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Basic Principles of Biofiltration and System Design

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Introduction

This bulletin is intended to describe the basic principles of biofiltration as they apply to aquaculture and discuss some of the generalized biofilter designs. In addition, examples are given which show some of the uses for biofilters in aquaculture. Throughout this bulletin, the term **recirculation system** is synonymous with **biofilter system**, but not **water reuse systems** which do not necessarily employ biofilters.

There is not enough information in this publication to enable a novice to design and construct a money-making biofilter system. However, sufficient information is given so that the reader will be able to talk to knowledgeable individuals about biofilter systems, and to question dealers about the efficiency of prepackaged.

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Interest in the use of water recirculation for aquaculture began in the early 1960's, when demand for fingerling salmon began to exceed the amount of flowing water available for their rearing. At this time, it was also recognized that fish hatcheries were the source of considerable organic pollution in streams and rivers in the northwestern U.S. Therefore the federal government initiated studies to determine the feasibility of utilizing waste-water treatment technology in fish culture (Burrows and Combs 1968; Liao and Mayo 1972). The concept of water recirculation is basically a modification of waste-water treatment utilizing particulate removal (primary treatment) and nitrification (tertiary treatment). Nitrification is the process by which ammonia, which is toxic to fish at low concentrations is converted to nitrates, which is relatively non-toxic. The nitrification process will be discussed later.

Advantages of Recirculating Systems

There are five major advantages that recirculating aquaculture systems have; low water requirements, low land requirements, the ability to control temperature, the ability to control water quality, and independence from adverse weather conditions.

Low Water Requirements

A properly designed and operated recirculating system should require little water, just enough to clean particulate waste filters and to replace water lost to evaporation. This permits construction of aquaculture facilities in areas where ground water is limited and even opens the possibility of an operation being located in an urban area and utilizing dechlorinated city water. The production facility can thus be located close to the market. For example, a recirculating system which produces the same poundage of fish as 1000 acres of ponds (about 4.8 million pounds of fish) would require about 4000 gallons of fresh water each day or 1.5 million gallons per year. However, to fill 1000 acres of ponds averaging 5 feet in depth, you would need 1.6 billion gallons of water.

Low Land Requirements

Since fish in a recirculating system are reared in tanks, with oxygen mechanically supplied and metabolic wastes (ammonia) removed with flowing water, they can be held at extremely high densities. Currently the target which designers of systems are striving to obtain is 1 pound of fish per gallon of water. However, many people consider 0.5 to 0.75 pounds of fish per gallon of water acceptable. In pond aquaculture, the common maximum density is about 0.003 pounds of fish per gallon of water. Therefore, a recirculating system can be located in areas where large amounts of level land are not available. The low land requirement also permits the facility to be located in areas where the soil cannot hold water or, again, in urban areas.

Control of Temperature

The low water requirement of recirculating systems opens up the possibility of economically controlling temperature. This capability is the greatest benefit of these systems. Control of water temperature allows the aquaculturist to produce species which could not normally be raised in a given area. It also permits the water temperature to be maintained at the optimum level to maximize food conversion and provide optimum growth. Growth can also occur throughout the year, maximizing production and allowing rapid turnover of the product. In theory, marketing of the product is also enhanced, since fish can be supplied each week.

Independence from Weather

By rearing the fish indoors, the culturist is no longer limited by weather conditions. A sudden cold spell can wipe out a years production by killing the larval fish or disrupting the normal spawning of the broodfish. In addition, pond culturists can loose their crop to low oxygen during the summer and winter. Having the fish indoors also permits harvest at any time, whereas heavy rain or snow would stop the harvest of pond fish.

Control of Water Quality

With recirculating systems, the aquaculturist has the opportunity to control water quality, both to the benefit of the fish and to the final product. By maintaining dissolved oxygen at optimum levels, the fish will have better food conversion and be less stressed, thus leading to greater disease resistance. In addition, the fish are isolated from potential environmental contaminants such as off-flavor caused by some algal growth and any potential soil pollution resulting from run-off or residual pesticides. This results in a clean, quality product.

Potential Uses of Biofilter Systems

Because of the advantages fish culture systems incorporating biofiltration have over pond culture, they can be utilized for special applications in addition to intensive food-fish production. Among these are 1) overwintering of warmwater fish or shellfish, 2) training of fingerling fish to accept commercial feeds, 3) rearing of delicate larvae, 4) combining fish culture with hydroponic vegetable production 5) production of specialty products, and 6) holding of aquatic organisms for sale.

In temperate regions such as the midwest, certain species of fish and shellfish can grow adequately during the summer but suffer thermal stress and die during the winter. Included in this group are threadfin shad, tilapia, and the freshwater prawn (Macrobranchium). Threadfin shad, although not a food-fish, has high market potential for sale to pond and lake owners as a source of forage for predatory sport fish (Heidinger et al. 1983). Large numbers of fingerling fish can be held in heated recirculated systems during the winter and then transferred to grow-out ponds when the pond temperature is adequate (or sold directly in the case of threadfin shad). Because small individuals are involved, and rapid growth is not critical for this purpose, a relatively small system can be used for this application. It should be noted here that special permits may be required for the culture of tilapia, freshwater prawns and other exotic species. In states like Illinois, the Department of Conservation will review permit requests for these species rigorously to prevent adverse effects to native fauna and flora by escaped culture organisms.

