Biosecurity: Principles and Practices in the Commercial Poultry Industry

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Preface: Conceptually, the rearing of poultry and fish in a commercial setting have much in common. Both involve the concentration and maintenance of large numbers of animals in a confined space. In fact, the only major difference between the two seems to be the medium of gaseous exchange. Therefore, it is natural to conclude that the principles of biosecurity which have application in the poultry industry may be of value in aquaculture. The purpose of this presentation is to familiarize aquaculturists with these basic principles and demonstrate their practice using poultry as a model. The material contained in this manuscript has been used to educate poultry producers. Thus, a knowledge of aquacultural management and medicine will be required to accurately extrapolate this information.

What is Biosecurity? Simply stated, biosecurity is the means by which you keep infectious disease off your farm or, in the event that you have a disease problem, how you can keep it from spreading to your neighbors!

How Do Diseases Transmit? Disease transmission occurs when infectious material travels from sick or recovered birds to susceptible ones. How this material gets from one place to another is a function of the disease agent itself. Some infectious agents can be passed from infected breeding stock through eggs. Some can be carried by the wind on loose feathers and in dust. Some are transmitted through contaminated water supplies. Most are transmitted by fecal material carried on everything from equipment to shoes and hands. Sometimes vermin like rodents, wild birds, skunks, raccoons, and even cats, and dogs can carry the infectious agents and never show any signs of sickness. Without question, the #1 way in which disease moves from farm to farm is people!

Biosecurity Self-Assessment: The following list may be helpful as you assess the level of biosecurity on your poultry farm. It is suggested that you walk around the premises and do a thorough inspection, responding to the statements as you go. If a statement doesn't

apply to your type of operation don't answer it. Otherwise do the best you can. Most importantly, don't fudge your answers…its your farm and your livelihood! In some cases there may be nothing you can do about your situation. But in other cases, if there's room for improvement, at least you'll know what needs to be done.

Principle # 1: <u>ISOLATION</u> helps you maintain a safe distance between your birds and potential disease threats.

Location

- The next poultry farm is a mile or more away as the crow flies. True False
- The processing plant is a mile or more away as the crow flies. True False
- The main route by which trucks travel to the processing plant is a mile or more away as the crow flies. True False
- My farm is more than a mile from a standing body of water (pond, lake) as the crow flies. True False
- The nearest rendering facility is a mile or more away as the crow flies. True False
- My farm is located outside Rockingham County. True False

Traffic On and Off the Farm

- I do not take farm vehicles off the farm. True False
- I do not lend or borrow equipment from other poultry operations. True False
- I have a gate that restricts vehicle access to the poultry houses. True False
- My poultry houses are surrounded by a fence. True False
- All visitors to the farm must sign a log book. True False
- I permit no visitors on the premises except authorized personnel that is, people who need to be there. True False
- I check vehicles coming onto the farm to see if they are clean. True False
- I ask vehicle operators if they have disinfected their tires prior to coming on the farm. True False
- I ask visitors where they have been prior to coming on the farm. True False
- My poultry houses are locked to discourage unauthorized entry. True False
- I have erected signs indicating that access is restricted. True False
- No one except myself, my employees, service personnel, and veterinarians are permitted in my poultry houses prior to load-out. True False
- Load-out crews are not permitted to go anywhere else on the farm except for house they are assigned to work in. True False
- I never visit other poultry farms. True False
- I never visit the live-side of the processing plant. True False
- Feed truck drivers are not permitted to enter poultry houses. True False
- I have a box for feed tickets on the feed bin so that the driver doesn't have to enter the house. True False
- Fuel truck drivers are not permitted to enter the poultry houses. True False

- I only have one age of birds on the farm during a given production cycle. True False
- When there are multiple ages of birds on the farm, the order of care is youngest to oldest or I have different employees caring for different ages. True False

Pest Management

- I have a rodent control plan. True False
- I regularly check bait boxes and traps to be sure that the bait is fresh and to remove dead rodents. True False
- I regularly check for rodent activity e.g., active holes near the foundations, chewed curtains and insulation, rodent droppings on sills and in ante-rooms. True False
- I do not let trash and junk pile up in my ante-room. True False
- I keep grass and weeds trimmed around the house. True False
- I have no debris, hay bales, or brush piles located within 100 feet of the poultry houses. True False
- I clean up outside feed spills promptly i.e., under the boot. True False
- I remove dead birds promptly and place them in vermin proof containers prior to disposal. True False
- I regularly check and repair the screening in the eaves of my poultry houses to prevent wild bird access. True False
- I regularly check and repair wire screening on the sides of the
- house to prevent wild bird access. True False
- I do not permit the feeding of wild birds on my farm. True False
- I do not leave the gable doors open after the house has been cleaned and disinfected. True False
- I have concrete pads at every entrance to the house. True False
- I regularly spray for insects using an approved insecticide. True False

Other Livestock and Animals

- I do not permit other livestock within 100 ft of my poultry houses. True False
- Livestock are not permitted to congregate near the well head. True False
- Dogs and cats are not permitted in the poultry houses. True False
- I do not own any other birds as pets. True False
- I do not own any other poultry, game birds, or waterfowl. True False

Principle # 2: Good <u>HYGIENE</u> prevents dissemination of infectious agent by reducing their numbers or eliminating them from the environment.

House Cleaning and Disinfection

- I've recently done a total cleanout of my facility. True False
- Litter that is removed from my houses is stored in a covered shed. True False
- I do not store used litter in uncovered piles. True False
- I compost litter in an approved, properly managed composting facility. True False
- Litter is not spread on fields adjacent to my poultry houses or those of my neighbors. True False
- I do not store used litter near clean litter. True False
- When removing litter from my houses I make sure that spills in roadways and entrances to the house are cleaned up. True False
- All equipment used during litter removal is properly cleaned and disinfected after use. True False
- After litter removal the house is thoroughly swept from top to bottom. True False
- All rafters, sills, lighting fixtures, fan blades, motors, louvers, heaters, brooders etc. are blown off or wiped clean. True False
- The entire facility, including curtains (inside and out), ante-rooms, and equipment is washed from top to bottom with a detergent spray. True False
- The entire facility is disinfected using an approved product at the concentration recommended by the manufacturer. True False
- A high pressure sprayer (200 psi) is used for washing and disinfection. True False
- All feed pans, feed lines, and hoppers are emptied prior to cleaning. True False
- All feed pans, cones, hoppers, and waterers are scraped, scrubbed, washed, and disinfected. True False
- The feed bin, boot, and auger are regularly cleaned and disinfected. True False
- I clean, descale, and sanitize water lines between flocks. True False
- Loose feathers and debris are cleaned up outside the house. True False
- I allow at least 2 weeks for the facility to dry out and remain open. True False
- I rebed using clean, dry, litter, which is free of any moldy smell. True False
- I do not use hardwood shavings or shavings containing pine bark. True False
- I use an approved insecticide on top of new litter if insects are a problem. True False
- I clean and disinfect removable equipment like feed trays and jug waters just prior to setting the house up for new birds. True False

Personal Hygiene and Apparel

- I regularly clean vehicles that leave the farm and disinfect the cabs and beds. True False
- I shower before going out to work in the poultry houses. True False
- I do not wear street clothes or shoes in the poultry houses. True False
- I have a separate cap and pair of coveralls for each house and / or each brooder and finisher unit. True False

- I regularly launder my caps and coveralls, especially between flocks. True False
- I have a separate pair of boots for each house and / or brooder and finisher unit. True False
- I clean and disinfect my boots before and after use. True False
- I clean and disinfect my hands between units. True False
- I have disinfectant dip pans at every poultry house entrance. True False
- I change the disinfectant in the pans every 2-3 days. True False
- All visitors who wish to enter my poultry houses must wear
- clean, sanitized caps, coveralls, gloves, and boots. True False
- All soiled, disposable, apparel is disposed of on the farm when visitors leave. True False

Principle # 3: <u>FLOCK HEALTH CARE AND MONITORING</u> are essential for early detection and prevention of disease

- I immediately call my service person when birds appear to be sick. True False
- Sick or dead birds are regularly examined (posted) to determine if infectiousagents may be responsible for the problem. True False
- Birds are routinely bled to determine if any infectious agents may be present on the farm. True False
- Birds are are only vaccinated for agents known to have caused problems on the farm in the past. True False
- When using vaccines, I always follow the manufacturers instructions. True False
- I only use antibiotics when birds are sick. True False
- I always administer antibiotics according to the dosage listed on the label or according to the instructions of a veterinarian. True False
- I always use antibiotics for the full treatment period prescribed on the label or by a veterinarian. True False
- I never use expired vaccines or antibiotics. True False
- I try to stay informed with regard to disease problems that may be going on around me. True False
- I have taken the time to learn more about the types of diseases that affect poultry. True False

Principle # 4: <u>GOOD MANAGEMENT PRACTICES</u> make for a healthy environment

- I follow the temperature guidelines prescribed by the company. True False
- If the birds look chilled, I supply more heat without compromising air quality. True False
- I ventilate according to company recommendations. True False
- I consider the air in my houses to be suitable for human consumption (long term). True False

- I routinely remove caked litter or till according to company recommendations. True False
- I top dress with dry, composted, mold free litter or fresh, clean litter. True False
- I clean and disinfect waterers several times a week. True False
- I use a chlorinator or some other means to reduce bacterial contamination in my water. True False
- I raise feeders and waterers at the appropriate time to reduce wastage and litter contamination. True False

How Biosecure Is My Farm? To obtain a rough assessment of the level of biosecurity on your farm, count the number of "Trues" and "False" that you circled. Divide the number of "Trues" by the total number of "Trues and False" and multiply this answer by 100. Your final answer will be a percent. The closer it is to 100% the better your biosecurity and the lower your risk of disease. If you are close to 100% it doesn't mean you won't have a disease problem, but it does mean you are doing just about everything you can do to prevent a disease outbreak on your farm.

Endnote: A similar type of biosecurity self-assessment may be generated for aquacultural operations. Use this questionnaire as a template. Consider how each principle is addressed by the question; then substitute the various conditions and variables that would make it relevant to aquaculture.

For Additional Information on Biosecurity, see the Poultry Resource Homepage: http://www.apsc.vt.edu/Faculty/Clauer/clauer.html or obtain a copy of *Biosecurity in the Poultry Industry*, American Association of Avian Pathologists, New Bolton Center, 382 W. Street Road, Kennett Square, PA 19348, Tel: 610-444-4282, Fax: 610-444-5387, Email: aaap@vet.upenn.edu.

Common Chemicals for Cleaning and Disinfecting Aquaculture Facilities

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One of the most important biosecurity components of a recirculating aquaculture facility is the establishment of a comprehensive cleaning and sanitizing program. Before pathogenic and undesirable microorganisms in a facility and production system can be eliminated through the application of sanitizing compounds, a thorough cleaning program must first be applied. An effective cleaning program will remove various types of soils that will both: (1) reduce the number of pathogens prior to the sanitation procedure; and (2) provide an opportunity for the sanitizing application to physically contact the pathogens.

Selection of the optimum cleaning and sanitizing program for a recirculating aquaculture system and facility is complex and difficult for many reasons:

1. There are many chemical compounds and physical treatments that are available thereby making selection somewhat complicated.
2. There are no information sources able to provide performance data on the various cleaning and sanitizing compounds currently available. Recirculating aquaculture is a rather new science and biosecurity is a developing technology for this industry.
3. There is no single identified microorganism or virus that can be used as an indicator of cleaning and sanitizing effectiveness. Consequently, the establishment of realistic cleaning and sanitizing schedules combined with a quality control program is difficult, if not impossible, to establish with any degree of certainty.
4. Some of the equipment in a recirculating aquaculture facility is not easily cleaned and sanitized. Unless all equipment can be cleaned and sanitized, the effectiveness of an integrated program is highly questionable and may be ineffective. For example, a rotating biological contactor (RBC) is virtually impossible to clean and sanitize while pumps and pipes lend themselves to a CIP (clean in place) system.
5. Cleaning and sanitizing some equipment may result in the interruption of a production facility. Cleaning a biological filter can reduce the microflora on the filter, thereby severely diminishing or eliminating the filter's capability to remove toxic compounds from the growing waters. Also, cleaning and

sanitizing a filter may require redundant equipment to normalize production schedules.

6. Microorganisms are capable of forming biofilms which provide protection from cleaning and sanitizing chemicals. An effective biosecurity program will depend on the ability to remove biofilms since they may harbor undesirable microorganisms.
7. The type of materials used in the construction of a recirculating aquaculture facility may not lend itself to easy cleaning and sanitizing. Concrete provides a more difficult surface to clean and sanitize than either stainless steel or fiberglass. When designing a recirculating aquaculture facility, equipment and construction material selection should be a major biosecurity consideration.

As recirculating aquaculture becomes a more defined science and technology, advances in biosecurity will continue but in the interim, fish health will continue to be a major production issue with control being a somewhat empirical science.

Microorganisms such as bacteria, molds, and yeasts depend upon soils, feed particles, and other similar materials for their survival in aquaculture facilities. Soil particles protect microorganisms during facility cleanups by neutralizing the germicidal effects of some sanitizing agents and by preventing other sanitizing agents from penetrating to the microorganisms. Consequently, without first thoroughly cleaning tanks, fish handling equipment, floors, walls, etc. with suitable cleaning compounds, followed by flushing away, sanitizing agents alone are of little use. In fact, it has been estimated that effective cleaning is 90 per cent of an entire sanitizing program, while use of sanitizing agents is 10 per cent.

Generally, the function of cleaning compounds is to lower the surface tension of water so that soils can be lifted and flushed away. Cleaning agents are not intended to kill or inactivate microorganisms and viruses; sanitizing agents have that function. However, large numbers of microorganisms and viruses may be removed during the cleaning operation when lifted soils are properly flushed away. After cleaning the surface, sanitizing agents are used to destroy remaining organisms that are exposed as a result of cleaning.

The first requirement for an effective cleaning program is the use of <u>suitable</u> water in conjunction with the cleaning compounds. Next to the selection of a good cleaning compound, water is the most important consideration. Basically, the water should be clear, cool, noncorrosive, and most importantly, free from microorganisms. In addition, the water should be "soft." It has been found that "hard" water (water which contains minerals) may interfere with the action of some cleaning compounds, thus limiting the ability of a cleaning compound to do its job. It should be mentioned, however that some detergents contain certain components designed to counteract the effects of hard water.

Synthetic detergents are the most common cleaning compounds used today. Like soap, the primary function of a detergent in water is to make an insoluble soil water-soluble so it may be easily flushed away.

Selecting a suitable detergent to use may not be simple. To begin with, there are probably dozens of detergent manufacturers and each may have dozens of types of detergents. Moreover, each manufacturing firm has its own brand names and codes making selection even more complex. However, with a basic understanding of the various components which make up cleaning compounds, and with some feel for how cleaning compounds do the job, selecting suitable cleaning agents is not too difficult.

In order to understand the actions of detergents and other cleaning compounds, it is necessary to review the terminology usually associated with the subject.

1. Chelating Agents. Agents which prevent hardness constituents and salts of calcium and magnesium from depositing on equipment surfaces by binding such salts to their molecular structure.
2. Emulsification. The intimate mixing of two normally immiscible liquids. One of the liquids becomes disperse in the other in the form of small droplets.
3. Rinsibility. The ability of a cleaning agent to be easily removed from a surface with little or no residue.
4. Saponification. The hydrolizing of fats by alkali into water soluble components.
5. Suspension. The process by which a detergent lifts and holds soil particles in solution.
6. Water Conditioning (Softening). The process of moving or tying up minerals present in water.
7. Wetting Agent. Chemical agents with the ability to lower the surface tension of water to allow water to better penetrate soils.

A synthetic detergent is composed of a variety of chemical components, each designed to serve a specific function during cleaning. Depending upon the cleaning operation desired, detergents can be tailored to meet very specific cleaning needs. A knowledge of the types and capabilities of the various detergent components is important in understanding how cleaning compounds work.

<u>Inorganic Alkaline Detergent Compounds</u>

These detergent ingredients work primarily by dissolving food solids. They are especially good saponifying agents; however, many times they may be corrosive or irritating to the skin. For this reason, they are normally used only in heavy duty cleaning. The following are some of the more common inorganic alkaline detergents:

1. Sodium Hydroxide (caustic soda) - Caustic soda is an extremely powerful detergent with excellent saponifying capabilities; however, it is also corrosive and a skin irritant. Like other inorganic alkaline detergents, it has little effect on mineral deposits.
2. Silicates (sodium metasilicate, sodium orthosilicate, and sodium sesquisilicate) -

These are good emulsifying and saponifying agents. Like caustic soda, they have excellent capabilities for removing fats. These compounds are not as corrosive as caustic soda; however, they are skin irritants.

