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DESIGN OF RECIRCULATING SYSTEMS FOR INTENSIVE TILAPIA CULTURE

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Tilapia is a species of fish belonging to the family Ciclidae originating in Africa. They have been cultured widely in the Middle East and Africa since before King Tut's time. In fact, it is widely believed to be the fish described in the Bible that was used to feed the masses, hence the name "St. Peters Fish" coined by Israeli producers.

Recirculating systems offer many benefits over pond culture including, but not limited to, control of environmental parameters (water temperature, dissolved oxygen, and water quality), and ease of handling and stock management. Tilapia are well suited for recirculating system due to their tolerance of high densities, lower dissolved oxygen levels, and less stringent water quality parameters.

Several critical issues must be addressed when designing a recirculating system (Table 1). Only after addressing these issues can design and sizing of treatment components begin.

The metabolic wastes produced by finfish are varied and complex in their make-up. In a recirculating system, **all** waste components (Figure 1) **must** be targeted for treatment. Unionized ammonia, and nitrite, are all toxic to fish, while carbon dioxide build-up directly influences pH and, consequently, the nitrification process. System managers must be responsible for all of these processes.

Table 1. Design Factors Which Must Be Addressed Before Configuring A Recirculating System.

Issue	Recommendation
Ammonia excretion rate.	9.0-14.0 grams/lb feed as TAN*
Maximum loading density of the system (lbs of fish/gallon of water)	1/4 to 1/2 lb fish/gallon water
Maximum feed rate (lbs of feed/lbs fish at maximum density).	Ability to feed 4% body weight at maximum density.
Water quality parameters and limitations.	see Table 4
State and Federal regulations	see Table 5

* Wheaton (1977) and Wimberly (1990).

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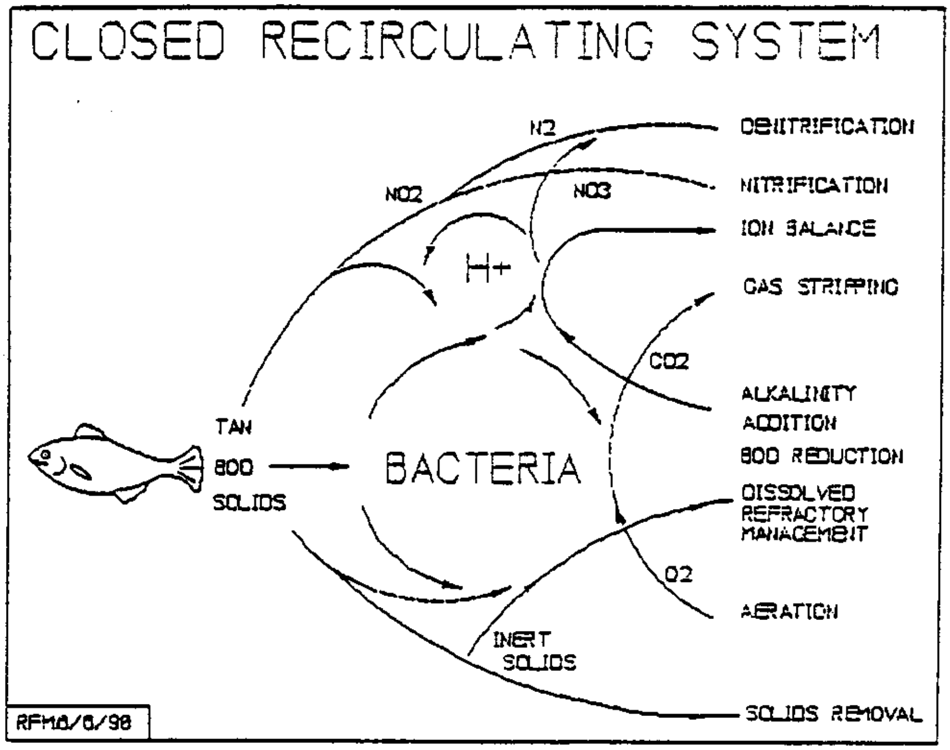

Figure 1. Finfish Waste Wake for Closed Recirculating Systems.