Certain species of fish such as largemouth bass, walleye, and striped bass do not readily accept commercial feeds. Fingerlings of these species must be concentrated at high densities in tanks and subjected to a training process to get them to accept commercial feed. Greater success in the training process is achieved when optimal temperatures and dissolved oxygen concentrations are maintained. Therefore, a recirculating system becomes attractive as a training facility because of the ability to control temperature.

Recirculating, biofiltered fish culture systems also have a definite advantage when rearing the delicate larvae of some fish species, such as walleye, striped bass and the hybrid striped bass, and the pikes. At hatching, larvae of these fish can be as small as 0.25 inches long and incapable of swimming. If stocked into ponds at this time, they can settle to the bottom and suffocate in the mud. They are also very vulnerable to predation from aquatic insects and to sudden cold spells. Therefore recirculating systems have been used to rear these fish. In addition, by rearing larvae and small fingerlings in a recirculated system, the culturist can potentially get an early start in the production of these and other species. Since the biomass of the fish is small during their early life stages, a large number can be reared in a relatively small system. Thus larvae obtained from the south could be reared indoors and then stocked into grow-out ponds when temperatures warm. These fish would then have a 1-2 month jump on fish spawned locally.

One of the principle waste products found in biofiltered fish culture systems is nitrate. This nitrate could be utilized for the production of hydroponically grown vegetables. Several studies conducted at the SIUC Fisheries Research Laboratory (Lewis et al. 1978, 1981; Sutton and Lewis 1982) have given positive results, with the fruit grown in fish culture water ranking much higher than that grown only with chemical fertilizers. However, in such a system, the optimum conditions for rearing the fish must closely match those of the plants. A balanced system will produce much higher yields of fruit or vegetables than fish.

Because of the tight controls over temperature and water quality available with a recirculated fish culture system, they can be utilized for the production of various specialty products such as soft shell crawfish and for rearing larval freshwater prawns. Soft-shell crawfish production is occurring in biofiltered systems on a large scale. Pre-molt crawfish are harvested and placed in a system maintained at the optimum temperature. Careful monitoring and shallow trays allow the growers to harvest the recently-molted crawfish at the ideal time.

The low water requirement of biofiltered systems also allows producers to rear small quantities of animals in salt water far from the ocean. This makes the culture of freshwater prawns feasible, since the prawns only require salt water during the larval stage. Adult prawn females which are carrying eggs can be transferred to a recirculating salt water system. There, the eggs hatch and the larvae reared until they can tolerate fresh water. They can then be stocked into ponds or a standard freshwater system. Because of the short time that salt water is required, and the small size of the prawn larvae, this system can be relatively small.

A third special use for recirculating fish culture systems is for the maintenance and off-season spawning of broodfish. The ability to control temperatures and photoperiods in these systems permits the producer to supply larvae and fingerling fish through-out the year.

Biofilter systems also have application for the continuous, but short-term holding of aquatic life. These systems are used by the wholesale and retail bait industry to hold minnows, crayfish, and other bait organisms at high density until sold. Biofilter systems are also the primary means of holding fish in the aquarium trade.

Basis Components of Biofilter Systems

There are numerous designs for aquaculture systems utilizing biofiltration, ranging from simple tank-biofilter to high tech designs with computer control. However, all systems have certain basic components. These components may be separate pieces, or several may be integrated into a single unit. All systems need a water supply, tanks to rear the fish in, a method of removing particulate waste, the biofilter, a method to re-oxygenate the water and a method to move the water. In addition, there are numerous support facilities which must be considered, including; the building to house the facility, the heating or cooling system (heat the water or the room), food storage facilities, quarantine facilities, pre-market holding facilities, transport facilities, and back-up equipment. In a recirculating system back-up equipment (pumps, air blowers, electric generator) can never be considered as optional.

Water Supply

Although water reuse with biofiltration greatly reduces the quantity of water needed for aquaculture, a certain amount of fresh water is required. The major use of water in recirculated systems is in backwashing particulate filters. Other uses are to replace evaporative loss and biofilter cleaning. When sufficient water is available, some aquaculturists will "purge" their fish with cool, fresh water before market to improve flesh quality. Therefore, the amount of water required will vary depending on individual need.

The ideal water supply would be one with no contaminants, either introduced or natural. Among the common natural contaminants are carbon dioxide, hydrogen sulfide, ammonia, iron, and salt. Moderately hard water with methly-orange alkalinities above 200 mg/Liter will assure adequate buffering for the acids produced in a biofilter. In small to moderate systems, the potential for using potable city water is feasible. The chlorine can be removed with charcoal filtration or chemically, with sodium thiosulfate. However, this will result in some additional cost. The "ideal" water would also have a temperature near the optimum for the species of fish being reared to reduce the costs of heating or cooling the water.