3. Trisodium Phosphate - Again, this detergent has excellent emulsifying and saponifying properties. It also has excellent water softening capabilities. It has no value as far as mineral deposit control.
4. Sodium Carbonate - This is one of the oldest alkaline cleaners used. The main function of this component in detergents is to serve as a buffering agent.

Inorganic and Organic Acid Detergent Components

Acid cleaners are especially valuable in removing mineral deposits formed as a result of using alkaline cleaners or other process activities. The organic acids such as citric, tartaric, sulfanic, and gluconic are also excellent water softeners, rinse easily, and are not corrosive or irritating to the skin. Inorganic acids, although excellent for controlling mineral deposits, can be extremely corrosive and irritating to the skin.

Surface Active Detergents (Wetting Agents)

The major components of these detergents serve the same function as soap; that is, emulsifying fats, oil, and greases. They are the components usually responsible for the formation of suds in detergents.

Basically, wetting agents may be divided into three major categories: cationic, anionic, or non-ionic.

1. Cationic Wetting Agents. Actually, detergents in this category are poor wetting agents, however, they do have the property of being strong bacteriocide agents. In fact, cationic wetting agents, like quaternary ammonia, are generally treated more as sanitizers than wetting agents. Chemically, these particular agents give positively charged active ions in aqueous solution.
2. Anionic Wetting Agents. These wetting agents are characterized by a negatively charged active ion when in solution. They are also the most commonly used wetting agents in detergents, since they are combative with alkaline cleaning agents and have good wetting qualities. Unlike cationic wetting agents, there are no bactericidal properties associated with them.
3. Non-Ionic Wetting Agents. Non-ionic wetting agents have no charge associated with them when in aqueous solution; consequently, they are effective under both acid and alkaline conditions. One of the major problems with non-ionic wetting agents, however, is their ability to produce large amounts of foam. Obviously, unnecessary amounts of foam may cause problems in drainage and sewage systems. A detergent does not have to foam to do a good cleaning job. One advantage of non-ionic wetting agents is that they are not affected by water hardness.

In review, wetting agents serve an important function as components in detergents. Most have strong emulsifying, dispersion, and wetting capabilities. They are non-corrosive, non-irritating, and are normally easily rinsed from equipment surfaces. Wetting agents are also responsible for suds formation produced by a detergent.

Phosphates

Phosphates such as sodium tetra-phosphate, sodium tripolyphosphate, sodium hexametaphosphate, and tetrasodium pyrophosphate, are excellent emulsifying, dispersion, suspension, and peptizing agents. In addition, they are easily rinsed away and are non-corrosive and non-irritating to the skin.

Enzymes

In some cases, detergents have enzymes as a component. These prove useful in removing protein buildups; however, because of the extended soak time for effectiveness, they are not usually practical to use in an aquaculture facility.

Components and Capabilities of Detergents

The preceding discussion addresses the basic components and capabilities of selected detergents. By using selected combinations of these components, detergents can be tailored to remove specific soils. The basic types of soils are: (1) fats, oil, and grease: (2) protein materials: (3) carbohydrate materials; and (4) mineral deposits.

1. Fats, Oils, and Grease. Obviously, one of the first requirements necessary to remove these kinds of soils is hot water. Hot water will melt or soften the fat, oil, or grease for easier removal. Coupled with this, a good detergent with saponifying and emulsifying properties should be used, usually one from the alkali group.
2. Protein Materials. Many proteins are soluble in the alkaline pH range; consequently, synthetic detergents with alkaline cleaners are useful in removing protein deposits.
3. Carbohydrate Materials. Since carbohydrate materials are readily soluble in water, nearly any of the synthetic detergents will readily remove these deposits.
4. Mineral Deposits. Mineral deposits may be a problem wherever hard water is used. Acid cleaners are usually the most effective in removing these deposits.

In addition to selecting cleaning compounds, some other basic factors affect the degree of cleaning:

1. The temperature and concentration of the detergent solution.
2. The amount of time the detergent is in contact with soils.
3. The amount of soil material to be removed.

4. The amount of agitation of detergent/soil interface.

Available Sanitizers

Before discussion of specific sanitizers and their use, the properties of an ideal sanitizer should be considered.

1. Should have good microbiological properties.
   a. Uniform, broad spectrum activity against vegetative bacteria, fungi, viruses, and molds.
   b. Produce rapid kill for inactiviation.
2. Should not be adversely affected by environmental factors.
   a. Organic matter (soil load).
   b. Detergent and soap residues.
   c. Water hardness and pH.
3. Should have good cleaning properties.
4. Must not be highly toxic or irritant to user.
5. Should be soluble in water in all proportions.
6. Should have a pleasant odor or no odor.
7. Should be stable in concentrate and use dilution.
8. Should be easy to use, readily available, and inexpensive.
9. Should be easily measured in use solution.

Now that we know the properties that an ideal sanitizer should possess, it can be stated that there is no such product on the market today. Further, there is no such thing as a "best" sanitizer. As we go from facility to facility, equipment, soil loads, cleaning procedures, and water supplies (to name a few factors) are different. This means that the sanitizer of choice will be different. Table I lists some commonly used sanitizers in the seafood industry and some characteristics of each. Table II describes the disadvantages of commonly used sanitizers.

Characteristics of Some Commonly Used Sanitizers

1. Steam. Sanitizing with steam is not a very effective way to do the job. The problem is that people mistake water vapor for steam and thus the equipment does not get the necessary contact time to do the job. Thus, it is very hard to have good control. With the soaring cost of energy, it is also an expensive procedure. Steam is not amenable to continuous sanitation of conveyors. If steam issued in a confined environment the steam flow should be maintained long enough to keep the thermometer reading above 170^{o}F for at least 15 minutes or above 200^{o}F for at least 5 minutes. When steam is used on assembled equipment, the temperature should be maintained at 200^{o}F for at least 5 minutes as checked at the outlet end of the assembled equipment.
2. Active Chlorine. Active chlorine solutions are extremely active sanitizers,

particularly as free chlorine and in slightly acid solutions. Those species are believed to act through protein denaturization and enzyme inactivation. Although effective against Gram-positive and Gram-negative bacteria, as well as some viruses and spores under certain conditions, it is quickly inactivated by organic soil and is corrosive. Active chlorine is economical to use, but is irritating. Concentrations of active chlorine can be easily measured by test kits and dispensed at a desired concentration.

3. Active Iodine. Active iodine solutions, like active chlorine solutions, can be rated as excellent all-around sanitizers. Combined with proper wetting agents to form iodophors, low staining and increased stability is imparted to the iodine. Iodophors are very stable products and therefore have a much longer shelf-life than hypochlorites. Iodophors are not as affected by organic soil as is chlorine, and they are active at a much lower concentration. They are also easily measured and dispensed, and the brown color gives visual control. Iodophors exhibit good penetration qualities, and their acid nature prevents film formation and spotting on equipment. The temperature of the use solution should not be above 120^{o}F, since free iodine will dissipate.
4. Quaternary Ammonium Compounds. The "quats" as they are commonly known, have become widely used on floors, walls, equipment, and furnishings. They are by nature wetting agents and thus have built-in detergency properties. They are good to use on porous surfaces, as they are good pentrants. Quats act against microorganisms in a different manner than chlorine and iodine compounds. They are often quite selective in the destruction of various types of organisms. They form a bacteriostat film when applied to surfaces which inhibits bacterial growth. Quat solutions are also easy to measure and they are more stable in the presence of organic matter than chlorine or iodine solutions.
5. Acid Sanitizers. The use of acid sanitizers combines the third and fourth steps of the cleaning procedure, that is, the rinse and sanitize steps. The acid neutralizes the excess alkalinity left behind by the cleaning procedure, prevents formation of alkaline deposits, and sanitizes. Acid sanitizers show good kill against both Gram-positive and Gram-negative bacteria. The mechanism of kill is believed to be caused by disruption of cell membranes. They are non-staining, odorless, stable, and easily measured in use solutions. They are limited, however, due to their effectiveness only at acid pH, and due to the generation of foam.
6. Dry Heat. Hot air ovens and chambers are not generally used because the method requires longer times and higher temperatures. When such cabinets are used, the temperature must be at least 180^{o}F for a holding period of at least 20 minutes.
7. Hot Water. An effective, non-selective sanitization method for food-contact surfaces, however, spores may remain alive even after an hour of boiling temperatures. The microbial action is thought to be the coagulation of some protein molecules in the cell. Hot water has several advantages: it is readily available, inexpensive, and nontoxic. Sanitizing can be accomplished by either pumping the water through assembled equipment or immersing equipment into the water. When pumping it through equipment, the temperature should be

maintained to at least 170°F for at least 5 minutes as checked at the outlet end of the equipment. When immersing equipment, the water should be maintained at a temperature of at least 170°F for 1-5 minutes depending on the size of the equipment.

8. Ultraviolet Radiation. Low pressure mercury vapor lamps which produce effective bactericidal action by the emission of radiation at a wave length of around 2500 A. have had limited use. Major applications has been with disinfection of air; however, installations of lamps have been reported on selected equipment and over open vats in breweries. Bacterial resistance will highly influence the lethal exposure time. Moreover, the light rays must actually strike the microorganism because the rays are absorbed by dust, thin films of grease and opaque or turbid solutions.
9. Chlorine Dioxide. Chlorine dioxide is becoming more popular as a sanitizing agent. The principal advantages of chlorine dioxide over chlorine are that it retains its antimicrobial activity in the presence of organic matter (as in slime layers) and at pH levels >7.5. In fact, high pH levels enhance the activity of chlorine dioxide. Traditionally, chlorine dioxide has been considered only for use in situations in which heavy organic loads are encountered. The presence of phenolic or nitrogenous compounds also indicate the need for this compound. Chlorine dioxide is corrosive and a skin irritant, therefore adequate control of the concentration must be exercised.
10. Phenols. Phenolic compounds have been in widespread use as a sanitizer, although their popularity has declined due to their potential toxicity and the fact they cannot be used on food contact surfaces. The antimicrobial activity of phenols is dependent on the exact formulation and concentration of the active components, temperature, pH, level of organic matter, and other factors. Higher-substituted phenolics tend to be insoluble and are frequently mixed with soaps to increase solubility. Phenolic compounds can only be used in conjunction with anionic detergents because both catanionic and nonionic surfactants destroy their sanitizing activity. This could lead to practical difficulties if phenolic disinfectants are used on surfaces where residuals from other disinfectants types are still present. Viral pathogens may be more resistant to phenols than the majority of bacteria.
11. Alcohols. Simple aliphatic alcohols are among the most widely studied disinfectant compounds. Alcohols do not appear to be affected by contaminating organic matter, but this may be because they are only effective at high concentrations. If the concentration of an alcoholic disinfectant is dropped below a certain critical level, then they rapidly become ineffective. It has long been known that the bacterial action of the aliphatic alcohols increases in the series: methyl < ethyl < propyl < butyl < amyl. Alcohols may or may not be effective against various viral agents, the effectiveness depends on the alcohol and the particular virus. Alcohols are also included in disinfectant formulations in lower concentrations to potentiate the action of other active components.
12. Aldehydes. The two principal aldehydes used as disinfectants are formaldehyde

and glutaraldehyde. The former is available as an aqueous solution of approximately 37% (w/w). However, the solution is relatively unstable and is usually supplied in a stabilized form containing 10 to 15% methyl alcohol. Formaldehyde gas, generated by heating the solid polymer paraformaldehyde, has been used to successfully disinfect surfaces contaminated with disease virus. Formaldehyde and glutaraldehyde are often considered as chemical sterilants because of their extremely broad spectrum of activity. Glutaraldehyde can achieve a rapid rate of kill against viruses as well as vegetative and spore forms of bacteria and fungi. The presence of organic matter does not appear to markedly interfere with the action of glutaraldehyde at its usual working concentration. Most glutaraldehyde-based disinfectants are used at 2% for high-level disinfection.

13. Bases. Basic compounds are not generally considered to be a disinfectant class on their own, but, rather, are included in disinfectant formulations as a means of modulating pH. In spite of this, many viruses are susceptible to high pH and many disinfectants are strongly basic in reaction. Caustic alkali solutions have also been recommended as disinfectants for particular animal viruses. One basic compound which has been tested against several viruses is sodium metasilicate.
14. Chlorhexidine and Polymeric Biguanides. Chlorhexidine is a cationic biguanide, available as dihydrochloride, diacetate, or gluconate salts. The gluconate salt is freely soluble in water and is the most commonly used in disinfectant formulations. However, contact with inorganic anions such as sulfate, phosphate, carbonate, nitrate, and chloride may result in a reduction of the disinfectant activity due to the precipitation of less soluble salts. These anions are commonly found in hard water and many biological fluids. Chlorhexidine shows a wide spectrum of activity against vegetative cells of Gram-negative and Gram-positive bacteria. It is mainly used as a topical antiseptic in either aqueous (hygienic hand wash) or alcoholic (waterless hand wash) solution because it combines a high rate of kill with persistence on the skin surface. Aqueous solutions are used for general-purpose disinfection and alcoholic solutions (60 - 90% ethanol or isopropanol) are also widely used in more critical areas. Polymeric biguanides are also available for general disinfection and are mainly used in conjunction with quaternary ammonium compounds for general disinfection.

Necessary Conditions for Sanitation

In order for sanitizers to be applied properly, it is critical that they be applied to surfaces free of visible soil. These soils include rust deposits, blood, grease, oil, protein, and mineral buildup. These soils provide areas for growth both below and within the soil, and in most cases hold food and water necessary for the bacteria's growth. Chemical sanitizers that would normally destroy the bacteria cannot adequately penetrate these soil deposits to do the job. That is why it is imperative to clean the equipment before sanitizing, or else the sanitation effort is largely a waste of time.

There are at least four physical/chemical factors affecting the use of sanitizers, including:

1. Time of Exposure. Studies have been shown that the death of a population follows a logarithmic relationship, so that if 90 per cent of a population were killed in a unit of time, the next 90 per cent of the remaining would be killed in the next unit of time, leaving only one per cent of the original number. The required time will not only depend on the preceding factors, but on microorganism populations and the populations of cells having varied susceptibility to the sanitizer due to cell age, spore formation, and other physiological factors of the microorganisms.
2. Temperature. The temperature dependency of the antimicrobial activity of a chemical agent represents a complex situation. Up to a point, the growth rate of the bacteria and the death rate due to application of the chemical will both increase with increasing temperature. However, a higher temperature also generally lowers surface tension, increases pH, decreases viscosity and effects other changes which may enhance its germicidal action. It should be noted that chlorine compounds are more corrosive at high temperatures, and iodine tends to sublime at temperatures above 120^{o}F.
3. Concentration of Sanitizer. In general, the more concentrated a sanitizer, the more rapid and certain its actions. Increases in concentration are usually related to exponential increases in effectiveness until a certain point when it accomplished less noticeable effectiveness.
4. pH. The activity of antimicrobials which occur as different species within a pH range may be profoundly influenced by relatively small changes in the pH of the medium. Quaternary compounds present a varied reaction of pH depending on the type of organism being destroyed. Chlorine and iodophors generally decrease in effectiveness with an increase in pH. These four factors must be kept in mind when applying sanitizers. If not, the sanitizer that is applied may not bring about the desired effect.

Biofilms

In their effort to maintain viability, microorganisms seek solid surfaces conditioned with nutrients for growth. When attached to a surface, microorganisms deposit, attach, and initiate growth. As they grow and multiply, the newly formed cells attach to each other as well as to the surface, forming a confluently growing colony of microorganisms. When this mass of cells becomes sufficiently large that it entraps debris, nutrients, and other microorganisms, a microbial biofilm is established.

Microbial attachment and biofilm formation may be detrimental and thus undesirable in a recirculating system. Potential problems exist, for example, in the attachment of pathogenic microorganisms to surfaces. Many investigators have studies the resistance of attached microbial pathogens to sanitizers. Microorganisms in biofilms were 150 - 3,000 times more resistant to monochloramine than were unattached cells. Biofilm resistance to sanitizers may increase with biofilm age.

In general, acidic quaterinary ammonia, chlorine dioxide, and peracetic acid were the most effective sanitizers on biofilms. Least effective were chlorine, iodophores, and neutral quaterinary ammonium compounds. When cleaning compounds prior to treatment with sanitizers were used, the bacteria in biofilms were inactivated. It has been reported that chemical cleaners were much more effective than sanitizers in eliminating specific pathogens in biofilms on stainless steel and plastic surfaces. A microbial biofilm is covered with deposited soil composed of fats, carbohydrates, proteins, and minerals. When treated with only a sanitizer, the chemical is inactivated by the deposited soil and becomes ineffective in reaching and destroying all the microorganisms. When the soil-covered biofilm is treated first with a detergent, however, the soil is solubilized and rinsed away. The sanitizer then is very effective in killing the exposed microorganisms.