	Flushing	Trickling filter	RBC	Settling basin	Upflow Sand Filter	Foam Fractionation	Packed Column	Fluidized Bed	Ozone	Activated Carbon	Bead Filter	
Denitrification	X											
Ion Balance	X											
Alk. supply	X											
Color removal	X								X	X		
Nitrification		X	X		X		X	X		X	X	
Gas stripping		X	X			X	X		X			
BOD reduction		X	X		X	X	X	X	X	X	X	
Aeration		X	X			X	X		X			
Suldge removal				X	X						X	

Figure 2. Treatment Checklist for Closed Recirculating Systems.

There are a variety of options available to handle the metabolic wastes generated by finfish (Figure 2). Basic system design necessitates all waste produced be targeted for treatment. However, practical experience reveals problems associated with designing a treatment system using this simplistic approach.

Solids capture is one of the most important processes in a recirculating system and often the most underestimated in terms of the amount of solids produced by finfish. On a live weight basis, fish generate a larger volume of waste than most other animals (Chen and Malone, 1991). The solids removal approach most widely utilized in most recirculating systems is sedimentation/settling. This process is generally labor and time intensive and fails to control fine solids, leading to a build-up of organics, overloading of the biofilter, and a breakdown in the nitrification process.

pH control is another element typically overlooked when designing a recirculating system. Failure to recognize the need for degasification can lead to pH depression via a build-up of carbon dioxide in the water. A severe pH depression will cause an inhibition of the nitrifying bacteria.

While solids capture and pH control are two of the most important processes, a recirculating system must meet numerous other criteria to ensure proper operation Table 2.

The treatment configuration currently under evaluation by the Civil Engineering Aquatic Systems Laboratory (CEASL) is presented in Figure 3. An expanded granular biofilter (EGB), specifically a bead filter, is recommended for solids capture and biofiltration. The advantages of these filters are the extremely low water loss associated with the removal of solids and the fact that it is capable of mitigate the extremely high waste loads associated with finfish. This new generation of filters is substantially more powerful at higher loading rates compared to the upflow sand filters used in crab and crawfish culture.

The bead filter employs low density polyethylene beads as a filter media in a pressurized upflow configuration. The filter physically traps suspended solids while providing a large specific surface area for the growth of crucial nitrifying and heterotrophic bacteria. A propeller system embedded in the bed is periodically activated for cleaning purposes. Underlying the filter bed is a cone shaped settling chamber to facilitate capture and removal of solids released during the back wash process.

Should additional nitrification be required, either a fluidized bed or rotating biological contactor is recommended. Fluidized beds typically have a specific surface area greater than 700 ft^2/ft^3 while RBC's range from 40 to 60 ft^2/ft^3. Capital costs are less for a fluidized bed and, if designed properly, it can be run in series with the bead filter with both utilizing the same pump.

Table 2. Fundamental Design Recommendations for Recirculating Tilapia Systems.

Design Criteria	Recommendation
Tanks	Round or oval constructed of fiberglass, concrete or plastic lined. Multiple independent system.
pH control	Counter current degasification column.
Specific surface area available for biofiltration.	14 ft^2/lb fish at feed rate of 4.0% body weight.
Solids capture	Capture suspended solids and particulate matter > 30 µm in size.
Recirculation rate	0.1 gpm/lb fish.
Fine solids capture	Foam Fractionation to remove fine suspended solids < 30 µm in size and dissolve organic matter (proteins).
Aeration/Oxygenation	Regenerative blower and air diffusers with possible need for pure O_2 injection as approach maximum density and feed rate are approached.
Emergency back-up systems and alarms.	Pumps, aeration/oxygenation, power source and alarms for power failure, D.O. and water level.
Secondary waste treatment to prevent release/escape eggs, fry, fingerlings or brood fish (as per LDWF regulations).	See Table 5. State Regulations
Biofouling	Clean-out ports and disinfection loops.
Electrical wiring	Should meet all requirements for outdoor use. Ground fault breakers.
Plumbing	Water and air lines should be PVC. Do not use copper pipe.
Heating/Cooling/Insulation	Units should be sized to maintain temperature within 2° C. Resistant to biofouling. No copper tubing. Insulate tank bottom, sides, and top.