Fish Tanks

The type of tank suited to a particular aquaculture system will depend, in part, on the species being reared. Other considerations include the amount of space available and the budget. Common tank shapes include long, narrow raceways or troughs, square or rectangular tanks, and circular tanks. Construction materials include concrete, block and mortar, fiber glass, stainless steel and coated steel.

Raceways are the easiest type of tank to harvest, and they do allow separation of several groups of fish by screening them into compartments. However, they can develop areas of low flow with resultant poor water quality. In addition, fish in the lower end (farthest from the incoming water) are often exposed to consistently poor water quality.

Square or rectangular tanks, although the most space- efficient, tend to develop dead areas in the corners. This type of tank is also not suited to some species of fish. Pelagic fish such as striped bass or hybrid striped bass tend to bump into the corners in their active swimming.

Circular tanks waste floor space, requiring more floor space per gallon of water. This type of tank is also somewhat more difficult to harvest. However, the circular flow produced in them eliminates any dead areas. Also, when larger fish are being reared, these tanks are virtually self-cleaning.

Tank construction materials are usually constrained by budget. However, a definite advantage to fiber glass tanks is the ability to move them if a change in system configuration is necessary.

The size of the rearing tanks will depend on your operating plan. Ideally, a tank which holds one "harvest unit" would be best. For example, if your plan of operation called for the harvest of 2000 pounds of fish per week, at 1 pound per gallon, you would need a tank holding 2000 gallons. However, this does not imply that fifty-two 2000-gallon tanks are needed (1 tank per week). The number of tanks needed will depend on the growth rate of the species being cultured. Smaller fish would be held at greater densities (number of fish per gallon) and only spread to more tanks as they grow.

Primary Clarifier

Solid wastes are produced by the fish and also result from uneaten food. This material should be removed from the water rapidly since it can be a major source of poor water quality and is the source of most biofilter problems. Particulate waste can contain 70 percent of the nitrogen load in the system (Liao and Mayo 1974). If this material enters the biofilter, it can cause problems in several ways. The particulate waste can clog the biofilter, resulting in low water flow through the filter or causing the nitrifying bacteria to die from lack of oxygen. Particulate waste entering the biofilter can also cause the growth of heterotrophic bacteria which produce ammonia while digesting the wastes. The particulate removal system is the key to a successful recirculating fish culture system.

Numerous means are available to remove particulate waste. However, there is still a search for a more efficient method. An efficient system should remove as much of the waste as possible and concentrate it for easy removal. It should also not require large amounts of water or energy to operate.

Early methods for removing particulate waste were through the use of settling basins or through sand filtration. Settling basins require a large area. (Davis 1977) recommends a 30 minute retention time to allow the solids to settle. Thus for a system moving 500 gallons per minute, a settling basin holding 15,000 gallons would be required. Sand filtration, although more compact and more efficient, requires frequent back-washing. Back- washing uses considerable water which must be replaced and heated (which costs money).

Recently, improvements have been made to the original settling basin. By adding a series of vertical plates or tubes, the efficiency has improved, thus allowing significant reductions in size. These filters have been shown to be effective on smaller systems. However, there have been reports that production-sized units did not adequately clarify the water.

Several recent designs of filters are currently being used in recirculating systems, including hydrocyclones, rotating screens, and triangle screens. Some of these have shown potential. Hydrocyclones are a conical type of filter in which the water spins down, forcing the particles to the side by centrifugal force. Although effective, these filters waste a lot of water since they continually discharge concentrated waste. Rotating screen filters are used by industry to effectively remove particulate waste from water. When used in aquaculture, they rapidly clog from organic growth. This necessitates frequent back-washing which wastes water. Triangle screen filters are designed around a slanted flate screen plate. The wastewater passing over the screens pushes some of the particulates which collect on the screens to a collection trough at the bottom of the plate. Most of the water passes through the screen. Like the rotating screen, the triangle screen need frequent washing,

With the existing technology, a combination of filters may be the choice for aquaculture. Filters like the hydrocyclones or triangle screens could be used to remove much of the particulate waste. The water wasted by these filters could then be directed to a settling basin. The reduced amount of flow from the filters makes a settling basin practical for this purpose.

Biofilters

The biofilter is the heart of a recirculating aquaculture system. Basically, a biofilter is simply a surface on which bacteria grow. While growing, the bacteria convert toxic ammonia produced by the fish and feed to much-less toxic nitrate.

NH_3(ammonia)->NO_2(nitrite)->NO_3(nitrate)

However, in reality, it is a complex system comparable to a living organism. The biofilter must be "fed" and supplied with oxygen in order to remain healthy and work properly.

As previously stated, the purpose of the biofilter is to convert ammonia to nitrate. Ammonia is the end product of protein metabolism. Fish and other aquatic organisms generally excrete ammonia in the pure form while mammals first convert it to less toxic urea. Ammonia in water can be in two forms, molecular ammonia (NH^3) and ionic ammonia (NH^{4+}). It is the molecular form that is toxic. Concentrations of molecular ammonia as low as 0.01 mg/L have resulted in sublethal toxic effects (clubbed gills, poor growth) in salmonids (Burrows 1964) while channel catfish show these effects at 0.12 mg/L (Robinette 1973). The temperature and pH (acidity) control the ratio of molecular ammonia to ionized ammonia in water, with pH having the greatest effect (Trussell 1972). As pH increases (less acidity), the percentage of total ammonia in the toxic molecular form increases logarithmically (Table 1). At a temperature of 69F and a pH of 7.0 about 0.4% of the ammonia in the molecular form. At a pH of 8.0, this increases to 3.8%, while at pH 9.0, 28.4 percent is molecular.