TABLE I

Advantages of Commonly Used Sanitizers

Hypochlorites	Iodophors	Quats
Inexpensive	Stable Long Shelf Life	Stable Long Shelf Life
Active against all microorganisms	Active against all microorganisms except bacterial spores and bacteriophage	Active against many microorganisms, especially the thermoduric types
Unaffected by hard water salts	Unaffected by hard water salts	Form bacteriostatic film
Water treatment	Non-corrosive	Prevent and eliminate odors
Active against spores	Not irritating to skin	Not irritating to skin
Active against bacteriophage	Easily dispensed and controlled	Non-corrosive
Easily dispensed and controlled	Acid nature prevents film formation	Stable in presence of organic matter
Non film forming	Concentration easily measured by convenient field test	Easily dispensed and controlled
Concentration easily measured by convenient field test	Visual Control (color) Good penetration qualities Spot-free drying	Stable to temperature changes Good penetration qualities May be combined with nonionic wetting agents to formulate detergent sanitizers
Use Concentration		
200 ppm C1	25 ppm I	200 ppm quat

TABLE II

Disadvantages of Commonly Used Sanitizers

Hypochlorites (liquid)	Iodophors	Quats
Short shelf life	Not as effective against spores and bacteriophage as hypochlorites	Incompatibility with common detergent compounds
Odor	Expensive	Germicidal efficiency varied and selective
Precipitate in iron	Should not be used at temperatures exceeding 120EF.	Slow in destruction of coliform and Gram-negative psychrophilic bacteria (like Pseudomonas)
Adverse effect on skin	Staining of porous and some plastic surfaces	Not effective in destruction of spores and bacteriophage
Corrosiveness on some metals	Germicidal action adversely affected by highly alkaline water or carryover of highly alkaline detergent solutions	Expensive Slow to dissipate (residual problem) Objectionable film on surfaces treated Foam problem in mechanical application
Use Concentration:		
200 ppm C1	25 ppm I	200 ppm quat

Isolation and Quarantine - Practical Considerations

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Diseases can cause the economic ruin of a business using recirculating aquaculture technology. Among the many reasons this is true are: the lack of approved chemotherapeutics, the problems associated with treating the pathogen without killing the nitrifying bacteria on the biofilter, and the fact that recirculating systems often are very stressful to the fish being grown. The high density, feeding patterns, artificial feeds, and compromised water quality can lead to catastrophic losses if a disease outbreak occurs.

For a disease outbreak to occur three factors must be present:

fish - always present since these are the animals being produced
stress - can be severe at worst, chronic at best
pathogen - try to keep from introduction through quarantine and isolation

There are various methods that a pathogen can find its way into a production facility. Some of these ways include: water, air, feed, fingerlings, equipment, and humans

Some practical aspects to isolation for each of these methods of introduction include:

water
- separate water from production area
- one way flow from isolation area to waste discharge - never from isolation to production area
- gradually acclimate incoming fingerlings to facility water

air
- insure exhaust fan from production area does not feed into inlet for isolation area

feed
- purchase feed from a reputable dealer with a proven track record
- be aware of truck and delivery person interactions with the isolation area

fingerlings
- incoming fish should be isolated for 60 days
- get disease diagnosis and analysis from aquatic veterinarian

- remember what a Adisease free@ fish really is - one from a batch where, in a very small sample, a specific pathogen was not diagnosed
- use prophylactic treatment if recommended by the vet
- buy fingerlings from a reputable dealer

equipment

- keep the equipment in the isolation area separate from production area equipment
- make the isolation area equipment highly visible so there is no confusion

humans

- have company policy in place regarding personnel activity in and around the isolation area that is:
  - well thought out
  - well understood
  - well enforced
- require clothing change before entering
- have a foot bath at the entrance to the isolation area
- minimize traffic into/out of the area
- only authorized personnel permitted in the area

By following these simple suggestions the risk of introducing a disease to your facility will be greatly reduced - not removed. Remember that nothing can replace good husbandry practices. If you keep the fish happy, they will make you happy at the end of the year when you total your annual profit/loss statement.

Biosecurity and Fish Health Monitoring for Aquaculture Facilities

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Biosecurity is the protection of living organisms from any type of infectious organism. Thus, biosecurity in aquaculture is the protection of fish or shellfish from infectious (viral, bacterial, fungal or parasitic) agents. Designing an effective biosecurity program requires an understanding of the aquaculture operation, general principles of disease transmission, and knowledge of the fish or shellfish maintained in the facility.

Mortality due to diseases or decreased feed efficiency and/or decreased growth rates due to infectious processes are major factors for economic loss in aquaculture. In addition, as the density of fish or shellfish in an intensive aquaculture facility becomes more concentrated, the probability of individuals coming into contact with a potential pathogen becomes greater. Thus, safeguards to protect the health of both fish or shellfish in an aquaculture facility becomes very important. While aquaculture has made rapid advances in the past few years in fish and shellfish diagnostics, disease prevention and disease control measures lag significantly behind.

The primary goal of a biosecurity program in aquaculture is to prevent the introduction of any infectious organism into an aquaculture facility. Since this is not always possible, the goal may have to be modified to eliminate or control infectious diseases within the facility.

There are numerous potential sources of entry for an infectious agent into an aquaculture facility. These include additions of new stock (eggs, fry, fingerlings, production fish and broodstock); contaminated water or feed; humans, animals or equipment (fomites), and subclinical (asymptomatic) carriers within the existing stock (production fish or broodstock). Each of these potential sources needs to be evaluated and continuously monitored to prevent the entry of infectious organisms into the facility. Thus, a sound biosecurity program for a fish or shellfish aquaculture facility would incorporate a) disease prevention, b) disease monitoring, c) cleaning and disinfection between production cycles, and d) general security precautions.

Disease prevention includes the methods used to prevent the entrance of all potential pathogens into the aquaculture facility. One of the principle methods used to avoid the introduction of certain pathogens into an aquaculture facility is to purchase fish or shellfish from a producer selling certified specific pathogen-free stock. Though this does not

eliminate all potential pathogens, it does help reduce the risk of introducing the major pathogens of a fish or shellfish. Unfortunately, only a few species of fish (i.e. salmonids) or shellfish are presently sold in this manner. Thus, many producers have established in-house broodstock or spawning facilities to provide stock for their production facilities. In addition to disease avoidance, a rigid quarantine program should be incorporated to isolate any new arrivals at a facility. The time interval required for a quarantine period can vary, but will generally take between 45-60 days. During this time, the fish can be closely monitored for clinical signs of disease, sampled for diagnostic health techniques, and treated if warranted. Vaccination is another means of disease prevention in aquaculture. Though only a small number of bacterins are APHIS approved and commercially licensed for sale in the United States, it is only a matter of time before additional bacterins and vaccines are available to prevent or control a wide variety of bacterial and viral diseases in aquatic animals.

Another important method of disease prevention includes providing a pathogen-free water source. Thus, an "infected" water supply may require modern technology (mechanical filtration, chemical treatment, UV filtration, ozonation, etc) to make the water acceptable for a biosecure facility. Finally, optimal management techniques, including stocking densities, nutrition, and genetics) are essential for all aquacultured species to develop and maintain an optimal health and immunological status to fend off any potential pathogens.

Disease monitoring should be an essential part of any biosecurity program. This consists of regularly scheduled health evaluations of all stock in an aquaculture facility. Depending on the particular situation, this may include either lethal or non-lethal sampling or both. Non-lethal techniques may include gill, skin and fin sampling, blood analysis for hematology, blood chemistries, and immunological assays, while lethal sampling may include bacterial cultures, viral isolation and histopathology. Though none of these assays can completely guarantee that there are no potential pathogens in a fish or shellfish population, they do help reduce the risk of maintaining a pathogen in a population. An initial or pre-purchase health evaluation of new stock will establish baseline information about the fish or shellfish, and can provide valuable information if a disease occurs in a facility. Periodic monitoring can also help determine the number of individuals within a population that are infected, and the level or intensity of infection within that population.

An important area of disease prevention and control that is often overlooked in the aquaculture industry is disinfection. Routine disinfection is used to reduce the pathogen load in a facility, thereby reducing the risk of spreading an infectious organism between groups of fish or shellfish in a single facility. For example, providing an adequate number of containers of appropriate disinfectant for nets and other shared equipment is one method used to inactivate potential pathogenic organism. However, having separate equipment (nets, feed buckets, water sampling jars, etc.) for each production unit would be optimal in helping to eliminate the risk of contamination between production systems. Disinfecting live-haul vehicles after delivery of stock to farms or other facilities also helps to avoid bringing back a potential pathogen from these other sites. In addition, cleaning and disinfection of the aquaculture facility and associated equipment between production

cycles is very important and helps reduce the risk of spreading an infectious agent from one production group to the next.

Finally, general security precautions need to be established for each facility to help support the activities of both disease prevention and disease control. A manual of standard operating procedures (SOPs) should be assembled to provide a set of standard rules for biosecurity measures and disease monitoring. This should include such things as facility design, facility flow for both personnel and stock, rules for limited or restricted access to facility, required visitor log book, disinfection procedures for both personnel and equipment, a waste management plan, pest control guidelines, and general husbandry and management procedures. This manual should also incorporate procedures to be instituted if a disease is detected or an outbreak occurs. Record keeping is paramount to the success of any biosecurity program because it can provides accurate historical information about the health status, weight gains, feed consumption, vaccinations or treatments, and management practices of the facility.

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Recirculating Aquaculture Systems as a Teaching Tool

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Virginia State University's Youth Aquaculture Program has been an effective approach to youth aquaculture education for the past decade. (Nerrie, B.L. and A.O. Reid. 1991) Secondary and vocational school aquaculture programs that VSU has assisted have been very diverse, including caged fish, recirculating aquaculture systems, and combination aquaculture/hydroponic units. Recirculating systems have been either purchased from aquaculture suppliers, or developed by schools from local materials. Tilapia, catfish, rainbow trout, and goldfish were utilized. System volumes range from 200 liter single tank units to 6000 liter multiple tank structures. A survey of ten participating programs was conducted to evaluate recirculating systems as a teaching tool. The major educational benefits included problem solving, water quality, environmental, economic, simplicity and public relations.

Although not originally planned, problem solving was the primary educational benefit that was experienced by students. The need for problem solving ranged from complex percent body weight feed quantity calculations, or determining fish weight by water displacement, to simple tasks such as retrieving dropped nets from the bottom of tanks. A common situation that required group discussion and test solutions, was the uneven flow of water among multiple tanks, sump and biofilter. Adult supervision was able to observe as teams were formed to develop solutions to obstacles that would occur on a regular basis.

In all cases students had minimal experience with water reuse systems. Some experience was indicated by students who maintained aquaria. Student leaders who took charge of these groups delegated responsibilities. The need for safety was identified as a key concern when groups were working with water and electricity. Group skills in developing simple solutions evolved that would utilize the resources available. Labor specialization resulted with individuals becoming experienced in a specific task. Innovations were developed. One such innovation was a weekend feeder using a timer activating an air blower to push feed from a platform into the tank.

Students learned about water quality and its importance not only to the fish being cultured, but also to biofilter effectiveness. Activities included monitoring and recording temperature, dissolved oxygen, alkalinity, pH, and ammonia. The relationships existing among each parameter, the cultured fish, quantity of feed offered, and bacteria associated with the biological filter were discovered. Graphs were developed to show fish growth over time. Mortalities due to poor water quality were common. This ecological concept was seen by many students as representative of the society in which we live. Humans have the ability to

maintain a sustainable environment for the benefit of all.

Other environmental lessons included waste removal. Although many original plans called for waste water and solids to be utilized as a fertilizer for plant production, it was not. The effort to integrate the material into a secondary production system was not made because of two main reasons. Students were unable to dedicate the time to identify a nearby site to develop plant beds, and it was too easy to discharge the waste into available sewer drains. A lack of educational "return" from the extra time and effort was reported by students.

Keeping the system as simple as possible was recognized as important. Low density fish populations minimized water quality problems. Each moving part would increase the probability of a serious difficulty.

The benefits of public relations was indicated to be the most important goal of a school's aquaculture system. Tours of school grounds would include stops at the recirculating system, and the opportunity for students to discuss their efforts. The initial primary goal was to harvest a product that could be consumed by school board members, and generate positive publicity for the agriculture program. Students realized the similarities between major political fund raising dinners and their own efforts.

Learning can be defined as gaining knowledge by study, instruction or experience. Recirculating aquaculture systems provide excellent experiential learning.

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The Aqua-Manna Experience

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Introduction

Aqua-Manna is located outside of Ladoga, Indiana, about a half-hour northwest of Indianapolis in an area known primarily for it's grain, dairy, and hog farms. From this background of traditional agriculture, Jim Bradley set out to convert his hog operation into an aquaculture facility. Through several years of experimentation and research, Jim and a close friend were able to develop recirculating systems and system components. Today, Aqua-Manna is a growing aquaculture enterprise specializing in the culture of tilapia and the innovative design of aquaculture technologies. The recirculating systems developed by Aqua-Manna are now used throughout the United States and Aqua-Manna has also established a facility, which has the capacity to raise 100,000 lbs. of tilapia/year.

History of Aqua-Manna

In 1978 Jim Bradley was a successful hog and grain farmer who was in the process of building a new furrowing house. In the years that followed, it became painfully evident to Jim that the economic outlook for the small, family hog farmer was dim at best. It was during this time that he first started to consider aquaculture as a viable alternative. Jim had read an article by the state aquaculture co-ordinator about yellow perch culture and he made a trip up to see LaDon Swann at Purdue University about the possibility. After more research into the "process" of fish farming and investigating current systems in use, Jim formed Aqua-Manna and removed the hog pens from the furrowing house in 1990. Aqua-Manna then began gaining experience with fish, holding bluegill and catfish in horse troughs using sump pumps and nylon filter bags to recirculate the water.

The following year Jim decided it was time to begin raising yellow perch. Important in this decision was a trip to a fish market in Ohio where Jim discovered first hand, the market potential for yellow perch. An Indiana high school, South Putnam High School, had recently started a recirculating aquaculture program. Jim also visited this new facility which laid the foundation for a new system design for the yellow perch culture. The system consisted of 800 gallon tanks with a settling chamber made out of a plastic barrel with a specially designed conical bottom and a biofilter which used film rollers for biomedia. They were able to get their first batch of yellow perch up to an average of 3/4lb. in a year. They soon discovered, however, that the normal market size yellow perch was three to four fish to one pound and that they would have to clean the fish before market. These problems were corrected during the next season.

Throughout this time Aqua-Manna had been researching and experimenting with new component designs, and talking with other entrepreneurs in recirculating aquaculture. A new biofilter was placed in production using a new type of biomedia, corrugated plastic sheeting, rolled up in a tank and used as a trickling filter. To increase efficiency they designed and built a new drum filter, subsequently named the SETO 5000, to replace their existing solids filtration. Once developed, Dr. George Libey started working with them testing and improving the new drum filter. After two years Aqua-Manna applied for and received a patent for the SETO.

With all the components designed, a friend of Jim's with interest in aquaculture bought two of these recirculating systems. The ensuing success of these systems led Aqua-Manna to expand its own facilities. A new building was built which could hold twelve of the new systems and the old furrowing house was transformed into a tilapia hatchery and fry grow out facility. Once investigative new animal drug permits became a requirement to sex reverse tilapia, Aqua-Manna began relying on outside breeders to supply their fry. The old furrowing house is now used a growout facility for the fry before they are transferred into the larger building. During this expansion, Aqua-Manna also hired an aquaculturist to help the technical aspects of nutrition and system management.

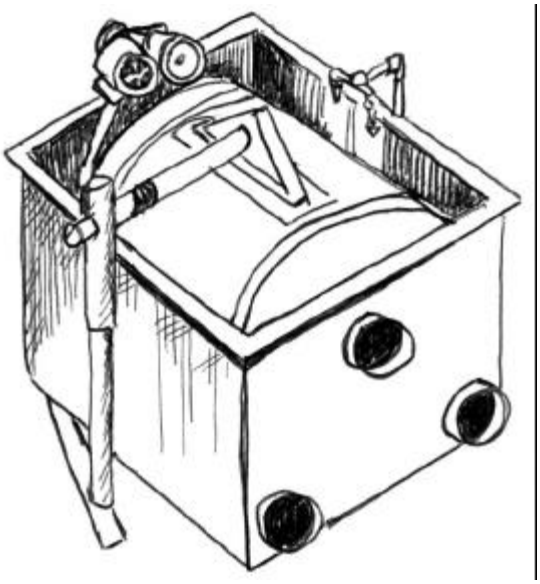
The new recirculating systems in the large building did well in the beginning, and they were able to reach production levels as high as 3,800 lbs per system. During this time they were also developing a market for the tilapia by working closely with another group of entrepreneurs, who were starting up their own live-haul business to supply various Asian markets throughout the Midwest. Aqua-Manna also began working with Purina Feeds to develop a tilapia feed for recirculating systems. The success of the new systems also led a farmer from Sheboygen Falls, Wisconsin to purchase two complete systems to raise yellow perch and these system are still in use today. Along with the new facility and increased production came local media, but problems were just beginning to surface. Technical problems with the pumps used with the systems started to occur along with production levels that stagnated at the 3800 lb. level. The main production problem was clogging of the biofilters. Through the use of a specialized, rotating, high-pressure sprayer, which was designed to clean the biofilters, along with the installation of different management practices they were able to overcome the production problems. Today, Aqua-Manna has been able to increase production levels to approximately 6000 lbs. per system. They have also continued to make improvements to their system along the way. A slightly different system was also set up for a farmer in La Porte, Indiana based upon the problems and successes of their own systems.

