Water quality requirements for Recirculatory Aquaculture Systems

Loveson Edward, L., Suresh Kumar, P., Sampath Kumar, G., Ravi K Avadhanula

Culture of marine finfishes in a controlled condition is an upcoming industry, which is very much essential to satisfy the rising demand for protein rich seafood. Traditional aquaculture ponds use huge quantity of water and land to produce lesser output. Whereas Recirculatory Aquaculture System (RAS) is one such system in which fishes are cultured in high density at controlled environmental condition with lesser usage of water and comparatively less area of land to produce higher output. RAS is designed to minimize or reduce dependence on water exchange and flushing in fish culture units. The systems have practical applications in commercial aquaculture hatcheries, holding tanks and aquaria systems as well as small scale aquaculture projects. Water is specifically recirculated, when there is a specific need to minimize water replacement, to maintain the quality condition which differ from the supply water or to compensate for an insufficient water supply.

Water Source

Good quality water source is a prime requirement for successful operation of RAS. While choosing a site, the water source must be checked for both quantity and quality. This will definitely eliminate the problems or complications arising due to water in due course. The two most commonly used water source in mariculture facilities are open sea / creek water and ground water for salinity make up. Most groundwater contains less dissolved oxygen and high toxic gases. Care should be taken while checking the quality of ground water for hardness and carbon dioxide too. While using direct sea or creek waters, surface waters are not advised as there may contamination due to various sources. Better to use submerged sea bed filters as this may be void of surface pollutants and other organisms.

Quantity Requirements

During the preliminary site selection process, one of the most critical factors to consider is the availability of an adequate water supply for both the present facility and any further future planned and unplanned expansions. When it comes to the availability of water, too much is definitely better than too little. A standard thumb rule for quantity wise assessment of water source is to provide 100% of water required for complete exchange at any given date and time through out the year.

Quality Requirements

The fish culture environment is a complex system with many water quality parameters influencing the growth of fish. Keeping every individual parameters constant and within the optimum range is very important. But the critical thing is the complexity of every parameter and its interaction with other parameters needs to be taken care. So a basic understanding of water chemistry is needed for the success of any RAS. A list of the most critical water quality parameters and its very general recommendations for each parameter is given in Table 1.

Table 1: Optimum water quality requirements for marine finfish culture

Parameter	Range	Optimum
Dissolved Oxygen mg/L	3– 7	>5
Temperature °C	21 - 30	26 - 28
Total Ammonia (TAN) mg/L	< 3.0	<1.0
Nitrite mg/L	< 1	< 0.1
Nitrate mg/L	0 – 400	< 200
pH	6.5 – 8.5	7.5 – 8.5
Total Alkalinity mg/L	50 – 300	80 – 150
Hardness mg/L	50 – 200	>100 - 150
Carbon dioxide mg/L	< 20	0 – 5
Calcium mg/L	4 – 160	50 – 100
Chlorine mg/L	<0.003	nil
Total Dissolved Solids	< 400	
Total Suspended Solids	< 80	

Water quality parameters

1. Dissolved Oxygen

Dissolved oxygen (DO) is one of the most important and critical parameter in RAS. DO has an inverse relationship with water temperature and other dissolved solids and gases. Its solubility decreases with increasing temperature and salinity. Even though atmospheric air contains oxygen, dissolving or inducing oxygen into the aquatic ecosystem needs aerators or oxygen diffusers. At low DO levels aquatic animals have to spend lot of energy for getting that oxygen to breathe. It is not only essential for breathing but also needed for several physiological processes and the general well being of fish. Apart from fishes nitrifying bacteria in the biofiltration unit also consumes large amounts of oxygen. It is consumed at the rate of 4.57 g for oxidizing every gram of ammonia-nitrogen to nitrate-nitrogen. So it is utmost necessary to replenish oxygen levels in the culture tanks. In general terms fish will eat feed better, grow faster and live healthier when DO concentration is maintained above 5 mg/L.