Table 1. Percent un-ionized ammonia solutions at various pH and temperature values (after Thurston et al. 1974).

Temperature	pH			
	7.0	7.5	8.0	8.5
50	0.19	0.59	1.83	5.56
59	0.27	0.86	2.67	7.97
68	0.40	1.24	3.82	11.20
77	0.57	1.89	5.75	16.20
88	0.80	3.48	7.46	21.30

Oxidation of ammonia in the biofilter is accomplished by a group of chemotrophic bacteria (chemical eaters). These are common bacteria, found in water and soil. One group of these bacteria (Nitrosomonas) utilizes ammonia (NH_3) and oxidizes it to nitrite (NO_2). However, nitrite is also toxic to fish. Nitrite ties up the oxygen binding sites in the blood hemoglobin, causing the problem which is commonly known as "brown blood disease." Toxic levels of nitrite are in the range of 24+ mg/L for channel catfish, but as low as 0.55 mg/L for salmon (Piper et al.1982). Fortunately, a second group of bacteria (Nitrobacter) utilizes nitrite and subsequently release nitrate (NO_3). In actuality nitrite and nitrate are released as nitric and nitrous acids, resulting in a decrease in pH (more acidity) unless the water is well buffered.

Table 2. Surface areas of some common biofilter media.

Medium	Surface Area / Volume		Fish Supported[a]
	sq-m/cu-m	sq-ft/cu-ft	
Granular Carbon[b]	3510	1070	54.1
No. 8 Stone[c]	584	178	9.0
3-cm Gravel[b]	330	101	5.1
1-cm Spheres[d]	323	98	5.0
1.9-cm Stone[c]	279	85	4.3
Rotating Disk[e]	210	64	3.2
Telpak Media[f]	130	40	2.0
PVC Modules[c]	89	27	1.4

[a] Based on 3% feeding rate, 0.027 kg ammonia/ kg feed and an oxidation rate of 200 mg ammonia/sq-m/day.

[b] From Paller and Lewis (1988).

[c] From Meade (1974).

[d] From authors' calculations.

[e] Based on 1/8-inch plates spaced 1/4 inched = 32 plates/ft.

[f] From Aquatic-EcoSystems, Inc.

The size of the biofilter needed will depend on the amount of ammonia added to the system. Ammonia production is most closely related to the feeding rate and the efficiency of food utilization. Feed utilization, in turn, depends on the size of the fish, the quality of the feed, temperature, activity level of the fish, and the feeding rate. Generally, 1 to 3 pounds of ammonia is produced for each 100 pounds of feed. Thus 10,000 pounds of fish getting 300 pounds of food (3 percent of body weight) would produce 9 pounds of ammonia per day.

The quantity of bacteria available to oxidize the ammonia is limited by the surface area of the biofilter media. As a bacterial population develops, it will coat the surface it is growing on to a limited depth. The efficiency of this bacterial coating is then controlled by 1) the mixing of the water to assure that the ammonia comes in contact with the bacteria, 2) the dissolved oxygen level, 3) the pH, and 4) the temperature. In warm-water fish culture systems nitrification occurs at a rate of 200 to 400 mg of ammonia per square meter of biofilter surface area per day (0.00037 to 0.00074 pounds per square yard per day). Thus to oxidize the 9 pounds of ammonia produced in the example above, a biofilter with 24,500 square yards of surface area would be required (15.2 acres). Thus, it is apparent that an important factor in biofilter design is to get the maximum amount of surface area into a given volume. The surface areas of some common fixed media are found in Table 2. As can be seen, the smaller the particle size, the more the surface area per unit volume. However, when the particle size is reduced the probability of filter clogging increases and the ability to mix the water within the biofilter decreases. The major engineering problem with biofilters is to develop a method to use small particles and assure that oxygenated water will circulate throughout the filter.

Re-oxygenation

Since the fish utilize oxygen dissolved in the water and release carbon dioxide and the biofilter also utilizes oxygen, a recirculating system requires a method to aerate or oxygenate the water. Maintaining high levels of dissolved oxygen (DO) in the water is critical to the success of the system. With low DO the growth rate of the fish will be lower and food conversion will decrease.

The amount of oxygen consumed by the fish is a function of fish size, feeding rate, activity level of the fish, and temperature. Meade (1974) determined that the oxygen consumption of salmon being reared at 57F was 0.004 pounds of oxygen per pound of fish per day. Lewis et al. (1981) determined that striped bass raised at 77F consumed 0.012 to 0.020 pounds per day. Consumption of oxygen by the biofilter bacteria is most closely related to the amount of ammonia entering the filter. Meade (1974) using the formulae of several authors determined that a biofilter will utilize 4.0 to 4.6 pounds of oxygen for every pound of ammonia oxidized. The basic equations are:

$$2NH_4 + 3O_2 - 2NO_2 + 2H_2O + 4H^+$$

for the conversion of ammonia to nitrite, and:

$$2NO_2 + O_2 - 2NO_3$$

for the conversion of nitrite to nitrate. However, due to the presence of other bacteria in the system, we recommend that a ratio of 6 pounds of oxygen to 1 pound of ammonia be considered.