Facility and Recirculating System Description

The Aqua-Manna facility is a mixture of older farm buildings and the new fish barn. The fry growout building is a remodeled hog furrowing house with the center drain mostly filled in, the walls reinsulated, and a water reservoir was installed. The new fish barn is 50’ x 150’ pole barn with a ten foot insulated ceiling and four to six inches of spray insulation covering the walls. It is equipped with a small propane heater (30,000 btu),

electric water heater (60 gal.), three 2,000 gal reservoirs, a large (200 hp) backup generator, and a 1 hp blower to provide suction for the SETOs. Water is supplied to both the hatchery and fish barn from a 20 gpm well, which is more than enough to replace the approximate 6,000 gal of water used on the farm each day. The waste from both the hatchery and fish barn flow into a pit below an old hog growout building. The solids settle out in this pit and the clean water then flows into one of two lagoons that are on site. Water flow and electrical outages are monitored constantly by alarms for all buildings.

Figure 1: SETO 5000 Vacuum type drum filter.

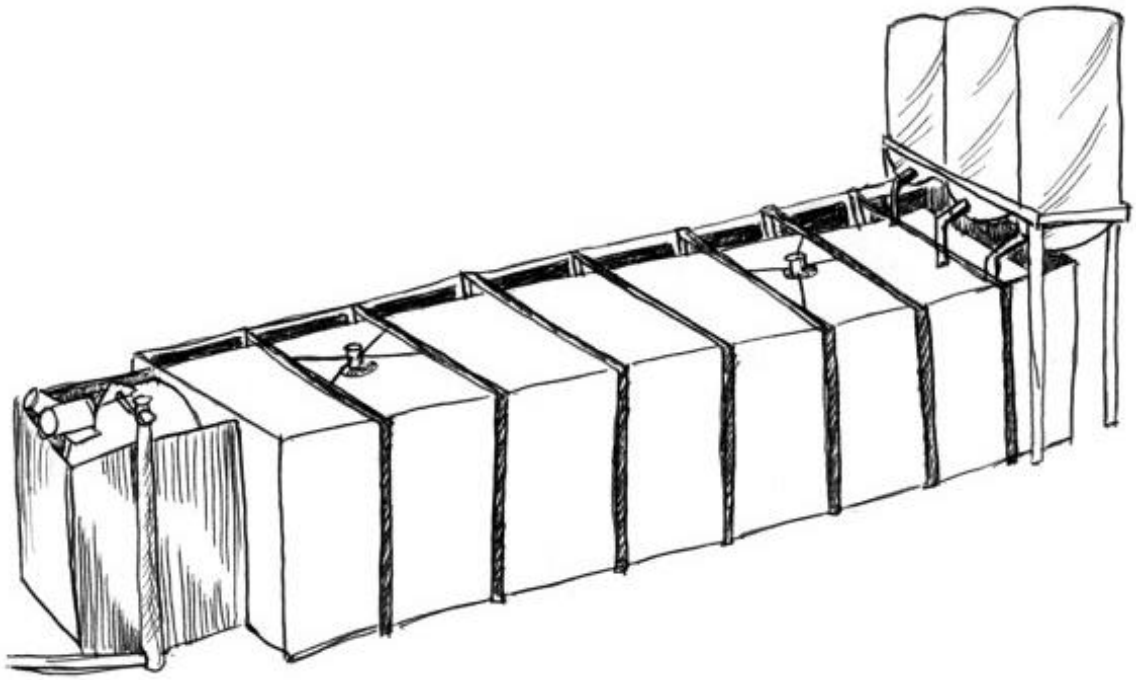


The system described here is the basic one designed by Aqua-Manna and there are several versions and alterations to this basic system. The Aqua-Manna recirculating system is designed for moderate amounts of fish production, 0.5 to 1 lb./gal. of tilapia. This system is able to support this production without the use of any exogenous oxygen because of the rapid flow rate, three to four tank volumes per hour. This rapid turn over allows for more aeration through the trickling filters and the only supplemental aeration is supplied by two 1/3 hp surface agitators. The flow rate also helps the trickling filters with their biofiltration by allowing more passes and therefore more nitrification to occur. The drum filter is a good solids filtration device for this system because of the high flow rate. A settling type filter would require an excessive amount of space. The SETO uses approximately 300 gal. of water each day, which is sucked off with the fish waste from the screen (Figure 1).

The basic system holds 7,000 gal. and consists of a 4'h x 8'w x 32'l culture tank. The culture tank is made of a snap together metal frame, with the bottom and side support supplied by plywood, and a 35mil PVC liner inside. Water gravity flows from the culture tank to the solids filter a SETO 5000. The SETO is a vacuum style drum filter and it

features a continuous drain and spray attachments for supplemental screen cleaning. It can handle a flow rate up to 500 gpm and provides up to 36 sq.ft. of filtering surface per minute. Clean water leaves the SETO and gravity flows back along the length of the culture tank to three high volume, low head, 1 ½ horsepower pumps. The water is then pumped to the top of the three trickling filters. The trickling filters, the BIO 5000, consist of a water conditioning tank filled with corrugated plastic sheeting and a rotating spray bar at the top. The BIO 5000 is 30" in diameter and 48" tall. It supplies 5000 sq. ft. of surface area, and can handle flows up to 170 gpm. From the biofilter water flows back into the culture tank through foam fractionators (Figure 2).

Figure 2: Aqua-Manna Recirculating Raceway



Jim Bradley has designed various other systems using these same components. In the hatchery building, the fry growout tank systems consist of two 1,000 gal. tanks. These two tanks share a SETO for solids removal and each has its own 1 1/2 horsepower pump and one trickling filter. With the addition of a surface agitator, this system can hold and grow more than 10,000 tilapia weighing 50gm each. The system which was set up in La Porte, Indiana is yet another adaptation of the same components. Two culture tanks (4'h x 4'w x 24'l) are connected to one SETO. From the SETO water flows to the two culture tanks, where a two horsepower pump, one for each tank, lifts it up to two trickling filters. Water flows back through the culture tank where there up to two surface agitators for additional aeration.

Cost Analysis

Throughout the past two years that the new fish barn has been operating, Jim has been able to estimate some the operating expenses for raising tilapia in his facility. Table 1 shows estimates of the variable operating costs for tilapia reared by Aqua-Manna and those reared in other recirculating systems (O'Rourke, 1990, Lasorda, et. al. 1991). Aqua-Manna is able to reduce costs of production in various categories: labor is reduced because the system can be operated by one person and weekly harvesting requires only two personnel, heating costs are reduced by the building insulation and the heat produced by the many pumps, and liquid oxygen is not required.

Table 1: Variable Operating Expenses for tilapia culture in three different recirculating systems.

	Aqua-Manna		**O'Rourke, 1990**		**Lasorda, et.al. 1991**	
Direct Operating Exp.	Cents/lb.	% of Cost	Cents/lb.	% of Cost	Cents/lb.	% of Cost
Feed	26.0	30%	29.0	20%	26.1	24%
Electricity	20.0	23%	11.0	8%	16.8	15%
Heating	1.5	2%	10.0	7%	3.3	3%
Liquid Oxygen	0.0	0%	20.0	14%	0.0	0%
Labor	5.0	6%	29.0	20%	16.9	15%
Fry	10.0	11%	11.0	8%	9.6	9%
Depreciation	15.0	17%	16.0	11%	18.2	17%
Maintenance	5.0	6%	10.0	7%	9.4	9%
Miscellaneous	5.0	6%	7.0	5%	10.0	9%
Total Cost per lb.	**$ 0.88**		**$ 1.43**		**$ 1.10**	

Past Experience and the Future of Aqua-Manna

The history of Aqua-Manna experience has been full of both successes and failures. Technical problems along with the need for a re-organization of Aqua-Manna'a corporate structure have taught Jim difficult but valuable lessons. One of the lessons learned however, is the need to constantly maintain and monitor the vital business relationships Aqua-Manna has formed over the years. One of the most important Jim has is with his bank and he considers constant communication a necessary component of his business.

Dealing with fish culture and system design is Jim's favorite part of the operation. After the aquaculturist left to pursue other career opportunities, Jim took over the day to day management duties. He has enjoyed the challenge of locating production problems and devising management practices to solve them. With this "hands on" approach Jim has able to constantly alter and improve the initial system design to increase production capacity. For example, Jim has found that with his large grow out tanks he only has to utilize two of the three biofilters at any one time. This allows him to adequately clean and unclog the third biofilter and this process of filter rotation not only maintains better water quality, but it also reduces electrical cost by running two pumps instead of three.

At this time Aqua-Manna offers its own recirculating systems and system components, ranging from commercial size to classroom scale systems. If a farmer or organization purchases a system, Aqua-Manna will deliver and help in the initial set up. Aqua-Manna also has services available to supply different sizes of tilapia, and they are a Purina fish food dealer in Indiana. If a farmer chooses to take advantage of these services and follows management practices suggested by Aqua-Manna, then Jim will also help with the marketing of their fish through the live-haul service which Jim uses.

Aqua-Manna has accomplished much over the past eight years, graduating from horse troughs to designing and managing an economically viable recirculating system. Further research and development projects include the design and use of airlift pumps and floating rotating biological contactors. The reduction of electrical costs will be a key feature of this new system. Jim is also in the process of planning an expansion of his current fish culture operation, which will increase capacity by three to four times. Aqua-Manna is also exploring the potential of other fish species to meet the demands of their growing markets. These projects along with design, consulting and production of recirculating systems for other farmers should keep Aqua-Manna on the path to success.

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Acknowledgements

The authors would like to thank Kim Shanks for his help with the illustrations.

IT WORKED, BUT...
A Short, Abridged History of Shenandoah Waters

William K. Stackhouse
Shenandoah Waters

Understanding that this is one of four papers, two winners and two losers, I put myself in your position to see what I would want to hear from this group of experienced people were I to be just starting out. This is not an academic piece. I intentionally wrote it in the first person to move it away from abstract thinking and bring it into the world you live in. My eyes have always glazed over confronted with academic treatises.

To quickly dispel any question of which of the two camps I represent here; it is that of the "loser." Overall, I put $1.2 million into a combination of capital assets and working funds. We ran into a number of problems that eventually closed the door. But, success was mingled in with the difficulty. I'll talk to both for you.

I had gotten my engineering degree from the Air Force Academy, picked up an MBA from Auburn, and had done some work at the PhD level in Organizational Psychology. Having had project management experience in both the Air Force and industry and having helped two other businesses get off the ground, I felt prepared for my own new start. It was the mid 80s. The plight of the oceans and the promise of aquaculture had not yet universally dawned. And, I was ready.

I was looking for a business venture when a small article about hybrid stripers grown in a tank appeared in the Washington Post. The chef of a good hotel had tried and liked it. He was in the hotel next to the building I worked in. A short talk with him revealed the price he paid. A quick call to a manufacturer gave me a feed price. Some more calls got me to Virginia Tech and Dr. Libey who gave me grow out data. I hypothecated some facility sizing, staffing and start up costs and whipped it all into a spreadsheet. The profit margin popped my eyes. I had my business.

Of course, aquaculture was all new. The chef had paid $5.00 a pound and the feed was for catfish out of Mississippi. I pressed ahead with abundant confidence and unflagging energy.

My first task was to find water. Hard water. For two years I looked all over Virginia. Finally, I called the State Hydrologist who faxed a map of where such water could be found showing it in shades of gray. The area around Strasburg where 66 and 81 meet looked like an ink blob. Got some land on a contingency, sunk a test well and ran it over night with an ammeter on the pump. The ammeter showed a DROP in current over time rather than an increase in draw, as you might expect. The driller had hit a seam in the fractured karst limestone. As the flow continued, it had cleaned out the passages leading to the pipe and the head actually came up

from 300' to 75' and never moved through the worst drought even though we pumped at 100gpm. Water tests showed good, clean water with no appreciable iron or sulphur. I had my water.

My walk-around money came from some stock in one of the businesses I had helped start. Now, with a site in hand, I needed a big chunk of cash to get going. I tried many, many avenues. Banks (What a laugh as their risk tolerance is nonexistent). Venture capitalists (Not far from banks and, if you don't watch out, they will wind up owning your business). Angels (Private investors who are the best bets). And some weird ones with weird schemes. In fact, the largest single contact category in the database I kept was for financial purposes. Financing is the single greatest hurdle for most wannabe aquaculturists. The aquaculture business is very capital intensive.

Finally, I went down the Small Business Administration (SBA) loan road using a non-bank lender. A non-bank lender is a financial institution which has money to lend and has done sufficient work with the SBA that they have only to notify the SBA when the non-bank lender has made a loan guaranteed by the SBA. As I got into the paper work, it became clear that the amount of collateral available was not enough to build the one or two tank system I wanted for starters.

By this time, my spreadsheet had become the mother of all spreadsheets capable of spitting out full financials with ratio analysis in both accrual and cash basis at the change of a feed price. If I came across a variable, say fish management - two tanks started at a time vs one or, three months between starts vs two - it was worked into the sheet. While playing with the numbers, I discovered that the bigger the facility, the more equity became available. It was just economies of scale kicking in, but the appraiser ran by a set of rules dictated by profit margins. I resized the facility to six tanks and submitted the paperwork. I had my money. Or, so I thought.

In negotiating the final amount with the lender, I let myself be talked out of the built in safety margin. This proved to be the undoing of the enterprise. Problems arose from the start.

The money was planned around a Spring go. The bulk of the money didn't come through until early Fall. The entrance of the unused county road we had planned on renovating was gated off by a property sale and my lawyer said it would be two years in court to get it opened. We had to build an unplanned road. An unplanned hill had to be leveled to get enough space for the building pad. Rains washed out the entire month of October. One challenge after another. Before the first fish had arrived, the enterprise had taken heavy hits. But, I could always see a way through by working the magic spreadsheet. Fine tuning. Sharpening the pencil. However, each time I found a way, the chain of "ifs" lengthened. "If this works out, then that'll be OK."

I don't mean to deprecate the value of a spreadsheet. It is a wonderful tool. In constructing

one, you are actually modeling your business. It is the best exercise available in forcing yourself into the hard numbers. Problems emerge from those numbers you could not possibly imagine without one and it lets you prepare in advance. It is the closest thing to a crystal ball on this planet.

After losing one or two people, we wound up with a gallant group of four, each with his own strengths and weaknesses. I led the parade - laying out buildings, rendering tank concepts to executable designs, showing where to dig for lines, getting utilities in, etc. We all did the physical work. My problem at this point was I had to do too much "Do this next." work. An older gentleman was recommended to me. He showed up and looked to be fragile. I thought there was no way he could cut it; but, he went into the lineup anyway. In two or three days my, "Do this next." activity stopped. The others were naturally going to him and he was leading the "doing" part of the work which greatly freed me. He was a retired Army Master Sergeant. Gentle, suasive, and able to look at something mechanical and intuitively know how it worked.

For the most part, these people had come from extremely hierarchical work backgrounds. The military is avant garde in the people business next to most of the companies in the area. From the beginning, I wanted the people in the organization to feel this was their business, too. I wanted them to participate in finding and fixing problems which I knew they would know about long before me. One of the most difficult, yet important, things to do as a manager is to allow people who work for you the latitude to fail. If you ever want to grow their trust, you have to trust them first. This is particularly so for a small start up. You haven't time for union rules. It pays off. They never failed.

On more than one occasion during the night when no one was on site, we would lose power, or an alarm would go off, or a compressor would overheat and drop off line. In every instance, I was the last to be notified and by the time I had the word, someone was on site with the rest close behind. They thought and cared about the business. It was "we", not "us and them." They had transformed from a production line mentality to self starters and they loved it. They had taken the enterprise's mission to heart. That attitude carried us far beyond the point at which a standard new start would have failed. I view this as the finest organizational achievement of the effort.

We pressed on with the construction and soon had the roads, buildings and tank systems completed and we commenced to raise hybrid stripers. The system worked OK, initially. Soon, however, it became apparent we needed a modification to the solids filtration system.

