxiliary 24 VDC

Washing Cycle:

- Inside and outside pre-washing with alkali (soda) water.
- Inside and outside recycled washing with detergent temperature adjustable around 70°, with automatic water level control , and temperature is controlled by detect sensors .
- Bottom emptying system with nozzles fed by compressed and microfiltered air supplied by the customer installed on the machine to eliminate the residue water on the bottom of bottle.
- Inside final rinsing with spring water or by ozonized water. (Ozone generator is optional).Two final water rinsing cycles to ensure the cleaning of bottles.

Technical Features:

- Machine completely made of Stainless Steel AISI 304.
- Intermittent movement of the machine will start and stop to finalize washing process.
- Closing cabin made of plexiglass on the bottle in-load and out-load area.
- Inside lighting of all phases of the washing cycle.
- Machine?s sides are fitted with large glass windows to see all the washing cycle.
- Electric plant according to CE rules complete with main power panel, control push-button panel made of Stainless Steel insulation class.
- Modular construction.

Technical Data:

Bottle Washer Production:

- Output: Bottle/Hour120

- Cycle Time:Second25

Mechanical Data:

- Total carrier: Number 3
- Bottles per carrier: Number 14
- Bottles per machine: Number 42

- Sanitization tank (Soda/Alkali):
- Detergent tank:

Consumption Details:

- Bottle Material: Polycarbonat
- Detergent temperature: °C60-70
- Water consumptions per bottle: Bottle20%-30% of 5 gallons
- Installed power (washer + filler+capper): Kw5
- Air compressed consumption (6 bar):m3/min0.3

The Unit Consists Of:

- Overflow-Pressure type filling system controlled by pressure filling structure with very high stability
- Filling Accuracy - 1%

Advantages Of This System:

- Filling accuracy
- Maintenance-free
- No water overflow
- A mechanical system centers the containers under the filling valves.
- When no bottle presented, there is no filling

Automatic Capping Machine:

- Linear capping machine for press-on caps, completed with caps distributor, caps chute, releasing head and closing pressing head.
- The cap is positioned on the releasing head and picked up by the bottle itself.
- The closing head, made by an inclined stainless steel chain, presses the cap on the bottle mouth.
- Before capping is possible to spray into the caps a sterilized solution trough a nozzle located on the cap chute. (Optional) and UV light is equipped to guarantee the sterilization of caps. (Optional)
- In the event of a missing bottle the releasing head does not release the cap.

Line Equipment ? Technical Specifications:

Power Supply Voltage
Panels supply380 VAC (±10%) 50 Hz 3PH + G + N
Coils and contactors24 VDC
Photoelectric cells 24 VDC
PLC inputs/outputs24 VDC & 220VAC

Electric Equipment:

- Switches
Automatic switchesTE
Main switchTE
Overload cut-outsTE
Proximity switches (IP 67)Omron
Single-phaseMitsubishi
- Photoelectric cells (IP 66)Omron
- Electric motors & reducerMotovario
- PLCMITISUBISHI
- Push-button panels and signaling devicesDigital

Appendix 4

- Motor reduction gears and adjustable speed drives Motovario

Pneumatic Equipment:

- Cylinders (Air-tac)
- Components (Air-tac)
- Pressure gauges (Air-tac)
- Magnetic sensors for cylinders (Festo)
- Air pressure regulator (Air-tech)

Sundry Items:

- Rubber and plastic technical equipment - Food Grade
- Air Pipe
- Pipe Point
- Filling Valve
- Connect Valve
- Cylinder Gasket
- Screw & Screw Bolt

Optional Equipment: (Not included in final price.)

- A) M-22 Air Blower/Cleaner (1 required for fill room) **USD \$2,561.00**
- B) Filling Line Installation Spare Parts Kit **USD \$890.00**
- C) Quality Assurance Kit (mini lab) **USD \$3,940.00**
- D) Stainless Packoff Table (for 45" turntable above): **USD \$488.00**
 - 3/4"w x 22-1/2" D tray extension