In the above example (10,000 pounds of fish, 9 pounds of ammonia) the oxygen requirement would be:

10,000 x 0.012 + 9 x 6 = 174 pounds of oxygen per day.

Not all of this 174 pounds would have to added either through mechanical aeration or through direct oxygenation, since some aeration occurs naturally with the movement of the water.

Several methods are available for aerating water. Oxygen can be dissolved in water either through aeration (adding air; 20 percent oxygen) or through oxygenation (100% oxygen). Methods of aeration include the aspirators of Burrows and Combs (1968), mechanical agitators, and air blowers. Although effective, aspirators require pressurizing the water, which adds to the pumping costs. Care must also be taken with these systems to prevent nitrogen supersaturation which is harmful to fish. Agitators are only suitable for relative small systems since a separate unit is required for each culture tank. Low pressure, high volume air blowers are probably the most effective method of aeration for medium to large systems. However, they also have the highest initial cost.

As the size of systems increase, the use of pure oxygen becomes more economical. Pure oxygen is available in either gaseous or liquid form. For use in a fish culture system, liquid oxygen is the only form which should be considered, both for economic reasons and for practical storage. Recently, oxygen concentrators have been introduced into fish culture. These units take compressed air and extract the oxygen by passing the gas through a semi-permeable membrane. Several problems exist with these units. The initial cost of these units are high, and their operation requires the use of a large high volume air compressor. In addition, a larger backup generator plant is required to run these units during line power outages. Therefore, unless a use for the high volume of pressurized off-gas is initially designed into the system, the cost of operation is also high.

The cost effectiveness of an oxygen system is limited by the efficiency in which the gas is dissolved into the water. The efficient transfer of oxygen depends on bubble size, pressure of the water and gas, temperature, contact time, and initial level of oxygen in the water. One of the most efficient devices for introducing oxygen in the water is the U-tube. This devise is simple (no moving parts) and take advantage of pressure differentials to increase the gas transfer without requiring a high-pressure pump. However, with a U-tube, it is only practical to introduce the oxygen at one central point. Thus it is advisable to have an alternative oxygen delivery system to each fish culture tank for use when there is no water flow (power outages and generator failure, and main pump failure). During normal operation, the main water supply would be oxygenated using a U-tube contactor. However, if water flow is disrupted, oxygen would be diverted to diffusers in the individual fish culture tanks.

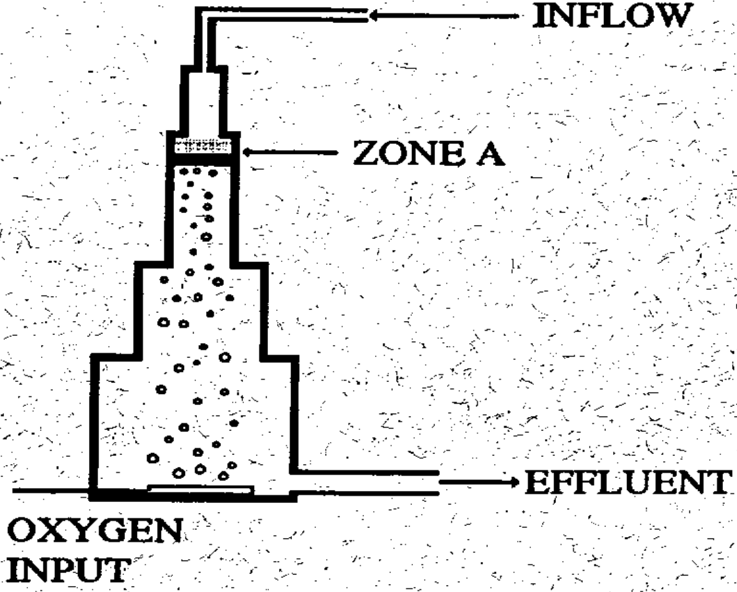

Figure 1. The oxygen cone. Zone A represents the area that the upward movement of the bubbles equals the velocity of the downward flowing water.

Another efficient way to add oxygen is with oxygen cones (Figure 1). These devices consist of a conical container with an oxygen bubbler located in the wide bottom. Water enterring the narrow top has enough velocity to keep the bubbles of oxygen down. However, at some point in the widening cone the velocity of the downflowing water will match the upward movement of the oxygen bubbles. The bubbles thus remain suspended until they are absorbed. Like the U-tube system, oxygen cones are usually designed to handle the entire system flow.