2. Temperature

Water temperature plays a crucial role in fish culture. Non-optimal water temperatures directly affects several physiological processes and leads to reduced feeding and poor growth. Fishes are generally characterized as warm water species (25-30 °C), cool water species (15-25 °C). Fishes are poikilothermic, which means animals having a body temperature that varies with the temperature of the surroundings. The efficiency of many physiological processes in fish will change by 6-10% per 1 °C change in body temperature. So it is utmost necessary to maintain the water temperature to its optimum level. To maintain optimal temperatures, suitable devices such as digital immersion heaters can be used. Care should be taken that an increased temperature also decreases solubility of gases in water and leads to lesser dissolved oxygen. Water temperature also plays significant role in nitrification process as 10 °C drop in temperature will lead to a 23% reduction in nitrification rate.

3. Total Ammonia, Nitrite and Nitrate

Total Ammonia (TAN), Nitrite (NO_2^-) and Nitrate (NO_3^-) are the derivatives of nitrogen and highly soluble in water. Ammonia content of the water is due to the release of metabolic wastes and decomposition of organic matter including feed remains and faecal matter. Every 1 mg/L of oxygen consumed by the fish will produced 0.14 mg of TAN. Ammonia occurs in aquaculture systems in two forms i.e., ionized and un- ionized. The un-ionized form of ammonia (NH_3) is extremely toxic while the ionized form (NH_4^+) is not. Both forms are grouped together as 'total ammonia'. As the temperature and pH of the culture system increases, the level of free ammonia increases and of ammonium ions decreases. Whereas in the case of salinity it is inverse as the toxicity of ammonia increases with decreasing of salinity.

The nitrites and nitrates are produced in culture system by bacteria *Nitrosomonas* spp. and *Nitrobacter* spp. respectively. Nitrite is toxic to fish as it binds the hemoglobin in blood and affects its ability to carry oxygen, whereas nitrate is less toxic even at higher levels. Therefore these are important parameters to be monitored and needs to be maintained at

↗ High temperature	↗ High free ammonia (NH3)
↗ High pH	↘ (low ammonium) (NH_4+)
Dangerous to fish	

↘ Low temperature	↘ Low free ammonia (NH3)
↘ Low pH	↗ (high ammonium) (NH_4+)
Relatively safe for fish	

its optimal level. The toxicity of ammonia, nitrite, and to some extent, nitrate can be reduced by removing and decomposing using biological filters or drum filters in RAS. In a newly built RAS, ammonia level shoots up initially, followed by nitrite and then nitrate. This is due to the process of accumulation of organic wastes and the time taken for the maturation of bio-filter and colony forming of nitrifying bacteria for transforming ammonia to nitrate. The performance of any RAS is judged based on its ability to convert the production of ammonia to nitrate and maintaining its level in optimum.

4. pH

pH value expresses the acidity or alkalinity of water which ranges from 1-14. A value of 7 is considered neutral whereas values below 7 are acidic and above 7 are basic. A buffering system to avoid wide swings in pH is essential in RAS. Fish have an average blood pH of 7.4; hence a pH range of 6.5 to 8.5 is more optimum and conducive to fish health. Seawater is buffered by the bicarbonate ions and has a relatively stable pH between 8.0 and 8.5. pH has an effect on solubility of several gases and parameters which are both necessary and harmful to fishes.When the pH > 9, the water is alkaline and corrosive to fish, damaging the fish body and gills. Meanwhile, pH has a significant influence on the nitrification of the bio-filter - a low pH will inhibit the growth of nitrifying bacteria. The alkaline environment at pH 7.0 to 9.0 are more suitable for the reproduction of nitrifying bacteria. Largely, pH in RAS is reduced by production of CO_2 by cultured fish as well as that produced by the microbes present in the system. The loss of alkalinity together with the increase in dissolved CO_2 will also cause a reduction in the pH of the RAS. So it is essential to retain the pH at its optimal level.