The touchstone for the design was a PhD Fisheries Scientist with experience in recirc systems and not of Virginia Tech background. He was a consultant, highly paid relative to the rest. His view was that a 100 micron filter would do the job. I designed a system using de-watering grates from the mining industry. Water flows across a top lip at about the height of the main tank, goes into smooth, laminar flow and drops vertically across thin bars horizontally placed.

The bars are stacked vertically for about two feet where the configuration begins to move outward to be nearly horizontal to the ground. Like a "J" without the upsweep. It operates on the Coanda principle whereby a liquid in laminar flow will adhere to a smooth surface through about 120 degrees of turn. They were rated at the required 100 microns of particulate separation.

I had early on expressed concern about the material integrity of solid fish waste thinking it was very susceptible to breaking up. Turned out it was. We had built a solid fish waste emulsifying machine. When the fish grew to a point that they were turning out a lot of waste, they were also big enough to beat their own waste up when feeding and we broke up what was left with the filter.

I now had a major fix to do and not enough money left. I found a venture capitalist (VC) who pledged $300,000 in exchange for preferred stock and positions on the board. The first draw was for half the amount. With that we were to begin the retrofit, start on four new tanks (the building would hold 10 tanks and the VC wanted it all up), and begin an in-house breeding facility.

As we had phased the fish in over time, some tanks were lightly loaded and some were empty. One of the group came up with a plan to spread the fish around while we did the mod. This let us get some fish to market.

The fish were extremely well received. We would chill shock them and put them on ice. When they reached their destinations, it was not unusual for them to begin flopping on the counters. In the DC area, this hadn't been seen for years and the old fish guys were amazed. We had live haulers stopping by. Individuals were calling us. Distributors wanted in. One fellow wanted us to get into perch because the Great Lakes production had been curtailed. Another wanted us to build a facility in the Boston area. They had processing capability, but no fish. It was bittersweet success.

Construction on the filters had just begun when the VC changed account managers. The old one had been pro aquaculture, the new one was from hi tech, knew nothing about the business, and did little to hide his disdain for such a lowly industry. Our remaining money was quickly frozen while we were midstream on the mod, which was the only path to profit. Only one filter was completed. The water in that tank was very good and our best fish were grown there. We changed to tilapia because it was far more tolerant of high particulate levels and low oxygen concentrations. We changed from propane to oil heat, suspending house radiators in the water. We rigged three tanks sets so that the center tank of each was a settling tank.

The operation continued for almost two more years, limping along on the sale of the meager amount of fish of which the crippled facility was capable while I looked for money. With the track record and an obviously hostile VC on board, I got sympathies, but no money. Finally,

a series of severe March storms did us in. A heavy snow was followed by a warm front with rain which was pushed out by an Arctic event, all within two days. Temperatures dropped into the teens. There were 12 inches of glass-smooth ice covering the three quarters of a mile of hilly road between us and an oil truck. When the storms passed, we had 10 blocks of fish-impregnated ice. It was over.

Shenandoah Waters went into bankruptcy and came off the auction block at $85,000. The facility is in complete disrepair today.

SOME THOUGHTS WHILE STROLLING

1. Start small. If you have a system that is working, you can find money. Investors will put money up if you can prove your way will work. The best way to do that is to produce fish and put them in the market. They will buy a 2x system scale up, but not a 10x scale up.

2. Be patient as you work your way past the start up phase. Get the bugs out of your system here. Investors don't like startups. They are the most risky investment of all. There was no money available for technology demonstrators when I started. Today, the Center for Innovative Technology near Reston has money for start up equipment demonstrators.

3. Estimate everything in your disfavor. Expenses high, revenues low, ramp up long. When you do get a number, be prepared for it to double in both cost and time.

4. Do a self survey. If you go into it, can the family stand the down side? Can you? You can lose everything. Raising a living thing that eats is an every day job. Much as it looks like a production line, it isn't. There is no whistle that closes out the day and the line shuts down.

5. Disabuse yourself of the notion that it's easy. It's not. There is a lot to learn. Water chemistry, feed rates, fish size estimation, marketing, buying consumables, small business paperwork and much more than you have conceived of yet. Virginia Tech is an outstanding resource. So are your fellow aquaculturists. There are two types of people in the business - those who think they have the answer to the aquaculture equation and put their arms around what they know without sharing, and those who will survive. Find those who will share and do the same for them. You are building an industry. You can do it together, but not alone.

6. Come quickly to an understanding that it's expensive. Beginners will focus on finding cheap tanks. Tanks are about the least expensive item in the list. Experienced folks will focus on pumps, valves, heating, feed, fish handling and marketing.

7. YOU are in charge. It's your fall to take if it doesn't go. If your gut tells you something is wrong, straighten it out. Even PhDs are wrong sometimes. The U-tube at Virginia Tech is only half as deep as it should be because a PhD (not of Virginia Tech) who made up the tables, got it wrong.

8. If you deal with financial people, make sure they can help you. The non-bank lender was out of St Louis. The venture capitalist firm was itself a new start with a hi tech focus. They will ask you for references as they do due diligence. You do the same. Working with a VC is like making a match. It only works if both parties are compatible. Remember, they are selling you money and you are the buyer.

9. If you establish a board, make sure they understand things that eat, grow, and can die. My VC and entire board came from a hi tech production background. In manufacturing, if something is out of kilter, you can throw a switch, shut down the line and fix it. That's what the second account manager I had was about when the money was held up. He engaged in an in depth review while the opportunity to fix the filtration problem slipped away. By the time he finally realized what was happening, the amount of money it took to fix the problem had to have added to it the cost of a growout restart. The board looked good on paper, but didn't work. You might want an advisory council rather than a board to start with.

10. Have a tape recorder at every board meeting for everyone's sake.

11. From the outset, establish a professional relationship with an accountant and lawyer.

12. Realize you are in the fish business, not the new, innovative systems business. If you can do your job with warm spring water running through feed troughs, do it. Forget about recirc. It's a means to an end, not the end.

13. Use a proven system. The early on PhD consultant considered the Virginia Tech system to be Neanderthal. It worked then. It's still working now.

14. Eventually, recirc will take over. Regulations and operating parameters are closing in from all sides. Total particulate emission controls and total chemical release rather than parts per million will rule. The ditty, "The solution to pollution is dilution." is cute, but passé. Already, some species, tilapia being a prime example, can only be raised in closed systems in many states, Virginia being one. Be prepared for these new regulations. Have the land and the money earmarked to deal with them. They'll be expensive.

15. Eventually, big systems will take over. Economies of scale dictate this. Check what Cosco or Home Depot or Staples have done to their industries. On the other hand, niche markets will continue to exist. If you plan to be small, just try not to be on the big guy's turf when he moves in. Offer something different. Differentiate your product. Your market will switch in a heart beat if they can get acceptable fish appreciably cheaper.

16. The approved bullets in the fish medicine cabinet are few. This is a major risk factor when determining whether you should go into the business and a major factor for investors.

17. If you have people working for you, your business is your people. Your peoples' business is the business. You have to create the conditions and find the resources to allow your people to function.

19. Should you go for a loan, all your assets may be included in the collateral package and your wife will have to cosign. The financial people penetrate the corporate veil with personal contracts backing up the loan. Unless you are well heeled, your house will be on the line.

20. Do not allow yourself to be deceived by accrual accounting. It makes the business look better than it is. Keep a set of your own numbers that you generate. Some say to do this by hand. I believe a spreadsheet can do a better job, faster and more legibly. You can also run excursions on "what ifs" to improve your understanding of what the numbers really mean. This doesn't have to be a mongo spreadsheet - just enough to know how much money you have coming in and going out for the next few weeks or months.

20. Pay yourself. Many people who run numbers don't include their salaries. They plan to take what is left after the fish are sold. Would you really go into the business knowing you might make only $.50 an hour?

21. Don't let anybody get between you and the market. Many in the catfish industry were harmed by allowing the processors to grow as a separate group in the chain. Wall street money went into the processors when aquaculture got a play. It was OK as long as a balance existed between producers and processors. But, when processors began to proliferate, there were only two ways for profit margins to be sustained - the processors could either put a lot of time and money into increasing market size or, they could lower their price and grab market share. The latter was quicker and less expensive up front and that's what they did. As new processors came on line, the profit squeeze was passed on to the producers who got less and less while their expenses continued to rise. I believe the best bet for small producers is to establish an association or coop.

22. Get into your own fingerling production ASAP. You will be able to: control quality, control almost all foreign disease vectors and, take the pick of the litter. I am told that some fingerling producers will ship culls to their new or small or infrequent customers while the best go to preferred customers. You won't know what you get until too late.

23. If you take fish from the outside, have a quarantine area away from your growout tanks in another building. Don't put anything in the tanks that hasn't been checked out.

24. Keep data. Do your water tests religiously and put them in a database. Same for feed and all other consumables. Set it up so you can get a variety of graphs out. Some growers fail to keep data. I don't understand how these people have a clue as to what happened when something goes wrong. Bounce your actual numbers against your projections.

25. Have at least one or two people who really understand animals. One of our group used

to spend a lot of time between feedings just looking into the tanks. He developed a sixth sense and could provide a heads up long before more apparent symptoms were noted.

26. Beware of gravity. It never tires; but, you and your people do. Our tank tops were six feet above ground level. We had a rock ledge under the building pad that precluded putting them down. At first, it was easy hauling fingerlings and their feed up and over. We were doing it manually. The fish did grow, however. Each day the feed load to be lifted increased until we wound up with two people with slipped disks. Fish handling was equally tough. Design your system to as little manual lifting as possible.

27. Stay away from poly buildings. They're cheap up front, but cause no end of problems.

POSTLOG

You may wonder what my current conditions are and what feelings I may have.

My marriage is intact. Never a doubt there. We're childhood sweethearts and will be forever.

Bank account is a different matter. Savings gone. No appreciable equity was left in the house after the SBA settlement.

Would I do it again? Of course, but differently. I regret the failure, not the attempt. Remember, only one in five new starts makes it. I would rather leave this world having tried and failed than leave it wondering.

I would like to express my particular appreciation for the efforts of Dr. George Libey and his staff in their support of the venture.

Finally, good luck to all who choose to strap on a new business.

Critical Considerations for Greenhouse Tilapia Production

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Introduction

Several Louisiana tilapia growers have developed semi-standardized, greenhouse-enclosed green-water recirculating systems that have been shown to be cost-competitive when compared to other growout approaches currently in use throughout the U.S. These systems utilize net pens suspended within rectangular growing tanks to facilitate concurrent batch stocking and harvesting, allowing physical isolation of specific size- or family groups within a system. The typical layout utilized by these producers has also been adopted by growers in Florida, Illinois and Maryland, and is receiving considerable interest from potential growers in a number of other states and countries.

As Louisiana's greenhouse tilapia industry has developed over the past decade, we have gained a number of insights that bear consideration by established producers as well as individuals considering an investment in tilapia aquaculture. This discussion will attempt to address both audiences by briefly raising a number of questions that must be considered prior to an investment of money and time, and a number of technical considerations regarding production and management.

Planning Considerations

Although the basic Louisiana tilapia greenhouse configuration would appear to be adaptable almost anywhere, site selection can be critical to the long-term success of an operation. Often, an individual or corporation will develop a facility on a specific piece of property they already own, leading to on-going problems once production begins. Would-be tilapia growers should first define the scope of their proposed operation and then find a site to fit their needs.

Quality of the available water supply is probably the single most important characteristic of a tilapia production site. In many areas, well water contains excessive amounts of compounds such as hydrogen sulfide, iron, and even ammonia, precluding its use in live hauling tanks or even for daily make-up water requirements. If a municipal drinking water supply is used, care must be taken that it has chlorine, and not chloramine, in solution. Chlorine can be fairly easily eliminated through aeration and aging, and small amounts can be added daily to the culture system directly with little or no impact on fish or biofilters.

The alternative domestic-use supply treatment, chloramine, is far more persistent and must be neutralized chemically before the water can be safely used even for daily make-up needs. Chloramine is often utilized in less densely-populated areas, where disinfectant activity must persist in supply lines over long distances or periods of time. Apart from day-to-day requirements for make-up water, an on-site source of high-quality chemical-free water is essential for filling hauling truck tanks if you intend to market live fish. Chlorinated or chloraminated tap water cannot be used directly for hauling fish without chemical neutralization, which can be expensive for the volume of water on most over-the-road live haul trucks.

Access is the second most critical aspect of site suitability for a tilapia greenhouse. Access to roads for deliveries and shipments. Access to fuel and electricity. Access to labor, equipment and parts. Access to supplies and markets. Conversely, greenhouse characteristics and siting on the property itself should minimize opportunities for unauthorized access. Other site considerations can become important over time. Space for future expansion and regional demand for a greenhouse facility should also be evaluated in the event that the business exceeds or fails to meet expectations.

Many system components can be at least partially developed out of sweat and ingenuity. On-site greenhouse erection and tank construction are preferred approaches to conserve capital. In these situations, however, operators must have access to labor as well as the proper tools and specialized equipment, such as bobcats and/or backhoes for excavation, boom trucks for setting greenhouse trusses, and nail guns and compressors for constructing tank walls.

Preliminary equipment lists often leave out smaller items, like a good tool set with a storage cabinet. They are often the most essential for success. One item which is omitted all too often is an emergency generator. In some cases, generators can be sized and configured into the electrical supply to provide power only to air blowers and and/or aerators, without having to operate pumps, lights, and other non-critical systems. If pumps are left without power for any period of time, however, a means should be in place to prevent biofilters from becoming stagnant and suffocating. The solution to this problem can often be as simple as draining the filters to allow bacteria access to atmospheric oxygen until pumping resumes. Other solutions may be required, but they must be thought out and ready for implementation whenever power supplies are interrupted.

The biggest financial constraint for most operations is not the high investment and operating cost, *per se*, but rather the cash flow requirements that result from day-to-day operations and hard-to-plan-for miscellaneous costs. In addition to big expenses like feed, labor, fingerlings and energy, regular purchases will be required for all sorts of supplies like water monitoring chemicals, record-keeping materials, motor oil, hydraulic fluid, air filters, fan belts, phone message pads, etc.

Another financial problem that pervades many small systems is inefficiency. Equiment inefficiency must be continually analyzed. Methods to re-aerate return water from filters

without using electricity are a simple example. Labor inefficiency is another area that should be continuously evaluated. With proper planning and special structures in place, one Louisiana grower has devised a method to harvest and load a 10,000 lb. shipment on a hauling truck with only 3 people in less than 4 hours. This is particularly important for small systems where labor may be limited.

Many start-up operations fail to consider when seasonal demand is highest and plan their construction and stocking schedules accordingly. Once a steady state production level is attained, this seasonality has little impact, but first year cash flow can be significantly impacted by the month in which harvests are initiated (Table 1).

Table 1. Seasonal live market price impact in relation to start-up date on first year revenues for Louisiana tilapia production.

	Revenues First 12 Months	Revenues First 24 Months
January Start-up	$34,998	$208,379
April Start-up	$37,557	$210,938
July Start-up	$35,566	$208,947
October Start-up	$36,561	$209,942

From Lutz and Roberts, these proceedings.

Operational Considerations

Maintaining broodstock and rearing fry requires good culture skills as well as special feed, tanks and other equipment. As a result, in many instances it is more economical to purchase fingerlings than to try to produce them on site. In either situation the quality of fingerlings from a genetic standpoint can vary greatly. While a pure species pedigree is not a requirement for good production traits, but hybrid-derived strains can be hard to characterize after several generations of random breeding.

Growth, of course, is probably the most important production trait. Growth rate, growth uniformity and size at which growth slows or ceases are all factors to consider when evaluating available strains of fingerlings. Growth uniformity is important in relation to labor and facilities available for grading throughout the production cycle, as well as to feed conversion efficiency. Some hybrid-derived strains of tilapia may grow exceptionally quickly during the first months of life, only to practically cease growing at weights of 350-400 grams, especially if their ancestry includes large contributions by mozambique tilapia, *Oreochromis mossambicus*.

While mixed-sex culture of tilapia can be economically feasible with proper management and growout densities, predominantly-male fingerlings produced through sex reversal or from YY-male broodstock demonstrate distinct advantages in terms of growth rate and growth uniformity. Lutz and Roberts (in these proceedings) demonstrate that moderate improvements in growth increase profitability in Louisiana greenhouse systems to a greater degree than large improvements in feed conversion efficiency.

Temperature tolerance is also an important bioeconomic consideration when comparing tilapia species and strains. Blue and nile tilapia are genetically superior to mozambique tilapia in this respect also. The wrong genetic background in tilapia fingerlings can have practical consequences in terms of increased heating costs to maintain growth during cool weather, and in turn increase risks of carbon dioxide build-up in poorly ventilated greenhouses and production systems where heat must be excessively conserved.