Water pumps

The method by which water is moved in a recirculating system will depend significantly on the system configuration. Systems which raise water to overhead biofilters or utilize an aspirator for aeration will require pumps which can deliver adequate water at 20 feet of head (10 psi). Low-head systems can be operated with high volume, low pressure pumps, or with the use of air-lift pumping. With small to moderate systems, an air-lift pumping system appears to be promising due to the large volume of water which can be moved at a relatively low horse-power, and due to its ability to aerate the water. The disadvantage of an air-lift system is in the requirement that all parts of the system be essentially at the same elevation, thus requiring more floor space and making tank harvest and draining difficult.

Whichever pump system is utilized, it is advisable to divide the pump load among two or three pumps. Therefore, failure of one unit will still permit limited operation and prevent loss of fish until a replacement unit is put in service.

Types of Biofilter Systems

There are four basic types of biofilter designs; submerged bed, trickle, rotating disk, and fluidized bed. In addition, the submerged bed type of biofilter can be divided into downflow, upflow, and lateral flow sub-categories.

Submerged bed biofilters

Submerged bed biofilters are characterized by having a fixed (non-moving) media that is constantly under water. The biofilter media (attachment surface for the bacteria) in these filters is highly diverse. Some of the materials which are used include gravel, oyster shell, solid plastic beads, extruded or molded high-surface-area plastic rings, and plastic screening.

Submerged bed biofilters are classified into three groups, depending on the direction of water movement. In downflow biofilters (Figure 2), water from the clarifier enters the top of the filter by gravity and flows through the filter to a sump. From there it is pumped to a head tank, oxygenated and flows by gravity to the fish culture tanks. Downflow filters are subject to frequent clogging and thus must be backwashed often. However, they are the simplest and less costly to construct. Some success has also been achieved by using large volumes of air to dislodge particulate matter during backwashing.

Upflow filters are similar to the downflow type in that they are operated by gravity. The advantage of upflow over downflow filters is that with the former, settling basins can be incorporated below the media. Generally a light weight, buoyant media is required. However, with the settling basins located below the biofilters, it becomes difficult to determine when to clean the basins. The settling basins can also use up the dissolved oxygen, reducing the efficiency of the biofilter. Without supplemental in-filter oxygenation, the maximum depth of upflow, and downflow, filters is limited to about 40 inches.

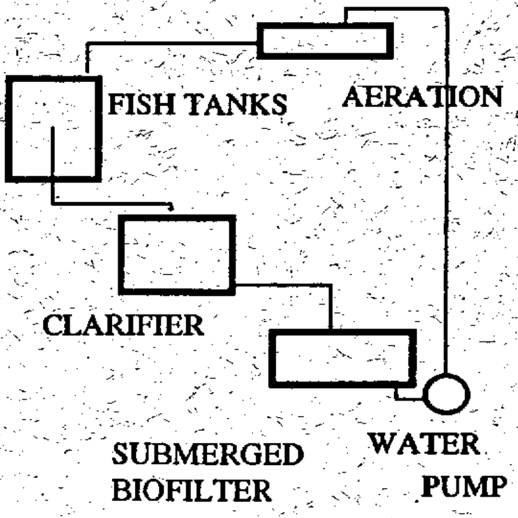

Figure 2. Schematic of a submerged-bed biofilter system.

In lateral flow biofilters, water enters the biofilter and flows laterally through the media. One commercially marketed design of this type of system utilizes a small chamber as well as part of the media for particulate waste removal. In addition, an air-lift is installed in the biofilter to move water from the filter back to the fish rearing tank. The applicability of this system type to large-scale production has yet to be tested.

Trickling filters

Trickling filters are similar to submerged downflow filters in that water enters the top and flows downward through the media. However, the trickling filter is elevated (Figure 3), and has an open bottom. This configuration allows the media to be exposed to the air, thus assuring adequate oxygen for the bacteria. In a properly designed trickling filter the water should cascade over the media in a thin film. Packed column aeration/degassification systems work on the same principle as a trickling filter.

One problem encountered with trickling filters is the sloughing of the bacteria. At times, enough bacteria will be lost to significantly reduce the nitrifying capacity of the filter. Davis (1977) needed to use a secondary (post biofilter) clarifier on a trickling filter to remove particulate material created in the filter.

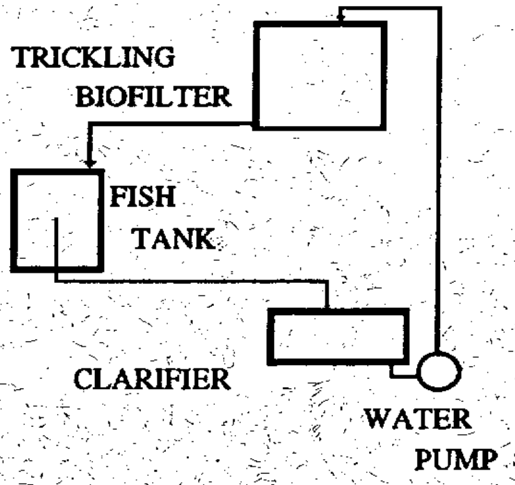

Figure 3. Schematic of a trickling filter system.