5. Alkalinity and Hardness

Alkalinity is the capacity of water to neutralize acids without an increase in pH. The ions that contribute to the alkalinity are bicarbonates & carbonates (CO_3^{2-} and HCO_3^-) and in rare instances, hydroxide (OH^-). Total alkalinity is the sum of the carbonate and bicarbonate alkalinities. Some water may contain only bicarbonate alkalinity and no carbonate alkalinity. Fish grow within a narrow range of pH values and either of the above extremes are lethal to fish. A culture system is considered well buffered when pH varies between 7.5 - 8.5 and total alkalinity ranges from 80-150 mg/L. There will be a reduction in alkalinity due to conversion of total ammonia-nitrogen (TAN) to nitrate-nitrogen(NO_3-N) by nitrifying bacteria. It is consumed at the rate of 7.14 g for reducing every gram of ammoia-N to nitrate-N. This reduction can be compensated by the addition of approximately 0.15-0.25 kg sodium bicarbonate ($NaHCO_3$) or sodium hydroxide per kg of feed, otherwise there will be reduction in alkalinity and pH of the system.

Hardness is the total concentration of calcium and magnesium salts in water expressed as its calcium carbonate equivalent. In general terms it is the ability of the water to precipitate soap. The total hardness is mainly used to classify waters into 'hard water' or 'soft water'.

Water with a total hardness of 0-75 mg/L is considered soft, 75-150 mg/L as moderately hard, 150-300 mg/L as hard and above 300 mg/L as very hard. Hard water is known to influence feed intake and growth of majority of fishes. Water with hardness of 50-300 ppm have been found to be optimal for the normal growth of majority of fishes.

6. Carbon dioxide

Carbon dioxide (CO_2) is highly soluble in water and produced in the system by respiration of fishes and decomposition of organic matter by microorganisms. Especially during conversion of ammonia to nitrite and nitrate, huge quantities of dissolved oxygen is consumed and CO_2 is released back into the RAS. 1.375 grams of CO_2 is produced for every gram of O_2 consumed (both fish and bacteria). Exposure to higher concentration of CO_2 reduces respiratory efficiency of fishes, higher concentration of CO_2 in blood and lowering of blood plasma pH. Carbon dioxide varies with fish biomass in different culture systems. For most fishes, free carbon dioxide concentrations should be maintained at less than 20 mg/L in the tank for good fish growth. Usually, CO_2 is removed from the RAS through gas transfer process by venturi type or free fall of water to the tank by trickling or sprinkling. This mixes the atmospheric air and will help in escaping the excess CO_2 from the water. For the well being of most fishes, a free CO_2 concentration should be maintained at less than 20 mg/L in the tank.

7. Salinity

Salinity is defined as the total concentration of dissolved ions in water, and is usually reported as parts per thousand (ppt) or grams of salt per kilogram of water. Each fish has an optimum range of salinity for growth and reproduction, but it can tolerate very wide range of salinity. The salinity requirements for cultivable marine fishes are given in Table 2.

Table 2: Salinity requirements of fishes

Species	Salinity range (ppt)	Optimal Salinity (ppt)
Seabass (*Lates calcarifer*)	0–33	15 - 30
Grouper (*Epinephelus* sp.)	10–33	15 - 30
Pompano (*Trachinotus* sp.)	5 - 35	15 - 30
Rabbit fish (*Siganus* sp.)	15–33	25 - 30
Snapper (*Lutjanus* sp.)	15–33	25 - 30

Water treatment and biosecurity

Treatment of incoming water is one of the most important steps for successful fish culture in RAS. Culture water should be free of suspended solids, plankton (e.g., protozoans, ciliates and other algal species), bacteria, lethally high concentrations of dissolved organic compounds (DOC), dissolved metals, and pesticides. Pre-treatment typically includes physical and chemical methods, sterilization or disinfection. The choice of treatment should be based upon species cultured, volume requirements and cost.

A. Physical methods

Mechanical filtration removes suspended solids, plankton and bacteria, protozoa and micro-algae. The type of mechanical filtration used depends on the condition of the incoming water and the volume of water to be treated.