Whatever the genetic background of any given production strain, however, the health status of every shipment of fingerlings entering a facility should be thoroughly evaluated. The potential risk of introducing diseases such as *Streptococcus sp.* dictate extreme caution in choosing a fingerling supplier. Fry and fingerlings are often in such short supply that growers are forced to accept suppliers' disease-free assurances at face value, a situation which has led to the contamination and shut-down of a number of facilities in recent years.

Regardless of whether you produce your own fingerlings or purchase them, feeding practices during early rearing of tilapia fry can have profound impacts on their performance through the rest of their life, until they reach slaughter weight. Diet during the first 3 weeks of life has been shown to determine the physiological development and competency of the tilapia digestive system (Bishop and Watts, 1998) and subsequent growth. Similarly, fish that are crowed and underfed as fingerlings never seem to realize their full growth potential thereafter, regardless of the growout conditions.

Research has also shown that feeding tilapia less than satiation diets in tank culture systems can result in greatly reduced growth throughout the production cycle (Kazmierczak and Caffey, 1995). For this reason, daily feed loads must be established based on biofiltration limitations and stocking rates adjusted accordingly to allow for full feeding per individual fish. Once significant size variation is established slower growers never appear to catch up to their faster counterparts, and less-than-optimum conditions serve only to magnify size variation.

Variations in feed conversion can have great impacts on profitability in tilapia systems, but mixed-size stocking prevents accurate determination of feed conversion and allows slower-growing runts and/or females to accumulate in production tanks. Conversely, in partitioned systems where size classes are physically segregated, the disturbance of grading must be minimized to avoid lost feeding days, especially as fish approach marketable sizes.

Although fluctuations in ammonia reduce the efficiency of feed conversion to some degree, frequent ration changes can have even more detrimental effects on feed conversion, even when using the same feed supplier. Changes in feed components, even sources of carbohydrates, can result in inflated feed conversions and lag times of several days or even more than a week before gut bacterial and enzymatic adaptation takes place and feed conversions return to levels associated with the previous diet. Accordingly, feed should be ordered in the largest lots practical, and new feed should be ordered well before the current supply runs out. Blending the last of the feed on hand with the new supply for at least a week before completely changing to the new feed appears to reduce this effect somewhat.

When projecting what their facilities will produce once operational, many growers fail to keep in mind the "learning curve" phenomenon. Aquaculture production is not like a factory operation; with a crew on an assembly line with a few simple tasks to learn. Some industry veterans have speculated that fish farming may never be truly industrialized due to the intuitive requirements and the need for intimate supervision of the production process. Inexperience, even of qualified personnel, will have to be reckoned with for the first several cycles, at least.

Production data from Louisiana systems (Lutz, unpublished data), bioeconomic modelling (Kazmierczak and Caffey, 1995), and empirical data (Malone et al., 1993, Golz et al., 1996) have shown that management of biofiltration and solids removal can profoundly impact water quality and fish performance in recirculating systems. Management in these areas is complex and intuitive due to feedback effects on total ammonia nitrogen and dissolved oxygen levels. The ultimate impact is to system profitability and economic survival (Table 2). Similar complexities in determining optimal levels of dietary protein and stocking densities in relation to biofiltration efficiency have been discussed by Kazmierczak and Caffey (1995) (Tables 3 and 4).

Table 2. Days to harvest and returns (cents/l/day) in relation to mechanical and biological filtration efficiency for tilapia fed 30% crude protein diet in recirculating aquaculture systems.

30% Crude Protein Feed	Mechanical	Filter	Efficiency	
Biological	0.50		0.33	
Filter Efficiency	Days to Harvest	Cents/L/day	Days to Harvest	Cents/L/day
1.00	247	0.034	250	0.033
0.98	263	0.029	265	0.028
0.90	293	0.018	294	0.018
0.85	333	0.009	337	0.008
0.80	403	-0.002	404	-0.003
0.75	502	-0.011	502	-0.011
0.70	603	-0.013	603	-0.014

From Kazmierczak and Caffey (1995).

Table 3. Returns (cents/l/day) for recirculating tilapia production in relation to biological filtration efficiency for three levels of dietary protein and fixed mechanical filtration efficiency.

Biological	Mechanical Filter Efficiency =0.50		
Fiber Efficiency	20% Protein: Cents/L/day	30% Protein: Cents/L/day	40% Protein: Cents/L/day
1.00	0.033	0.034	0.035
0.95	0.028	0.029	0.027
0.90	0.025	0.018	0.015
0.85	0.019	0.009	0.001
0.80	0.013	-0.002	-0.011
0.75	0.005	-0.011	-0.015
0.70	-0.003	-0.013	-0.015

Table 4. Returns (cents/l/day) for recirculating tilapia production in relation to biological filtration efficiency for four density levels and fixed mechanical filtration efficiency

	Mechanical Filter Efficiency =0.50			
Biological	Cents/L/day	Cents/L/day	Cents/L/day	Cents/L/day
Fiber Efficiency	0.007 1-g fish/L	0.09 1-g fish/L	0.11 1-g fish/L	0.13 1-g fish/L
1.00	0.035	0.042	0.048	0.041
0.95	0.027	0.031	0.032	0.030
0.90	0.015	0.010	0.001	-0.009
0.85	0.008	-0.010	-0.019	-0.026
0.80	-0.011	-0.018	-0.023	-0.026
0.75	-0.015	-0.019	-0.022	-0.024
0.70	-0.015	-0.017	-0.020	-0.021

The topics presented here are only examples of the types of insights gained through numerous trials and errors in the development of Louisiana's greenhouse tilapia industry. In summary, many critical aspects to profitability and economic survival of small recirculating systems require continuous evaluation and improvement through innovative means. Operators who insist on taking these considerations for granted are at far greater risk for failure than those that are continously scrutinizing their production processes, inputs, and management practices.

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The Use of Process Control Software for the Monitoring and Control of Aquaculture Systems

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Introduction

The field of aquaculture has been considered by many of its practitioners to be as much an art as a science; success of aquaculture operations has been closely associated with the intuition of the farm manager rather than with understanding of the physiology, ecology and behavior of the cultured species. Hence, farm managers have been hesitant to trust their crops to automated management systems. However, recent research and commercial operations have begun to adopt new technologies and aquaculture as a science is evolving (Lee, 1995). Real-time trending of system parameters provide the manager with unprecedented insights into the physical and biological conditions of the aquaculture facility. These insights would be impossible with manually monitored aquaculture systems because of the labor required to collect and enter data and then to prepare graphs and reports. Recirculating aquaculture systems have the most obvious needs for this technology but pond and offshore aquaculture systems can benefit as well.

Advantages and Benefits of Process Control Systems

The main reasons for applying process control technology to aquaculture is socioeconomic, especially in developed countries. Three major factors are responsible: (1) variable climate, (2) high labor costs and (3) increased competition for dwindling water and land resources coupled with an unsympathetic regulatory bureaucracy. These factors are pushing the US and other developed nations toward the use of intensive recirculating water filtration systems (Fridley, 1993). However, the price performance of current recirculating filtration technologies limits their use to high value species (Lee, 1995). High efficiency, automated filtration systems would reduce simultaneously the need for high quality make-up water and the volume of pollutant-laden effluent. Anticipated benefits for aquaculture process control systems are (1) increased process efficiency, (2) reduced energy and water losses, (3) reduced labor costs, (4) reduced stress and disease, (5) improved accounting and (6) improved understanding of the process.

The use of computer monitoring and automation in aquaculture has grown during the last ten years. Applications include food production (Rusch and Malone, 1991, 1993), feed management (Hoy, 1985), automated filtration systems (Whitson et al., 1993; Lee et al., 1995; Turk et al., 1997), vision systems (Whitsell et al., 1997) environmental monitoring and control (Hansen, 1987; Ebeling, 1991, 1993; Munasinghe et al., 1993) and integrated system

management (Lee, 1991, 1993; Lee et al., 1995; Turk et al., 1997). This migration toward intensification and automation parallels the development of other forms of agriculture. Automated broiler coops (Campbell, 1988; Allison et al., 1991), nursery greenhouses (Baker et al., 1988; Hooper, 1988; Jones et al., 1990), dairy barns and feedlots (Leonard and McQuitty, 1982) and crop irrigation systems (Rao et al., 1992) are demonstrating the profitable application of process control technologies. These agricultural production systems represent managed biological systems that supply commodity markets (i.e. high production and low profit margins) similar to intensive aquaculture systems (i.e. ponds, sea cages or tanks). Process control technology is big business; control system integration revenues were expected to reach US $10 billion in 1998 and the industry has been growing at a rate of >15%/yr over the last five years (Kuhfeld, 1994).

Use of process control technology in aquaculture will allow the aquaculture industry to: (1) site production closer to markets; (2) improve environmental control; (3) reduce catastrophic losses; (4) avoid problems with environmental regulations; (5) reduce management and labor costs and (6) improve product quality and consistency (Lee, 1995). The overall design and implementation (i.e. hardware and software) of an aquaculture process control system has been reviewed (Lee, 1991, 1995). Therefore, this review focuses specifically on process control software and its capabilities.

Process Control Software Characteristics

Operating Systems

The choice of computer platform and operating systems are the first choice to be made in selecting a process control system (Wolske, 1989; Chandler, 1994; Labs, 1994). The most appropriate criteria to use for selection are (1) functionality or suitability to task, (2) compatibility and interconnectivity, (3) architectural expandability and (4) price performance.

System Architecture

There are four basic designs for automated control systems used in aquaculture (Lee, 1995): (1) closed loop controller or data logger systems that are simple, inexpensive, local control systems, lacking communications capabilities but including some data storage (Szabo, 1993); (2) programmable logic controller (PLC) systems that perform control functions at the lowest system level, are highly redundant to avoid system failure, do not store the I/O as files and have limited display capabilities unless attached to a computer and monitor (Cleaveland, 1993a; Bonanomi 1994); (3) microcomputer-based supervisory control and data acquisition (SCADA) systems that are dedicated systems, allowing real-time analysis (analog and digital) and storage of I/O in a database for historical trending (Bailliet, 1987; Yingst, 1988); and (4) distributed control systems (DCS) that provide greater multi-tasking, redundancy and data storage capacity by networking multiple microcomputers and/or PLCs (George, 1992; Spennato and Noblett, 1992; Grenier, 1994).

Modules

I/O drivers. The first thing that process control software must do is acquire information from the process (i.e. analog and digital inputs and outputs; I/O). The software should provide a wide variety of I/O drivers that support industry standard I/O devices each of which will have its own specific protocols and reference manuals. These industry standard devices include sensors, meters, data multiplexers or PLCs. For each specific I/O device there is a specific I/O driver that should provide capabilities for automatic communication error detection, reporting and recovery and support for redundant communications.

Process database builder. The heart of the process control software is the process database, a representation of the process created using process control logic. The process

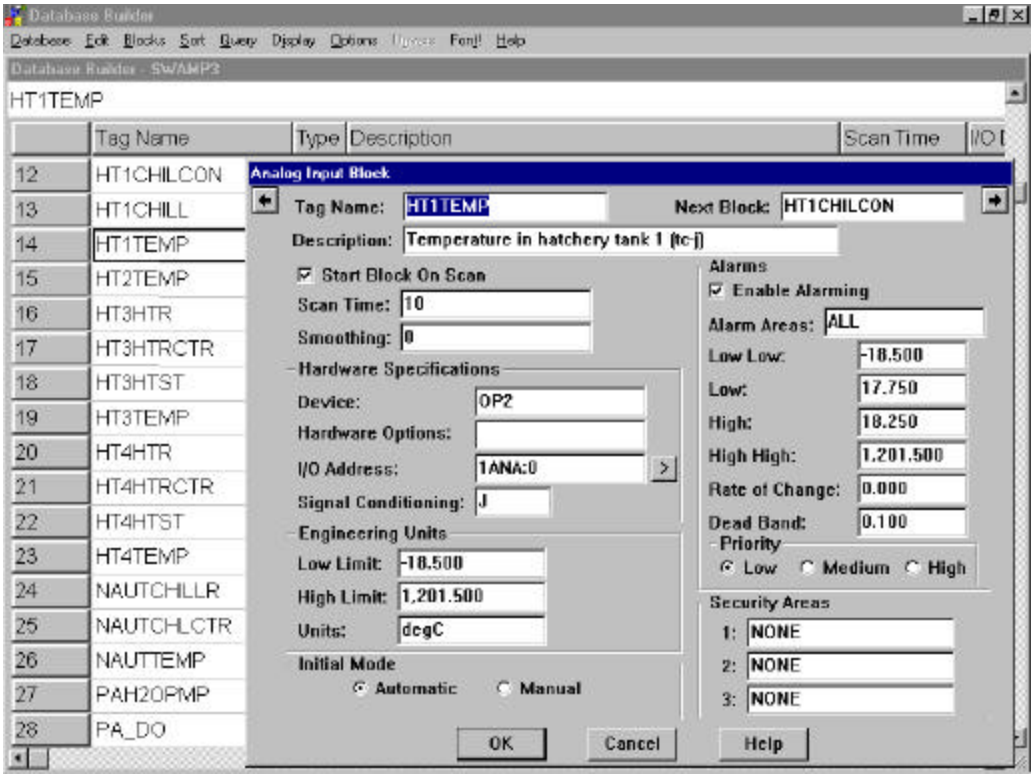

Figure 1. This database block is an Analog Input Block for temperature. It has fields for tagname, description, device and I/O addresses, engineering units, alarm set points and security areas. In the background are additional tagnames for other database blocks.

database consists of blocks (i.e. coded set of process instructions that perform a specific task) and chains (i.e. series of connected blocks that create a monitoring or control loop) (Figure 1). There are two general types of blocks; primary that read data from or write data to the DIT and secondary that manipulate data passed to them by a primary block. Blocks have also referred to as tags in certain software. Most process paradigms require several chains to be created. For example, the monitoring of temperature and control of a heater relay requires an Analog Input Block from a thermocouple to be connected to a Digital Output Block with a

low set point for temperature that will actuate a digital relay, thereby turning on a heater (see Figure 1).

Man-machine interface. If the database builder is the heart of process control software, then the man-machine interface (MMI) functions as the sensory system (e.g. eyes, ears and touch) for the software because it provides the window into the process (Cleaveland, 1993b; Labs, 1993). It requires output (e.g. video display and message boards) and input (mouse, track ball, keyboard, touch screens and voice activation) hardware. The MMI is the component of a process control system that most process managers use routinely because it allows the manager to acquire needed trending information and to interact with the process (Figure 2). Remember that you are using a personal computer so have the software application personalized to meet you specific requirements.

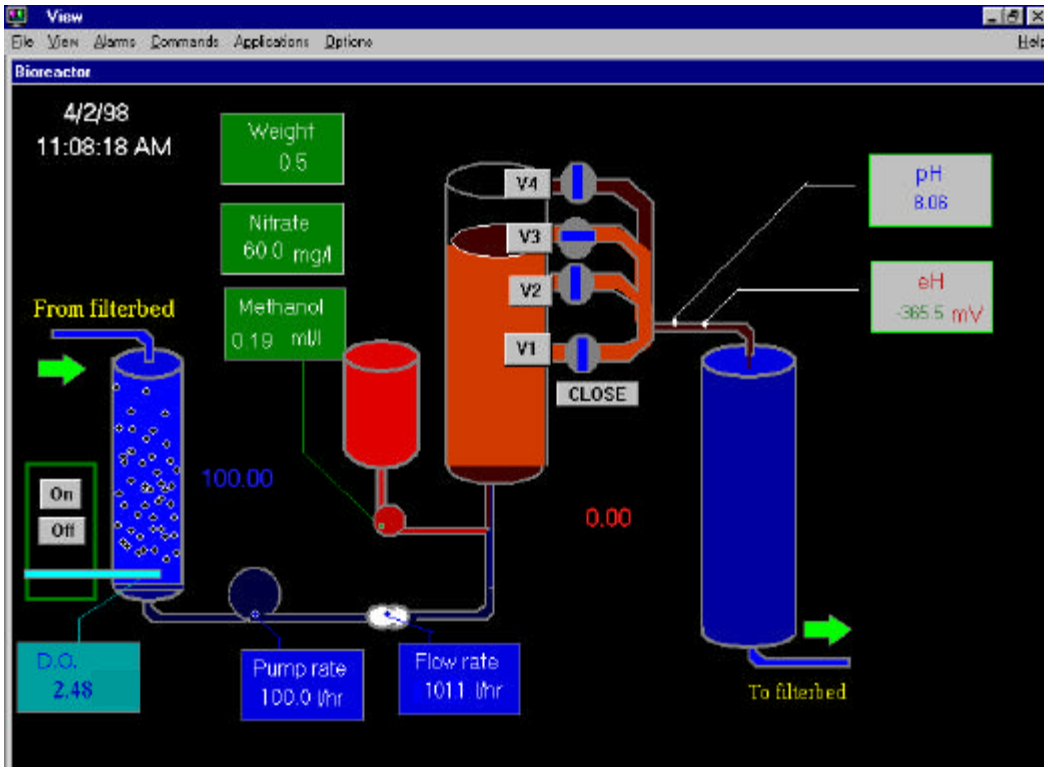

Figure 2. The MMI for an automated denitrification filter (Lee et al. 1995). Note the data windows, interactive buttons for valves, on/off buttons and animation of bubbles.