Rotating Disk

The rotating disk biofilter (also called rotating biological contactor or rotating bio-contactor) has recently gained popularity. In this system (Figure 4), the substrate for the nitrifying bacteria consists of a series of parallel circular plates which are mounted on a shaft with a small (0.25- to 0.5-inch) gap between them. The disks are partially submerged and rotated on the shaft, using either a low speed gear motor or a paddlewheel driven by the water flow. Usually several of these units are placed in series.

The advantages of the rotating disk biofilter include its tendency to be self-cleaning, its low head requirements, and its ability to maintain high levels of dissolved oxygen (Lewis and Buynak (1976). Because of the rotation, a thin film of

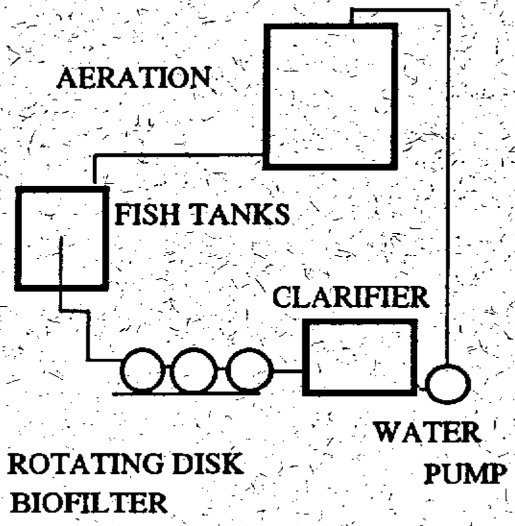

Figure 4. Rotating disk biofilter system.

water is constantly being exposed to the air, assuring adequate oxygen to the bacteria. Because of this, the nitrification process is consistent. With other systems partial clogging, variations in dissolved oxygen, and variations in water flow can result in fluctuations in their nitrifying capacity.

Among the problems associated with rotating disk biofilters are their limited surface area, the additional costs to operate them, and a tendency for them to cool the water through evaporation. With a 0.25-inch spacing between the plates, rotating disk biofilters have only 62 ft^3/ft^2 of surface area (Table 2). Thus, a large area is required for placement of this filter system since biofilter size is a function of the amount of surface for the nitrifying bacteria to attach. Since most rotating disk biofilters are operated by an additional motor, the cost of running that motor and the additional maintenance must be considered. The third problem with rotating disk biofilters, evaporation, will only affect systems which have a high air exchange rate. The rotation of the disk constantly exposes a thin film of water to the air. This is the same process used in many home humidifiers. Since evaporation causes cooling, this temperature drop must be taken into account. Generally it is recommended that systems incorporating a rotating disk biofilter be located in a tightly closed insulated building. In addition, because of the tendency for self cleaning, a secondary clarifier is required.

Fluidized Bed

Fluidized beds are a relatively new concept in biofiltration. In a fluidized bed, water enters the bottom of a cylinder with sufficient velocity to expand the medium (Figure 5). This permits the use of extremely fine materials for the bacterial substrate. Graded sand is one of the more common substrates used in fluidized bed filters. However, because of its density, a considerable amount of water is required to make it expand. Paller and Lewis (1988) examined the use of bone charcoal granules as a substrate in these filters. They found that a flow of 11 gpm per square foot of dimensional surface was sufficient to expand a filter bed 24 inches deep.

Two major benefits of fluidized beds are apparent. The most obvious is the amount (ft^2) of bacterial substrate which can be fitted into a small filter (Table 2). The second is their tendency not to clog. The suspended particles will coat with bacterial growth, but the constant churning prevents excessive growth and adhesion of the particles.

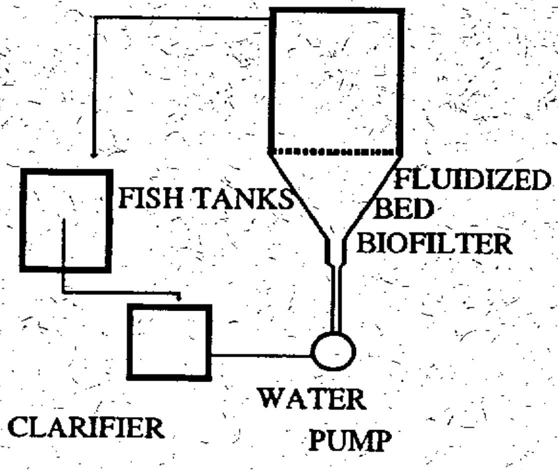

Figure 5. Schematic of a system with a fluidized-bed biofilter.

The major problem associated with this filter type is the need for a relatively high pressure pumping system to suspend the substrate. This results in higher pumping costs than some lower pressure systems. A post-biofilter clarifier may be required with fluidized beds because of the self cleaning of the particles.

Biofilter Conditioning

The development of Nitrosomas populations in a biofilter bed is favored by high ammonia concentrations. Nitrobacter, however, is inhibited by high ammonia levels, thus requiring the oxidation of much of the ammonia to nitrite prior to the development of Nitrobacter populations (Lees 1952). This is most evident in new systems stocked with a moderate load of fish. Ammonia levels will increase due to the presence of fish and then decline as Nitrosomas populations develop and oxidize the ammonia to nitrite (Figure 6). Only after much of the ammonia is converted will Nitrobacter populations develop and begin oxidizing the nitrite to nitrate. Therefore, unless the system is pre-conditioned, a large mass of fish cannot be stocked. This phenomenon can also occur in operating systems. A surge of ammonia resulting from overfeeding or improper tank cleaning can inhibit Nitrobacter. Nitrate resulting from oxidation of some of the ammonia can cause loss of fish, while ammonia levels remain below the lethal limit.