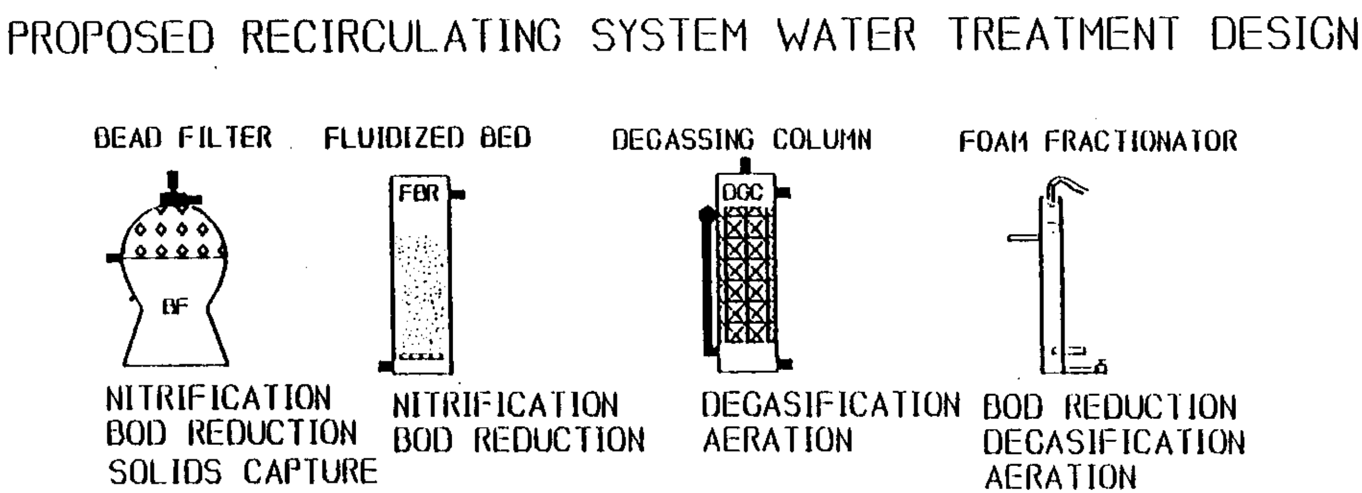

Figure 3. Recirculating System Water Treatment Configuration Currently Under Evaluation by CEASL.

pH control is accomplished by a counter current degasification column. Design criteria call for a maximum water flow rate of 25 gpm/ft^2 x-sectional area and a counter current air flow rate with a minimum ratio of water flow to air flow of 5 to 1 on a liquid volumetric basis (cfm). The column should contain a minimum depth of 3 ft. of lightweight, plastic media having a high specific surface area and a low resistance to flow. The ratio of column diameter to media diameter should be a minimum of 8 to 1. Column media should have a diameter of no less than 1 inch and a porosity greater than 92% (Piedrahita and Grace, 1991). Degasification also provides the added advantage of raising the dissolved oxygen concentration of the water to 90% of air saturation level just before the water is introduced back into the grow-out tank.

Foam fractionation is employed to remove the fine suspended solids (< 30µm in size) and dissolved organic matter (proteins). Foam fractionation is accomplished by bubbling air through water to produce a foam which traps the solids and organics (Weeks et al., 1991). The foam is easily removed from the system. There are two general types of foam fractionators: counter current foam fractionators which utilize regenerative air to form the bubbles and venturi foam fractionators which generate bubbles using water under pressure and a simple venturi. Both types of foam fractionators are easily constructed using standard PVC pipe and fittings. Additional aeration is also acheived during foam fractionation.

Aeration is acheived through the use of low pressure, regenerative blowers and air stone diffusers which are supplemented by aeration from the degasification column and foam fractionator. Blowers and air stones should be sized to provide a minimum of 6 mg/l of dissolved oxygen at the optimal temperature and maximum density and feed rate. Should additional aeration become necessary as peak densities are approached, supplemental aeration utilizing pure oxygen is recommended.

Heating/cooling units should be sized to maintain the temperature with 2°C of the optimal temperature. Experience shows that it is much more efficient to heat the tank water than the building and makes for a more pleasant working environment. Tanks as well as the building in which they are housed should be insulate to reduce heat loss and conserve energy.

The success or failure of any recirculating system depends not only on proper design but also on having and implementing an appropriate management strategy. Management recommendations and water quality guidelines are presented in Table 3 and 4, respectively.