1. Sand filters / Biological filters
2. Polyester filter bags (20 to 35 µm)
3. Rotating Drum Filter
4. Rapid Sand Filter (RSF)
5. Foam fractionation system.

Heat sterilization is also followed for large volume of incoming source water after filtration with glass lined water heater or 500 to 1000 W submersion heaters.

B. Chemical Methods

Dissolved inorganic carbon (DIC) and dissolved organic carbon (DOC), metals, pesticides, and other contaminants can prevent or retard growth of fishes, although detecting them can be complicated and costly. Activated carbon (charcoal) filtration is helpful in reducing DOC, while deionization resins are effective in removing metals and hydrocarbons. Activated carbon can be housed in a filter or a filter bag and all the water can be passed through it.

Chlorination is the simplest and most common method of chemical sterilization. Active chlorine level of 10-20 ppm in the water for 12-24 hours is sufficient to kill most pathogens. Filtered water can be sterilized (20 ppm active chlorine) with sodium hypochlorite solution at 200 mL of liquid chlorine (10% sodium hypochlorite) per 1000 L of water. Sterilization occurs in a short period of time, usually 10 to 30 minutes, but a longer time without aeration (12 hours or overnight) is given for a margin of safety. Before use, the residual chlorine is neutralized by adding sodium thiosulphate solution at the rate of 1 ppm (1g/m^3) for every 1 ppm of chlorine left in solution along with vigorous aeration for 2-3 hrs.

C. Sterilization / Disinfection

Diseases induced by bacteria and virus are serious constraints to high-density aquaculture systems such as RAS. Hence, to prevent the outbreak of diseases, it is necessary to remove pathogenic microorganisms in water in advance. Either UV or ozone can be used to disinfect culture water, although both are most effective after mechanical filtration has removed suspended particulates.

After the removal of suspended particulates through mechanical filtration, disinfection of culture water can be done either through UV or ozone or by using both were found to be more effective. Ultraviolet radiation (germicidal energy) is an efficient, simple and reliable way to kill microorganisms in culture water. However, the killing power of UV is affected by turbidity/coloration of the incoming water, distance from the UV source, exposure time (flow rate) and species of organisms present. Dosage of UV is measured as mW-sec/m^2. Minimum dosages vary widely for different microorganisms: 15 mW-sec/m^2 for most bacteria, 22 mW-sec/m^2 for water borne algae, 35 mW-sec/m^2 for bacteria/viruses, and 100 – 330 mW-sec/m^2 for protozoans, fungi and moulds. So a common standard dosage can be fixed with in this range from 2-230 mW-sec/m^2 at 254 nm for better disinfection of water.

Ozone (O_3) as a strong oxidizing agent, is more effective in removing dissolved organics, pesticides, colour and nitrates. Due to unstable nature it gets quickly reverted back to O_2, however, being highly corrosive and hazardous to health, it should be handled with precautions. Ozone oxidation can kill microorganisms, but for a given period of contact time; disinfection of water requires a certain dissolved ozone concentration. A residual ozone concentration of 0.1 - 2.0 mg/L for a period of 1 - 30 minutes, is required to be maintained for complete disinfection. Moreover, disinfection also depends upon the target microorganism. Care should be taken since a residual level of even 0.01 mg/L can kill fish and shrimp larvae. Apart from disinfection ozone treatment is suggested for fine solids removal and converts nitrite to nitrate relatively quicker.

Aeration

Aeration/oxygen supply system is extremely important in RAS. An efficient aeration system is highly necessary for high density fish culture in RAS. The most popular aeration system used in hatcheries and culture tanks are with air stones and pipes, which produces larger air bubbles which rise quickly to the surface and hence the dissolution of oxygen is low. However, for high density fish culture systems ordinary aeration system cannot provide sufficient oxygen required. Oxygen generators which produce pure oxygen can effectively dissolve oxygen in water. Now-a-days usage of air diffusers are preferred in RAS. These diffusers produce many micro and nano bubbles in the water. These small air bubbles within the tank rise through the water column in a large surface area and dissolve oxygen with extremely high efficiency.