Historical trending. Historical trending is used to analyze process trends, archive process data, monitor efficiency of process, and analyze post-process data. The historical assign, collect and display programs allow the manager to sample real-time data from the DIT at user selected rates and then to store to disk and display as process displays. The historical assign program defines your collection strategy, allowing you to identify data that you want to collect (i.e. place in a database). The historical collect program collects data that is stored in disk files; historical display programs are used to display data in user-defined trend charts.

Recipe builder. This module allows the manager to design, implement and run recipes for a process. It also provides a flexible method for keeping an audit trail; this is particularly useful if the process requires the operator to change many process database values frequently. Examples of aquaculture applications would be batch processes such as algae or micro-invertebrate culture. The manager would first create a master recipe using the database builder and tagnames. This master recipe would embody the expertise of the algae culturist. For each particular batch of algae, it might need to be modified somewhat based on batch size and species so that a control recipe would be formulated from the original master recipe.

Tag group editor. This module simplifies recipe and display management by providing a means for accessing similar database information at different times using a single picture or symbol. For example, a large aquaculture facility is generally composed of many similar tank systems in which only some variables may vary (e.g. feeding rate, temperature and photoperiod). It would be unnecessarily repetitious to use the database builder to configure every individual system. The tag group editor allows you to reduce development time by defining one display and/or one control logic chain for all the similar groups of tagnames (i.e. tanks).

Report generator. The report generator is used to collect essential or critical data into a report for use by the manager or other users to make decisions on the process efficiency. Report generation can be internal to the process control software or require a NetDDE® link so that any DDE compatible application (e.g. Excel® or Lotus®) can be used to prepare reports. Either method can be automated such that certain reports are printed or displayed on a video monitor on a fixed schedule. Examples of useful reports would be production statistics, feed efficiency projections or weekly water quality records.

Relational databases interface. This interface module lets the manager collect and write real-time data from the process database to an external relational database (e.g. Access®, dBase® and Oracle®) for future use. These relational databases must conform to industry standards for open database connectivity (ODBC) and sort, query & logic (SQL). It also allows you to read data stored in relational databases and write it back to a process database.

DDE server. One of the attributes of the Windows® operating system is dynamic data exchange (DDE) in which real-time and historical data can be exchanged between two DDE compliant programs, using shared memory automatically. This exchange of data can occur on a single computer or across a network to a remote node. The ability to act as a server (application that provides data) or client (application that receives data) to other application software opens up many possibilities for control paradigms and report generation. In order for DDE to work, your computer's software must have both a NetDDE® server and client mode (these are provided in Microsoft's Windows for Workgroups™ and higher operating systems or may come as part of the process control software).

Security. The process control software should allow the manager to assign various levels of access to the different modules, monitor displays, critical program functions and databases comprising the complete software system. This is usually done through a password that enables a user to access certain security areas. A security area is a group of database blocks or chains with the same security level. A user who signs on in a particular security area can

change database blocks in that area but not in other security areas. In practice, this might mean that a technical level employee might be able to access the monitor displays and acknowledge alarms for their area of responsibility but that they could not make any changes to database blocks. A financial officer might only be able to access security areas dealing with materials flow and utilities. The manager could have access to all areas.

Alarm and messaging. Process control software should have capabilities for generating, displaying and storing a variety of alarms and messages. You should be able to route these alarms or messages to any computer linked to the system (i.e. node), printers, disk-based files, alarm summary displays, alarm history displays, message boards and phone dialers. The most common is a database block alarm in which a database block generates an alarm when block values fall outside the upper or lower set point, a change in state occurs or when communications fail. These alarms are displayed in an alarm manager display and can be routed to audible bells, message boards and/or phone dialers; they usually require acknowledgment from the user. The second is a block message that usually goes to a printer or alarm history file to document an event at that block. The third is a operator message that makes a historical record of important operator actions. The fourth is a system message that generates messages associated with errors in the software. The fifth is an application message that documents activity in another software module (e.g. recipe builder and historical collect).

Remote dialer. The remote software should make real-time, historical and alarm information available across a modem to other process control nodes in remote locations. To be most useful a remote node should be able to (1) receive real-time alarms and messages from the process node, (2) view the real-time monitor displays on the process node, (3) make changes to the database blocks, (4) retrieve and display historical data and (5) copy files over the modem. The remote utility should have adequate security in place so that only those users with privilege for a specific security area can access the process node from a remote node.

Statistical control. The theory of statistical process control (SPC) is based on the assumption that a process will remain stable (i.e. within statistical limits) unless an unexpected event occurs. The role of the SPC software is then to resolve this event from background process noise as soon as possible, connect the process back to its stable range and identify the cause for the instability (Dybek, 1989). A statistical control module enables the user to use statistical analyses to trend the process, setting the upper and lower control limits of the process based on any combination of input and output blocks. These modules provide not only control features but usually include a variety of statistical analysis presentation graphics (Wolske, 1989).

Artificial intelligence. Modern artificial intelligence (AI) systems can be divided into three main classes, expert systems, fuzzy logic systems and neural nets (Rock and Guerin, 1992; Bechtold, 1993; Studt, 1994). In the past, AI software was very expensive and had greatly varying functionality. Expert systems require defined rules (IF and THEN statements) or graphical knowledge (flow charts or logic trees) to be formulated by process experts (Bechtold, 1993, 1994). Fuzzy logic systems do not require defined rules or knowledge but use fuzzy rule-bases that emulate the intuition of process experts (Czogala and Rawlik, 1989; Karr, 1993). Neural nets behave differently in that they use three-dimensional neurons

(processing elements) to learn to control a process using incoming real-time data (Chester, 1992). While all of these systems have their specific advantages (Padala and Zilber, 1991), the use of fuzzy control logic most closely approximates the routine management decisions made by an aquaculturist who is part scientist and artist (Lee et al., 1995; Whitsell et al., 1997).

Simulation development. Process simulation can be used to replicate or model an existing or proposed process. It is most useful for evaluating the function of a control paradigm before implementation but can be used to fine tune or to train personnel in the operation of an existing process control system (Dowling and Sullivan, 1993). The simulation software should (1) operate on the same hardware and in the same operating system as the control system software, (2) allow development to be interactive, (3) have predefined algorithms as well as user-defined algorithms for process functions and (4) allow implementation with minimal changes to control system software. Interactive modeling in real-time is the key advantage of such systems; estimates of the time saved in implementing a new process control paradigm suggest that development time can be cut dramatically (Nisenfeld, 1989).

Basic Set-up and Operation

The first task is to use your specific I/O driver configuration software to specific the data that you need to acquire for the DIT. The second step is the creation of the process database, including reads and writes to the DIT, calculations, process control logic and outputs to MMI devices. The database builder is used to configure how each data point and database block will be processed. The third step requires the use of the graphics application to construct the MMI, archive and access data and generate reports. Once the process database is constructed, you use a draw program to create displays (i.e. easy-to-understand pictures) of the process data. You can then use any number of other modules (e.g. tag group editor, recipe builder, macro editor, historical collect and assign, DDE server and report generator) to customize the software to meet the manager's requirements. Finally, the manager will define the security areas in the system and assign security levels to all employees who will use it.

Purchase criteria

The selection of software almost always comes down to some combination of perceived price performance and trust in the manufacturer.

Functionality/intuitiveness. You should evaluate whether the potential software can accomplish the bottom line goals that you have set for your automated system. These should be production or economic goals not engineering goals. The software should not require an excessive time for the manager and staff to navigate through the screen displays and find the information that they need but may require higher level computer skills to install and set-up. The most effective way to evaluate the functionality of the product is to acquire a demonstration copy and verify all control functions, displays, alarms and messages, security procedures, DDE links and mathematical algorithms with valid and invalid data inputs before purchasing (Walters, 1994). Other good methods to access functionality is to (1) determine the extent to which the product is used in your industry, (2) discuss its functionality with

current users and (3) evaluate the vendor's experience in solving the kinds of problems that will be critical for your control system.

Modularity/flexibility. Modularity provides the benefit that system components can be added, moved or deleted as necessary without jeopardizing the integrity of the whole control system (Wolske, 1989; Walters 1994). This is important for both the software and the hardware. The benefits for modularity in software are that you will not have to buy unnecessary features and that you can upgrade features later. With hardware, the selection of modular communication devices, transmitters, meters, sensors and actuators means that a system can be implemented quickly and modified without major time delays. Modular design also means that once one aquaculture tank monitoring and control system is designed and implemented in your facility, it is easily replicated for all other tank systems.

Compatibility. Compatibility or connectivity is the measure of how a software product will function with the myriad other product choices that you will be making in designing and implementing your control system. In terms of hardware compatibility, it means your software should offer a wide range of I/O drivers that are simple to implement (Wolske, 1989). In terms of software compatibility, it means using software that contains most of today's enhancements (e.g. direct dynamic exchange, DDE; object linking and embedding, OLE; shared libraries or dynamic link libraries, DLL; object-oriented programming; wizards and multimedia systems). If the software is a proprietary product designed for only a small range of hardware, you will undoubtedly encounter a problem with interfacing a second party sensor or phone dialer.

Upgrade path/service. Upgrade path is the most critical aspect for evaluating a software program, yet it is the hardest to evaluate because its effects will be felt in the future. One of the salient characteristics of computer technology is that nothing will remain static for very long. In practical terms, this means that process control software will continue to improve; it will become more demanding on system resources, requiring software and hardware upgrades (Labs, 1992). The best recent example of this has been the migration of PC users from Microsoft's DOS™ to Windows™ to Windows for Workgroups™ to Windows 95-97™ to Windows NT™. There are three things that you should remember; (1) you do not have to upgrade, it's your decision (Huber, 1994), (2) if you buy from stable vendors, your applications will work well with whichever operating system it is designed to use, and (3) your process control system will become so valuable to you that you will be seeking to improve its productivity constantly.

Price performance. Finally, all the above criteria must be balanced against the cost of purchase of the software. This decision should be made based on a "Top Down" approach, meaning that the selected system must meet your economic goals not just make the process easier to manage (Christie, 1989; Lee, 1995). While the latter may be important to your employees, the real business reason for considering a process control system is to increase production, reduce labor and material costs and/or reduces waste.

Acknowledgments

This research was supported by grants from the Texas A&M University Sea Grant Program (#R/M-58) and from the Small Business Innovative Research Program of the Department of Commerce.

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Water Quality – Types of Analyses and the Equipment Used

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In Aquaculture the quality of the water being used is critical to the success and viability of the products grown. Some of the parameters that are measured include:

- pH
- Alkalinity
- Hardness (Ca^{2+}, Mg^{2+})
- Dissolved Oxygen
- Temperature
- Ammonia, Nitrate and Nitrites
- Total Dissolved Solids/Salinity

pH

Sorensen first introduced the concept of pH in 1909 to measure the acidity of water used in the brewing of beer. It is a measurement of the H^+ activity in solution. The standard pH scale is 0 – 14 and this refers to the H^+ concentration of 10^0 to 10^{-14}.

$$pH = -\log\{H^+\}$$

The hydrogen activity may be thought of as the free ion rather than the total.
For example the pH of 0.1M HCl is ~ 1.03 and the pH of 0.1M Acetic acid is ~ 3.
This is because HCl is almost completely dissociated whereas acetic acid is mostly associated. The hydrogen activity is 10^{-3} in acetic acid.

The activity of the hydrogen ion can also be affected by the presence of salts in solution. In dilute solutions a cloud of neutral water molecules surrounds the H+. Whereas, if a significant amount of salt is added the H^+ moves through a cloud of charged species and is "less free". This means we can change the hydrogen ion activity (hence, pH) by adding an inert salt like KNO_3 or NaCl.

The warmer water gets the easier it is dissociated into H^+ and OH^-. Neutral pH is when $[H^+] = [OH^-]$, as the dissociation constant increases the pH changes i.e. as the temperature increases the more H^+ is free which reduces the pH value (more acidic).

For years pH measurements with the use of indicators was acceptable. In the modern lab the requirements are more stringent the standard method is to use the versatile glass pH electrode and an appropriate meter.

Thanks to modern technology, the potential of the external surface of the glass membrane parallels to a remarkable degree that of the hydrogen gas electrode, the primary reference for hydrogen ion measurements.

The glass electrode is still the standard measuring element in the measurement of pH. Although in recent years the use of microfabrication techniques has produced the solid state electrode which parallels the glass electrode very well. Each has its use in different applications, especially in areas where glass poses a hazard to the sample environment.

Orion offers a number of products to meet the needs of the market. Our line consists of the Standard, Ross and the Per**pH**ec**T**® electrode lines. The Standard line utilizes the Ag/AgCl reference junction and is economically priced. Ross utilizes the unique reference system that offers stable fast results regardless of temperature or sample composition.

The Ross electrodes give a better temperature compensation due to the liquid/liquid reference junction. It has no metal ions hence reduces the possibility of clogging of the reference with precipitated AgS.

The unique design of the Sure-Flow reference junction facilitates easy cleaning for difficult samples.

The per**pH**ec**T** line of pH electrodes with either Ross or Ag/AgCl reference offers the most accurate pH measurements that Orion has to offer especially when using the Per**pH**ec**T** line of pH meters containing our patented digital LogR™ technology.

The meters are either handheld or bench type with a variety of features which include waterproof, RS232, temperature compensation, automatic shut off, millivolt/ORP, reading 0.1/0.01pH range.

For customers that do not require the sophistication of an electrode and a meter but requires a screening device for pH we have AQUAfast™ test strips for the ranges 1 – 12 and 4 – 9 pH.

Selecting the Right pH Electrode

Cross-reference the required pH precision with the sample type or condition to find which Orion pH electrodes are appropriate for your application.

Required pH Precision	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**	**0.05 to 0.1**
Sample Type or Condition	Per**pH**ec**T** Model No.	ROSS Line Model No.	Standard Line Model No.	Tris Line Model No.	Micro Model No.	Economy Model No.
General Purpose Most sample types	82-02, 82-56, 82-72, 92-02, 92-06, 92-07, 92-56, 92-72	81-01/80-03. 81-01/80-05, 81-02, 81-04, 81-56, 81-72	91-01/90-01, 91-02, 91-04, 91-07, 91-56, 91-57, 91-62, 91-65, 91-72	71-02	—	91-06
Biological/Pharmaceutical Proteins, Tris, Enzymes	82-02, 82-03, 82-72, 92-72	81-01/80-05, 81-02, 81-03, 81-65, 81-72	91-01/90-02, 91-65, 91-67, 91-72	71-02, 71-03, 71-10	—	—

Required pH Precision	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**	**0.05 to 0.1**
Education/Student Use	82-56, 92-06, 92-07, 92-56	81-56, 81-65	91-07, 91-56, 91-57, 91-65	—	—	91-06
Emulsions						
Foods, Cosmetics, Oils	82-72, 92-72	81-01/80-03, 81-65, 81-72	91-61/ 90-01, 91-65, 91-72	—	—	—
Petroleum Products, Paint	82-72, 92-72	81-01/80-03, 81-72	91-61/90-01, 91-72	—	—	—
Extreme pH						
pH > 12 or < 2	82-72, 92-72	81-01/80-03, 81-65, 81-72	91-01/90-01, 91-65, 91-72	—	—	—
Acid/Fluoride	—	—	93-01/90-02	—	—	—
Flat Surfaces Foods, Cheese, Paper, Agar	82-35	81-35	91-67	—	—	91-36
Harsh Environments						
Field or Plant Use	82-56, 92-06, 92-07, 92-56	81-56, 81-65	91-07, 91-56, 91-65	—	—	91-06
Rugged Use	82-56, 92-06, 92-07, 92-56	81-01/80-03, 81-01/80-05, 81-04, 81-56, 81-65	91-61/90-01, 91-04, 91-07, 91-56, 91-57, 91-62, 91-65	—	—	91-06
High Ionic Strength Acids, Bases, Brines	82-72, 92-72	81-01/80-03, 81-65, 81-72	91-01/90-02, 91-65, 91-72	—	—	—
Large Sample Sizes Tall Flasks or Bottles	—	—	—	—	98-26	91-26
Low Ionic Strength Treated Effluent	82-02, 82-72, 92-02, 92-72	81-01/80-03, 81-02, 81-62, 81-65, 81-72	91-01/90-01, 91-61/90-01, 91-02, 91-62, 91-65, 91-72	71-02	—	—
Non-Aqueous Solvents, Alcohols, etc.	82-72, 92-72	81-01/80-03, 81-65, 81-72	91-61/90-02, 91-72	—	—	—
Semi-Solids Fruit, Meat, Cheese	82-63	81-63	91-63, **71-20**	—	—	—
Small Sample Sizes						
Test Tubes, Small Flasks	82-03, 82-35, 92-03, 82-63	81-03, 81-15, 81-35, 81-63, 81-75	91-03, 91-67	71-10	98-02, 98-03, 98-10, 98-26	91-16, 91-26
NMR Tubes	—	—	—	—	98-26	—
Micro-titer Plates	—	—	91-67	—	98-03	—
Steam Sterilizable	—	—	**91-90, 91-91, 91-92, 91-93, 91-94, 91-95**	—	—	—
Titration	—	81-01/80-03, 81-62, 81-66	91-64, 91-66	—	—	—
Viscous Slurries, Suspended Solids, Sludge	82-72, 92-72	81-01/80-03, 81-65, 81-72	91-61/90-01, 91-65, 91-72	—	—	—
Waters						
Acid Rain, Boiler Feed, Distilled, Rain, Well	82-02, 82-72, 92-02, 92-72	81-01/80-03, 81-02, 81-62, 81-65, 81-72	91-01/90-01, 91-02, 91-65, 91-72	71-02	—	—
Drinking, Tap	82-02, 82-72, 82-56, 92-02, 92-06, 92-07, 92-72	81-02, 81-04, 81-65, 81-72	91-01/90-01, 91-02, 91-04, 91-07, 91-57, 91-65, 91-72	71-02	—	91-06
Sea water	82-72, 92-72	81-01/80-03, 81-65, 81-72	91-02/90-02, 91-65, 91-72	—	—	—
Waste water	82-72, 92-07, 92-72	81-01/80-03, 81-65, 81-72	91-61/90-01, 91-07, 91-57, 91-62, 91-65, 91-72	—	—	91-06

Alkalinity

Alkalinity of water is due to compounds such as sodium or calcium hydroxide, carbonates or bicarbonates. The methods available for the measurement of alkalinity rely on either titration or colorimetric reactions some require the use of a photometer. Most of the kits available measure up to 300 ppm $CaCO_3$.