Two fundamental obstacles must be overcome before the full production potential of recirculating technologies can be realized. First, cost effective design strategies which minimize the complexity and energy intensity of recirculating systems must be developed (Mui, 1981; Van Gorder, 1990).

Table 3. Management Recommendations.

Issue	Recommendation
Water source	Ground water or dechlorinated city water.
Flushing	Capacity to flush 25% of total system volume a day.
Feeding	By hand. 3-6 times daily on a regular basis.
Stock Management	Stocking density should be manipulated to utilizes tank space efficiently, ensure adequate water quality, and provide for a continuous harvest capability.*
By-pass valves	Ability to bi-pass biological filters to protect during chemical treatments.
Sterilization	All nets, boots etc. should be dipped in chlorine after each usage and before moving to another tank.
Species	T. nilotica, T. aurea or Their hybrids.
Sex	Monosex culture of all male Tilapia. Males grow up to 40% faster than females.
Use of pumps, motors and blowers.	Where ever possible use two smaller units rather than one large unit for safety. Energy efficiency should also be taken into account.

* Van Gorder, 1991

Table 4. Water Quality Typically Observed In Recirculating Tilapia Systems.

Parameter/Frequency	Recommended Range
Dissolved Oxygen (Daily)	Above 6.0 mg/l in culture tank. Above 2.0 mg/l leaving the filter.
Total Ammonia Nitrogen (Daily)	Below 5 mg/l NH_3-N + NH_4-N in culture tank.
Nitrite-Nitrogen	Below 5.0 mg/l NO_2-N in culture tank.
Unionized Ammonia Nitrogen (Daily)	Below 0.5 mg/l NH_3-N in culture tank. (Temperature, pH, and TAN dependent)
Nitrate (Weekly)	Below 100 mg/l NO_3 in culture tank.
Temperature (Daily)	Optimal 82° to 84° F in culture tank. Range 78° to 86° F.
pH (Daily)	Between 7.0 and 8.0.
Alkalinity (Daily)	Above 150 mg/l as $CaCO_3$.
Chloride Level (Weekly)	Range 100 to 250 mg/l as NaCl or $CaCl_2$.
Total Hardness (Monthly)	Above 50 mg/l as $CaCO_3$.

Second, training methodologies need to be cultivated since few potential operators have adequate training in all areas essential to the successful operation of a recirculating aquaculture system.

As a consequence, recirculating systems have been commercially sustainable only in areas where the unit cost of production ($/lb.) has been able to compensate for complexity and energy consumption such as niche markets. Losordo and Westerman (1991) preformed an economic analysis of a small Tilapia recirculating system using a computer model. Inputs into the model were actual performance data demonstrated on site. Cost of production was determined to be approximately $1.27 per lb. A sensitivity analysis of the model revealed the greatest gains in system profitability were associated with increased production capacity and/or decreased system cost; although, extreme caution must be used so as not to sacrifice system reliability.

Table 5. Louisiana Wildlife and Fisheries Regulations Pertaining to the Culture of Tilapia.

Regulation	Recommendation
Culture site elevation and relation to 100 year flood plain.	Self explanatory (S/E)
Present use of area.	S/E
Detailed description of closed system including a drawing.	S/E
Describe culture tanks and number.	Round or oval. Fiberglass, concrete or plastic lined. Multiple independent tank/treatment systems.
Will hatchery be established.	S/E
Measures taken to ensure culture system will prevent escapement of Tilapia eggs, fry, and brood fish.	Requires secondary treatment of waste water. Options:slow sand filter, chemical treatment, physical treatment, electrical treatment, screening or a combination of any of the above.
Describe water source and plans for discharge of waste water.	Ground water with secondary treatment prior to discharge.
Only the following species and their hybrids are allowed: Tilapia aurea Tilapia nilotica Tilapia mossambica Tilapia hornorum	Pure strain T. nilotica, T. aurea, or the hybrids of these species.
Source of Tilapia	S/E
Species certification source and most recent date of certification.	S/E
Ultimate use of Tilapia.	S/E
Do you plan to sell fingerlings?	S/E
Describe security measures to prevent theft or accidental release.	S/E

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