Solid waste removal

Suspended solids adversely impact all aspects of RAS. The foremost objective of any RAS is the removal of solid wastes. Suspended solids are the result of feces, biofloc (dead and living bacteria), and residual food. These suspended particles will vary greatly in size from centimeter (cm) size to micron (µm). It will negatively impact the water quality by affecting the performance/efficiency of the water treatment units.

There are several methods used to remove suspended solids from fish culture system

1. Gravity separation - Gravity separation works on the principle of sedimentation and settling. Large particles (larger than 100 µm) can be effectively removed by settling.
2. Filtration - Particle removal from the water can be accomplished by one or more filtration processes such as drum filter, RSF etc
3. Flotation - In a flotation process, particles attach onto air bubbles and are separated from water.

The biological filtration (BOD removal and nitrification) is a fundamental water treatment process in every recycling method for the cultivation of aquatic animals. It mainly digests dissolved organic material (heterotrophic bacteria) and oxidizes ammonium-ions via nitrite to nitrate (two-step nitrification) by bacteria like *Nitrosomonas* sp., and *Nitrobacter* sp. A solid medium is used as substrate for the attachment of the micro flora. Conventional biofilters employ sand or coral gravel as filter media. Modern filters make use of various plastic structures as grids, corrugated sheets, balls, honeycomb-shaped or wide-open blocks. The main goal is to provide a big active surface area for the micro flora settlement. Usage of bivalve shells in the biological filter, will help not only in increasing the surface area for development of bacterial biofilm but will also help in maintaining the alkalinity at a desired level. The bivalve shells are mostly (95%) constituted of calcium carbonate ($CaCO_3$). Calcium carbonate from the bivalve shells could have leached into the water and dissoluted to form Ca^{2+} and CO_3^{2-} (calcium ions and carbonate ions). The carbonate ions has the potential to absorb two hydrogen ions (H^+) formed during the nitrification process and therefore, it helps in increasing and maintaining the alkalinity in recirculating water.

The rapid sand filter (RSF) was filled with white sand of 2 mm particle size to remove the solid waste of more than 60 µm particle (depends on manufacturer specification). RSF is attached with multiport valve and the main function of the valve includes filter, backwash, rinse and recirculation. Depending on the need, the valve position can be changed.

Many of the fine suspended solids and dissolved organic solids that build up within intensive recirculation systems cannot be removed with traditional mechanisms. Foam fractionation is used to remove and control the build-up of these solids. This process, in which air introduced into the bottom of closed column of water creates foam at the surface of the column, removes dissolved organic compounds by physically adsorbing on the rising bubbles. Fine particulate solids are trapped within the foam at the top of the column, which can be collected and removed. Apart from solid waste removal, foam fractionation sucks atmospheric air and mixes with water and will free fall into the biological filter / tank. This will also help in removing the excess free CO_2.

Conclusion

Several water quality parameters will influence the functioning of RAS either individually or collectively. In the name of ameliorating and improving the water quality, one should not go for high end filters and treatment methods, which may lead to high production costs. However, prevalence of unsuitable water quality parameters will definitely lead to unfavourable culture conditions, which indirectly affect the health of fish, environment leading to less production and compromised profits. So a collective thought on the effect of various parameters on the RAS and its way to remediate it is needed and it will be of enormous help in efficiently managing it.

References

Timmons, M.B., Ebeling, J.M., Wheaton, F.W., Summerfelt, S. and Vinci, B.J., 2002. *Recirculating aquaculture systems*. Northeastern Regional Aquaculture Center, Ithaca, New York.

Takeuchi, T. ed., 2017. *Application of Recirculating Aquaculture Systems in Japan*. Springer.

Ranjan, R., Megarajan, S., Xavier, B., Raju, S.S., Ghosh, S. and Gopalakrishnan, A., 2019. Design and performance of recirculating aquaculture system for marine finfish broodstock development. *Aquacultural Engineering*, *85*, pp.90-97.