Most methods are based usually on titration using a buret or a “drop count” technique. Samples are titrated with an acid solution, which neutralizes the alkaline spieces present. Endpoint determination is observed by a color change or by titrating to a pH value of 4.5.

The volume of titrant is then used to calculate total alkalinity. Hence the terms total alkalinity or phenolphthalein alkalinity.

Both methods have limitations, since sample color or turbidity can affect the ability of the operator to detect the color change. Also the use of a burette or dropper is time consuming and not conducive to field use.

Orion offers a method for the measurement of Alkalinity using a standard pH meter and electrode with a specialized reagent and a pH conversion wheel.

The principle of the Orion test kit is the same as the conventional titration. A reagent composed of several acids react with the alkaline species in the sample. As a result the pH of the sample changes. The observed pH reading after the addition of the reagent varies directly with the total alkalinity. Each pH reading corresponds to a unique value for alkalinity, expressed in ppm $CaCO_3$.

Hardness

The methods available for calcium and magnesium hardness testing are all based on titration with EDTA. There are a few companies that utilize the titration in a kit form. The range of measurement for the kits is 0 – 30, 0 – 300 ppm and 100 – 4000 ppm. Orion Research offers a titration method for Hardness using our model 960 titrator.

We also have AQUAfast™ test strips for measuring total hardness in the range of 0 – 445 ppm.

Dissolved Oxygen

Dissolved Oxygen (DO) levels in natural water depends on the physical, chemical and biochemical activities in the water. The analysis of the dissolved oxygen content of water used for Aquaculture is a key component to a viable business.

The classical method of measuring DO in water is with the Winkler or Iodometric titration. This method is tedious and is a “snapshot” of the dissolved oxygen in the water and does not lend itself to measurements in the field. Modern methods include the use of meters and probes for the measurement of DO. Their portability and ease of operation and maintenance make them particularly convenient for field applications. The probes are either of the galvanic or polarographic types.
The oxygen sensitive membrane electrodes of the polarographic or galvanic type are composed of two solid metal electrodes in contact with supporting electrolyte separated from the test solution by a selective membrane.

The basic difference between the galvanic and the polarographic systems is that in the former the electrode reaction is spontaneous, while in the latter an external source of applied voltage is needed to polarize the indicator electrode. Polyethylene and

fluorocarbon membranes are used commonly because they are permeable to molecular oxygen and are relatively rugged.

Membrane electrodes are commercially available in some variety. In all of these instruments the diffusion current is directly proportional to the concentration of molecular oxygen in solution. The current is converted easily into concentration units by a number of calibration procedures.

The rate at which oxygen crosses the membrane is directly proportional to the partial pressure of oxygen in the solution. There are a number of factors that affect the sensor operation. The partial pressure of oxygen will change with altitude (barometric pressure). Since the sensor consumes oxygen, the sample must be stirred to present fresh oxygen to the membrane i.e. oxygen must arrive at the membrane faster than the sensor consumes oxygen.

The rate at which oxygen diffuses through the membrane varies with the temperature. Coefficients are typically 3 to 5% per ^{o}C. Changing the temperature from 20 to 15 ^{o}C can reduce the oxygen diffusion by 20%.

The best meters and probes have separate thermistors to measure probe temperature and correct for change in diffusion rate.

Exposure to high levels of gases such as Nitrous Oxide and Chloride can poison the sensor.

The sensor reads the partial pressure of the oxygen, to convert to a meaningful unit such as concentration means knowing the solubility of oxygen in water at that Temperature, Total pressure and Salinity. This is accomplished by look up tables also some meters have the tables built in to them.

We sometimes use percent saturation which is the actual concentration compared to the "theoretical" complete saturation.

To understand why the pressure, temperature and salinity affect oxygen solubility, consider Henry's law: "The partial pressure of a gas dissolved in a liquid is the same as the partial pressure of the gas in the vapor above the liquid".

In warm solutions the amount of oxygen that will hit the surface increases, therefore the oxygen content is reduces as a result of increases in temperature.

Oxygen Concentration in Air-Saturated Water

Temp. in ^{o}C	**O_2 mg/l**	**Temp. in ^{o}C**	**O_2 mg/l**	**Temp. in ^{o}C**	**O_2 mg/l**	**Temp. in ^{o}C**	**O_2 mg/l**
0	14.64						

1	14.23	11	10.99	21	8.90	31	7.42
2	13.83	12	10.75	22	8.73	32	7.3
3	13.45	13	10.51	23	8.57	33	7.18
4	13.09	14	10.28	24	8.41	34	7.05
5	12.75	15	10.06	25	8.25	35	6.94
6	12.42	16	9.85	26	8.11	36	6.83
7	12.11	17	9.64	27	7.96	37	6.72
8	11.81	18	9.45	28	7.82	38	6.61
9	11.53	19	9.26	29	7.69	39	6.51
10	11.25	20	9.08	30	7.55	40	6.41

Salts dissolved in solution also affect the dissolved oxygen concentration. Salts in solution take up water (hydrate) leaving less water for the oxygen to dissolve in.
As a result as the salinity increases the dissolved oxygen decreases.

Dissolved Oxygen probes and meters are calibrated using either water saturated air or air saturated water. This is due to the fact that the partial pressure of oxygen in water and the vapor phase are the same at equilibrium. In practice calibration is done in water saturated air, since it is very difficult to determine if water is fully saturated with air.

Orion offers a number of systems for the measurement of DO, they vary in feature such as temperature compensation, salinity correction, barometric correction, RS232 etc. The probes vary in the needs of the market that they serve, all probes feature a removable membrane cap with fill solution. They also vary in cable lengths and whether they are dual or single thermistors.

Ammonia, Nitrate and Nitrites

Measurement of Ammonia, Nitrates and Nitrites is very important in the Aquaculture market. High levels of Ammonia can kill fish. There are a variety of methods to measure these species most are based on analysis by titration. However, the ISE (ion specific electrode) has become a standard for quick low level analysis. Large ranges of species are available and methods for a number of diverse applications exist.

The total papers being written with applications for the use of ISE technology is increasing year after year. In 1989 alone there were almost 7,000 papers on ISE's.
Why so much interest in ISE? Well, because the technology:

- Well accepted
- Rugged and Durable
- Simple to use
- Inexpensive
- Numerous applications

The electrodes come close to the ideal analytical device “a probe that can be dipped in any sample and the concentration read out directly”.

ISE’s have a membrane that is slightly permeable to one specific ion. If there is a difference in the concentration of the ion on the two sides of the membrane, it will tend to diffuse from the high side to the low side, but the law of electroneutrality prevents this. The “tendency” to diffuse expresses itself physically as a potential difference.

The total number of ions that actually diffuse across the membrane is very small. However, the potential across the membrane is proportional to the logarithm of the difference in concentration on the two sides of the sensing membrane.

The types of sensing electrodes are Solid State, Liquid membrane, Glass membrane and Gas sensing electrode.

The solid state sensing element is a solid crystalline material i.e. Bromide, Chloride, Chlorine, Fluoride electrodes etc.

The Liquid membranes the sensing element is conductive plastic i.e. Ammonium, Calcium, Nitrate electrodes etc.

The Glass membrane the sensing element is a special type of glass i.e. pH and Sodium electrodes.

The Gas sensing electrode’s work by measuring the pH change caused by diffusion of a gas through a hydrophobic but porous membrane.

Orion has a large offering to the ISE user with electrodes from Ammonia, Nitrate, Nitrite to Water Hardness with the appropriate Ionic Strength Adjusters, calibration standards and filling and maintenance solutions.

We also offer AQUAfast™ test strips for Nitrate and Nitrite in the range 0 – 500 ppm and 0 – 80 ppm respectively.

Total Dissolved Solids/Salinity

Total Dissolved Solids and Salinity can be measured with a Conductivity electrode and meter. Based on the reading of conductivity value lookup tables will give the appropriate Salinity value, most meters have the lookup tables built in.

Conductivity is an inherent property of a material at a particular temperature and will always have the same conductivity. It can be measured using two parallel platinum plates of 1 sq. cm. at 1 cm apart.

The conductance of a sample depends on how the measurement is made i.e. how far apart the electrode plates are, the volume of sample between the plates etc. It is defined as the reciprocal of the resistance in ohms. The basic unit of conductance is ***Siemens*** **(S)** and was formerly called the mho.

Because the measurement gives conductance , techniques have been worked out to convert the value into conductivity, this is done by measuring the cell constant for each setup.

The cell constant (k) is related to physical characteristics of the measuring cell.

In practice the cell constant is entered into the meter and the conversion to conductivity is done automatically. The k value used varies with the linear range of the cell selected. Typically, a cell with a k=0.1 cm^{-1} is chosen for pure water measurements, while for environmental water and industrial solutions a cell with k of 0.4 to 1 is used. Cells with k values of up to 10 cm^{-1} are best for high conductivity samples.

Some Conductivity Values of Typical Samples

Samples at 25 ^{0}C	**Conductivity, uS/cm**
Ultapure Water	0.055
Power Plant Boiler Water	1.0
Drinking Water	50
Ocean Water	53,000
5% NaOH	223,000
50% NaOH	150,000
10% HCl	700,000
32% HCl	700,000
31.0% HNO_3 (Highest Known)	865,000

Some Typical Temperature Coefficients

Sample	**Percent/ °C (at 25 °C)**
Ultrapure Water	4.55
Salt Solution (NaCl)	2.12
5% NaOH	1.72
Dilute Ammonia Solution	1.88
10% HCl	1.32
5% Sulfuric Acid	0.96

98% Sulfuric Acid	2.84
Sugar Syrup	5.64

4-Electrode Cell Theory and Practical Advantages

The approaches discussed earlier can not correct for deposits which form on the surface of the electrodes, and which subtract from the measured conductivity of the sample. A more sophisticated approach uses the 4-electrode technique. The operational theory is discussed below. Not only is the 4-electrode technique superior in terms of ability to function in "dirty" solutions, but one cell with a single cell constant can cover almost the entire 7 decade range (except for pure water) of three ordinary cells. A number of technical advancements allow this.

4-Electrode Cell Measurement Theory

4-electrode conductivity measurements offer the user significant advantages, particularly in high conductivity solutions. These advantages include minimizing the effect on measurement accuracy from electrode polarization and contamination, as well as eliminating error from cable resistance and connector resistance.

4-electrode conductivity cells contain two drive (current) electrodes and two sense (voltage) electrodes. An alternating voltage powers the drive electrodes, and the alternating current that flows is measured to determine the conductivity. The voltage measured at the sensing electrode controls the amplitude of the alternating voltage applied to the drive electrodes. Since the sense electrodes are positioned in a low current area of the cell, and this voltage is measured using a high impedance circuit, it represents with high accuracy the strength of the electric field within the cell. Using this signal to maintain the cell field strength at a constant, the current that flows at the drive electrodes is proportional to the conductivity of the sample, and the errors due to polarization, contamination and cable resistance’s are minimal.

Polarization Errors

Polarization errors occur in the case of 2-electrode cells at the boundary layers between the measuring electrode and the ion conducting measuring medium. These effects can be compensated for with the 4-electrode system, and do not contribute an error.

Contamination of Electrode Surfaces

Deposits on the electrode surface of a 2-electrode cell have a similar effect to polarization errors that is the conductivity reading is lower than actual. These effects are also compensated with the 4-electrode system. Conductive deposits will have no effect on the accuracy of the cell, and errors due to insulating deposits have been shown to be three times lower than comparable 2-electrode cells.

Cable Resistance

Cable resistances add to the measured sample conductance in the case of a 2-electrode cell. This resistance is compensated for with the 4-electrode cell, and no error occurs. This is of particular importance in environmental work, where measurement in wells and boreholes may require cable lengths of up to 100 meters.

Geometry Related Errors - Fringe Field Effects

Fringe field effects also cause errors. This is the part of the measuring field that "bulges" outside the theoretical 1 cm cube described previously. This error can be calibrated out of the measurement, but can subsequently affect the measurement if anything interferes with the field, such as the side of the measuring vessel. Advanced conductivity cells are designed to minimize this effect. If the entire measuring field is contained within the body of the electrode, then the side of the sample vessel cannot cause fringe field errors.

Durability

Cell materials should be chosen to fit the needs of the application. For field and demanding laboratory applications, many users choose a cell constructed with an epoxy body and carbon measuring electrodes, as this has been shown to be extremely durable and chemically resistant. For especially demanding applications, some manufacturers supply probe guards, which can be attached to the probe for additional protection. For pure water applications, stainless steel is frequently the material of choice. It is very durable, can be manufactured to precise tolerances, and for low conductivity, low contact resistance’s are not required. For chemically reactive samples, glass and platinum are frequently the optimum choice, as they have the best overall chemical resistance of all commonly used cell materials.

Orion offers cells and meters for a variety of industries with different features such as Salinity, TDS, temperature correction, data-logging capabilities etc. The variety of probes range from glass with platinum to the epoxy graphite 4 cell probe.

Various Types of Meters and Transmitters for Use in Aquaqculture, Their Proper Placement, Maintenance and Operation

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Abstract not available at time of printing.

Water Quality Monitoring and the Fifth Age of Computing

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Abstract

Perhaps because of the perception of complexity and cost, only a small percentage of aquaculture practitioners have adopted computerized process control technology to achieve reductions in operating costs, and/or increases in production yields. Where utilized, such systems are frequently maintained by skilled employees using custom programmed applications dedicated solely to the monitoring high-value species.

Recent trends in the computer and networking industry are beginning to have an impact on the design of water quality instrumentation. Low-cost *application specific* monitoring and control instruments that are designed specifically for aquaculture applications are just now being introduced. Programming and operating these instruments is very similar to programming a cellular telephone. English language menu prompts entirely replace cryptic programming methods. The need for specialized programming skills is significantly reduced or eliminated.

We are now entering the age of ubiquitous computing –an era that some refer to as the *Fifth Age of Computing.* In this era, we will use all sorts of devices –each with more computing power than the PCs of the 1980s or the mainframes of the 1960s and 1970s. These devices will be optimized for specific applications such as managing recirculating aquaculture systems. But they will also be capable of inter-operating with other devices to create a complete network-based decision support system –all at a fraction of the cost you would expect.

The purpose of this paper is to introduce the Fifth Age of Computing where sensors will be connected directly to a network, and where the LCD instrument display will be replaced by a portable PDA or Windows CE computer. A special emphasis will be placed on discussing the important role that the Internet and wireless communications will play in the design of monitoring and control devices of the future.