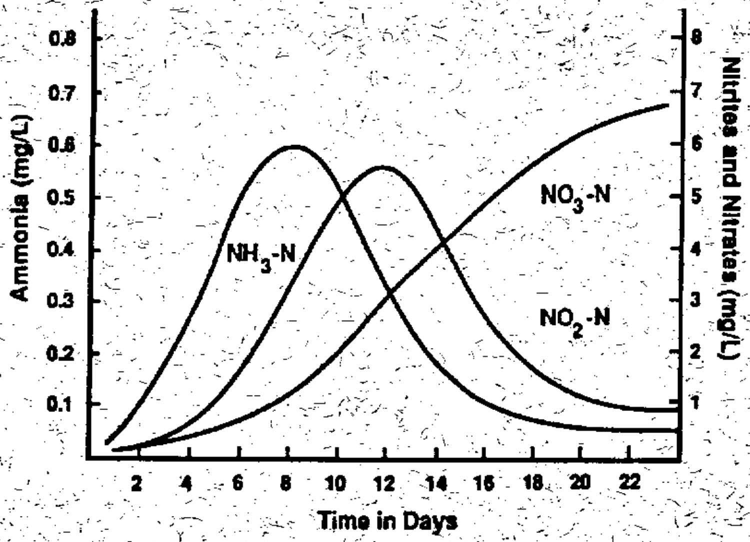

Figure 6. Typical result of the development of nitrifying bacteria in a new culture system.

Pre-activation of a biofilter system involves seeding the filter bed with bacteria and feeding them with ammonia. Nitrifying bacteria are abundant in rich garden soils so many people use a small amount of this as a bacterial seed. Commercially concentrated bacteria cultures are also available. Once the filter has been seeded, sufficient ammonia is added to maintain about 3 mg/Liter of ammonia. A good source of ammonia for this purpose is household ammonia without added detergent, although ammonium- nitrate and ammonium-phosphate fertilizers have been used. Ammonium-nitrate is not the best choice since the presence of nitrate is a good measure of the activation process.

Initial additions of ammonia will disappear rapidly, by being incorporated into the bacteria. After the first week of pre-activation, ammonia it will be necessary to add ammonia daily. After several weeks, nitrite and nitrate will occur in appreciable levels. Once biofilter conditioning has occurred, nitrite levels should have risen to 5 to 10 mg/Liter and then stabilized below 1 mg/Liter, and nitrate levels should be steadily increasing. This process can take as long as 4 to 6 weeks.

As an alternative to pre-activation, a staggered stocking regime can be used. Here, the biofilter is seeded as above and then the system in stocked with a small load of fish. When the biofilter bacteria populations grows to meet this ammonia load, additional fish are stocked. When this technique is used, a sufficient water supply for emergency flushing should be available.

Disease Treatment

When working with biofiltered aquaculture systems, caution must be taken when using some of the therapeutic chemicals available to fish culturists. The potential exists that the chemical could destroy the biofilter bacteria. Antibiotics have this potential, although they are generally administered in the feed. Formalin-F, a commonly used chemical for the control of protozoan and trematode infections does not destroy the bacteria. However, this chemical will increase the ammonia in the system by killing fungus and other organisms in the filter (Lewis et al. 1981). Breakdown of these organisms results in the release of ammonia. Formalin-F also complicates the analysis of ammonia in the fish culture system because it registers as ammonia in many of the water quality test kits.

Disadvantages of Biofiltration Systems

As stated earlier, there are five major advantages in using recirculated fish culture systems incorporating biofiltration; low water and land requirements, control of temperature and water quality, and independence from the effects of weather. However, there are also certain disadvantages of these systems, and most of these start with a $.

The initial set-up costs of a biofiltered fish culture system are formidable. Along with costs of the tanks, biofilters, pumps and plumbing, the costs of the building and insulation must also be considered. Other important initial costs include feed storage facilities and back-up and emergency power equipment. If it necessary to borrow money for these, the interest on this capital must be considered in the operating costs.

Operating costs of a recirculating system are also substantial. The costs of producing fish should include the costs of feed, the cost of energy to heat and pump water, the costs of that water, whether it comes from a well or municipal source, the cost of treating or otherwise disposing of effluents (particularly back-wash from clarifiers), the costs of labor and the costs of transportation of the fish to the market. In addition, the costs of insurance and maintenance of the equipment should also be considered, as well as the cost of the fingerlings whether they are purchased of raised on site.

These costs must be carefully and accurately determined so that they can be included into a production plan. That plan should show how many fish can be produced at what size, and what will be the cost to produce them. From this, the price per pound which needs to be attained can be determined. Then one needs to find out if anyone is willing to pay that price.

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